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The Advantages and Barries in Implementing of Industry 4.0 and Key Features of Industry 4.0

Endüstri 4.0'ın Uygulanmasındaki Avantajlar ve Engeller ve Endüstri 4.0'ın Temel Özellikleri

Abstract

Since the publication of the term "Industry 4.0" in 2011, the digital transformation required by Industry 4.0 has immediately attracted the attention of industrialists and governments around the world. Majority of the countries around the world are dealing with the difficulty of producing more goods from limited and consumed natural resources to meet the ever-increasing consumer demand worldwide with the first industrial revolution in the 18th century due to environmental and vital issues. Therefore, the sustainability impacts of Industry 4.0 and the way it contributes to sustainable economic, environmental and social development are getting more and more attention. Nowadays, Industry 4.0 is about digitalization in all industrial and consumer markets, from smart production systems to all distribution channels. Industry 4.0 digital transformation involves the digitization and integration of the entire value chain of the product life cycle. Industry 4.0 is a technological concept that contributes to the sustainability of businesses in today's conditions. Industry 4.0 changes the organization, business models, products, supply chain and strategies of companies. Industry 4.0 enables businesses to be more agile and flexible by integrating people, machines and data. Nowadays, countries such as Germany, the United States of America, India, China, Japan, the United Kingdom and Brazil have been developing policies for the implementation of Industry 4.0. However, the adequacy and implementation of Industry 4.0 technologies can be difficult for both industry representatives and countries. In this research, the advantages and barriers in implementing of Industry 4.0 were expressed. In addition, Industry 4.0 and its main features have been explained.

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Öz

2011 yılında "Endüstri 4.0" teriminin yayınlanmasından bu yana, Endüstri 4.0'ın gerektirdiği dijital dönüşüm, tüm dünyada sanayici ve hükümetlerin dikkatini hemen çekmiştir. Dünyadaki ülkelerin çoğunluğu, çevresel ve hayati sorunlar nedeniyle 18. yüzyılda ilk sanayi devrimi ile dünya çapında giderek artan tüketici talebini karşılamak için sınırlı ve tüketilen doğal kaynaklardan daha fazla mal üretmenin zorluğu ile uğraşmaktadır. Bu nedenle, Endüstri 4.0'ın sürdürülebilirlik üzerindeki etkileri ve sürdürülebilir ekonomik, çevresel ve sosyal kalkınmaya nasıl katkıda bulunduğu giderek daha fazla ilgi görmektedir. Günümüzde Endüstri 4.0, akıllı üretim sistemlerinden tüm dağıtım kanallarına kadar tüm endüstriyel ve tüketici pazarlarında dijitalleşme ile ilgilidir. Endüstri 4.0 dijital dönüşümü, ürün yaşam döngüsünün tüm değer zincirinin dijitalleştirilmesini ve entegrasyonunu içermektedir. Endüstri 4.0, günümüz koşullarında işletmelerin sürdürülebilirliğine katkıda bulunan teknolojik bir kavramdır. Endüstri 4.0, şirketlerin organizasyonunu, iş modellerini, ürünlerini, tedarik zincirini ve stratejilerini değiştirmektedir. Endüstri 4.0, insanları, makineleri ve verileri entegre ederek işletmelerin daha çevik ve esnek olmasını sağlar. Son zamanlarda Almanya, Amerika Birleşik Devletleri, Hindistan, Çin, Japonya, Birleşik Krallık ve Brezilya gibi ülkeler Endüstri 4.0'ın uygulanması için politikalar geliştiriyorlar. Bununla birlikte, Endüstri 4.0 teknolojilerinin yeterliliği ve uygulanması hem endüstri temsilcileri hem de ülkeler için zor olabilir. Bu çalışmada, Endüstri 4.0'ın uygulanmasındaki avantajlar ve engeller ifade edilmiştir. Ayrıca Endüstri 4.0 ve temel özellikleri açıklanmaya çalışılmıştır.

Introduction

The introduction of smart technologies into the production environment has revealed industry 4.0 as the fourth industrial revolution. Industry 4.0 represents a business environment where

machines, devices, employees and corporate systems are connected through cyber-physical systems and the internet. Technologies that provide Industry 4.0 significantly improve the quality of products and services provided by firms with autonomous and dynamic production. These technological innovations have made sustainable performance a key feature in smart factories by ensuring the efficient use of resources (Fatorachian & Kazemi, 2020).

Industry 4.0 is a new paradigm that is deeply changing human-machine interaction in the manufacturing / production environment. Industry 4.0 is a new production concept that aims to integrate industrial automation and new production technologies to improve working conditions, increase productivity and quality (Nardo, Forino & Murino, 2020). Firms can develop with Industry 4.0, their agility and profitability by improving the connectivity of machines, products, supply chains and customers, and using the systems' increased decision-making capabilities. It is likely to achieve operational performance levels previously unattainable with the use of the Internet of Things, cyber-physical systems and cloud computing, (Rosin et al., 2020).

The statement "Industry 4.0" was first used at the Hannover Fair in 2011. Later, the term Industry 4.0 was adopted by the German government in 2013 as a strategic attempt to revolutionize the manufacturing industry. Recently, there is a growing interest in Industry 4.0 due to the numerous benefits it provides to production organizations. (Raj et al., 2020). As can be seen from this increasing interest, it is possible to find many research on Industry 4.0 in the literature (Oztemel & Gursev, 2020; Osterrieder, Budde & Friedli, 2020; Gulot et al., 2020). Industry 4.0 is defined as the fourth industrial revolution (Silveira et al., 2021). Industry 4.0 and the other 3 industrial revolutions can be seen in Figure 1.

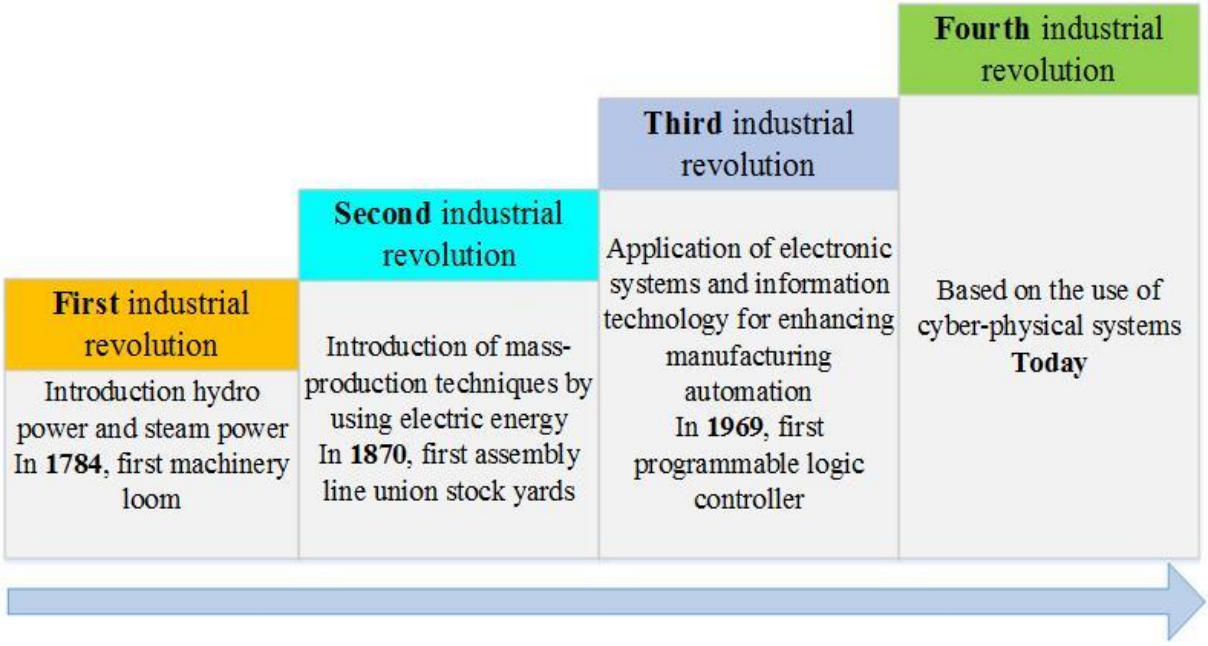

Figure 1. Stages of the four industrial revolutions
Source: Anderl, 2014

Industry 4.0 is about highly advanced automation and digitization operations and the use of information technologies and electronics in services and production. Industry 4.0 enables factories to be made more flexible, intelligent and dynamic by equipping the manufacturing environment with autonomous systems and sensors. Industry 4.0 ensures that value-added integration is realized vertically and horizontally during the production step. The manufacturing process in Industry 4.0 requires more microchips, sensors and autonomous systems due to the rapid development of technologies (Lu, 2017). The integration framework that expresses the interoperability of Industry 4.0 with digital technologies such as machine, human, sensor and automation can be seen in figure 2.

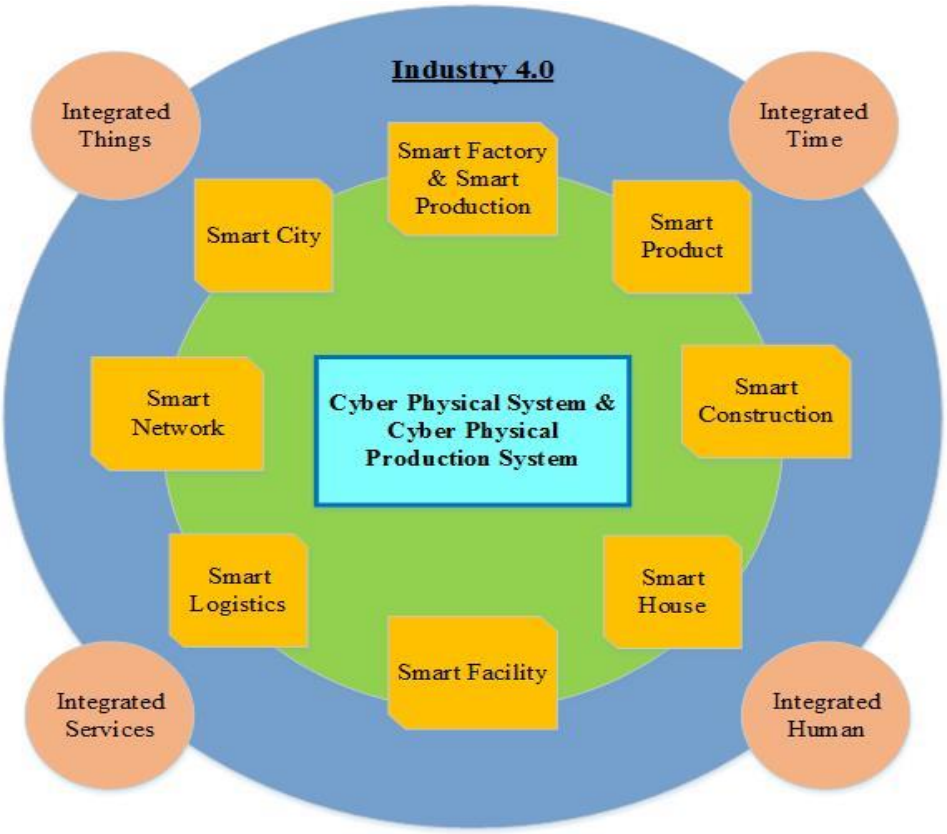

Figure 2. Integration framework of Industry 4.0
Source: Lu, 2017

The technologies underlying the Industry 4.0 concept are aimed at reducing costs, increasing flexibility, increasing speed and improving quality (Olsen & Tomlin, 2020). The digitization principle of Industry 4.0 and the sensor data obtained from the physical environment offers very important opportunities for optimization of production processes. The use of industrial robotics, automation and additive manufacturing for the development of the modularity principle of Industry 4.0 facilitates an agile, flexible and decentralized production environment that effectively adapts to constantly changing customer needs (Ghobakhloo, 2020).

If the spread of Industry 4.0 is not geographically homogeneous, economically and socially disadvantaged countries will be negatively affected. As a result of this situation, the gap between developed and developing countries will gradually increase (Bonilla et al., 2018). It is very important to state the advantages and barriers in the application of Industry 4.0 to eliminate this gap between countries and to distribute Industry 4.0 homogeneously. In this study, the advantages of Industry 4.0 and the barriers in its implementation have been tried to be explained.

1. Key Features of Industry 4.0

Industry 4.0 can be expressed as a combination of various emerging concepts and new technologies such as big data, smart sensors, robotics, cloud computing, machine learning, augmented reality, artificial intelligence and Internet of Things. Advanced technologies included in Industry 4.0 enable the restructuring of all production systems by converting centralized and analog workflows into decentralized and digital manufacturing operations (Raj et al., 2020). Industry 4.0 is a revolution that allows communication between people and machines using automated systems such as cloud computing, cyber-physical systems and Internet of Things and etc. (Nardo, Forino & Murino, 2020).

The basic elements of Industry 4.0 can be expressed as cloud computing, cyber-physical system, internet of things, augmented reality, 3D printers, artificial intelligence and machine learning,

simulation, big data analytics and autonomous robots (Soylu, 2018; Şekkeli & Bakan, 2018; Jena, Mishra & Moharana, 2019; Olsen & Tomlin, 2020; Shafiq, Sanin & Szczerbicki, 2020; Ghadge et al., 2020; Tehci & Ersoy, 2020). The main components of Industry 4.0 were given below.

Cyber-Physical System: Cyber-physical systems are referred to as converter technologies for controlling systems interconnected between physical presences and calculation capabilities. In current industrial applications, cyber-physical systems are integrated with production, logistics and services, enabling today's factories to be transformed into an Industry 4.0 factory with considerable economical potential (Lee, Bagheri & Kao, 2015: 18).

Internet of Things: Recently, the development of wireless technologies has led to the emergence of a new paradigm called the Internet of Things. Internet of Things is applied in many areas such as healthcare, smart building, logistics and the environment. Thanks to the Internet of Things, businesses have the opportunity to collect and analyze very different and large amounts of data that they can use to develop their industrial performance. (Khan et al., 2020).

Three-Dimensional Printers (Additive Manufacturing): Additive manufacturing is expressed as combining materials in three-dimensional printers in the form of layers to produce objects from three-dimensional data. It is also defined as three-dimensional production, additive production, additive processes, additive techniques, additive layer production, layer production and free-form production (Fraizer, 2014).

Cloud Computing: Cloud computing technologies provide computing, storage services and networking in whole facilities in the Internet of Things system. Private cloud service models are not a viable option for small and medium-sized businesses, as setting up data centers and hiring technical crew requires high expenditure. However, large and multinational companies prefer private cloud computing technologies to ensure security, safety information privacy, deal with industrial information theft and gain a competitive advantage. (Khan et al., 2020).

Augmented Reality: Augmented Reality (AR) technologies assist industrial personnel during complex processes such as complex industrial products, assembly/disassembly of machines, and mission-critical systems. AR technologies enable the monitoring of workers and machines during operations and instant changes or notifications to minimize errors (Khan et al., 2020). Industrial augmented reality is one of the fundamental elements of industrial digitization concepts that superimpose digital information and connect employees with the physical world (Masood & Egger, 2020).

Artificial Intelligence and Machine Learning: Artificial intelligence and machine learning are a technological revolution for companies in different sectors. Together with artificial intelligence machine learning techniques, it enables the automation of a production process that increases productivity, efficiency, optimizes production cost and reduces errors (Balamurugan et al., 2019). Today, the development of machine learning as a branch of artificial intelligence is now quite fast. Recently, the use of machine learning has become widespread in areas such as intelligent manufacturing, medical science, pharmacology, agriculture, archeology and so on (Cioffi et al., 2020).

Autonomous Robots: In our age, robotic technology is used in different fields such as production, transportation, e-commerce and health. Nowadays, these robots have finally begun to interact with each other, work harmoniously and safely with operators, and provide support to operators. In the future, these robots are expected to be more economical and have more capabilities and features than currently used models. (Ghadge et al., 2020).

Big Data Analytics: Big data analytics are technologies and techniques used to extract unknown and valid information from a variety of applications to analyze large-scale and complex data. For this reason, big data analytics includes an ecosystem of complex, interconnected and multi-layered high-capacity networks, users, applications, and services required to store, visualize, process and deliver results from different data sources to target applications (Chalmeta & Santos-deLeon, 2020).

Simulation: Simulation is widely used in business models to model the real working environment in a virtual ecosystem using available real-time data. Data collected and processed from big data and cloud systems can be used in a virtual model to analyze whole feasible situations

related to the development, research and production of the product. Businesses can see the risks, setup times, costs that may occur in business processes, and make improvements for future operations and services with the help of simulation (Ghadge et al., 2020).

2. Advantages and Barries in The Application of Industry 4.0

2.1. Advantages of Industry 4.0 in Its Implementation

Industry 4.0 has a great advantage in speed up production with higher output and lower cost. It creates a smart factory environment with smart production, smart energy, smart engineering and smart transportation. Industry 4.0 aims to develop and upgrade production technologies by integrating the physical systems of the factory with cyber-physical systems, Internet of Things and cloud computing. The integrated framework helps to monitor human, machine, material movement and similar parameters and processes through real-time communication and enables smart conclusions (Jena, Mishra & Moharana, 2019).

It is possible to classify the opportunities of Industry 4.0 under six main headings. These are; production flexibility arising during the production of small batches, greater output capacity, speed of serial prototypes, higher product quality and less production rejection, lower setup costs and less error and machine downtimes, and improvement of customers' view of the product (Büchi Cugno & Castagnoli, 2020).

Modgil et al., (2020) have determined the advantages of Industry 4.0 in their studies. These are; innovation, effective globalization, optimum use of resources, seamless product flow, efficient continuous real-time monitoring, efficient energy consumption, autonomous control, greater flexibility to meet high-end last-minute changes, for every step in cloud storage safe and reliable backup system, detailed end-to-end product transparency in real-time. Mian et al., (2020) have stated the advantages of industry 4.0 as higher productivity, accelerated enterprise growth, better control and streamlining of processes, greater flexibility, sustainability development.

Some researchers acknowledge that Industry 4.0 can provide some opportunities for social and environmental sustainability beyond economic advantages (Stock & Seliger, 2016; Kiel et al., 2017; Brozzi et al., 2020). Brozzi et al. (2020) have investigated the advantages of Industry 4.0 applications in terms of sustainability. In the study, using a questionnaire, it has been investigated to what extent manufacturing companies consider Industry 4.0 as an advantage in terms of environmental and social sustainability? According to the results of the research, the advantages in implementing Industry 4.0 were; reduction of errors, management of logistics, time savings, lower physical stress of partners, reduction of costs, reduction of workforce, sustainability (lower environmental impact). As a result of the study, the evaluation of economic opportunities was superior to environmental and social opportunities.

2.2. Barriers of Industry 4.0 in Its Implementation

On the other side, the many advantages of Industry 4.0 technologies, there are some obstacles in their application. Barriers in the implementation of Industry 4.0 can be classified as lack of management support, financial constraints, resistance to change, legal problems, lack of expertise, lack of government policy and support, insufficient research and development practices, lack of infrastructure, lack of digital culture, poor quality data (Ghadge et al., 2020: 674).

Raj et al., (2020) have examined the barriers to the application of Industry 4.0 technologies in the production industry within the framework of both developed and developing economies. In the study, 15 barriers have been evaluated using Gray Relational Analysis (GRA) and DEMATEL methods. Barriers used in the research; high capital in Industry 4.0 application, lack of certainty about economic benefit, risk of a security breach, difficulty in value chain integration, irregularity, low-quality level of the desired technology, disruption in the existing business, lack of standards, regulations and certification forms, lack of infrastructure, difficulties in ensuring data quality, lack of digital skills, in-house digital culture and lack of training, ineffective change management, resistance to change and resource scarcity, as well as the absence of a digital strategy. As a result of

the study, "lack of a digital strategy as well as resource scarcity" emerges as the most important barrier in both developed and developing economies.

Da Silva et al., (2020) have expressed the barriers of Industry 4.0 in its implementation. These were; lack of government regulations and policies, the weak technological infrastructure of firms, confusion of technologies, lack of specialized and diversified suppliers, poor organizational management, lack of knowledge from a multidisciplinary perspective, lack of methodological processes for the adoption of the Industry 4.0 concept, firms and suppliers understanding of potential benefits and cooperation between organizations, internal resistance to organizational changes, lack of qualified workforce, new skills and training needs, financial uncertainties regarding return on investment, lack of financial infrastructure, data security.

Kumar, Singh & Kumar (2021) have definied some of the barriers in the application of Industry 4.0 as short-term corporate goals, insufficient legislation and controls, lack of skilled workforce, lack of awareness of Industry 4.0, lack of waste management and ineffective performance framework. In the study, 15 barriers have been evaluated using Analytic Hierarchy Process (AHP) and Elimination and Choice Expressing Reality (ELECTRE) methods. According to the results of the study, lack of funding for Industry 4.0 and insufficient strategy for integration of Industry 4.0 and circular economy have been determined as the main barriers.

3. Results and Discussion

According to the results of the study, the important advantages of Industry 4.0 in its application are; production flexibility, efficiency, quality improvement, smooth product flow, optimum use of resources, reduction of cost and errors, sustainability development, accelerated enterprise growth, time-saving, innovation and improvement in customer satisfaction. The most important barriers of Industry 4.0 are; legal problems, insufficient research and development practices, lack of infrastructure, lack of digital culture, resource scarcity, lack of government regulations and policies, poor quality data, the weak technological infrastructure of companies, poor organizational management, internal resistance to organizational changes, lack of qualified workforce, new skills and training needs, financial uncertainties regarding the return on investment, lack of financial infrastructure, data security, lack of funding, insufficient strategy for integration of Industry 4.0 and circular economy, lack of waste management, lack of awareness of Industry 4.0.

Developed and developing countries must make more effort to facilitate the applicability of Industry 4.0. When evaluated from this perspective, it is understood that companies should use new technologies together with Industry 4.0 to be successful in the sector. On the one hand, enterprises should develop strategies to meet the needs of qualified personnel in the technological components of Industry 4.0 such as cloud computing, artificial intelligence, machine learning. Moreover, it is understood that the integration of information, machine, human and technology is of great importance for the successful application of Industry 4.0.

Conclusion

Today, the many businesses want to apply technological and organizational innovation. Technological developments such as the Internet of Things, machine learning, simulation and cloud computing enable solutions for customer needs. The development of the industry is a process of complexity and agility integrated between man and machine. Industry 4.0 technologies ensure the improvement of product quality. In addition to the convenience, it provides in the application, Industry 4.0 brings several important difficulties to companies in terms of technological, organizational and management. Determining the advantages and barriers of Industry 4.0 in its implementation is very important for the sustainability of enterprises in the global competitive environment.

It is thought that this study will contribute to those who will conduct research on this subject and to the companies and organizations in the future. This study can serve as a guide for businesses to prepare for the barriers of Industry 4.0 in its implementation. Examination of barriers of Industry 4.0 in its implementation such as lack of financial infrastructure and lack of digital culture can be

considered as another research subject in the future. Determining the importance levels of the barriers of Industry 4.0 in its implementation by using multi-criteria decision-making methods may be another research subject to be in the future.

References

Anderl, R. (2014). Industrie 4.0-advanced engineering of smart products and smart production. *In Proceedings of 19th International Seminar on High Technology*, Piracicaba/Brasil, October 9, 2014. 1-15.

Balamaurugan, E., Flaih, L.R., Yuvaraj, D., Sangeetha K., Jayanthiladevi, A., & Kumar, T.S. (2019). Use Case of Artificial Intelligence in Machine Learning Manufacturing 4.0. *2019 International Conference on Computational Intelligence and Knowledge Economy (ICCIKE)*, Dubai, United Arab Emirates, 656-659. doi: 10.1109/ICCIKE47802.2019.9004327

Bonilla, S.H., Silva, H.R.O., Silva, M.T., Gonçalves, R.F., & Sacomano, J.B. (2018). Industry 4.0 and Sustainability Implications: A Scenario-Based Analysis of the Impacts and Challenges. *Sustainability*, 10(10), 1-24. https://doi.org/10.3390/su10103740

Brozzi, R., Forti, D., Rauch, E., & Matt, D.T. (2020). The Advantages of Industry 4.0 Applications for Sustainability: Results from a Sample of Manufacturing Companies. *Sustainability*, 12(9), 1-19. https://doi.org/10.3390/su12093647

Büchi, G., Cugno, M., & Castagnoli, R. (2020). Smart factory performance and Industry 4.0. *Technological Forecasting & Social Change*, 150, 1-10. https://doi.org/10.1016/j.techfore.2019.119790

Chalmeta, R., & Santos-deLeon, N.J. (2020) Sustainable Supply Chain in the Era of Industry 4.0 and Big Data: A Systematic Analysis of Literature and Research. *Sustainability*, 12(10), 1-24. https://doi.org/10.3390/proceedings2019039022

Cioffi, R., Travaglioni, M., Piscitelli, G., Petrillo, A., & Felice, F.D. (2020) Artificial Intelligence and Machine Learning Applications in Smart Production: Progress, Trends, and Directions. *Sustainability*, 12(2), 1-26. https://doi.org/10.3390/su12020492

Da Silva, V.L., Kovaleski, J.L., Pagani,R.N., De Matos Silva, J., & Corsi, A. (2020) Implementation of Industry 4.0 concept in companies: empirical evidences, *International Journal of Computer Integrated Manufacturing*, 33(4), 325-342. https://doi.org.10.1080/0951192X.2019.1699258

Fatorachian, H., & Kazemi, H. (2020) Impact of Industry 4.0 on supply chain performance. *Production Planning & Control*, 1-19. DOI: 10.1080/09537287.2020.1712487

Frazier, W.E. (2014) Metal Additive Manufacturing: A Review. *Journal of Materials Engineering and Performance*, 23, 1917-1928. https://doi.org/10.1007/s11665-014-0958-z

Ghadge,A., Kara, M.E., Moradlou, H., & Goswami, M. (2020). The impact of Industry 4.0 implementation on supply chains. *Journal of Manufacturing Technology Management*, 31(4), 669-685. DOI 10.1108/JMTM-10-2019-0368

Ghobakhloo, M. (2020) Industry 4.0, digitization, and opportunities for sustainability. *Journal of Cleaner Production*, 252, 1-21. https://doi.org/10.1016/j.jclepro.2019.119869

Gulot, G., Nassimbeni, G., Orzes G., & Sartor, M. (2020) Behind the definition of Industry 4.0: Analysis and open questions. *International Journal of Production Economics*, 226, 1-15. https://doi.org/10.1016/j.ijpe.2020.107617

Jena, M.C., Mishra, S.K., & Moharana, H.S. (2020). Application of Industry 4.0 to enhance sustainable manufacturing. *Environmental Progress & Sustaniable Energy*, 39(1), 1-11. https://doi.org/10.1002/ep.13360

Khan, W.Z., Rehman, M.H., Zangoti, H.M., Afzal., M.K., Armi, N., & Salah, K. (2020) Industrial internet of things: Recent advances, enabling technologies and open challenges. *Computers and Electirical Engineering*, 81, 1-13. https://doi.org/10.1016/j.compeleceng.2019.106522

Kiel, D., Müller, J.M., Arnold, C., & Voigt, K-I. (2017). Sustainable industrial value creation: Benefits and challenges of industry 4.0. *International Journal of Innovation Management*, 21(8), 1-34. https://doi.org/10.1142/S1363919617400151

Kumar, P., Singh, R.K., & Kumar, V. (2021). Managing supply chains for sustainable operations in the era of industry 4.0 and circular economy: Analysis of barriers. Resources, Conversation & Recycling, 164, 1-12. https://doi.org/10.1016/j.resconrec.2020.105215

Lee, J., Bagheri, B., & Kao, H-A. (2015) A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters*, 3, 18-23. https://doi.org/10.1016/j.mfglet.2014.12.001

Lu, Y. (2017) Industry 4.0: A survey on technologies, applications and open research issues. *Journal of Industrial Information Integration*, 6, 1-10. https://doi.org/10.1016/j.jii.2017.04.005

Mian, S.H., Salah, B., Ameen, W., Moiduddin, K., & Alkhalefah, H. (2020). Adapting Universities for Sustainability Education in Industry 4.0: Channel of Challenges and Opportunities. *Sustainability*, 12(15), 1-31. https://doi.org/10.3390/su12156100

Masood, T., & Egger, J. (2020) Adopting augmented reality in the age of industrial digitalisation. *Computers in Industry*, 115, 1-14. https://doi.org/10.1016/j.compind.2019.07.002

Modgil, A., Saif, M., Nath, U., Jaiswal, A., & Srivinas, V. (2020) Application of Industry 4.0 in manufacturing. *EPRA International Journal of Multidisciplinary Research (IJMR)*, 6(5), 98-104. DOI: 10.36713/epra2013

Nardo, M., Forino, D., & Murino, T. (2020). The evolution of man–machine interaction: the role of human in Industry 4.0 paradigm. *Production & Manufacturing Research*, 8(1), 20-34. https://doi.org/10.1080/21693277.2020.1737592

Olsen, T.L., & Tomlin, B. (2020) Industry 4.0: Opportunities and Challenges for Operations Management. *Manufacturing & Service Operations Management*, 22(1), 113-122. https://doi.org/10.1287/msom.2019.0796

Osterrieder, P., Budde, L.,& Friedli, T. (2020) The smart factory as a key construct of industry 4.0: A systematic literature review. *International Journal of Production Economics*, 221, 1-16. https://doi.org/10.1016/j.ijpe.2019.08.011

Oztemel, E., & Gursev, S. (2020) Literature review of Industry 4.0 and related technologies. *Journal of Intelligent Manufacturing*, 31, 127–182. https://doi.org/10.1007/s10845-018-1433-8

Raj, A., Dwivedi, G., Sharma, A., Jabbour, A.B.L.S., & Rajak, S. (2020). Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective. *International Journal of Production Economics*, 224, 1-17. https://doi.org/10.1016/j.ijpe.2019.107546

Rosin, F., Forget, P., Lamouri, S., & Pellerin, R. (2020) Impacts of Industry 4.0 technologies on lean principles. *International Journal of Production Research*, 58(6), 1644-1661, DOI: 10.1080/00207543.2019.1672902

Shafiq, S.I., Sanin, C., & Szczerbicki, E. (2020) Knowledge based virtual modeling and simulation of manufacturing processes for Industry 4.0. *Cybernetics and Systems*, 51(2), 84-102, https://doi.org/10.1080/01969722.2019.1705546

Silveira, F.D., Neto, I.R., Santos, B.M.D., Gasparetto, R.M.D.O., Machado, F.M. Rodrigues, P.C.C. & Amaral, F.G. (2021). Industry 4.0 perspectives in the health sector in Brazil. *Independent Journal of Management & Production (IJM&P)*, 12(1), 1-14. DOI: 10.14807/ijmp.v12i1.1289

Soylu, A. (2018) Industry 4.0 and new approaches to entrepreneurship. *Pamukkale University Journal of Social Sciences Institute*, 32, 43-57. DOI: 10.30794/pausbed.424955

Stock, T., & Seliger, G. (2016) Opportunities of Sustainable Manufacturing in Industry 4.0. *Procedia CIRP*, 40, 536-541. https://doi.org/10.1016/j.procir.2016.01.129

Şekkeli, H., & Bakan, İ. (2018) By the effect of the Industry 4.0 on Logistics 4.0. *Journal of Life Economics*, 5(2), 17-36. DOI: 10.15637/jlecon.247

Tehci, A., & Ersoy, Y. (2020) Industry 4.0: New Approaches in Production Management and Marketing. *Advanced Manufacturing: Progress, Trends and Challenges,* Ed. Mohammed Arezki Mellal, Nova Science Publisher. ISBN: 978-1-53618-870-7.