Design principles, enabling technologies and challenges for smart manufacturing systems towards industry 4.0*

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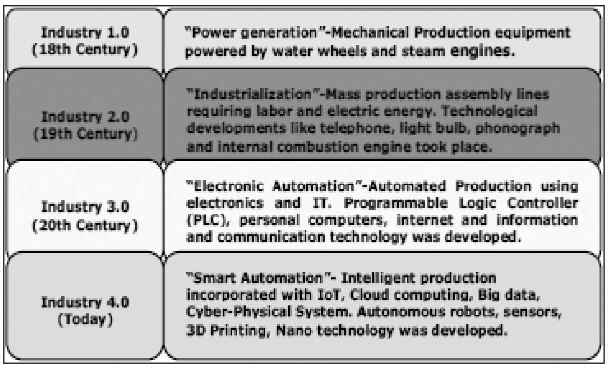
ABSTRACT

Keywords:
Industry 4.0,
Smart Manufacturing system,
Industrial Internet of Things (IIoT),
Cloud Manufacturing,
Intelligent Manufacturing,
Integration Manufacturing,
Additive Manufacturing,
Cyber (digital) — Physical Manufacturing system,
Big Data and Analytics,
Cloud Computing and
Database wireless Sensors.

The revolution of industry 4.0 has resulted in continuous rapid growth of industry and the global market environment. Many manufacturing firms are rethinking & reshaping their traditional process to the smart process and make a step to develop a smart manufacturing system. By adopting the advanced manufacturing techniques such as Artificial Intelligence Manufacturing, Integration Manufacturing, Cyber-Physical system and many more enabling techniques like Big data & analytics, Industrial Internet of Things, Smart Sensors, it is possible to enhance the effectiveness of plant operations. According to the changes of trends in global market, manufacturing firms are turning towards smart manufacturing system. Smart thinking, new innovations in manufacturing sectors result in facing effectively the global and local challenges. Other benefits are increase in operational efficiency, improvement in the machine performance, low manufacturing cost, and many more. The main aim of this paper is to review the related studies on Smart Manufacturing, and its key enabling technologies. From these studies, it gives an idea to implement the advanced technologies in present manufacturing system in the organization and achieve both economic growth of the country and also personal growth of the organizations.

1. Evolution of Industry 4.0



Industry 1.0 (18th Century)	"Power generation"-Mechanical Production equipment powered by water wheels and steam engines.
Industry 2.0 (19th Century)	"Industrialization"-Mass production assembly lines requiring labor and electric energy. Technological developments like telephone, light bulb, phonograph and internal combustion engine took place.
Industry 3.0 (20th Century)	"Electronic Automation"-Automated Production using electronics and IT. Programmable Logic Controller (PLC), personal computers, internet and information and communication technology was developed.
Industry 4.0 (Today)	"Smart Automation"- Intelligent production incorporated with IoT, Cloud computing, Big data, Cyber-Physical System. Autonomous robots, sensors, 3D Printing, Nano technology was developed.

Fig. 1. Shows the key aspects of Industry 1.0-Industry 4.0[1]-[3].

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2. Smart Manufacturing Towards Industry4.0

Smart manufacturing is a new trend, new innovations evolved from the industry 4.0. Smart manufacturing defines a production system or environment which is rapidly growing with the key technologies and it is entirely driven by internet. By adopting the key technologies in manufacturing process according to conditions, its applications and smartness of the technologies, makes traditional manufacturing move towards smart manufacturing. The integration of smart techniques, smart materials, smart machines, smart tooling and smart process and smart sensors are adopted according to production environments and entire system is driven through Internet of things (IoT), which is served as a smart production system and develop smart products according to changing scenario. Such a system is often called as Smart Manufacturing system or Smart Factory (Fig.2) [4].

2.1 Design principles for smart manufacturing: readiness for Industry 4.0

In smart manufacturing system, the design principles of industry 4.0 are adopted & implemented in system. The design principles are grouped into six types as follows:

1) Interoperability: The ability to communicate the technical information within system components which includes objects, machines, & people through the Internet of things,& the Internet of people. Products communicate the business information or data between manufacturing enterprises and customers. A standardized mechanical, electrical, and communication information is very much essential to enhance the interoperability [2] [5].

2) Virtualization/Information transparency: The ability to simulate and create a virtual copy of the actual environments. Cyber physical system

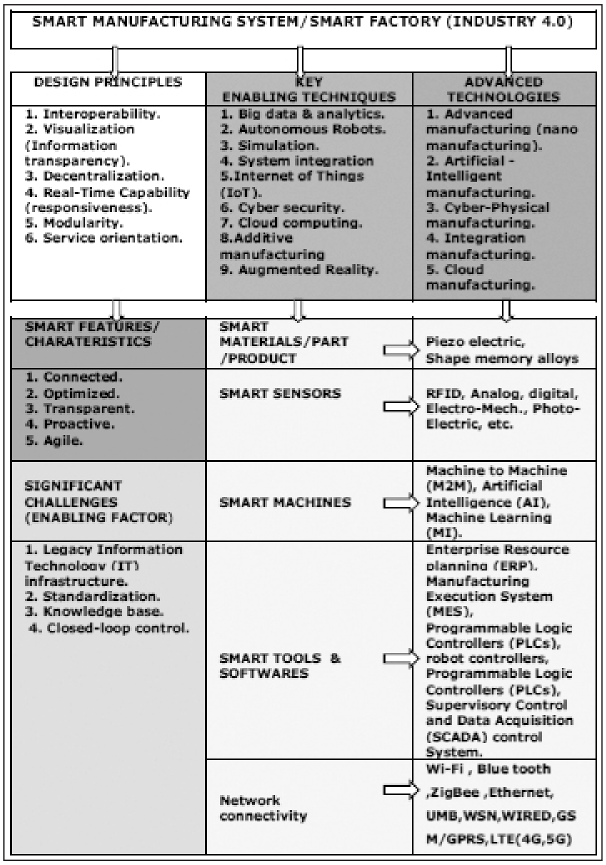


Fig. 2. Overview of smart manufacturing system towards industry 4.0.

(CPS) monitors an objects existing in surrounding environment. From Information transparency of cyber physical system (CPS) and the aggregation of sensors data which enables the creation of Virtual environments. Virtual system (VS) helps to monitor and control its physical aspect which sends data to update the virtual model in real time .Virtual system enables the implementation of designs, creating digital prototypes that are very similar to the real ones. Virtual reality (VR) & Augmented reality (AR) integrates with the mobile devices which provide detailed design of their products to the customers and allow them to track the manufacturing process at each phase [2] [6].

3) Decentralization: The ability to work independently, which gives place for customized products and problem solving. System elements like modules, material handling, products, decisions on their own, unsubordinated to a control unit. The decision is made autonomously in real time without violating the organizational goal. In this system the employees make decisions about ordinary matters on time and change their strategy and direction according to the change in business situations and environments [7]. Decentralization creates a more flexible environment for production, in cases of failure or having conflicting goals [2] [5].

4) Real-Time Capability (Responsiveness): The ability of a system to respond to changes on time like changes in customer requirements, status of production system, malfunctions and resource failures. A smart factory/ smart manufacturing will be able to collect the data, store, analyze, and make decisions according to new findings in real time [8]. Real time capability is not only limited to market research but also to internal processes such as the machine failures. Smart objects must be able to identify the defects and re-delegate tasks to other operating machines. It also contributes greatly to the flexibility and the optimization of production [9].

5) Service-Orientation: Production must be customer-oriented. People and smart objects/ devices must be able to connect efficiently through the Internet of Services to create products based on the customer's specifications. Today, manufacturing industries outsource some of their services, focusing on their core businesses, the idea that manufacturing industries will shift from selling products to selling and services. By this concept Manufacturing industries are becoming service providers as their products have reached competitive equality. By using such a strategy, a product can be sold to customers with almost suitable margin or profit. Not only focus on profit from selling the product, the organizations also focus on selling the service [10] - [12].

6) Modularity: It refers as a design of system components and ability to adapt to a new market. Modularity is defined as the capability of system components to be separated and combined easily and quickly. In some case, it would take a week to study the market and change its production accordingly. On other hand, smart factories must be able to adapt fast and smoothly to changes in market trends [13].

2.2 Key enabling techniques (components) drives the smart manufacturing towards industy 4.0

The nine main key technologies that progressively make up the base of Industry 4.0 are Big Data and Analytics, Cloud computing, Internet of Things (IoT) /Industrial Internet of Things (IIoT), Simulation, Autonomous robots, Augmented reality (AR), Cyber Physical system (CPS), Additive Manufacturing /3D Printing and System Integration. (Fig.3.) [14] [15].

1) Big data and Analytics: One of the major challenges with data has been its quantum; the too many data makes it difficult to identify the relevant information. And it is to be resolved by the means of some intelligent analysis. Big data and analytics techniques make it possible to identify the performance of an individual component and its operating conditions to prevent the future production issues and take preventative action. The collection and comprehensive evaluation of data from many sources like production equipment and systems, and also enterprise and customer-management systems, it will become standard to support real-time decision-making [16].As indicated by Forrester's definition, Big Data consists of four dimensions such as Volume/Variety/Value of data, Velocity of generation of new data and analysis [17].The applications of big data use in manufacturing industries serves many benefits such as Optimize production and enhance efficiency, Predict machine failure and reduce downtime, Increasing energy efficiency, Optimize the supply chain, Enhance product quality, and cut manufacturing cost.

Fig. 3. Key technologies of smart manufacturing towards industry 4.0. (Source: automation.isa.org)

2) Cloud computing: Cloud computing serves as a technical backbone for the connection and communication of manifold elements of the application centre of Industry 4.0. From Industry 4.0, organization needs increasing data sharing across the sites and companies, i.e., achieving the reaction times in milliseconds or even faster [16].“Digital production/Cyber production” is a concept of having the connections of different devices to same cloud to share information with one another and can be extended to the set of machines from a shop floor as well as the entire plant [18]. Outfitting cloud capacities to collect data from manufacturing process and distribute the data to different users and partners is a useful asset helps to save money, enhance safety and security operations, optimize production processes, and speed up project implementations. Cloud computing provides manufacture with abilities for implementing advanced software applications, extending portability & supporting new technologies which are driven through Internet- IoT/ /IIoT, Big Data & Artificial Intelligence activities.

3) Internet of things (IoT) / Industrial internet of things (IIoT): Internet of things (IoT) is a main key used in Industry 4.0 to derive the solutions. The Internet of Things is global network interconnected with uniform addressed objects that communicate via standard protocols. Internet of Things (IoT) is also known as Internet of Everything (IoE), which consists of Internet of Service (IoS), Internet of Manufacturing Services (IoMs), and Internet of People (IoP), Embedded System and also Integration of Information & Communication technology (IICT).It is also defined as the system of inter related computing devices, mechanical & digital machines. Setting, pervasiveness, and optimization are the three key features of IoT in which setting refers the possibilities of cutting edge object communication with a current situation, and immediate response to the off chance that anything changes. Pervasiveness provides information of location, physical or air atmospheric conditions of object. Optimizations illustrates that the present items are something other than association with system of human administrators at human-machine interface. Internet of things (IoT) is also called Industrial Internet of things (IIoT) where Smart sensors and actuators are utilized to upgrade manufacturing and modern procedures. The Industrial of things (IIoT) empowers the intensity of smart machines and ongoing examination to exploit the information or data that put a way in the machines. Software and data are main two key elements of IIoT which are used for intelligent planning & control of machines and factories of the future. Benefits of IIoT in manufacturing process and control includes: 1) Enabled connection between machines & manufacturers. 2) Control over joint systems. 3) Deeper insight into the manufacturing business decisions. process. 4) Data analysis helps to make smarter 5) Enhanced production work flow by automation & optimized production processes. 6) Devices connected to the network allow equipment management and control from any location. 7) Sensor data provides a better overview of power consumption. 8) Time-saving & cost prevention. 9) Reduced downtime. 10) Better product quality. 11) Reduced risks of human error. 12) Easy machine assessment to determine whether the machine needs a repair. 13) Improved safety. 14) Real-time overview of ongoing activities. 15) Improved management of the global supply chain. 16) Customer satisfaction [19].

4) Simulation: The simulations of systems analyze the various situations occur within the manufacturing system. After evaluating the situation area, cost effective solutions can be developed, tested and enforced much quicker, which leads to reduced cost and time to market. It is extensively used in plant operations to leverage real-time data and to mirror the physical world in a virtual model, it includes machines, products, and humans. There will be reduction in down time of machines and setup times leading to increased quality [16].The simulation of produc -tion processes not only shorten down times and changes it &also reduce the production failures during the startup stage [20].Quality decision making can be improve d by easy and fast way with the help of simulation [21].

5) Autonomous robots: To automate production methods across the various sectors, autonomous robot are used and it’s powered driven by the conception of Internet of Things (IoT). This connects devices & computer machines to communicate with one other, materials can transport across the factory floor through autonomous mobile robots (AMRs), avoiding obstacles, coordinating with fleet mates, identifying where pickups and drop offs area unit are required in real-time. By connecting to a central server/database, the actions of robots that can be coordinated & automated, at a larger extent can be achieved than ever before. Autonomous robots can complete tasks precisely and intelligently, with a minimal human input focus on safety, flexibility, versatility and collaboratively [16].

6) Augmented reality (AR): Augmented reality support a variety of services, such as selecting parts in a warehouse, and sending repair instructions over mobile devices. Industry can use of augmented reality to provide workers with real-time-information to improve decision-making and work procedures. Workers may receive instructions to repair, & think on how to replace a particular part as they are looking at the actual system needing repair [16]. Leveraging the application of 3D & IoT technology can create compelling augmented reality that help to build better products, enable safety, improve efficiencies and more productive environment for workers customers [15].

7) Cyber Security and Cyber Physical Systems (CPS): The security of information becomes paramount as we tend to move away from closed systems towards increased connectivity (network) from the IoT and cloud. Security and reliability empowers the successful implementation of a genuinely present day and digitized production work flow, by utilizing all the advantages of a connected environment. Increased in the connectivity and the use of standard communications protocols from the revolution of Industry 4.0, the need to protect critical industrial systems and manufacturing ines from cyber security threats increase dramatically. As a result, the secure, reliable communications, sophisticated identity, and access management of machines and users has become essential [16]. The strong connectivity of the physical, the service and the digital world can improve the quality of information which is essential for planning, optimization and operation of manufacturing systems. Cyber security helps to preserve the details like design data, and other production details. The Cyber Physical System is defined as the systems in which natural and human made systems (physical space) are integrated with computation, communication and control systems (cyber space) [17]. Decentralization and autonomous behavior of the production process is the main characteristics of Cyber Physical System [10]. Use of proper sensors in CPS will find out the failure occurring in machines automatically and prepare for fault repair actions on CPS. These results in the optimum utilization of operation performed on that station, increase the efficiency and reduced the cycle time.

8) Additive manufacturing/3D printing: The individual objects or personalized products, that offers construction advantages, such as complex, lightweight designs. Its use either directly with the customer or by suppliers to improve becomes important and continuously increasing for small-batch production applications and production of the existing designs with increase in performance, flexibility, and cost-effectiveness. High-performance, decentralized additive manufacturing systems will reduce transport distances and stock on hand [16]. The production process should be faster, and it is manufactured at cheaper rate, by the use of additive manufacturing technologies like fused deposition method (FDM), selective laser melting (SLM), and selective laser Sintering (SLS.) As the needs of customer is changing continuously the challenge of increasing individualization of products and reducing time to market are faced by many companies. These difficulties can be overcome with increasing digitization, IT penetration and networking of products, manufacturing resources and processes.

9) System Integration: Most of the systems are highly automated within their own operations, and struggle to communicate with other systems. A standards and open architectures support to transfer the information easily for both to the business and to the customer/end user. This could use to defining common languages for data exchange. E.g, for job information-JDF, color information - CFx, etc.In industrial organization,Integration and self-optimization are the two major mechanisms widely used .From the revolution of Industry 4.0, integration system is outlined, such as horizontal integration across the entire value creation network, vertical integration networked manufacturing systems and end-to-end engineering across the entire product life cycle [11].

2.3 Smart manufacturing systems embedded with advanced technology

The Various Technologies discussed in the previous section have been used to develop Smart Manufacturing Systems (SMS's) such as i) Intelligent Manufacturing System: Artificial Intelligence (AI) play an essential role in this system ii) Internet of Things (IoT) - enabled Manufacturing system: Real –time data and Softwares are key elements of this systems, iii) Cloud manufacturing System: Cloud deployment modes, manufacturing resou- rces modeling requirements, and services are key terms consider in cloud manufacturing system, iv) Integrated Manufacturing System: The Machine to Machine (M2M) integration and cloud data play an important role in this system,v) Physical-digital-Physical Manufacturing system /Cyber-Physical Manufacturing/Digital Manufacturing System: Integration of Key Enabling technologies in system which helps to support & complete the physical to digital to physical cycle. vii) Advanced manufacturing system: Digital modeling and fabrication, nano-manufacturing, power-electronics and semi-conductor manufacturing technologies are considered in the advanced manufacturing system. Based on physical manufacturing technology the advanced manufacturing system are grouped into Flexible Manufacturing System (FMS), Reconfigurable Manufacturing system (RMS), Computer Integrated Manufacturing (CIM),Nano Manufacturing , Additive Manufacturing [12] [27].

2.4 Smart Sensors - smart machines for smart manufacturing

a) Smart Machines enable through Smart Sensors: A Smart machine defined as a device which is embedded with Machine-to-Machine (M2M), Cognitive computing technologies like Artificial Intelligence (AI), Machine Learning (ML) which is use to solve problems, make ultimate decisions, and take action. Smart machines include robots, self-driving cars and other cognitive computing systems that are designed to work through tasks without human intervention. The Smart Machines capabilities will continue evolving greater autonomy, flexibility & adaptability. Self-monitoring and prognostics enable smart machines to detect the problems and even analyze issues. The machine is retrofitted with prognostic capabilities which include smart sensors driven through internet. By analyzing the data collected from sensor, optimize the maintenance plans, increase the up time and avoid excessive expenses for preventative maintenance [22].

b) Smart sensors drives through connective networks IoT: Smart sensors are not the same as sensors, the smart sensors are propelled stages with advanced technologies which include: microprocessors, storage, diagnostics, and connectivity tools which empower to change the customary input signals into genuine digital insights. These smart sensors give the convenient and profitable information to control. To communicate and transfer the data through internet, enable networks such as Wi-Fi, Bluetooth, RFID, and others are used [23].

2.5 Smart network connectivity (wireless connective technologies & standards) driven by Iot

For computing, communication and control, the technologies are integrated to other system which composed on support of existing wireless communication networks and standards. The different standards which integrate various technologies are used in different areas for communication for example, ZigBee- low data rate, low power consumption, low cost, Bluetooth- short range with slow power consumption, Wi-Fi high range with high speed, LoRaWAN- Long Range & low power, Passive Optical Network (PON)- works without any power requirements or active electronic parts, Mobile Cellular Networks-LTE,3G/4G/5G) [24].

2.6. Smart/materials/products/parts

The Characteristic of a material can change its configuration to be reused in the same form or other form, and then it is termed as a "Smart material". For example consider resilience is one of the characteristics of smart material. It is defines as the ability by which a material/ product/part/ would be able to retain its original form after. In intelligent control system, resilience can be placed, because a part may require intelligent control to return in its original form. The Sensing technology (Tracking and tracing technology) can find the past and present locations of product by using sensors and these sensors are referred to as “Smart sensors”. The configurations of smart sensors with processors and software, for an efficient exchange of data, it is termed as "Smart products/parts". Smart Materials detect the adjustment in condition and activities with the assistance of sensors and take the restorative activities by using smart sensors and actuators. For instance smart materials like piezoelectric gadgets, shape memory & combinations of their uses in industry, the incorporating of material, product and parts in the manufacturing system is named as Smart Material/Product/Part [25].

2.7 Smart tools and softwares for smart manufacturing (IT based production system)

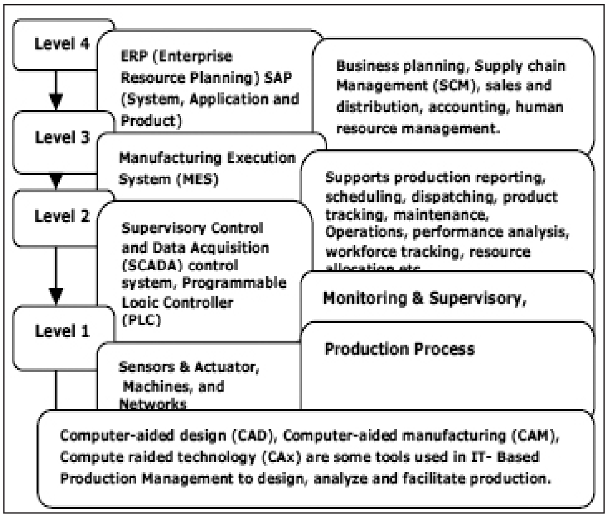


Fig. 4. Tools and software used in smart manufacturing system [4] [23].

2.8 Smart features or smart characteristics of smart manufacturing

The smart manufacturing system has five major features such as i) Connectivity- Processes, machines, and humans are connected to provide real-time data to make decisions. ii) Optimization - Uptime and productivity, highly automated with minimal human interaction. iii) Transparency- Visibility of customer demands forecasts, order tracking, & other live metrics that allow for real-time decision-making. iv) Proactive - Constantly stocking and replenishing materials, early identification of supplier quality issues, and real-time safety monitoring. v) Agile-Adaptable scheduling changeovers, implementation of product changes in real time, and configurable factory layouts, and equipment. Each smart feature play an role in enabling decisions and help organizations improve the production process [26].

2.9 Significant challenges of smart manufacturing

There is development of new trends and innovation in smart manufacturing towards industry 4.0 from all advance technologies in manufacturing systems, but still it faces significant challenges mainly in the following areas: i) Legacy Information Technology (IT) infrastructure: In many organizations, basically Information Technology (IT) infrastructures were developed as communication networks for linking the different data or information pools. It is efficient for limited data handling and becoming more and more difficult to deal with huge amounts of data and information across different manufacturing platforms. This particularly faces significant ant security challenge while adopting a powerful cloud computing system. And Legacy Information technology (IT) infrastructure must be re-evaluated or replaced for the new manufacturing paradigm. ii) Standardization: Standardization as become essential in every organization, to integrate different elements in manufacturing systems, including both hardware and software. The communication of input/output and protocols must be standardized for efficient and secure data transfer at device level. Interfaces between software modules must be standardize so that the potential of computational intelligence can be fully utilized. iii) Knowledge base: The implementation of intelligent manufacturing technology in the organizati- ns and the availability of an effective knowledge base is still the bottleneck stage. Although the Machine Learning (ML) techniques have been adopted for the construction of knowledge bases from data, the significant challenges remain the same because of the high levels of uncertainty in the manufacturing environment. Many associates are working together to build a knowledge base, but a practical and the effective knowledge base is yet to be developed for monitoring and controlling the manufacturing system. iv) Closed-loop control: In intelligent manufacturing, the Predictive analytics have been playing as significant role. However, the implementation and impact on the factory floor is still very limited. The connection between analytics and actuation must be relatively closed so that a truly intelligent closed-loop control system strategy can be implemented in the next generation of intelligent manufacturing. At this point both hardware and software innovations are urgently required for the development of cloud manufacturing systems [27].

4. Conclusion

This paper mainly focused on the concept on industrial revolution, Industry 4.0, which leads to build a Smart Production System (Smart Factory), Smart Production Process (Smart Manufacturing). Design principles, key technologies, enabling factors which drive the smart manufacturing system are discussed. From this study it gives an idea of implementing / adopting the Smart design principle, Smart technologies driven by Smart enablers like IoT, could computing, smart sensors and smart tools and software with Smart characteristics in manufacturing system. The smartness serves not only to compete globally but organizations can gain many benefits like precise quality, produce customized product with reasonable cost at effective time at the same time gain profit to the organizations and achieve all possible goals set by the organization.

References

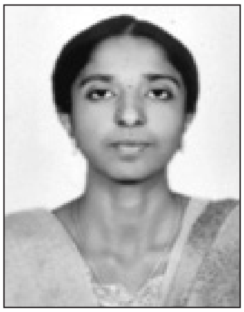
1. Xu, Min; David, Jeanne M; Kim, Suk Hi: The Fourth Industrial Revolution: Opportunities & Challenges, International Journal of Financial Research, vol. 9, no. 2, 2018, 90-95,Doi:10.5430/ijfr.v9n2p90.
2. Mabkhot, M; Al-Ahmari, A; Salah, B; Al-Khalifa. H: Requirements of the Smart Factory System: A Survey and Perspective, 'Machines', vol. 6(2), 2018, 1- 22, Doi: 10.3390/machines 6020 023.
3. Koch, V; Kug; Geissbauer, DR; Schrauf, S; Industry 4.0: Opportunities & Challenges of the Industrial Internet, 2015, 1-52, https://www.strtegyand.pwc.com/media/file/Industry4.0.pdf.
4. Sameer Mittal; Muztoba Ahmad Khan; David Romero; Thorsten Wuest: Smart manufacturing: Characteristics, technologies and enabling factors, 'Journal, Engineering Manufacture', vol. 233, no. 5, 2019, 1342-1361, Doi:10.1177/0954405417 736547.
5. Tantik, E; Anderl, R: Integrated Data Model and Structure for the Asset Administration Shell in Industrie, Procedia CIRP, vol. 60, 2017, 86-91, https:// doi.org /10.1016/ j.procir.2017.01.048.
6. Zawadzki, P; Zywicki, K: Smart product design and production control for effective mass

customization in the industry 4.0 concept, Manufacturing & Production Engineering Reviews, vol. 7, no. 3, 8 October 2016, 105 -112, https://doi.org/10.15 15 /mper-2016-0030.

7. Shamim, S; Cang, S; Yu, H; Li, Y: Examining the feasibilities of Industry 4.0 for the hospitality sector with the lens of management practice, Energies, vol. 10, no. 4, April 2017, 1-19, Doi:10.3390/en10040 499.
8. Hofmann, E; Rusch, M; Industry 4.0 and the current status as well as future prospects on logistics", Computers in Industry, vol. 89, 2017, 2-34, http://dx.doi.org/10.1016/j.compind .2017.04.002.
9. Penas, O; Plateaux, R; Patalano, S; Hammadi, M: Multi-scale approach from mechatronic to Cyber-Physical Systems for the design of manufacturing systems, Computers in Industry, vol. 86(C), April 2017, no: 52–69, Doi:10.1016/j. compi nd.2016.12 .0 01.
10. Landherr, M; Schneider, U; Bauernhansl, Ivanov, D; Sokolov, B; Ivanova, M: Schedule Coordination Cyber-Physical Supply Networks Industry 4.0, IFAC conference, Elsevier, vol. 49, no. 12, 2016, 836–839, https://doi. org/10.1016/j.ifacol.2016.07.87 9.
11. Stock, T; Seliger, G: Opportunities of Sustainable Manufacturing in Industry 4.0, 13th Global Conference on Sustainable Manufacturing - Decoupling Growth from Resource Use, Procedia CIRP, vol. 40, 2016, 536-541, Doi: 10.1016/j.procir.2016.01.129.
12. Li, B; Hou, B; Yu, W; Lu, X; Yang, C: Applications of artificial intelligence in intelligent manufacturing: A review, Frontiers of Information Technology & Electronic Engineering, vol. 18, no. 1, 2017, 86-96, Doi: 10.1631/FITEE.1601885.
13. Hermann, M; Pentek, T; Otto, B: Design Principles for Industrie 4.0 Scenarios: A Literature Review, Research Gate, Working Paper No. 1/2015, January 2015, 1-16, Doi:10.13140/RG.2.2.29269.222 48.
14. Chouhan, Swarnima; Priyanka Mehra; Ankita Daso: India's Readiness for Industry 4.0 - Global Innovation & Technology, Grant Thornton India LLP, 2017.
15. Bohan, Mark: Next Level: 9 Components of Industry 4.0, Heidelberg Connect, August 30, 2016, https://news.heidelbergusa. com/2016/08/9components of 4-0/.
16. Rubmnn, Michael; Lorenz, Markus; Gerbert, Philipp; Waldner, Manuela; Justus, Jan; Engel, Pascal; Harnisch, Michael: Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries, The Boston Consulting Group (BCG), vol. 09, April 2015, https://www.zvw.de/media.media.72e472f b-1698-4a15-8858-344351c8902f. orginal.pdf.
17. Witkowski, K: Internet of Things, Big Data, Industry 4.0- Innovative Solutions in Logistics and Supply Chains Management, 7th International Conference on Engineering, Project, and Production Management, 'Procedia Engineering', vol. 182, 2017, 763-769, Doi:10.1016/j.proeng.2017.03.197.
18. Marilungo, E; Papetti, A; Germani, M; Peruzzini, M: From PSS to CPS design, a real industrial use case toward Industry 4.0, The 9th CIRP IPSS Conference, Circular Perspectives on Product/Service - Systems, 'Procedia CIRP', vol. 64, 2017, 357-362, Doi: 10.1016/j. procir.201 7.03.007.
19. Rita Sharma: How IoT Works in Manufacturing Industry, Finoit,https://www.finoit.co m /blog /Iot-manufacturing-industry.
20. Simons, S; Abe, P; Neser, S: Learning in the AutFab – the fully automated Industrie 4.0", learning factory of the University of Applied Sciences Darmstadt, 7th Conference on Learning Factories, CLF 2017, Procedia Manufacturing, vol. 9, 2017, 81-88, Doi: 10.1016/j.promfg.2017.04.023.
21. Saurabh Vaidya; Prashant Ambad; Santosh Bhosle: Industry 4.0 – A Glimpse, 2nd International Conference on Materials Manufacturing and Design Engineering, Procedia Manufacturing, vol. 20, 2018, 233-238, Doi:10.1016/j.promfg.2018.02.034.1016/J. ENG.2017.04.009.
22. What are smart machines?–Definition, WhatIs.com – Search CIO, https://searchcio. techtarget.com/definition/smart-machines/.
23. Rojko, Andreja: Industry 4.0 Concept: Background and Overview, 'International Journal of Interactive Mobile Technologies (iJIM)', ECPE European Center for Power Electronics e. V., Nuremberg, Germany, vol. 11, no. 5, 2017, 77-99, https://doi.org/10.3991/ ijim.v 11i5.7072.
24. Deloitte source using smart sensors to drive supply chain innovation https://www2. deloitte.com / content/dam /Deloitte/us/ Documents/process-and-operations/us-conss martsensors.pdf.
25. Penas, O; Plateaux, R; Patalano, S; Hammadi, M: Multi-scale approach from mechatronic

to Cyber-Physical Systems for the design of manufacturing systems, Computers in Industry, vol. 86(C), April 2017, 52-69, Doi:10.1016/j. compi nd.2016.12 .0 01

26. Burke, Rick; Mussomeli, Adam; Laaper, Stephen: Marty Hartigan.,Brenna Sniderman., The smart factory, Deloitte University Press, 2017, https://www2.deloitte. com/content/dam/insights/us/articles/4051_The-smart-factory/DUP_The-smart-factory.pdf.
27. Chen, Yubao: Integrated &Intelligent Manufacturing: Perspectives & Enablers, 'Engineering', vol. 3, no. 5, October 2017, 588-595 ◘



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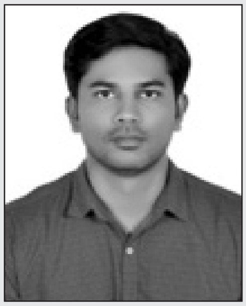

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