Smart Manufacturing: A Primer

[1]Matthew N. O. Sadiku, [2]Olaniyi D. Olaleye and [3]Sarhan M. Musa,
[1,3]Roy G. Perry College of Engineering, Prairie View A&M University, Prairie View, TX, USA
[2]Barbara Jordan-Mickey Leland School of Public Affairs, Texas Southern University, Houston, TX, USA

Abstract: Today, manufacturers are facing the challenges of shortened product lifecycle, increasing customer-oriented value, global competition, and sustainable development. Smart manufacturing (SM) is envisioned as a good approach to tackle these challenges. It may be regarded as an integration of multiple users, multiple systems, and multiple technologies of information processing. It is expected to have the abilities to assist in decision-making, to adapt to new situations, and correct fabrication problems in a dynamic manufacturing environment. This paper provides a primer on smart manufacturing.

Keywords: *Smart Manufacturing, Data-Driven Smart Manufacturing, Smart Factory, Industry 4.0*

I. INTRODUCTION

Manufacturing is the process of creating a product out of raw materials. The manufacturing industry includes many sectors such chemical industry, metal machinery industry, and electronics industry. Manufacturing has gone through transformations and become more automated, computerized, and sophisticated. The increasing impact of ICT and digital technologies on manufacturing industry is leading to the development of new methods and tools that support the adoption of new production and product development technologies. The manufacturing system is moving toward a more reliable and intelligent direction. The future of manufacturing is geared towards producing customer-specific products ensuring short product life cycles, quick delivery times, zero defect production, and resource-efficient manufacturing [1]. The features can be achieved by smart manufacturing, which is also known as intelligent manufacturing. Due to environmental and resource limitation, smart manufacturing seems to be the only way to improve the level of manufacturing systems.

Smart manufacturing (SM) has gained significant impetus as a breakthrough technological development that can transform the landscape of manufacturing today and tomorrow. It aims to take advantage of advanced information and manufacturing technologies to enable flexibility in physical processes to address a dynamic and global market. It is becoming the focus of global manufacturing transformation and upgrading.

Interest in smart manufacturing has continued to increase under different terms:

smart manufacturing in the United States, Industry 4.0 in Germany, and Smart Factory Korea. This indicates several initiatives of the same concept in many locations across the globe [2]. As illustrated in Figure 1, smart manufacturing represents the fourth industrial revolution, arrived after the invention of the steam engine, mass production and industrial automation [3]. The fourth industrial revolution is transforming global manufacturing. It is based on the application of Internet of things and servitization concepts into manufacturing companies.

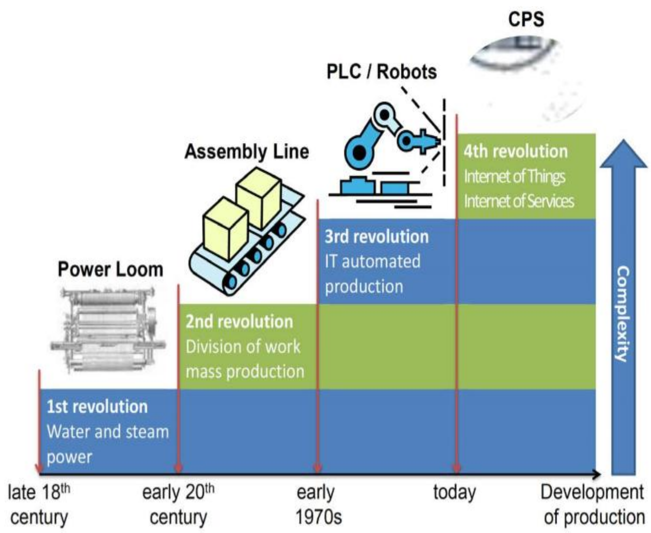

Figure 1: Four industrial revolutions [3].

II. OVERVIEW OF TRADITIONAL MANUFACTURING

Manufacturing is the way of transforming resources into products or goods which are required to cater to the needs of the society. It started from a small-scale production line of crafts in 1800s. It has evolved into large-scale mass production. The 2000s is the era when computerized and personalized manufacturing systems came into existence for mass production lines [4]. Manufacturing is typically a series of processes comprising of selection of raw materials, production of objects, assembling of parts, inspection, and dispatching [5]. It may include foundry, forging, jointing, heat treatment, painting, etc. It involves using resources to meet the delivery date, cost, quality, and optimal economic goals in limited resources condition. It often involves mass production and heavy energy consumption such as coal or electricity.

The traditional or current manufacturing processing techniques consume lot of energy, mainly for production and utility. They also produce a lot of pollution and add to the deterioration of the global environment. Because of this, manufacturers are gradually transforming their manufacturing systems from traditional mass production to flexible lean systems. With rapid changes in technology, manufacturing itself is constantly transforming and evolving [6]. It now takes a proactive role in the development of cleaner manufacturing processes. In order to minimize the environmental damage due to manufacturing, there is a need of new manufacturing process.

In modern times, two types of manufacturing systems have emerged emphasizing waste minimization. They are "lean" manufacturing systems and "green" manufacturing systems that both reduce waste. Lean manufacturing seeks to eliminate all types of wastes generated within a production system. In lean manufacturing, there are eight categories of waste that should be monitored [7]: (1) Overproduction, (2) Waiting, (3) Inventory, (4) Transportation, (5) Over-processing, (6) Motion, (7) Defects, and (8) Workforce.

Smart manufacturing will transform traditional manufacturing from cost operations into added-values operations and increase competitiveness. It is a value-creation process from design to production, logistics, and service. Through SM, manufacturing is shifting from knowledge-based intelligent manufacturing to data-driven and knowledge-enabled smart manufacturing [8]. In SM systems, data analytics plays an important role in turning data into valuable insights to assist decision making.

III. FEATURES OF SMART MANUFACTURING

Smart manufacturing (SM) is a term coined by several agencies in the United States and increasingly used globally. Other initiatives such as Industry 4.0, cyber-physical production systems, smart factory, intelligent manufacturing, and advanced manufacturing are frequently used synonymously with smart manufacturing. SM is characterized by the integration of new-generation information communication technology (ICT) and manufacturing industry. The core of achieving integration refers to the Cyber-Physical Systems (CPS) capable of connecting real physical world and virtual network world. Thus, SM incorporates several technologies, including CPS, IoT, robotics/automation, big data analytics, cloud computing, artificial intelligence (AI), and smart sensing, and cognitive technologies. Some of these enabling technologies are shown in Figure 2 [9]. These technologies enable manufacturing digitalization in the smart manufacturing context. They have brought valuable opportunities to the manufacturing industry such as providing a new way to carry out smart production and precision management. They also make a manufacturing system become ‘‘smart.’’

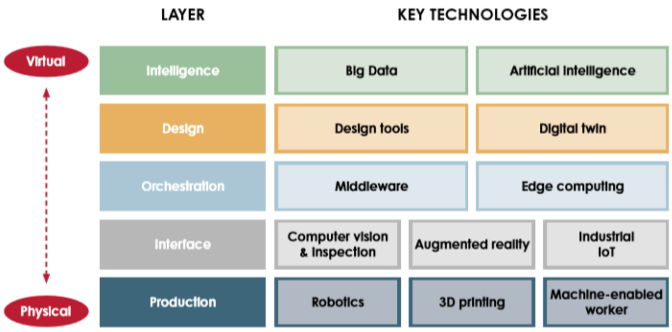

Figure 2: Some enabling technologies [9].

Cyber-physical system (CPS) is a key technology for smart manufacturing. CPS consists of physical entities (such as machines, vehicles, work pieces, etc.), which are equipped with technologies such as RFIDs, sensors, microprocessors, telematics or embedded systems. The Internet of things (IoT) is essentially the connection of machines, devices and “things” wirelessly. IoT allows devices to be monitored and controlled remotely over the communication network. It has shown great potential in device communication, connections, and data collection, thereby laying a solid foundations for cyber–physical integration. The key trends in smart manufacturing and supply chain are illustrated in Figure 3 [10].

Figure 3: Key trends in smart manufacturing and supply chain[10].

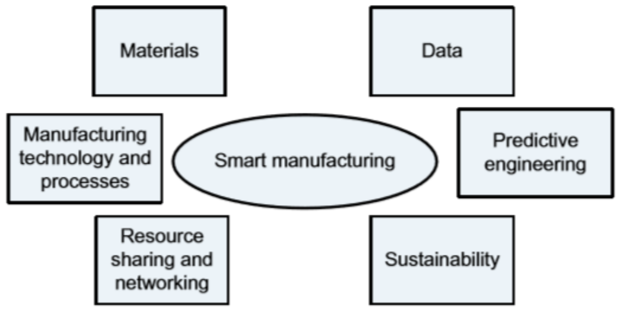

Figure 4: Six pillars of smart manufacturing [11].

Smart manufacturing, which is the fourth revolution in the manufacturing, has its own identity captured in the following six pillars [11], shown in Figure 4: (1) manufacturing technology and processes, (2) materials, (3) data, (4) predictive engineering, (5) sustainability, (6) resource sharing and networking. Three more pillars can be added [12]: (7) improved efficiency, (8) risk reduction, (9) and agile decision making. Smart manufacturing (SM) systems include data collection, data management, and data analysis, which provide real time actionable information required to build system intelligence into manufacturing operation.

Smart manufacturing often involves making available the right data in the right form, the right people with the right knowledge, the right technology and the right operations. Thus, smart manufacturing system covers four areas [13]:

(1) *Smart Parts:* The sensor technique is applied to the components so that they can have self-sensing capability of sensing temperature and vibration to improve reliability and service life.

(2) *Smart machine:* This collects information on the operating status of various parts of the machine, conduct big data analysis, detect abnormalities as early as possible.

(3) *Smart Production Line:* The machines on the production line can communicate and support each other to increase the production efficiency.

(4) *Smart Factory:* This is linked with consumer needs and provide customized services. The Internet is used to link the

management systems between factories to control the production schedule of products.

IV. GOALS OF SMART MANUFACTURING

Modern manufacturing industry seeks to improve competitiveness through the convergence with cutting-edge ICT technologies. Smart Manufacturing is the collection of technologies that support effective and accurate engineering decision-making in real time [14]. The main goals of smart manufacturing are as follows: to foster technological and economic growth, build a customer-aware agile platform, make resources available when they are needed, create the required workforce, improve safety and sustainability in the manufacturing industry, reduce energy use and waste streams from manufacturing plants, and seamless interoperation of manufacturing automation equipment from different vendors allowing plug-and-play configurations [15].

Applying the SM concept to the future smart factory may require equipping it with robots, advanced sensors, and intelligent machine. The improved SM processes will handle and manage more operational complexity [16].

Several groups have been formed to advance smart manufacturing, with the most prominent being the Smart Manufacturing Leadership Coalition (SMLC), Industry 4.0, and the Industrial Internet Consortium. These groups comprise industry, academic, and government partners [17].

V. APPLICATIONS

Some typical applications of smart manufacturing include the following.

- *Chemical Industry*: The chemical industry can apply smart manufacturing for chemicals with target final properties. For the chemical process industry, smart manufacturing should not only maximize economic competitiveness, but also significantly reduce safety incidents.
- *Semiconductor Manufacturing*: The semiconductor manufacturing technologies are the prime mover of consumer electronics market. As technologies advance, semiconductor manufacturing processes are becoming more and more complicated and how to maintain their production yield becomes an important issue. A smart manufacturing platform can be designed to realize yield enhancement and assurance [18].
- *Energy System*: Fuel cell vehicles utilize onboard stored hydrogen to produce onboard electricity to power the electric motor. The Department of Energy (DOE) has set some targets for onboard hydrogen storage, which includes a limit on the operating temperature and refuel rate of the hydrogen storage system. Smart manufacturing technologies can be adopted to address the operational challenges in the onboard hydrogen storage in metal hydride.
- *Smart Machining*. In smart manufacturing, smart machining can be achieved with the help of smart robots and various other types of smart objects that are capable of real-time sensing. CPS-enabled smart machine tools are used for producing products. For example, CPS-enabled smart machine tools can capture the real-time data so that machines tools and their services could be synchronized to provide smart manufacturing solutions. Various sensors and data acquisition devices are deployed in the machine tools to collect real-time machining data [19].

Other applications include smart monitoring, smart control, the blade smart manufacturing system, and resin transfer molding.

VI. BENEFITS AND CHALLENGES

Today, manufacturing is getting smart. Smart manufacturing will transform how products are designed, fabricated, operated, and used. Potential benefits of smart manufacturing include cost reduction, production flexibility, shorter product times-to-market, energy efficiency, environmental impact reduction, increased productivity, and quality gains. SM technologies can help you create highly differentiated, cost-effective, and competitive products that meet today’s market needs. SM promotes energy and environmentally efficient production. With the shortage of engineers today and the pressure to maintain competitive edge, SM can help deliver the right products, at the right cost, at the right time. It can make industry more efficient, profitable, and sustainable, reducee energy usage, zero incidents, and faster technology and product adoption. Through increased efficiency of labor and materials, creating new jobs, and having more reliable results, most companies using SM will see an ROI on their investments within a short period of time [20].

Smart manufacturing offers both benefits and challenges. A major bottleneck in smart manufacturing is achieving the communication and interaction between the physical and virtual spaces of manufacturing. SM technologies cannot be adopted independently. The workforce skills gap generated by a more-connected manufacturing system must be addressed and given a top priority in companies planning to adopt SM. Security must play a major role in the development of future smart manufacturing systems.

CONCLUSION

Modern manufacturing systems require timely and efficient production tasks. Almost of all aspects of manufacturing will need to change as the industry transitions to become fully digital. Smart manufacturing systems will basically transform product manufacturing, customization, and delivery. They can optimize the entire business processes and operation procedure of manufacturing with the goal of achieving higher level of productivity and quality gains.

The transition from current manufacturing to smart manufacturing is an daunting task. Although smart manufacturing is still under development, it is becoming indispensable in global manufacturing. Globalization and competitiveness are forcing companies to re-think and innovate their production process. Smart manufacturing has been a topic of great interest among practitioners, strategists, academicians, and governments. Various governments have proposed SM initiatives to facilitate the development of their own manufacturing industries. Most large companies have started to adopt SM [21]. More information on smart manufacturing can be found in the related journals: *Journal of Engineering Manufacture* and *Journal of Manufacturing Systems.*

References

[1] N. Anwer, B. Eynard, and L. Qiao (eds.), “Editorial for the special issue on ‘smart manufacturing and digital factory’,” *Journal of Engineering Manufacture***,** vol. 233, no. 5, 2019, p. 1341.

[2] S. Jain. D. Lechevalier, and A. Narayana, "Towards smart manufacturing with virtual factory and data analytics," *Proceedings of the 2017 Winter Simulation Conference*, 2017.

[3] P. P. Khargonekar, "Future of smart manufacturing in a global economy," http://faculty.sites.uci.edu/khargonekar/files/2018/05/Smart_MFG_1.0.pdf

[4] Y. Nukman et al., "A strategic development of green manufacturing index (GMI) topology concerning the environmental impacts," *Procedia Engineering*, v. 184, 2017, pp. 370 – 380.

[5] D. Swathisri and D. S. S. Kumar, "Green manufacturing technologies – A review,"https://www.researchgate.net/publication/305731124_GREEN_MANUFACTURING_TECHNOLOGIES_-_A_REVIEW

[6] https://www.engr.uky.edu/ism

[7] G. D. Maruthi and R. Rashmi, "Green manufacturing: It's tools and techniques that can be implemented in manufacturing sectors," *Materials Today: Proceedings*, vol 2, 2015, pp. 3350 – 3355.

[8] F. Tao et al, **"**Digital twins and cyber–Physical systems toward smart manufacturing and Industry 4.0: correlation and comparison," *Engineering*, vol. 5, no. 4, August 2019, pp. 653-661.

[9] L. Ogbeveon, "Smart manufacturing: The rise of the machines," June 2019https://oden.io/blog/smart-manufacturing-the-rise-of-the-machines/

[10] "4 Key trends to watch in smart manufacturing and supply chain,"August 2016, https://tla.edu.sg/4-key-trends-watch-smart-manufacturing-supply-chain/

[11] A. Kusiak, "Smart manufacturing," *International Journal of Production Research*, vol. 56, no. 1-2, 2018, pp. 508-517.

[12] "Smart manufacturing," https://grantek.com/capabilities/smart-manufacturing?utm_source=google&utm_medium=cpc&utm_campaign=smart_manufacturing&gclid=EAIaIQobChMIj92SjZq65QIVgobACh0h2ATwEAMYASAAEgIo_vD_BwE

[13] T. C. Chan, "The development of smart manufacturing and cases study in Taiwan," *Proceedings of IEEE International Conference on Advanced Manufacturing*, 2018, pp. 117-118.

[14] H. S. Kang et al., "Smart manufacturing: Past research, present findings, and future directions," *International Journal ff Precision Engineering and Manufacturing-Green Technology*, vol. 3, no. 1, January 2016, pp. 111-128.

[15] G. S. Ogumerem and E. N. Pistikopoulo, "Smart manufacturing," *Kirk-Othmer Encyclopedia;* John Wiley & Sons, 2019.

[16] "Smart manufacturing – The landscape explained," White Paper #52, A MESA International white paper,2016 http://www.mesa.org/en/resources/MESAWhitePaper52-SmartManufacturing-LandscapeExplainedShortVersion.pdf

[17] P. O'Donova et al., "An industrial big data pipeline for data‐ driven analytics maintenance applications in large‐ scale smart manufacturing facilities," *Journal of Big Data*, vol. 2, 2015.

[18] Y. C. Lin et al., "Development of advanced manufacturing cloud of things (amcot)—a smart manufacturing platform," *IEEE Robotics and Automation Letters*, vol. 2, no. 3, July 2017, pp. 1809-1816.

[19] P. Zheng et al., "Smart manufacturing systems for Industry 4.0: A conceptual framework, scenarios and future perspective," *Frontiers of Mechanical Engineering*, January 2018.

[20] "What's so smart about smart manufacturing?" March 2018, https://professional.mit.edu/news/news-listing/whats-so-smart-about-smart-manufacturing

[21] S. Mittal et al., "A smart manufacturing adoption framework for SMEs," *International Journal of Production Research*, 2019.

ABOUT THE AUTHORS

Matthew N.O. Sadiku is a professor in the Department of Electrical and Computer Engineering at Prairie View A&M University, Prairie View, Texas. He is the author of several books and papers. His areas of research interests include computational electromagnetics and computer networks. He is a fellow of IEEE.

Olaniyi D. Olaleye is a project management professional. He is currently working towards a Ph.D. in Urban Planning and Environmental Policy at Texas Southern University with emphasis on urbanization and infrastructural sustainability.

Sarhan M. Musa is a professor in the Department of Electrical and Computer Engineering at Prairie View A&M University, Texas. He has been the director of Prairie View Networking Academy, Texas, since 2004. He is an LTD Sprint and Boeing Welliver Fellow. His research interests include computer networks and computational electromagnetics.