Handbook of Sustainable Development through Green Engineering and Technology

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Smart Factories: A Green Engineering Perspective

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8 Smart Factories: A Green Engineering Perspective

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CONTENTS

8.1 Introduction.......148
  8.1.1 First Industrial Revolution.......148
  8.1.2 Second Industrial Revolution.......149
  8.1.3 Third Industrial Revolution.......149
  8.1.4 Fourth Industrial Revolution.......149
8.2 Industry 4.0.......150
  8.2.1 Definition of Industry 4.0.......150
  8.2.2 Key Pillars of Industry 4.0.......151
    8.2.2.1 Big Data.......151
    8.2.2.2 Cloud Manufacturing.......152
    8.2.2.3 Internet of Things (IOT).......153
    8.2.2.4 Cyber Physical System (CPS).......155
8.3 Smart Factory.......156
  8.3.1 Design Principle of a Smart Factory.......157
  8.3.2 Smart Factory Architecture.......159
  8.3.3 System Integration in Industry 4.0.......160
8.4 Challenges for Implementing Smart Factory.......162
  8.4.1 Employee Resistance.......162
  8.4.2 High Cost.......162
  8.4.3 Technical Issues.......162
  8.4.4 Security Issues.......163
  8.4.5 Integration Issues.......163
8.5 Requirement of Smart Factory.......163
  8.5.1 Relevance of Smart Factory with respect to Green Engineering and Sustainability.......163
    8.5.1.1 Case Study 1: Petrochemical Industry.......164
    8.5.1.2 Case Study 2: Fabrication of Glass Reinforced Polymeric Centrifuged Pipes.......165
    8.5.1.3 Case Study 3: Management of Workshop of Aircraft Jet Engine Production.......165
8.6 Conclusion.......165
References.......166

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8.1 INTRODUCTION

The technological change has impacted the manufacturing industry in a considerable way. Complex processes and high standards in the manufacturing industry lead to a competitive market. Traditional manufacturing has become outdated and obsolete because of dynamic customer demands and will not be able to compete in future. The future manufacturing factories are required to meet the volatile demand, highly customized products, and shorter product life cycle in a timely and efficient manner. The evolution of technologies like big data, Internet of Things (IOT), automation, cloud computing, and virtualization has put the manufacturing sector in the spotlight and thus led to the emergence of Industry 4.0 in which all these technologies are being integrated. Therefore, smart factories are a new emerging concept in the manufacturing sector. It is an intelligent system wherein the various machines and components integrate and interact with each other. Green manufacturing is being adopted by the manufacturing industry for sustainable development. The green engineering focuses on new materials, processes, and products suitable for the environment and humans. The objective of green engineering is prevention of waste, management of materials, and the development of systems and processes for maximum utilization of energy and space. Through green engineering and applying smart factory concepts using the latest technologies, the manufacturing industry can considerably reduce waste, increase usage of nonhazardous materials, and employ cleaner alternatives in the industry. The industry has evolved over time, starting from the first industrial revolution to the current ongoing fourth industrial revolution. The various revolutions are discussed in detail.

8.1.1 First Industrial Revolution

The first Industrial Revolution started in 1760 and lasted until 1840 in Great Britain. The first revolution brought several major changes where daily life was influenced. It has impacted the standard of living of people, especially in the western part of the world. The transitions include the change from manual production methods to machines and machine tools and automated factories using steam power. This industrial change produced a lot of employment, output value, and capital investment, especially in the textile Industry. The invention of the steam engine in 1782 by James Watt was a major breakthrough. The other popular invention was the spinning jenny developed in 1764. The machine allowed workers to spin more wool, thus enhancing productivity. The first industrial revolution also witnessed the invention of sewing machines, thereby decreasing the sewing work in the textile industry, previously done manually. The sewing machine, invented by Thomas Saint in 1790, transformed the clothing industry, thus improving the production considerably at that time. Ashton (1948) highlighted the role of iron and textile industries in the industrial revolution. Britain conducted the first world fair in 1851 and showcased revolvers, sewing machines, steam hammers, reaping machines, and telegraphs to the world. The Industrial revolution resulted in better transportation through canals, roads, and rails. The banking and financial system also improved to run the business smoothly.

8.1.2 Second Industrial Revolution

The second industrial revolution happened around the year 1870. It was characterized by intense mechanization combined with electrification. The technological development in the industries of gas lighting, chemicals, transport, paper, and glass making played a central role during the second industrial revolution. The industry got stimulated after the invention of electricity, thus ensuring mass production and emergence of new markets. Sir Henry Bessemer invented the Bessemer process for the production of steel during the second industrial revolution. The furnace was able to convert molten iron into steel in this process. Henry Ford introduced the assembly line for the manufacture of cars in 1913. Agarwal and Agarwal (2017) concluded that a large number of banks increased in Britain during the second industrial revolution. The banking and finance sector during that time saw the emergence of clearing banks, declining of bills, and the cheques system.

8.1.3 Third Industrial Revolution

The third industrial revolution initiated around 1970 and the development of computers and microprocessors was done. It was the major change that developed the internet and set the base for the information age.

Markillie (2012) and Rivkin (2011) highlighted the major change during the third revolution with the help of new materials and processes like use of robots, 3D printing, and online manufacturing services. The third industrial revolution has impacted every aspect of society. This revolution has impacted various sectors like defense, advanced manufacturing, education, finance, health, and communication, etc. These sectors developed and continued to rise because of new innovations and discoveries of various services and products. The third industrial revolution also led to the development of numerically controlled machines. There was a huge shift of traditional manufacturing to the flexible and automated manufacturing system by the use of electronics and IT communication. This revolution began after 1970 and has also seen the emergence of fields like new materials, cleaner technology, biotechnology, etc. It also witnessed the internet, mobile telecommunication, and high-speed railways and renewable energies. The third industrial revolution had a huge impact on the developing nations and represented the importance of the global market. The high productivity was recorded during this period because of the use of information technology and advanced manufacturing techniques.

8.1.4 Fourth Industrial Revolution

The current industrial revolution involves transformation of traditional manufacturing and industrial products to automate the process using smart technology. Integration of the Internet of Things (IOT) and large-scale machine-to-machine communications improve self-monitoring and automation in Industry 4.0. This concept was first introduced by Klaus Schwab in 2015 by the executive chairman of the World Economic forum. Industry 4.0 integrates hardware, software, and cyber physical systems and emphasizes advances in communication and interconnectivity of devices. Internet of Things, artificial intelligence, robotics, nanotechnology, biotechnology, Industrial Internet of Things, quantum computing, and fully autonomous vehicles and 3D printing have emerged in this industrial revolution.

This current revolution is disrupting every industry throughout the world. Businesses are experiencing exponential growth during the fourth industrial revolution. It is impacting the complete business chain, like production, management, and governance of the enterprise. The new upcoming technologies like IOT, robotics, artificial intelligence, 3D printing, and fusion of these technologies are going to impact and transform life in a big way.

All machines, appliances, and devices, including systems and processes, are able to communicate with one another through digital technologies like artificial intelligence and Internet of Things. Machine-to-machine communication brings efficiency and extra security in the production system. The communication is without human intervention, making use of sensors and meters via a communication network to software, thereby converting the raw data into useful information. Various machines, appliances, industrial tools, and processes are connected with the internet in today's world.

8.2 INDUSTRY 4.0

The world is changing very rapidly and dynamically, and traditional manufacturing is unable to adjust with the increased production capacity and different varieties of products. The traditional manufacturing processes have the limitations of less monitoring and lack of automation to produce customized products at low-cost efficiently and profitably. The traditional manufacturing systems have fewer applications and poor integration between the various product life cycles and are unable to cope with the challenges generated by the changing and ever-growing technologies. The traditional manufacturing processes are non-profitable and getting obsolete with the blooming in the area of electronic technology. Automation and computerization is the need of the hour. The enterprises nowadays are using agile and lean management to optimize and improve the various production processes. The business enterprises are using various concepts to maximize the utilization of resources and assets. With the growing expectation of customers, especially during turbulent times in the era of globalization, there is an urgent need to reassess the manufacturing and production capabilities.

To curb the limitations of existing manufacturing systems, many researchers proposed some advanced-manufacturing schemes like flexible and agile manufacturing. Xu et al. (2016) highlighted that the manufacturing is experiencing the transformation from traditional practices to intelligent manufacturing, thus impacting the manufacturing throughout the world. The term Industry 4.0 was used at the beginning of this decade.

8.2.1 Definition of Industry 4.0

Industry 4.0 was denoted as the fourth industrial revolution by many researchers and business enterprises. Some of the definitions are summarized below:

Sanders et al. (2016) defined that the principles of cyber physical systems, the internet, and future technologies are applied with enhanced human-machines interaction paradigms.

Koch et al. (2014) defined Industry 4.0 as controling the complete value chain of the product lifecycle. It elevates the organization for a customized requirement.

Pfohl et al. (2015) defined Industry 4.0 wherein all the innovations implemented in a value chain check the change in digitization, network collaboration, automation, modularization, transparency, mobility, and socialization.

8.2.2 Key Pillars of Industry 4.0

Hermann et al. (2016) considered cloud computing, big data, CPS, IoT, and smart factories as main constituents of Industry 4.0. The main components are discussed in detail.

8.2.2.1 Big Data

With the emergence of novel technologies and the internet, there is a continuous production and growth of digital data. The term “big data” can be referred to the heterogeneous mass of digital data produced by companies and individuals. It requires sophisticated computer storage and analytical tools. Big data provides the user the right information at the right time from a large amount of data. The United Kingdom Government office for Science (2014) stated that around 20–100 billion devices will be connected by 2020, leading to more data collection, thereby highlighting the need for applying big data analytics. Big data emphasizes the following three issues (Boyd and Crawford, 2012):

1. **Analysis:** Exploring large data sets to identify data patterns
2. **Technology:** Using computational tools to analyze large data sets
3. **Mythology:** The large data generated leading to better knowledge and intelligence

Big data is turning out to be an important application in the IT Industry. Big data application is generally in the fields of finance, medical field, telecommunication, and commerce industries where a large amount of data is generated (Song and Lee, 2015). Integration of big data with the manufacturing industry is required since the manufacturing industry is complex and diverse. It is essential to improve flexibility and quality of manufacturing process, reduction of cost, and improvement of equipment effectiveness. Therefore, integration of big data analytics and the manufacturing sector is required for the smart manufacturing process and achieving manufacturing excellence. Big data is defined as large data sets, and those can’t be captured, stored, managed, and analyzed by typical software (Yin and Kaynak, 2015). Big data is getting attention because of huge data generation by machine and devices, and it is expected that more than 1000 exabyte data is generated annually and is growing by 20 times in the next ten years. The recently emerging areas like cloud, cyber physical systems, and Internet of Things has further necessitated the need for big data. Kagermann et al. (2013) emphasized that big data can play a role in Industry 4.0. Big data can achieve cost-effective and fault-free running of the

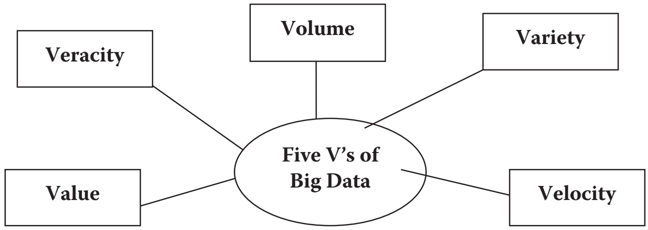

FIGURE 8.1 Five V's of big data.

process in industrial applications. Mckinsey suggested that manufacturers could reduce 50% cost in product development and assembly. It also claimed that working capital gets reduced by 7% by using big data. The optimum and efficient use of big data can enhance productivity and better managed supply chain, thus resulting in increased competitiveness in the various industrial sectors. The key description of the 5 V's of big data are discussed below and displayed in Figure 8.1.

Volume: Katal (2013) highlighted the issue of huge data generation currently existing in petabytes and the increasing use of mobile and social media. It would increase to zettabytes in the next few years. International data corporation (IDC) has estimated that 79.4 zettabyte (ZB) data will be generated by 2025 because of 41.6 billion connected IOT devices.

Velocity: Velocity is the rate at which the data flow and data is captured.

Variety: Data generated and collected is not from a single source. It is in the unstructured form obtained from web, sensors, texts, emails, etc.

Veracity: This is the ambiguity within the data because of existing noise and abnormalities in the data.

Value: The unstructured data available need to be structured so as to add value to the system.

Figure 8.1 indicates 5 V's of big data, i.e. high velocity, high value, high volume, high variety, and high veracity. The better analysis of large volumes of data can help in making advances in various disciplines and thereby improve productivity and profitability of the enterprise.

8.2.2.2 Cloud Manufacturing

Improvement in the domain of information and communication technology (ICT) has impacted the various sectors and is also playing a considerable role in modern manufacturing. Cloud manufacturing applies the basic concept of cloud computing and manufacturing domain.

Cloud manufacturing (CM) is an industrial version of cloud computing, as shown in Figure 8.2. In Industry 4.0, the enterprises need increased data sharing across the various channels. The main advantage of cloud manufacturing is that the data is stored in an internet service provider, and it can be easily accessed and retrieved remotely (Yu et al., 2017). Cloud is applied in Industry 4.0 to achieve the reaction time in milliseconds or even faster, thereby increasing the efficiency and productivity of the system (Rüßmann et al., 2015). Cloud facilities can be employed, thereby enabling the offerings in various ways, which include private,

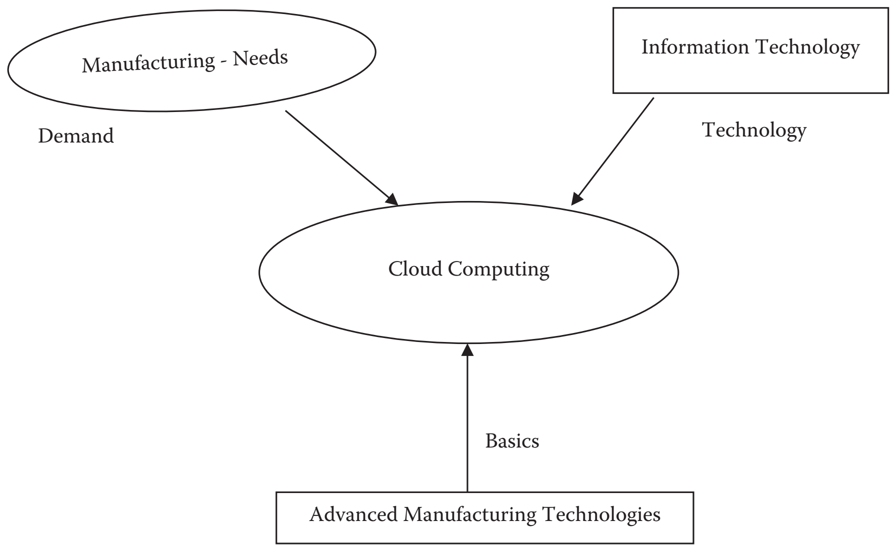

FIGURE 8.2 Cloud manufacturing.

public, and hybrid and community cloud (Luo et al., 2012). Each model of cloud provides consumers with different services, e.g. product offering of end consumer can be found on public cloud and organization employees can find the details on private cloud.

8.2.2.3 Internet of Things (IOT)

Internet of things (IoT) is considered as a major founding technology in the manufacturing sector in Europe, especially in Germany in Industry 4.0. Trappey et al. (2017) explained that actuators and sensors are implanted in each device in the manufacturing system and also connected with the internet. Sensors and actuators interact with the manufacturing system. Sensors collect the data and useful information is later processed. The stored data is processed and then sent to a remote server. Suitable feedback is shared to the system on a results basis. Sethi and Sarangi (2017) explained that servers, actuators, sensors, and the communication network are the main information of the IoT. Shariat zadeh et al. (2016) defined it as a future wherein every physical object like people and system (things) are connected in the shop floor by the internet to build the services necessary in the manufacturing. Kevin Ashton first introduced the term IoT in 1999 at the auto-ID center at the Massachusetts Institute of Technology (MIT). He expressed the use of radio frequency identification (RFID) to tag and track products in the Procter & Gamble supply chain.

a. Definition of Internet of Things (IoT)

Many researchers discussed the Internet of Things (IoT) in the literature.

Atzori et al. (2010) explained that IoT consists of two words: internet and things. The first part is the internet, or the network component, and the second one is the component.

Dorsemaine et al. (2015) explained it as "Collection of Infrastructures interconnecting objects and access of the generated data to the management."

Gubbi et al. (2013) defined Internet of Things (IoT) as sharing information of platforms collected from sensors and actuators through a common network.

Xu et al. (2014) described the Internet of Things (IoT) network as having more essential layers:

Sensing layers for integrating various forms of "things" like RFID tags, sensors, and actuators. It is the physical layer that senses and gathers information about the environment. Networking layers to connect the smart things, networking devices, and servers, and support the information transfer either from wireless or through wired network. A service layer is added to integrate service and application through middleware technology. Interface layer is used to display information to the user.

IoT has potential applications in practically all areas of our daily life. The application covers areas such as transportation, building, lifestyle, agriculture, emergency, healthcare, factory, environment, etc. IoT is very useful in the detection of leakage of gasses and chemicals in industry and mines. The IoT sensors can monitor the toxic gas and oxygen level inside the chemical plant. It also finds good applications in maintenance and repair, especially in predicting the equipment malfunction well ahead of actual failure of the machine component.

b. Sensor

Sensors in the Internet of Things (IoT) are the main component. It changes a nonelectrical signal input into an electrical signal, which is then sent to the electrical circuit. Institute of Electrical and Electronic Engineers (IEEE) defined sensors as: "An electronic device producing electrical, optical or digital data derived from a physical condition or event. The data produced obtained from sensors is then electronically transformed by another device into information i.e. output which is useful for decision making."

c. Characteristics of Sensors

Some of the few important factors that define the suitability of the sensors for a particular specification are:

1. Accuracy
2. Repeatability
3. Range
4. Noise
5. Resolution
6. Selectivity

d. Types of Sensors

TABLE 8.1
Different Types of Sensors Used for Different Applications

Sl. No.	Type of Sensors	Description	Sensor Example
1.	Position	The position sensor measures the position of the object.	Proximity sensor, Potentiometer.
2.	Occupancy and Motion	It detects the presence of living being in a particular area.	Electric Eye, RADAR (Radio detection and Ranging)
3.	Velocity and Acceleration	It measures the movement of object.	Accelerometer, Gyroscope
4.	Force	It detects the physical force.	Bourdon gauge, Barometer,
5.	Flow	The flow sensors detect the flow of liquid.	Piezometer, mass flow sensors, Anemometer.
6.	Acoustics	These sensors measure the sound level.	Microphone, hydrophone
7.	Humidity	It detects the humidity level in the air.	Humistor, soil moisture sensor, Hygrometer.
8.	Light	It detects the presence of light.	Photo detector, Flame detector, Infrared sensors
9.	Radiation	It detects the radiation in the environment.	Scintillator, Neutron detector.
10.	Temperature	It measures the amount of hotness or coldness present in the system.	Temperature gauge, Thermometer, Calorimeter.
11.	Chemical	It evaluate the concentration of chemicals present in the system.	Breathdyer, Smoke detector
12.	Biosensors	These detect the biological entities such as cells, organisms, nucleic acids, proteins and tissues.	Electro cardio graph, Biosensors, Oximeter, Blood glucose

8.2.2.4 Cyber Physical System (CPS)

The cyber physical system originated in the United States in 2006 at the National Science Foundation (NSF). Wolf (2007) described it as a digital system that collaborates various components that can communicate, control, and engage with the physical system.

Wikipedia (2020) described a cyber physical system (CPS) as a system in which a computer-based algorithm is being monitored or controlled in a computer.

Shi et al. (2011) described it as a system that imbeds control capabilities and communication into physical devices to monitor and control the various physical activities. Cyber capabilities through actuators, sensors, and embedded systems integrate with physical systems in the cyber physical system.

Lee (2006) explained it as “Integration of Computation with the physical processes.”

Gunes et al. (2014) described CPS as a large complex multidisciplinary physical system that integrates physical and cyber systems.

Poovendran (2010) highlighted that CPS is the integration of physical and cyber elements and that they achieve a lot of improvement on scalability, interactivity, intelligence, and re-configurability. It resulted in remarkable advances in the field of manufacturing, healthcare, aerospace, defense, etc.

This is a need for a cyber-physical system because of the increased connectivity between various physical objects and, as a result, some secure and reliable system is essential to protect the critical industrial system and manufacturing systems from various cyber attacks. The strong communicating link of the physical object and services considerably improves the quality that is required for various operational and administrative activities of the manufacturing system. CPS is the main production unit of the Smart Factory having two components, i.e. physical system and the other component is at cyber level (Ergunova et al., 2017).

Gurjanov et al. (2019) discussed the model of a cyber-physical system consisting of following components:

1. Controller
2. Actor model
3. Work chamber model of technological process
4. Sensor model

Cyber physical systems are interconnected systems. These systems communicate with each other, and the complete environment or system will perform the operation intelligently. This is also called a smart system consisting of a warehousing system, machines, and production facilities that are integrated digitally. The smart factory conception of industry 4.0 is that in which the physical process is monitored by CPS and a similar virtual copy of the physical system is created and thereby decentralized decisions are taken. Lee and Seshia (2011) concluded that CPS is the integration of computer networks and physical systems. CPS is considered as major support to the various smart-manufacturing strategies proposed by various countries. CPS is an emerging area having great potential for the future manufacturing systems.

8.3 SMART FACTORY

The emerging technologies like IoT and CPS, along with their implementation in the manufacturing system, have added new capabilities and assisted in managing the complex manufacturing system so as to cope up with the rapid changes in production volume. These new technologies help in assisting people and machines to complete and execute the various tasks. The German government initiated the technology concept in 2010 with an aim to develop and encourage innovation in the manufacturing systems (Zuehlke, 2010). Smart factory is considered to be the main concept of Industry 4.0 (Mabkhot et al., 2018; Wagire et al., 2019; Shi et al., 2020). Smart factory is synonymously termed as digital factory, digital manufacturing, innerconnected factory, integrated industry, advanced manufacturing, and smart production

(Nieuwenhuize, 2016). Radziwon et al. (2014) explained it as a flexible and adaptive production process to solve issues arising out of manufacturing facilities because of increased complexity and dynamic changes in business conditions. Automation of the manufacturing system will lead to optimization, thereby reducing labor and waste of resources. Park (2016) explained that the smart factory is an integrated manufacturing system that collects all the data of the manufacturing system in a real time thus implementing an optimized and ever dynamic production system. Lu (2018) defined smart factories as intelligent production systems in which fault detection and the various issues of troubleshooting collected through data analysis are supervised through assistance of cloud and self-diagnosed manufacturing systems. In the smart factory all the physical entities are connected with each other thereby exchanging information and assessing the situation. The integration of the physical and cyber world is shown in Figure 8.3.

8.3.1 Design Principle of a Smart Factory

Hermann et al. (2016) designed the principle of the smart factory in Industry 4.0. This will surely help architects to create smart factories or upgrade existing ones into a smart factory.

The various principles proposed are:

i. Modularity

It is the ability or the ease of the components to separate or combine quickly. Weyer et al. (2015) emphasized that the smart factory must have high modularity thereby allowing fast integration. High modularity results in better responsiveness to the

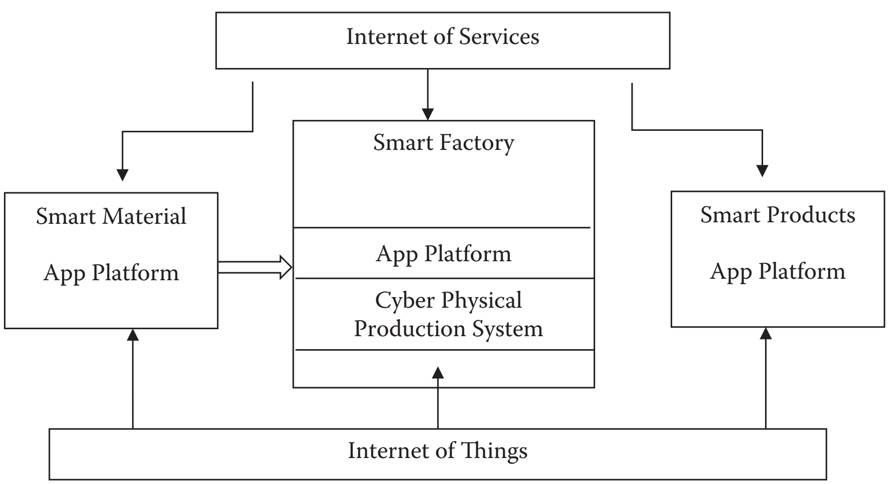

FIGURE 8.3 The concept of smart factory.

changing customer requirement and thereby overcoming the malfunction of the system.

ii. Interoperability

Interoperability refers to the ability wherein technical information of various components is being shared within the system. It also shares the related information between the manufacturing organization and the end customer.

iii. Decentralization

It is the ability of the system and its elements to make decisions on their own. Cyber-physical systems are adjusted to make decisions independently as per the design of the model. It was ensured that while changing decisions, the organizational goal is not affected. In this type of system, the employee makes various decisions without wasting time and implements a new strategy that considers the business environment. Tantik and Anderl (2017) highlighted that these interconnections assist in adapting and enabling low-cost and customized products.

iv. Virtualization

It is the ability of the system in simulating an artificial factory environment with cyber-physical, which is virtual to the actual physical environment. Lee (2015) explained that virtual systems analyze the physical system and the actual data in real time. The virtual system implements the design, digital prototype that is very similar to the real physical system (Zawadzki and Żywicki, 2016). Virtualization helps in checking and modifying the design, and the virtual product needs to be tested before making a physical system. Virtualization is also helpful in assisting and training the workforce, assisting in diagnosing, and predicting and guiding maintenance workers to fix any malfunction.

v. Service Orientation

Service orientation will transform the manufacturing system to sell the combination of products and services. Fischer et al. (2012) highlighted that in the smart factory system, the organization should focus on selling the services rather than concentrate on profit from product sale. Product and services need to be integrated and sold together.

vi. Real-Time Capability

It is the responsiveness of the system during changes immediately. The system should respond to customer requirements and can be analyzed in real time. In this type of system, the current situation in the enterprises is permanently and continuously monitored, and any deviation or machine failure is taken accordingly without wasting any productive time.

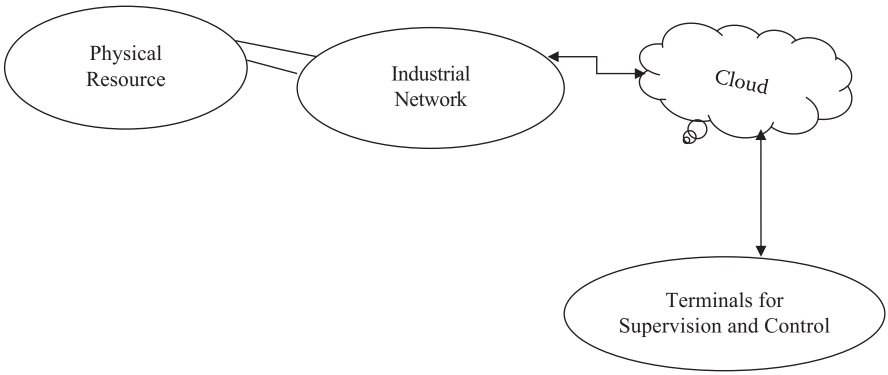

FIGURE 8.4 Basic structure of smart factory for industry 4.0.

8.3.2 Smart Factory Architecture

The smart factory concept is going to bring changes in business models and consumer behavior because of flexible manufacturing, dynamic reconfigurations, and production optimization. It is basically an engineering system concept that focuses on three main parameters, i.e. interconnections, collaboration, and execution. The architecture of a smart factory is important as it is different from the traditional manufacturing industry. Chen et al. (2017) described that architect of smart factory consist of four layers including (Figure 8.4):

1. Network layer
2. Physical resource layer
3. Terminal layer
4. Data application layer

i. Network Layer

The industrial network layer is an important kind of infrastructure that not only connects but also communicates with the physical resource layer and the cloud layer. Industrial wireless networks (IWN) must have high reliability and accuracy with low latency in smart factories. Li et al. (2017) highlighted that latency and reliability are the core requirements of industrial network communication. The network layer has the advantage of improved resource utilization and efficiency. The data-transmission performance also gets improved as it is implemented in different network tasks. Chen et al. (2018) highlighted that with the use of artificial technology and cognitive computing, the learning and cognitive ability of the system improved considerably, as the number of data nodes and volume data increased in the smart factory.

ii. Physical Resource Layer

Wang et al. (2016) explained the physical resource layer consisting of various components such as smart machines, smart products, smart conveyors, etc. These physical devices collaborate and communicate smartly with each other through the network to achieve system goals. Chen et al. (2017) suggested that smart factories can work intelligently and independently with flexible scheduling. The manufacturing unit has equipments like robot, mechanical arm, and machining center, etc., to improve dynamic scheduling of the system. The modular manufacturing unit must coordinate and cooperate with each other to complete the common organizational goal. The production line of the smart factory must be flexible and have the ability to reconfigure the process path. These manufacturing enterprises must be able to manufacture the products with different varieties in small batches. The production line of the smart factory must have a capability of manufacturing different products with variable schedule and scalability as an important basis for the flexible manufacturing in the smart factory. Wireless sensor networks (WSN) are generally used in the smart factory for gathering and monitoring the data. Some of the commonly used WSN are ZigBee, Radio Frequency Identification (RFID), and Bluetooth. These sensors collect data in manufacturing areas since they are having low prices and consume less energy (Choudhury et al., 2015).

iii. Terminal Layer

Chen et al. (2017) discussed the use of the terminal layer in devices like computers, electrical boards, and smart phones. They are distributed in workshops, offices, and other regions. The purpose of the terminal layer is to analyze the result of cloud processing and remotely monitor the operation and maintenance of the system. Wang et al. (2016) elaborated the basic structure of the smart factory concept in the Industry 4.0 context.

iv. Data Application Layer

The smart factory generates a lot of data, and thus, application of big data is developing fast, along with the cloud platform in the smart factory. Big data in smart factories have data generated in real time from sensors, machine logs, and manufacturing. (He et al., 2018; Sharp et al., 2018) highlighted that the machine-learning application in smart manufacturing is rapidly increasing with the advancement of big data, especially in the field of extraction of knowledge, decision-support system, and lifecycle management of product and equipment.

Basically, the terminal layer connects the people to the smart factory. Chen et. al. (2017) highlighted the three layers, i.e. network layer, physical resource layer, data application layer, and the terminal layer are the components of smart factory architecture. Therefore, it is essential that all these components must be connected with each other, exchange relevant information, and integrate the physical system with the cyber system.

8.3.3 System Integration in Industry 4.0

The main purpose of Industry 4.0 is to utilize upcoming latest technologies to implement the Internet of Things (IOT) and other services to the business processes.

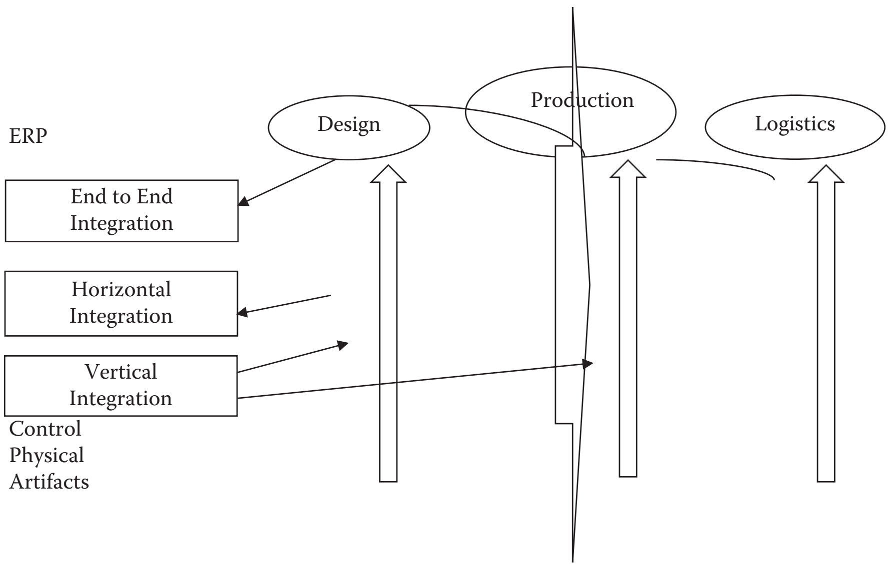

FIGURE 8.5 Depicts the three integration of smart factory.

These processes are connected with each other and work in a flexible and efficient manner to produce products having better quality and low cost. Wang et al. (2016) described that there are three kinds of integration of Industry 4.0, which are essential for making a smart factory.

1. Vertical Integration
2. Horizontal Integration
3. End-to-End Integration

The three types of Integration were illustrated by Wang et al. (2016). (Figure 8.5).

i. Vertical Integration

Smart factories have many physical systems, such as sensors, actuators, and various control systems. Vertical integration is essential to integrate various physical systems across different levels so as to have a flexible manufacturing system. The main objective of integration is to collect the massive information and thereby make the production process transparent and flexible.

ii. Horizontal Integration

Wang et al. (2016) discussed that one corporation should act together with other related corporations. By horizontal integration, the information related to material and finance can be exchanged among corporations, thereby producing an efficient ecosystem.

iii. End-to-End Integration

These are a number of activities that are involved, like design and development of product, planning of production, services, and maintenance. The integration will help in the development of a consistent product model that can be revised at every level. By integration, it is very easy to assess the impact of product design on production systems and services using software so that customized products can be manufactured at a low cost with high quality.

The emerging technologies like cloud computing, Internet of things, artificial intelligence, and big data are the backbone of Industry 4.0. With the integration of these technologies with automation, businesses can bring a considerable improvement to the industry. Through the use of artificial intelligence and microprocessors, the products and machines become smart, and these are connected with each other as well as with the internet. The IoT and services is the main foundation of all three kinds of integration. In vertical integration, the physical artifacts can be reconfigured in a dynamic way, generate a lot of data, and then added on to the cloud. Software tools are used for integration.

These emerging technologies are employed and integrated in industry across all the three verticals. The integration can help in producing high-quality products.

8.4 CHALLENGES FOR IMPLEMENTING SMART FACTORY

Various authors highlighted many issues for implementation of the smart factory concept in Industry 4.0. Some of the common challenges faced in implementing smart factory are:

8.4.1 Employee Resistance

Resistance to change is the biggest challenge in implementing smart factory. Most of the staff and other employees are not certain about the advantages and benefits of smart factory. They have a fear of losing their job. Sjödin et al. (2018) highlighted the issue of factory staff lacking common vision for understanding and implementing smart factories.

8.4.2 High Cost

The smart factory involves usage of the latest technologies. Park (2016) emphasized the horizontal and vertical integration of the manufacturing system, thus producing customized production. The smart factory must require customized machine tools and workstations, highly skilled workforce, real-time monitoring, and control. All these equipment and elements require huge investments, thus increasing the cost of implementing the smart factory.

8.4.3 Technical Issues

Many researches highlighted the different technical issues that need to be addressed to implement the concept of smart factory. Wang et al. (2017) discussed that communication and high-speed bandwidth networks are the main requirements in implementing smart factories. Chen et al. (2017) highlighted the issue of generation of large volumes of unstructured and real-time data in the smart factory. This data cannot be utilized directly for better performance. So, (Song et al., 2017; Wang et al., 2017) emphasized the need of huge storage space, better collection, and quick analysis of data along with the high bandwidth as the major requirement of producing high-quality products and the efficient working in the smart factory. There is a lack of funds and resources in the traditional organization, especially in small and medium-size enterprises.

8.4.4 Security Issues

Wan et al. stressed that smart factories are at higher risk compared to traditional enterprises. This is because of limitations of proper architecture in smart factories and massive amounts of critical data and equipment are vulnerable to cyber attacks. RÜßMANN et al. (2015) addressed that the critical industrial systems and manufacturing lines need to be protected from cyber threats.

8.4.5 Integration Issues

Smart factory requires the integration of various technologies. Sjödin et al. (2018) highlighted that the traditional work processes need to be digitized. All the verticals of the business enterprise from product design and development, manufacturing, marketing, sales and supply chain need to be integrated.

8.5 REQUIREMENT OF SMART FACTORY

Mabkhot et al. (2018) highlighted 26 factors that are the major requirement of smart factories. These factors mainly included tools, equipments, infrastructural facilities, modern architecture, and skilled workforce. Besides these, the need for online data analysis and monitoring, cloud computing, cloud connection were also emphasized.

8.5.1 Relevance of Smart Factory with respect to Green Engineering and Sustainability

Smart factory, or intelligent factory, is the future of manufacturing in Industry 4.0. In manufacturing, green engineering resulted in the reduction of waste in the overall supply chain, like selection of material, manufacturing process, and logistics. In green engineering, there is a better usage of energy, raw material, and other resources. The smart factory concept focuses on 3R, i.e. reuse, recycle, and reduce. The green manufacturing in the digital factory concept of Industry 4.0 uses appropriate technologies and materials and focuses on modern production processes to reduce pollution and minimization of waste. The concept of smart factory is being adopted in various industries. Few case studies are discussed in detail:

8.5.1.1 Case Study 1: Petrochemical Industry

Li (2016) discussed the smart factory perspective in the petrochemical industry. The petrochemical Industry is facing new challenges because of rules regarding the environmental protection and conserving energy, cost reduction, and efficient management of the supply chain of various raw materials.

A smart factory concept in the petrochemical industry is characterized by greenness, high efficiency, high safety, better management of supply chain, and in-depth integration of industrialization to achieve the high operational excellence of the factory. Smart factory concept in petrochemical industry is based on the following points:

1. Integrating management and production verticals for the refining and chemical industries
2. Integrating the supply chain of the petrochemical industry
3. Integrating the design and operation for the petrochemical industry

TABLE 8.2
Strategic Framework of Petrochemical Industry (Li, 2016)

Sl. No.	Framework	Content
1.	Objective	Operational excellence achieved
2.	Three Main Integration	• Integrating the management and production. • Integration of supply chain • Integrating the design and operation
3.	Key Capabilities	• Forecast and early warning • Optimization • Location awareness • Scientific decisions
4.	Characteristics	• Digitization • Automation • Visualization • Modeling • Integration
5.	Business Domain	• Supply chain management • Management of production and control • Energy management • Assest management • Decision making • Health safety and environment management

The intelligent and smart petrochemical industry features integration of human and computer, and thus, improving the decision-making ability of the petrochemical industry. The various trends in the field are:

1. High dimensional and heterogeneous manufacturing and massive information.
2. 3-D display and simulation of design, production, and operations based on virtual reality.
3. Human-machine collaborative decision-making assistive technology in smart manufacturing.
4. Utilization of human computer integrating techniques supporting visual analysis in production and manufacturing environments.

8.5.1.2 Case Study 2: Fabrication of Glass Reinforced Polymeric Centrifuged Pipes

Aversa et al. (2016) presented the case study of fabrication of glass-reinforced polymeric (GRP) centrifuged pipes using the experimental verification of intelligent processes. The centrifuged pipe manufacturing must maintain quality control and smooth wall thickness. Any variation from the said parameters leads to increased deflection, distortion, and buckling of the pipe and chance of joint leakage. These pipes are generally used in water and sewage transport. Mathematical models were used to analyze the thermo-kinetic and chemorheological features of the polymerization of unsaturated polymers. The study used an electronically controlled automatic centrifugal casting system. The process controlled the various parameters like material quantities, mould rotation speed, and temperature to achieve the desired result.

8.5.1.3 Case Study 3: Management of Workshop of Aircraft Jet Engine Production

Shpilevoy et al. (2013) presented the design principle of smart factory for resource management of aircraft jet engine production in real time. Digital factory agent is employed to enhance the efficiency and productivity of the factory by automating scheduling, forecasting, supply chain, and control of the manufacturing in machine assembly. Resources of the workshop adopted the dynamic scheduling on the basis of multi-agent technology, architecture, and user-interface employed. The traditional resources optimizations have a large number of limitations like interdependency of orders and resources, issues in adaptive planning in real time, lack of adjustment of decisions. All these issues reduce the efficiency and productivity of the existing process and system. However, the adaptive method developed for synchronous scheduling is built on the multi-agent technology that includes the equipment, product specification, and the technological processes as well as skill set of the workers. Productivity of the aircraft engine workshop increased by 10%–15%. The work on task allocation, coordination, scheduling, coordination, and monitoring was reduced by 3%–4%. The efficiency of resources increased to more than 15%. The adopted technology in the workshop reduced response time by 2%–3%.

8.6 CONCLUSION

The chapter discussed in detail the history and inventions occurred in various industrial revolutions. The Industry 4.0 perspective is also discussed, where disruption is happening in every industry and the new technologies, like IoT, artificial intelligence, robotics, and 3D printing, are impacting the complete business chain and governance of the enterprise. The chapter highlighted the concept of smart factory with the perspective of green engineering, which is a main concept of Industry 4.0 where all the machines and equipments are interconnected and exchanging information. The smart factory is considered an intelligent system because it integrates the services and manufacturing. The chapter elaborated in details the challenges and requirements of the smart factory by discussing the various case studies in different sectors.

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