FACTORIES OF THE FUTURE

TECHNOLOGICAL ADVANCEMENTS IN THE MANUFACTURING INDUSTRY

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Contents

Preface

As the title suggests, this book covers the factories of the future and other technological advancements in the manufacturing industry. Basically, the book is divided into two parts: emerging technologies and advancements in existing technologies. The chapters on emerging technologies consist of topics on Industry 5.0, machine learning, intelligent machining, advanced maintenance and reliability; whereas the chapters on advancements in existing technologies cover digital manufacturing, artificial intelligence in machine learning, the internet of things, product life cycle, and the impact of factories of the future on the performance of manufacturing industries. Since these technical advancements are not currently available in a single book, an attempt has been made to cover all these topics in one book.

Presently, a major concern of all manufacturing industries is to remain agile in order to be competitive in the market. To achieve this goal, industries have to adopt new technologies in order to provide customers with better quality products and reduce lead time. In addition to this, a subsequent issue facing manufacturing is helping to save the environment with the introduction of "green" practices, otherwise known as "green manufacturing."

Nowadays, even research is concentrating on these technical advancements; thus, the intended audience of this book will find material regarding these advancements collected in a single volume. Furthermore, they will develop an understanding of the social, economic and technical justifications for these advancements. In addition to this, the role different technologies play with each other is investigated.

This book will be useful to researchers, academics and faculty in industrial production, mechanical engineering, electronics and other allied branches of manufacturing, and even those in business analytics programs, as case studies and analytical tools related to manufacturing performance are provided. It will also be helpful to those in industrial R&D departments, as industries are always adopting new technologies as advancements are continually being made in this sector. So, on the whole, it will be helpful to both academicians and industrialists.

Technological advancements in manufacturing is a pressing topic, as industries have to sustain their performance when adopting advanced production techniques, and while doing so, they have to keep green issues in mind. Therefore, this is a vastly important book as it involves improving the performance of businesses while creating technical advancements, thus making them more competitive. Since this book contains detailed information on the technological advancements made in manufacturing production and maintenance, it will provide insights into the various technologies currently adopted by industries and those yet to be adopted, that will impact the future performance of industrial manufacturing.

Dr. Chandan Deep Singh and Dr. Harleen Kaur
December 2022

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Factories of the Future

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Abstract

Rapid progress of smart technologies result in drastic changes in industrial production processes thereby building a roadmap for "The Factories of the Future" with a clear vision of how producers should improve productivity through advancement in plant structure, plant digitization, and plant processes in order to establish production systems that are more flexible and adaptable to external changes with high sustainability. The full integration of different support systems in the digital factory will strengthen communication across all R&D, production, marketing, and other organizational activities and thus facilitate customers to view the production of their products in real time and can suggests last minute modifications. This chapter presents the scenario of current manufacturing facilities which are still lacking in predictable maintenance, decision performance, early awareness, self-optimization and self-organizing features of the Industry 4.0. The Factories of the Future (Industry 4.0) will produce products in a smarter and more integrated, flexible and efficient way. Integrated sensors and IT systems can share and analyze data to predict failures, redesign, and trigger automatic repair processes and thus resulting new levels of performance to produce quality goods at reduced cost. The key technologies of the future industry such as virtual reality, simulation, augmented reality, cyber physical systems (CPS), artificial intelligence (AI), Internet of Things (IoT) and Industrial Internet of Things (IIoT), cloud computing, big data, and additive manufacturing have been highlighted in the chapter. In addition, the chapter also discussed state-of-the-art production technologies to meet quality improvement, reduce costs, and reduced lead time challenges owing to global competition, rapidly changing customer needs and low domestic productivity. At the end of chapter, socio-econo-techno justification of the Factories of the Future has been presented.

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1.0 Introduction

Industrial change is the transition to advanced production strategies. These changes include shifting from manual manufacturing to machinery, production of new chemicals, increased use of unconventional production processes, development of machine tools and the growth of the digital industry system. Industries are currently aiming to move from mass production to customized production. The step towards entry into production strategies, which were completely different from the past, is called industrial revolution (Figure 1.1).

First Industrial Revolution
The First Industrial Revolution began in the 18th century and focused on the strength of steam and textile industries. During this time revolutionists from Europe and the United States built tools and machinery for the production of machinery. The original fibers were produced in simple spinning wheels, and a new mechanical version resulted in eight times higher production. Steam power was already known. Its use for industrial purposes was a great achievement for increasing human productivity. Steam engines could be used for weaving looms instead of man power. Developments such as steam locomotives brought about major changes because people and goods could travel long distances in just a few hours [2].

Second Industrial Revolution
The Second Industrial Revolution, which began in the 19th century, focused on the steel industry, the automotive industry, the production line, and the development of electricity. Henry Ford (1863-1947) introduced the concept of integration in the production of cars. In the assembly line, the complex work of assembling the many parts into a finished product was divided into

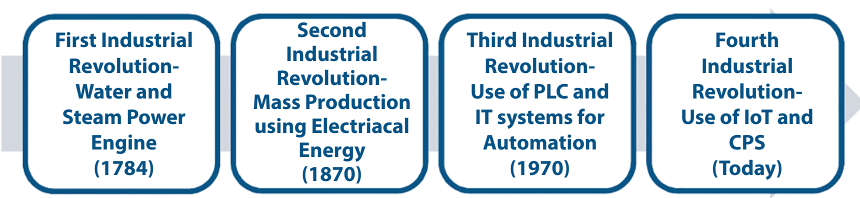

Figure 1.1 Industrial revolution [1].

a series of smaller tasks, resulting in higher productivity as each worker was required to assemble one or two parts in its place in the assembly line.

Third Industrial Revolution
The Third Industrial Revolution, also known as the "Digital Transformation" began in the 20th century and used electronic and information technology (IT) to produce production using programmable logic control (PLC) and computers. This technology is able to automate the entire production process without human intervention using programmed robots.

Fourth Industrial Revolution
Today, the Fourth Industrial Revolution, also known as "Industry 4.0" is based on the development of the Third Industrial Revolution. The Federal Government of Germany introduced Industry 4.0 as an emerging structure where production systems and goods in the form of Cyber Physical Systems (CPS) make extensive use of global information and communication network for automated information exchange for production and business procedures [3]. The four main drivers of Industrial 4.0 are Internet of Things (IoT), Industrial Internet of Things (IIoT), cloud-based production and intelligent production that helps transform the production process into a complete and intelligent digital [1, 4]. When these resources come together, Industry 4.0 has the potential to bring about dramatic improvements in the factory environment. Examples include machines that can predict failure and trigger automatic repair processes or self-programming that respond to unexpected changes in production [2].

1.1 Factory of the Future

The development of new technologies is making drastic changes in industrial production processes, resulting in "the factory of the future." The industry of the future is a vision of how producers should improve productivity by making progress in three phases: plant structure, plant digitization, and plant processes to establish production systems that are more flexible, adaptable to external changes and high sustainability [5, 6].

1.1.1 Plant Structure

The future factory plant structure has a flexible, multi-dimensional structure, with the setting of modular lines and environmentally sustainable production processes. The multidirectional structure employs driverless transport methods and is individually controlled by production in conjunction with production equipment. Such transport systems are guided by a laser scanner and the technology to detect radio frequency instead of a fixed transmitter thus making the integration structure fully flexible with flexible line modules. The future factory is designed for environmentally sustainable production, which combines energy efficiency with building materials for example enabling all LED lighting in the industry resulting in very low energy consumption.

1.1.2 Plant Digitization

Smart automation or Plant digitization can be done in a variety of ways as listed below for product development:

- Using robots that will ensure repetition and reproduction in complex tasks compared to workers. Robots can also collect information on each piece of work produced and automatically adjust their actions to their features. Robots can also support people in completing tasks in hard-to-reach areas.
- Using additive manufacturing or 3D printing, a computer-controlled process that creates three-dimensional objects by inserting objects, usually in layers. With additive manufacturing, design changes can be made quickly and efficiently during the production process with minimal or no damage.
- With augmented reality, such as smart mirrors, enables employees to see information as the overlay of their viewing field. This information is especially useful, for example, in assembling, maintenance and repairing things.
- Implementing simulations using real-time data, 3D production presentations to improve processes and flow of goods. 3D flow simulation simplifies dynamic responses to changes and allows operators to see work flow before adjusting the production line [5].
- Training methods have been developed that use 3D simulations to help staff learn in a real-world environment.

1.1.3 Plant Processes

Through the use of new digital technologies, manufacturers further develop their product designs and production processes continuously according to customer requirements.

1.1.4 Industry of the Future: A Fully Integrated Industry

Figure 1.2 shows the full integration of value chain with different support systems in the future factory. The value chain on the left side consists of suppliers, a manufacturing component, a press shop, a body shop, a paint store, a final assembly line and a customer, while, the support systems on the right side incorporate digital logistics, production simulation, and

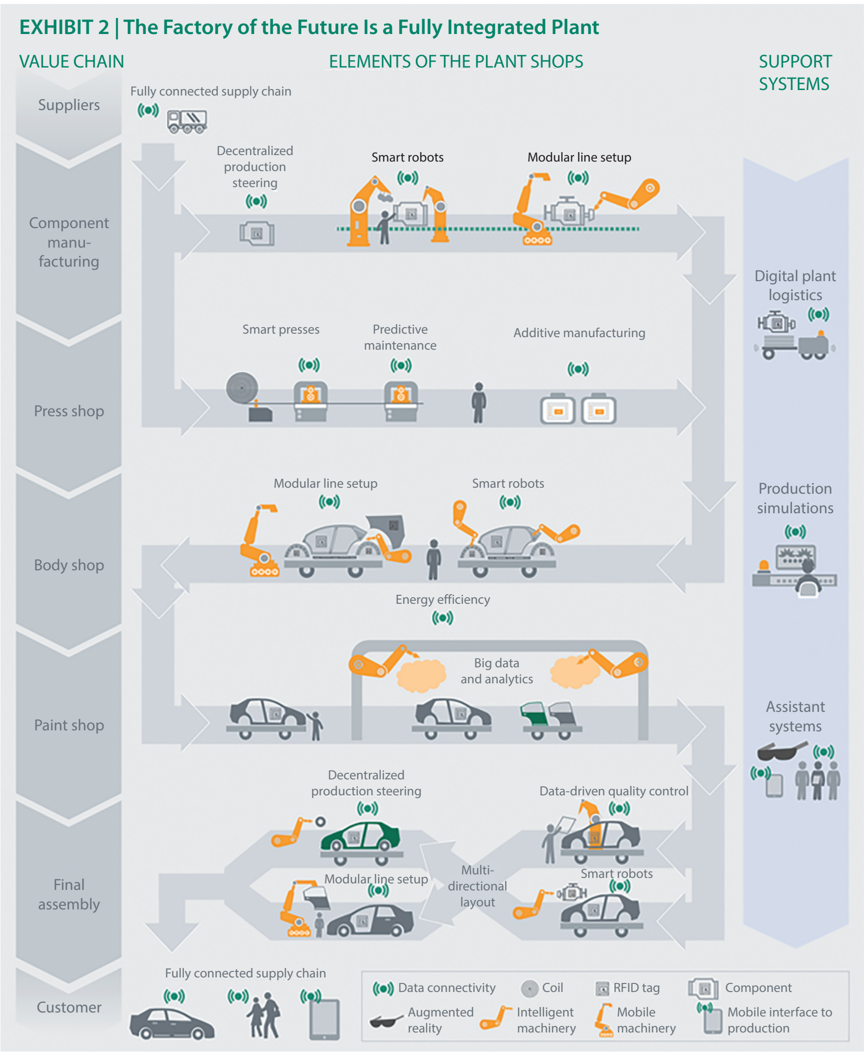

Figure 1.2 Factory of the future: Fully integrated plant [5].

various auxiliary programs. Throughout the value chain, production will be facilitated by the full integration of IT systems such as intelligent robots, modular line configurations, data-driven quality control etc. This integration will strengthen communication across all R&D, production, marketing, and other organizational activities. Customers will be able to view the production of their products (cars in this case) in real time and request changes at the last minute.

1.2 Current Manufacturing Environment

Figure 1.3 shows that the current manufacturing facility does not have many components and functions compared to the Factory of the Future. The various current production environments (Table 1.1) such as single station automated cells, Automated assembly system, Flexible manufacturing system (FMS), Computer-integrated manufacturing system (CIMS) and Reconfigurable manufacturing system (RMS) are still lacking in predictable maintenance, decision performance, early awareness, self-optimization and self-organizing features of Industry 4.0 [7, 8].

Figure 1.4 shows the basic differences between today's factory and the factory of the future. Today's industry is concerned with the integration of people into the production process, sustainable development and focuses on value-added activities through a soft management approach that

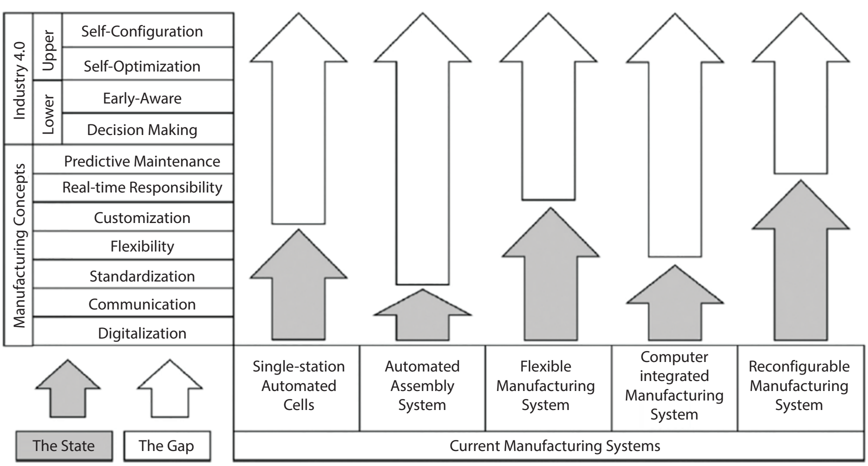

Figure 1.3 Technology gap between the current manufacturing system and Industry 4.0 [8].

Table 1.1 Current manufacturing environments.

Single station automated cells	A fully automatic production machine unattended for more than one cycle of operation. This system is an automated system that is simple and inexpensive to use with low labor costs and high productivity levels compared to the human-controlled cellular system.
Automated assembly system	The automated assembly system employs mechanical and automated devices to perform different assembly functions in an assembly line or cell. Automatic integration systems are usually designed to perform a consistent sequence of steps on a specific product that is produced in very large quantities.
Flexible manufacturing system (FMS)	A Flexible Manufacturing System (FMS) is a production system designed to easily adapt to changes in the type and quantity of a product being produced. Computer equipment and systems can be configured to produce various components and to adapt to changing production standards. Example: a NC machine, a pallet changer and a part buffer.
Computer integrated manufacturing system (CIMS)	CIMS refers to the use of computer-controlled equipment and automated production systems. CIMS integrates operations, marketing, design, development, production management, process management and other business processes to provide a seamless production process that reduces manual labor and creates repetitive tasks. The CIMS method accelerates the production process and uses real-time sensors and closed loop control systems to perform the production process automatically. It is widely used in the automotive, aviation, space and shipbuilding industries [9, 10].
Reconfigurable manufacturing system (RMS)	RMS has the ability to redesign hardware and manage resources at all operational and organizational levels, in order to quickly adjust production capacity and performance in response to sudden market changes or regulatory requirements [11].

		Today's factory		Factory of the future	
	data source	main characteristics	main technologies	main characteristics	main technologies
compo-nent	sensor	precision	smart sensors and failure detection	knowledge of own operations, predictive ability	monitoring of all features, life expectancy forecasts
machine	controller	manufacturability and performance	state-based system monitoring and diagnostics	knowledge of own operations, predictive ability, comparability ability	real-time preventive status indicators
manufac-turing system	networked	performance and total asset efficiency	Lean operations: work and waste reduction	self-configuration, self-maintenance, self-organizing ability	risk exemption, performance

Figure 1.4 Comparison of today's factory and the factory of the future [14].

reduces complexity and cost by eliminating waste. Provides strategies to engage all employees in continuous review and improve efficiency.

However, the future factory (Industry 4.0) will produce products in a smarter and more integrated, flexible and efficient way. Integrated sensors and IT systems can share and analyze data to predict failures, redesign, and adapt to change. Individual segregation occurs in decision-making processes and enables real-time independent decisions at the machine level as well as flexible decisions regarding production processes based on timely data. Manufacturers can reach new levels of performance. They can, for example, move forward from prevention to predictable correction, which means that corrective actions are performed only when necessary. Better monitoring of products and production processes can also increase relationships with suppliers, produce quality goods and reduce costs [12, 13]. By increasing clarity, improving forecasting, and, finally, enabling automated systems, Industry 4.0 promotes faster, more flexible, and more efficient processes.

1.3 Driving Technologies and Market Readiness

Communication, automation, and optimization are the driving technologies of Industry 4.0 digital transformation. The key technologies of the future industry are discussed below:

(a) Virtual Reality (VR): A virtual reality space where people can do things and participate in that environment using VR glasses. VR has been used in the design process to provide a more precise display and immersive creation of 3D models. VR has also been used in productive training programs, problem solving and remediation programs [7, 15, 16].

(b) Simulation: Simulation model demonstrates the performance of an existing or proposed system such as running an assembly line, production planning and scheduling. Simulation can also used to prepare the pre-production machine tool settings in a visible area without physical examination and thus resulted in saving time and money during testing of the production system.

(c) Augmented Reality (AR): Augmented Reality (AR) technology integrates virtual reality with real world using multimedia, 3D-Modeling, Real-time Tracking, Intelligent Interaction, Sensor and more. AR uses computer-generated visual information, such as text, images, 3D models, music, video, etc., in the real world after imitation [17]. This integration of simulated computer simulations in real-world contexts helps to identify a product in an existing environment. The training of new staff and product testing by showing the various conditions in the developed area have been found to be effective and save time.

(d) Cyber Physical Systems (CPS): A Cyber Physical System (CPS) or intelligent system is a computer system in which a machine is controlled or monitored by computer-based algorithms. In CPS, sensors, actuators etc. (physically) are closely integrated with computing, storage, communication and control systems (cyber) [1, 18]. CPS sensors are able to detect mechanical failures and automatically configure error correction actions. CPS is also used for the efficient use of each work station with the help of operational cycle time for that station [19]. Some of the major CPS features are listed below:

(1) Intelligent Grid: Cyber Physical Systems is used in the production, transmission, distribution and operation of power generation components, thereby providing dual and control communication between the power grid and users [20].

(2) Smart Transport Systems: CPS is used in the transport system to improve traffic management performance.
(3) Public Infrastructure Monitoring: Different CPS sensors are used for accurate and continuous monitoring of buildings, dams, and bridges etc.
(4) Aeronautic Applications: Cyber-Physical Systems used for aircraft inspection equipment, communications with Pilot, Structural Health Monitoring, In-flight testing, and aircraft maintenance etc.

(e) Artificial Intelligence (AI): Artificial intelligence (AI) is the ability of a computer or computer-controlled robot to perform tasks that are normally performed by humans because it requires human ingenuity and judgment. The artificial intelligence system is able to self-determine, optimize and automatically respond to physical changes such as changing production schedules, suspension or operation of any machine units, automatic machine tools and automatic warning of uncontrolled conditions [7, 21, 22].

Examples of Artificial Intelligence:

- Production robots
- Self-driving cars
- Smart helpers
- Effective health care management
- Automatic investment
- Visible travel booking agent
- Social media monitoring, etc.

(f) Cloud Computing: Cloud computing means storing and accessing data and programs online instead of your computer's hard drive. Cloud computing brings a variety of computer services such as servers, storage, websites, network, software, statistics, and online intelligence ("cloud") to provide faster innovation, flexible resources, and scale economy. In the future industry, different plant machinery and devices are connected to the same cloud to share information with each other in digital production facilities [1, 23].

(g) Big Data: Big data is a combination of formal and informal data collected by organizations for information and use in machine learning projects, predictable modeling and other advanced mathematical applications.

Big data is usually seen with three V's [24]:

- Large *volume* of data in many areas;
- Wide *variety* of data types that are usually stored in large data systems; and
- The *velocity* at which the data is collected and processed.

Big data analysis helps in real-time intelligent production decisions by considering customer feedback and their own ideas on the products they use or intend to use, and from that knowledge, manufacturers focus on their product design to attract more and more customers.

(h) Internet of Things (IoT) and Industrial Internet of Things (IIoT): IoT is used for common home applications such as starting a coffee machine with your phone, adjusting your air temperature, car tracking apps, and so on. Household items or everyday items connected to the internet and are therefore controllable from a distance.

IIoT refers to the IoT branch which focuses on the manufacturing and agricultural industry, which connects everything that is visible through the internet. This collaboration between each component ensures that production facilities run smoothly and at low cost. With the IIoT system, data and information flow is faster and efficient; staff can work safely and at high speed. IIoT also assists in production planning, predictable correction and error detection, improved human machine interaction, efficient use of resources.

(i) Additive Manufacturing (AM): Additive manufacturing is a specific 3D printing process. This process creates layers in layers by inserting materials according to 3D digital design data. Additive manufacturing technologies such as selective laser melting (SLM), fused deposition method (FDM), and selective laser sintering (SLS) result in faster and more economical production [25]. AM is also employed in prototyping testing and design of parts/structures for low cost and customer satisfaction.

1.4 Connected Factory, Smart Factory, and Smart Manufacturing

A connected industry or intellectual industry is a manufacturing facility that uses digital technology to allow seamless sharing of information between people, machines, and sensors.

There are two main principles for allowing communication in the industry or factory. The first is to reach the right level of continuous production, self-improvement, and quality. This leads to higher profits. The second goal of the connected factory is to empower staff. The combination of control, visibility, and flexibility offered by the new digital solutions makes it possible for production workers to make further, impactful improvements. Figure 1.5 shows intelligent or integrated production including various digital technologies such as virtual reality, simulation, additive manufacturing, IoT, CPS, AI, cloud computing, etc. A smart or "connected" factory is one where almost every aspect of the factory is visible and available for analysis. Using data and updates, digital processes, and tools enable the entire organization, from management to shop floor staff reach to a new level of efficiency and profitability.

The connected industry uses consistent data distribution to adapt to the changing needs of intelligent production within an organization in a fully integrated and flexible system. Automatic workflow, real-time tracking and scheduling, as well as energy efficiency result in reduced costs and wastage [26].

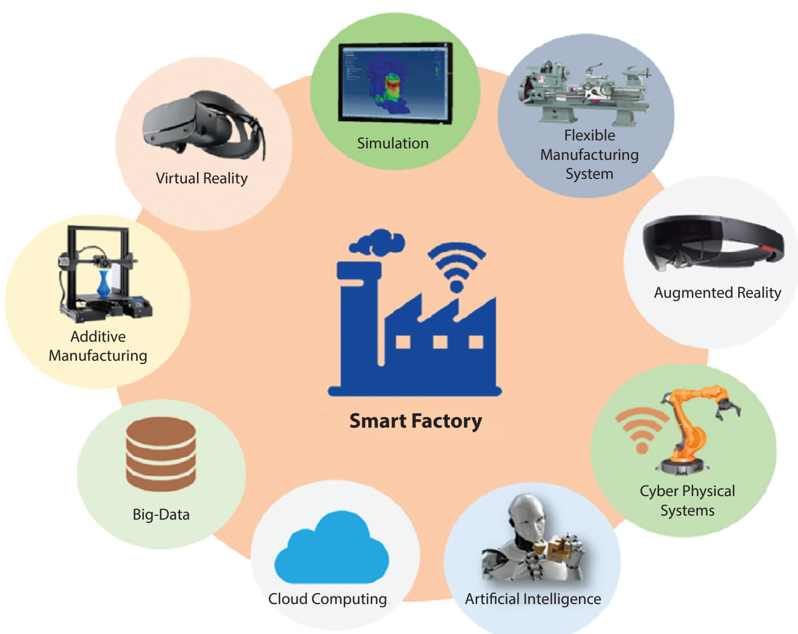

Figure 1.5 Connected industry or smart factory [7].

1.4.1 Potential Benefits of a Connected Factory

(a) High Productivity – Connected industries can perform jobs at a faster rate and run more efficiently leading to improved productivity and lower labor costs.
(b) Advanced Flexibility – Intelligent industries are designed for different production settings and demand flexibility. This provides complete flexibility of operation.
(c) Better Safety – The automation of tasks such as sorting, picking, packing, transporting, and delivering allows people to focus on safer jobs.
(d) Better Quality – The connected industry can detect quality problems quickly and can identify the cause.
(e) Lower Cost – More cost-effective processes, including asset management, better decisions, and improved service delivery.
(f) Flexible and effective communication as the factory floor and front and back offices share a single powerful data source [26, 27].

1.5 Digital and Virtual Factory

1.5.1 Digital Factory

Digital industry comprises network of digital models that replicate the features of a virtual factory. Digital Factory includes a list of methods and tools such as simulation and 3D visualization, all managed by integrated data management systems. The main goal of the digital industry is complete planning, continuous testing, and the development of a real productive factory [28]. The digital industry focuses on the following:

1. Improved quality of planning and economic efficiency
2. Shorter go-to market time
3. Clear communication
4. Similar planning standards
5. Managing competent information

What are the business benefits of a digital industry?
Complete and real-time data generated by digital factories promotes efficiency, productivity, safety and compliance. It also improves the flow

control of production work and the mobility of everything from immature items to continuous work and to finished goods. It also provides real-time access to operational data, so that managers can quickly overcome roadblocks and inefficiencies [29].

1.5.2 Virtual Factory

Virtual factory is based on integrated model that incorporates various software, tools, and solutions to any real-time production system problem. This model sees the real industry as a combination of various subsystems and integrates them. In practice, it creates a visual simulation work that helps to replicate the real life situation and that helps in design and implementation.

Virtual factory benefits include [30]:

- It assists in building skills to support rapid development in the manufacturing sector by bringing together professionals.
- It helps to provide solutions in a fast and inexpensive way.
- Eliminates the need for testing or pilot studies and replaces it with virtual simulation through software.
- It helps in optimum decision making.

1.6 Advanced Manufacturing Technologies

Manufacturing organizations use state-of-the-art production technology to meet quality improvement, reduce costs, and reduced lead time challenges posed by global competition, rapidly changing customer needs and low domestic productivity [31]. Advanced production technologies include:

- **Computer Technology (e.g., CAD, CAE, CAM)** – CAD, computer-assisted design, computer use to design 2D and 3D models. CAD provides a preview of the final product with digital visibility of the final product and its components and thus improves the quality of the design with greater accuracy and minor errors. Computer-assisted engineering (CAE) is the use of computer software to simulate performance in order to improve product designs or to help solve engineering problems in many industries. This includes the