1 Industrial Process Automation

1.1 DEFINITION OF PROCESS

As per the dictionary, a process is defined as a series of actions which are carried out in order to achieve a predefined result. It is nothing but a systematic economic activity pertaining to manufacturing/service. In the case of manufacturing industry, raw materials are converted into finished products through some physical and/or chemical procedures.

In general, processes can be of various types like agriculture, aviation, automotive, banking, broadcasting, governance, media, mining, servicing, education, health care, retail, insurance, transportation, industry, and a host of others. Popular industrial processes are chemical, petrochemical, fertilizer, power, metallurgical, food processing, pharmaceutical, etc. In any 'process', productivity with assured quality is the most important aspect. Automation techniques are increasingly being incorporated in various processes to increase productivity with desired quality.

1.2 MEANING OF AUTOMATION AND CONTROL

The word 'Automation' is derived from Greek words 'Auto' (self) and 'Matos' (moving). Therefore, 'Automation' is the mechanism for systems that 'move by itself'. 'Automation' is a set of technologies that results in operation of machines and systems without significant human intervention and achieves the desired performance superior to manual operation.

To operate an industrial process in a desired manner, control of its operation is needed at every possible step. Control is a set of policies and techniques that helps to achieve the desired variations of operational parameters and sequences for processes in manufacturing units and systems by providing the necessary input signals.

Here, it is important at this stage to understand the role of control in 'Industrial Automation'.

- An automation system may include a control system, but the reverse is not necessarily true.
- The main function of any control system is to ensure that output must follow the set point or desired value. However, automation systems may contain more functionalities, such as computing set points for control system, monitoring system performance, plant startup or shutdown, job and equipment scheduling, etc.

Control engineering, as one of the cornerstones of automation, enables automation tasks to be accomplished physically.

- The job of a controller is essentially to capture a process variable and to compare the same with the set value to produce necessary control action, thus ensuring that in the steady state, the value of the process variable is in line with the specified set values.
- A controller is the most important block for running a plant/process in a desired manner; otherwise, without control, it would result in the process variables deviating from the set value. So, the use of controllers is vital with respect to economy, reproducibility, product quality, service quality, safety, and environmental protection.
- In order to meet these criteria, plant operators always try to continuously improve upon automation systems. Starting with classical pneumatic Proportional-Integral-Derivative (PID) controllers of early days, at present software-based digital PID controllers are being increasingly employed.
- In addition to PID controllers, various other additional features like data acquisition, sequencing, recipe scheduling, alarm handling, etc. are incorporated in plant automation.

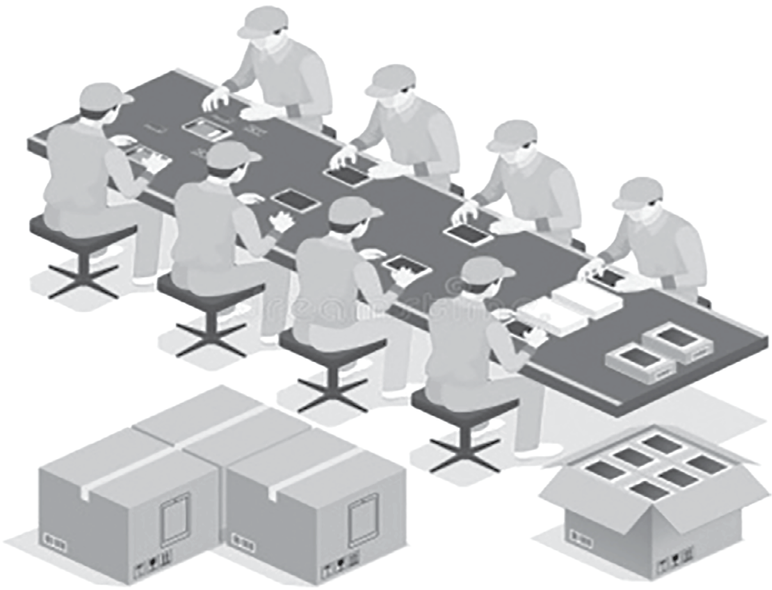
1.3 NECESSITY AND EVOLUTION OF AUTOMATION

In early days, different units of a process plant usually used to behave as isolated islands, i.e., individual units of a process plant were not integrated. Coordinating these individual units cohesively is highly labor intensive. But, today's manufacturing and process industries provide quality product in shortest possible time with lesser production cost and least downtime. Figures 1.1a and b show assembly line processes without and with automation, respectively.

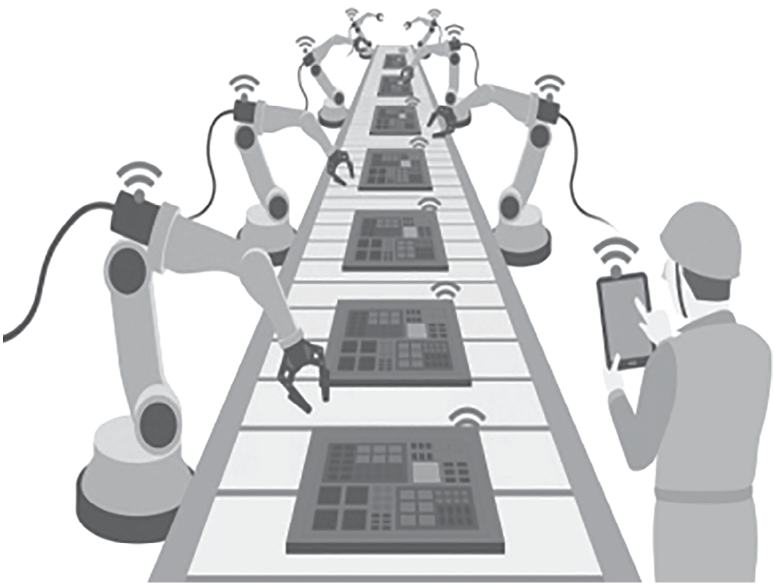
Thus, profit can be maximized by producing quality products in larger volumes with lesser production cost and time. Figure 1.2 shows the major parameters that affect the cost per unit of a mass manufactured industrial product.

To accomplish the aforesaid task, i.e., to maximize profit, a production process must satisfy four crucial parameters – all of which depend on interconnected hardware, software, and the plant or process equipment.

- **Flexibility:** The need to stay ahead in the competition and to get improved product quality requires reconfiguring assembly lines and redesigning processing facilities.
- **Quality control:** Today's quality assurance (QA) or quality control (QC) demands high levels of coordinated data acquisition and analysis.
- **Inventory control:** Just-in-time business strategies mean lower overhead by reducing or eliminating warehousing needs.
- **Speed:** People who need products are also operating on just-in-time principles. If the same is not delivered on time, they would lose production time, and the suppliers of these products would ultimately lose customers.



(a)



(b)

FIGURE 1.1 (a) Labor-intensive assembly-line process without automation. (b) Assembly-line process with automation.

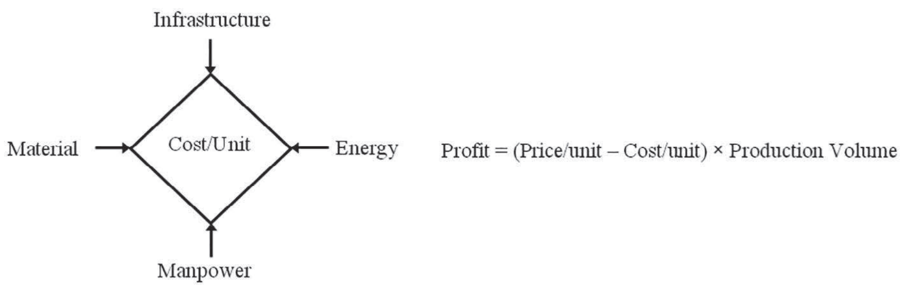


FIGURE 1.2 Cost and profit relation.

Hence, well-designed automated hardware, software, and systems running on local area networks (industrial network) in the plant or factory floor can help to achieve these goals economically.

Automation in the manufacturing and process industries has evolved over the years starting from basic hydraulic and pneumatic systems to today's modern robotic control systems. Most industrial operations are automated with the goal of boosting productivity and reducing the cost of labor. Since its inception, industrial automation has made rapid strides in the domains that were previously taken care of manually. A manufacturing organization that uses the latest technologies to fully automate its processes typically ensures improved efficiency, production of high-quality products, and reduced labor and production costs. Figure 1.3 shows the evolution of automation technologies over the years culminating in today's robotic automation systems.

In the early 1970s, Enterprise Resource Planning (ERP), i.e., the business management software came as the first Manufacturing Resource Planning solution from Systems, Applications, Products in data processing (SAP). ERP standardized business practices with its reconfigurable features, but it is not customized. Enterprises typically developed code on top for their ERP systems to modify or replace inbuilt processes. But, as the ERP is not inherently designed for this, these

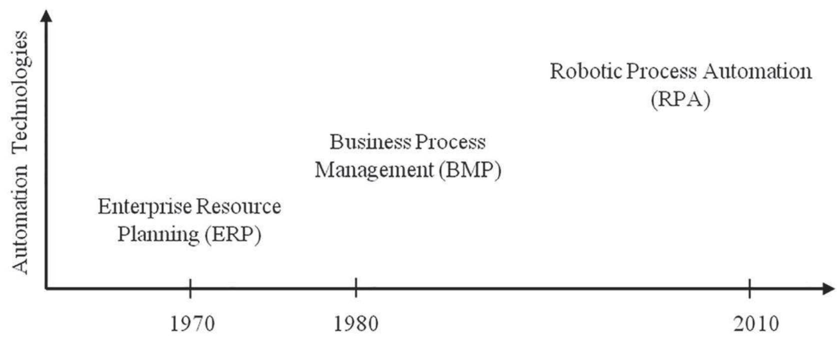


FIGURE 1.3 Evolution of automation technologies.

organizations eventually found themselves carrying significant information technology (IT) overhead.

In the mid-1980s, ‘digital workflow’ systems eventually evolved to Business Process Management (BPM) software when IBM introduced system-to-system messaging between mainframes. It is customizable and Application Program Interface (API) driven. *BPM is a strategic approach that concentrates on reshaping an organization’s existing business processes to achieve optimal efficiency and productivity.* The BPM software is the foundational backbone to facilitate completion of an organization’s projects, providing a variety of tools to help, improve, and streamline how business processes are performed. BPM software components may include business analytics, workflow engines, business rules, web forms, and collaboration tools.

The concept of Robotic Process Automation (RPA) appeared on the automation technology scenario in 2012. *RPA is a software technology that enables employees to better focus on high-priority tasks by pushing routine, monotonous tasks to software ‘robots’ to complete.* These robots work directly across application user interfaces, automatically inputting data and triggering actions across multiple systems, acting on behalf of an employee. Due to its platform and API independency, it is a user-friendly tool that does not involve any programming. Robotic process automation technology enables nontechnical professionals to self-serve and configure robots to solve their own automation challenges.

1.4 ROLE OF AUTOMATION IN PROCESS INDUSTRY

Automation can play an imperative role in various segments of industrial processes. For example, an automated detailed market study can help to decide the proper time for raw material purchase, and the automated feedback survey helps to incorporate additional features in the product redesigning. Thus, by introducing automation in industrial processes, a number of benefits are straightway accrued, which are detailed below.

- **Reduced production cost:** A quick return on investment (ROI) outweighs the initial setup costs.
- **Decreased part cycle time:** Robotics can work longer and faster, which increases the production rate.
- **Improved quality and reliability:** Automation is precise and repeatable, which ensures the product is manufactured with the same specifications each time.
- **Better floor space utilization:** Reduced work area by automating the parts in a production line; the floor space can be better utilized for other operations and make the process flow more efficient.
- **Reduced waste:** Robots are so accurate that the amount of raw material used can be reduced, decreasing costs on waste.
- **Staying competitive:** Automation helps to achieve the highest throughput while keeping the production schedule and cost within the specified constraints.

1.5 ARCHITECTURE OF INDUSTRIAL AUTOMATION NETWORK

In modern industrial automation networks, usually a five-layered communication hierarchy model is used. It describes the equipment required, network architecture, communication modes between equipment, and the nature of information flow and its control. The five-layered hierarchy is discussed below.

- **Field level:** The field level comprises sensors, actuators, switches, etc. which are installed in the tanks, vessels, and pipelines that make up a process plant. Sensors provide information about the process variables (temperature, pressure, flow, level, etc.) and pass the signals to the I/O (input/output) level. These signals are then passed on to the actuators which control the opening/closing of valves or start/stop of pumps.
- **I/O level:** The main purpose of the I/O level is to marshal together input and output signals. The signals from the sensors are directed to the controllers and those from the controllers are directed to the actuators.
- **Control level:** At the control level, signals from the sensors (located in the field) are processed, and based on the desired process outputs, commands to the actuators are generated. Usually Programmable Logic Controller (PLC), Distributed Control System (DCS), and Supervisory Control And Data Acquisition (SCADA) are present in this layer.
- **HMI level:** The Human Machine Interface (HMI) level is primarily concerned with the organized and systematic display of plant operations passed from the control level. Data acquisition, recipe management, asset management, maintenance schedule tools etc. are used in this layer for better process management. Operators have entire plant information through schematic representation and they can take corrective measures for any process variable to prevent or rectify its alarm situation. Other options available at this level are alarm logging, historical report generation, audit trail, etc.
- **Enterprise level:** At the enterprise level, entire information flows into the Management Information System (MIS). Here, managerial decision-making like ordering, production scheduling, billing, shipment, future planning, etc. are done through different software tools.

The enterprise-level network can even be extended beyond the respective plant automation network. To assess the market scenario, availability of information is also required from other production houses. In such cases, the plant automation network is connected with the World Wide Web (WWW or internet). This facility enables the plant personnel to get access to the useful plant information from any part of the globe.

The five-layered structure of an industrial automation network is shown in Figure 1.4.

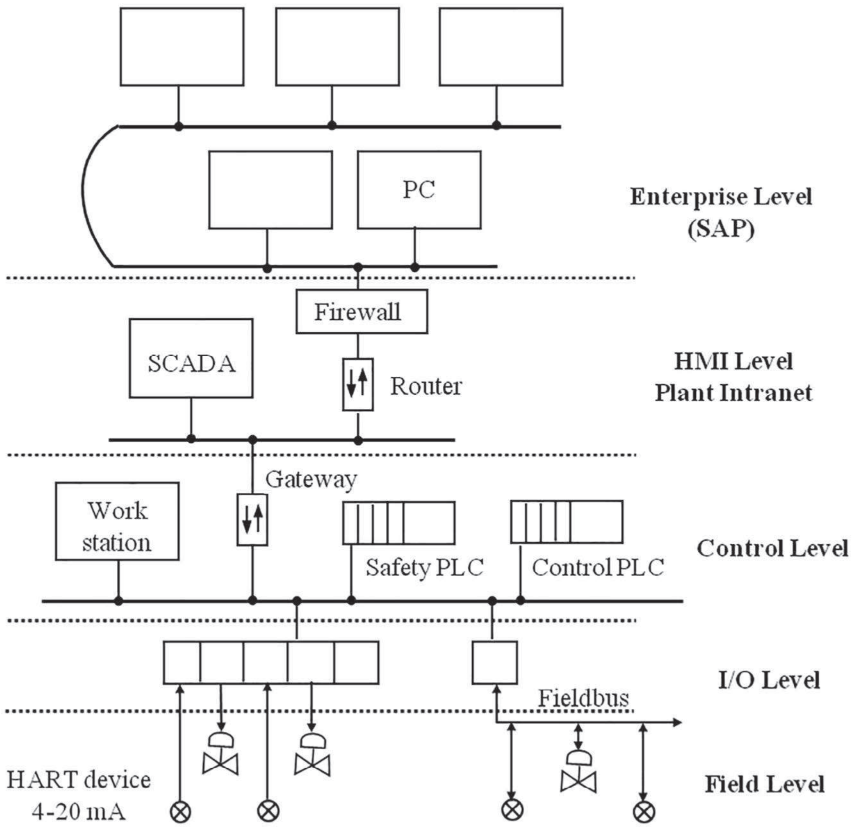


FIGURE 1.4 The five-layered structure of industrial automation network.

1.6 TYPES OF AUTOMATION SYSTEMS

Based on the integration level and flexibility, the industrial automation systems may be classified into three basic categories:

- Fixed automation
- Programmable automation
- Flexible automation

Fixed automation: In this category, sequences of operations are designed by the mechanized equipment configuration. Operations involved in the sequence are usually simple but integration and coordination of many such operations makes the system complex. Typical features of fixed automation are:

- High initial investment for custom-engineered equipment
- High production rate
- Relatively inflexible in accommodating product alteration

Fixed automation is economically justified if the product demand is very high over a considerable time span. Examples of fixed automation include mechanized assembly, paint shop, conveyors, machining transfer lines, etc.

Programmable automation: In this automation category, there is flexibility to change the sequence of operations to accommodate different product configurations. The operation sequence is controlled by a set of instructions which can be altered or modified based on the requirements. Some of the distinct features that characterize programmable automation are listed below:

- High investment in general-purpose equipment
- Low production rates relative to fixed automation
- Flexibility to deal with changes in product configuration
- Mostly suitable for batch production

Programmable automation systems are used in low- and medium-volume production processes. Here, the parts or products are typically made in batches. To produce each new batch of a different product, the system must be reprogrammed and reorganized to correspond to the new product. This changeover procedure takes time. Consequently, the typical cycle for a given product includes a period during which the setup and reprogramming take place, followed by a period in which the batch is produced. Examples of programmed automation include numerically controlled machine tools and industrial robots.

Flexible automation: It is an extension of programmable automation. A flexible automated system is the one that is capable of producing a variety of products with virtually no time loss for changeovers from one product cycle to the next. No production time is lost while reprogramming the system and altering the physical setup (tooling, fixtures, and machine setting). Consequently, the system can produce various combinations and schedules of products instead of requiring that they are made in separate batches. The features of flexible automation are summarized as follows:

- High investment for a custom-engineered system
- Continuous production of variable mix of products
- Medium production rates
- Flexibility to deal with product design variations

The essential features that distinguish flexible automation from programmable automation are as follows: capacity to change part of the programs or to change the physical setup with no loss in production time. These features allow the automated production systems to continue production without any downtime between batches that is the characteristic of programmable automation. Changing the part of programs is generally accomplished by developing the programs offline on a computer system and electronically transmitting the programs to the automated production process. Thus, the time required to do the programming for the next job does not interrupt the production of the current job. Changing the physical setup between parts is accomplished by making the changeover offline and then moving it into place simultaneously as the next part comes into position for processing. For these

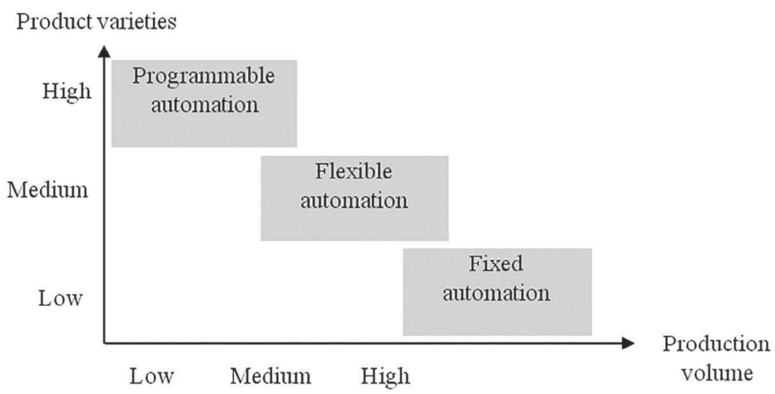


FIGURE 1.5 Relative positions of the three types of automation for different product volumes and product varieties.

approaches to be successful, the variety of parts that can be made on a flexible automated production system is usually more limited than a system controlled by programmable automation. Figure 1.5 shows the relative positions of automation for different product volumes and product varieties.

1.7 ROLE OF INFORMATION TECHNOLOGY IN PROCESS AUTOMATION

Industrial automation extensively uses IT for its implementation and smooth running. Some of the main IT areas used in the industrial automation contexts include communication and networking, control and signal processing, real-time computing, managing database, designing, simulation, analysis, and optimization. Figure 1.6 shows the different components used in an IT domain.

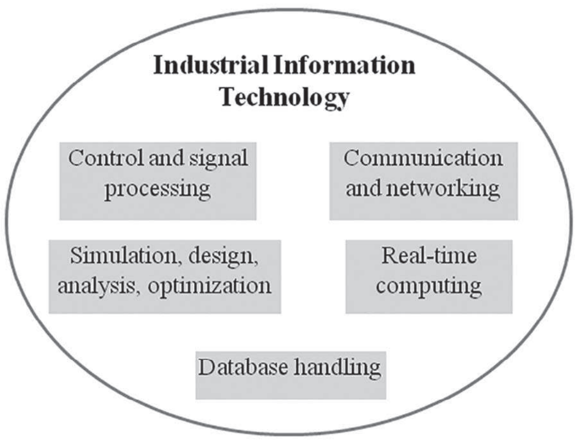


FIGURE 1.6 Components in an industrial IT system.

However, the industrial automation technology and industrial IT are not identical – in fact, they differ distinctly in the following senses:

- Industrial automation involves significant amount of hardware technologies related to instrumentation and sensing, actuation and drives, electronics for signal conditioning, communication and display, embedded as well as standalone computing systems, etc.
- As industrial automation systems grow more sophisticated in terms of knowledge and algorithms they use, they encompass larger areas of operations comprising several units of an industry, or even several of them; and as they integrate manufacturing with other areas of business such as sales and customer care, finance, and the entire supply chain of the business, the usage of IT increases dramatically.

1.8 PROCESS AUTOMATION WITH SMART AND INTELLIGENT INSTRUMENTS

Maintenance of instruments to keep them healthy is a prerequisite for successful running of a process plant. Smart instruments are designed to anticipate equipment failures, thereby preventing unscheduled process shutdowns. But, in cases where conventional instruments are still in operation, 'fix-it-when-it-breaks' maintenance is still the norm. Many companies still follow preventive routines based on historical experience to improve their maintenance practices, but this strategy has also proven to be wasteful and costly (incurs more than 10% of the manufacturing costs).

In modern process automation technology, smart instruments are employed; thus, maintenance practices shift from preventive to predictive ones, which is called condition-based monitoring. It helps to achieve better performance, lesser maintenance, and more uptime. Smart instruments also reduce disruptions by informing plant operators of a current or pending compromise in operation in advance, to prevent a total instrument failure. A smart instrument usually contains features like signal conditioner, one or more digital communication options, self-diagnostics, in situ calibration and configuration facility, time stamping, engineering unit conversion, data security, etc. To avoid wiring of the conventional instruments placed in difficult-to-reach locations, wireless communication features of smart instruments play a very useful and crucial role when it comes to communicating with each other.

Self-diagnostic features of a smart instrument are very useful in identifying any malfunctioning of the instrument as well as its improper installation. Operators can enquire different information from a smart instrument located in the field by generating query from its local handheld terminal or from a networked PC through HMI. Multiple parameters can be measured; for example, Coriolis flow meter can measure or calculate mass flow, viscosity, density, temperature, and totalized flow. In some cases, communication among the smart instruments helps to calculate some additional information. For example, two gauge pressure transmitters can be linked to produce a differential pressure value.

New smart instruments are available with Safety Instrumented System (SIS) features following IEC 61508 device design, manufacturing, and life-cycle management guidelines. Safety system designers often adhere to IEC 61511, ISA, and ANSI 84.01-2004 safety system life cycle management standards, in part by using IEC 61508-certified instruments with internal diagnostics. These certified instruments help designers to achieve the required Safety Integrity Level (SIL) for the process. Fieldbus-based safety process instruments will come into wider use, as instrumentation is now being developed to meet safety-relevant recommendations like NE 97 and standards like IEC 61508-2. Safety-certified instruments will work in tandem with Fieldbus safety protocols such as CIP Safety, Foundation Fieldbus SIS, and PROFIsafe.

For efficient data exchange with smart instruments, descriptors are used. The two main standards currently in use for this purpose are Electronic Device Description Language (EDDL) and the Field Device Tool (FDT). For smooth integration of smart instruments in a developed network, major instrument manufacturers and Fieldbus protocol organizations have agreed on an integrated Field Device Integration (FDI) specification. This FDI specification will consolidate the existing EDDL and FDT specifications, and would result in a truly universal field device integration scheme to connect nearly any field device with any Fieldbus network.

1.9 CHALLENGES OF PROCESS AUTOMATION

In the present age, a lot of benefits are accrued by deploying industrial process automation. However, any new benefit always comes with some new challenges. So, as automation technologies are becoming an integral part of our modern process industries, some new challenges are being faced:

- High capital expenditure is required for investment in automation as an automated system can cost millions of dollars to design, fabricate, and install. As a result, only big industry houses can sustain and the rest will gradually perish.
- High level of automation always requires higher sophistication in maintenance, which can be realized only with skilled manpower which requires high maintenance cost.
- Any automated production system usually has a lower degree of flexibility in terms of possible products.
- Requirement of manpower decreases substantially with increasing automation. Consequently, it leads to higher unemployment.
- With increasing use of motorized actuators as part of modern automation, power demand and industrial waste will rise leading to more pollution.

With industrial automation firmly in place, of late, the focus has shifted to home automation. The Internet of Things (IoT) technology is applied in home automation such that individual gadgets at home can simply be automated as per the convenience of the user. Home automation has its own advantages, but the flip side is that overdependence on automation is making us slaves to advances in technology. Also, privacy of humans is being increasingly compromised by vast computer data networks. Any unintentional human error in the management of technology may affect a large population, endangering their safety. Apart from these dangers, automation technology, if used wisely and effectively, can yield substantial benefits for the civilization.

1.10 INDUSTRY 1.0 TO INDUSTRY 4.0

Industries have gone through enormous changes and improvements to reach their present form, and it has been a journey comprising two centuries. At the beginning of the 18th century, most of the goods including food, clothing, housing, weapons, tools, and household items were manufactured by hand or by using work animals. This practice started changing toward the end of the 18th century with the introduction of manufacturing processes. Thereafter, the progress has seen rapid strides before culminating in its present form – normally termed as Industry 4.0. Figure 1.7 shows this journey from Industry 1.0 to Industry 4.0.

- **Industry 1.0**
  The first industrial revolution began in the 18th century through the use of steam power and mechanization of production. A mechanized version of the spinning wheel achieved an eightfold increase in production than the simple manual setup of the same time. The use of steam power was the greatest breakthrough for increasing productivity. Developments such as the steamship and later on the steam-powered locomotive brought about further massive changes because humans and goods could move great distances in less time.
- **Industry 2.0**
  The second industrial revolution began in the 19th century through the discovery of electricity and assembly-line production. The concept of mass production came through the division of labor, where each worker does a part of the total job using assembly line for increased productivity. Henry Ford (1863–1947) took this idea of mass production from a slaughterhouse in Chicago and implemented this concept into automobile production, and it drastically changed the entire production process. Earlier, a single station used to assemble an entire automobile; now the vehicles are produced in partial steps on the conveyor, significantly faster and at a lower cost.

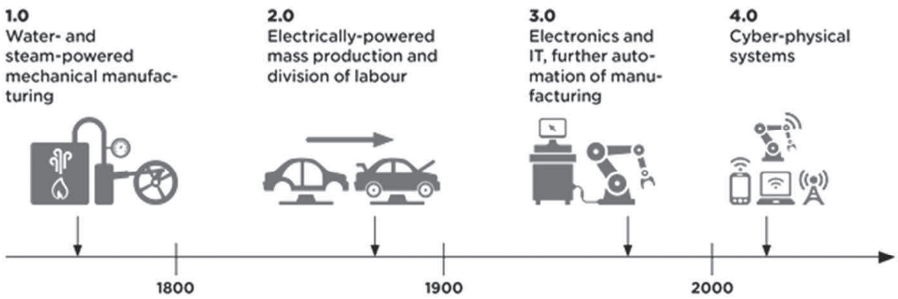


FIGURE 1.7 Journey of automation from Industry 1.0 to Industry 4.0.

- **Industry 3.0**
  The next industrial revolution resulting in Industry 3.0 was brought about in the last few decades of the 20th century supported by the advances in the electronics industry. The invention and manufacturing of a variety of electronic devices including transistor and integrated circuits automated the machines to a great extent, which resulted in reduced effort, increased speed, greater accuracy, and even complete replacement of the humans in some specific cases. PLC, which was first built around the 1960s, was one of the landmark inventions that signified automation using electronics. The integration of electronics hardware into the manufacturing systems also created a requirement of software systems to enable these electronic devices, consequentially fueling the software development market as well. Apart from controlling the hardware, the software systems, later known as IT, enabled many management processes such as enterprise resource planning, inventory management, shipping logistics, product flow scheduling, and tracking throughout the factory. The quest to further reduce production costs forced many manufacturers to move to low-cost countries. The dispersion of the geographical location of manufacturing led to the formation of the concept of supply chain management.
- **Industry 4.0**
  Rapid growth of internet and communication technology in the 1990s revolutionized the way exchange of information takes place. It also resulted in a paradigm shift of the industrial automation technology used in manufacturing industry. There is a merging of boundaries between physical and virtual world production operations. Cyber-physical systems (CPSs) have further blurred this boundary resulting in numerous rapid technological disruptions in the industry. CPSs allow machines to communicate with each other more intelligently with almost no physical or geographical barriers.

  Industry 4.0 using CPSs shares, analyzes, and guides intelligent actions for various processes in the industry to make the machines smarter. These smart machines can continuously monitor, detect, and predict faults to suggest preventive measures and remedial actions. This allows better preparedness and lower downtime for industries. The same dynamic approach can be translated to other sectors in the industry such as logistics, production scheduling, optimization of throughput times, quality control, capacity utilization, and efficiency boosting. Cyber physical production systems (CPPSs) also allow an industry to be completely virtually visualized, monitored, and managed from a remote location, thus adding a new dimension to the manufacturing process. It puts machines, people, processes, and infrastructure into a single networked loop making the overall management highly efficient.

  As the technology vs cost curve becomes steeper by the day, more and more rapid technology disruptions will emerge at even lower costs and revolutionize the industrial ecosystem. Industry 4.0 is still at a nascent stage of its development and the industries are slowly trying to adapt to the new systems. Industries must embrace the new cutting-edge technology as fast as possible to stay relevant and profitable. Industry 4.0 is here to stay, at least for the next decade, until a new technology comes on the horizon to supersede it.