3. Automation: What It Means to Us Around the World

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The meaning of the term *automation* is reviewed through its definition and related definitions, historical evolution, technological progress, benefits and risks, and domains and levels of applications. A survey of 331 people around the world adds insights to the current meaning of automation to people, with regard to: *What is your definition of automation? Where did you encounter automation first in your life?* and *What is the most important contribution of automation to society?* The survey respondents include 12 main aspects of the definition in their responses; 62 main types of first automation encounter; and 37 types of impacts, mostly benefits but also two benefit–risks combinations: replacing humans, and humans' inability to complete tasks by themselves. The most exciting contribution of automation found in the survey was to *encourage/inspire creative work; inspire newer solutions*. Minor variations were found in different regions of the world. Responses about the first automation encounter are somewhat related to the age of the respondent, e.g., pneumatic versus digital control, and to urban versus farming childhood environment. The chapter concludes with several emerging trends in bioinspired automation, collaborative control and automation, and risks to anticipate and eliminate.

3.1 The Meaning of Automation

What is the meaning of automation? When discussing this term and concept with many colleagues, leading experts in various aspects of automation, control theory, robotics engineering, and computer science during the development of this *Handbook of Automation*, many of them had different definitions; they even argued vehemently that *in their language, or their region of the world, or their professional domain*, automation has a unique meaning *and we are not sure it is the same meaning for other experts*. But there has been no doubt, no confusion, and no hesitation that automation is powerful; it has tremendous and amazing impact on civilization, on humanity, and it may carry risks.

So what is automation? This chapter introduces the meaning and definition of automation, at an introductory, overview level. Specific details and more theoretical definitions are further explained and illustrated throughout the following parts and chapters of this handbook. A survey of 331 participants from around the world was conducted and is presented in Sect. 3.5.

3.1.1 Definitions and Formalism

Automation, in general, implies *operating or acting, or self-regulating, independently, without human intervention*. The term evolves from *automatos*, in Greek, meaning acting by itself, or by its own will, or spontaneously. Automation involves machines, tools, devices, installations, and systems that are all platforms developed by humans to perform a given set of activities without human involvement during those activities. But there are many variations of this definition. For instance, before modern automation (specifically defined in the modern context since about 1950s), *mechanization* was a common version of automation. When automatic control was added to mechanization as an intelligence feature, the distinction and advantages of automation became clear. In this chapter, we review these related definitions and their evolvement, and survey how people around the world perceive automation. Examples of automation are described, including ancient to early examples in Table 3.1, examples from the Industrial Revolution in Table 3.3, and modern and emerging examples in Table 3.4. From the general definition of automation, the automation formalism is presented in Fig. 3.1 with four main elements: platform, autonomy, process, and power source. Automation platforms are illustrated in Table 3.2.

This automation formalism can help us review some early examples that may also fall under the definition of automation (before the term *automation* was even coined), and differentiate from related terms, such as *mechanization*, *cybernetics*, *artificial intelligence*, and *robotics*.

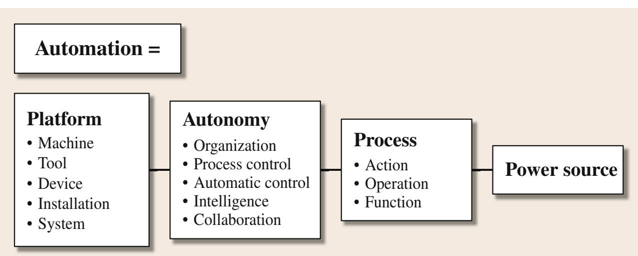

Fig. 3.1 Automation formalism. Automation comprises four basic elements. See representative illustrations of platforms, autonomy, process, and power source in Tables 3.1–3.2, 3.6, and the automation cases below, in Sect. 3.3

Automaton

An *automaton* (plural: automata, or automatons) is an autonomous machine that contains its own power source and can perform without human intervention a complicated series of decisions and actions, in response to programs and external stimuli. Since the term automaton is used for a specific autonomous machine, tool or device, it usually does not include automation platforms such as automation infrastructure, automatic installations, or automation systems such as automation

Table 3.1 Automation examples: ancient to early history

	Machine/system	Autonomous action/ function	Autonomy: control/ intelligence	Power source	Replacing	Process without human intervention
1.	Irrigation channels	Direct, regulate water flow	From-to, on-off gates, predetermined	Gravity	Manual watering	Water flow and directions
2.	Water supply by aqueducts over large distances	Direct, regulate water supply	From-to, on-off gates, predetermined	Gravity	Practically impossible	Water flow and directions
3.	Sundial clocks	Display current time	Predetermined timing	Sunlight	Impossible otherwise	Shadow indicating time
4.	Archytas' flying pigeon (4th century BC); Chinese mechanical orchestra (3rd century BC) Heron's mechanical chirping birds and moving dolls (1st century AD)	Flying; playing; chirping; moving	Predetermined sound and movements with some feedback	Heated air and steam (early hydraulics and pneumatics)	Real birds; human play	Mechanical bird or toy motions and sounds
5.	Ancient Greek temple automatic door opening	Open and close door	Preset states and positions with some feedback	Heated air, steam, water, gravity	Manual open and close	Door movements
6.	Windmills	Grinding grains	Predefined grinding	Winds	Animal and human power	Grinding process

Table 3.2 Automation platforms

Platform	Machine	Tool	Device	Installation	System	System of systems
Example	Mars lander	Sprinkler	Pacemaker	AS/RC (automated storage/ retrieval carousel)	ERP (enterprise resource planning)	Internet

software (even though some use the term *software automaton* to imply computing procedures). The scholar Al-Jazari from al-Jazira, Mesopotamia designed pioneering programmable automatons in 1206, as a set of dolls, or humanoid automata. Today, the most typical automatons are what we define as robots.

Table 3.3 Automation examples: Industrial Revolution to 1920

	Machine/system	Autonomous action/function	Autonomy: control/ intelligence	Power source	Replacing	Process without human intervention
1.	Windmills (17th century)	Flour milling	Feedback keeping blades always facing the wind	Winds	Nonfeedback windmills	Milling process
2.	Automatic pressure valve (Denis Papin, 1680)	Steam pressure in piston or engine	Feedback control of steam pressure	Steam	Practically impossible otherwise	Pressure regulation
3.	Automatic grist mill (Oliver Evans, 1784)	Continuous-flow flour production line	Conveyor speed control; milling process control	Water flow; steam	Human labor	Grains conveyance and milling process
4.	Flyball governor (James Watt, 1788)	Control of steam engine speed	Automatic feedback of centrifugal force for speed control	Steam	Human control	Speed regulation
5.	Steamboats, trains (18–19th century)	Transportation over very large distances	Basic speed and navigation controls	Steam	Practically impossible otherwise	Travel, freight hauling, conveyance
6.	Automatic loom (e.g., Joseph Jacquard, 1801)	Fabric weaving, including intricate patterns	Basic process control programs by interchangeable punched card	Steam	Human labor and supervision	Cloth weaving according to human design of fabric program
7.	Telegraph (Samuel Morse, 1837)	Fast delivery of text message over large distances	On-off, direction, and feedback	Electricity	Before tele-communication, practically impossible otherwise	Movement of text over wires

Table 3.3 (cont.)

	Machine/system	Autonomous action/function	Autonomy: control/intelligence	Power source	Replacing	Process without human intervention
8.	Semiautomatic assembly machines (Bodine Co., 1920)	Assembly functions including positioning, drilling, tapping, screw insertion, pressing	Connect/disconnect; process control	Electricity; compressed air through belts and pulleys	Human labor	Complex sequences of assembly operations
9.	Automatic automobile-chassis plant (A.O. Smith Co., 1920)	Chassis production	Parts, components, and products flow control, machining, and assembly process control	Electricity	Human labor and supervision	Manufacturing processes and part handling with better accuracy

Robot

A *robot* is a mechanical device that can be programmed to perform a variety of tasks of manipulation and locomotion under automatic control. Thus, a robot could also be an automaton. But unlike an automaton, a robot is usually designed for highly variable and flexible, purposeful motions and activities, and for specific operation domains, e.g., surgical robot, service robot, welding robot, toy robot, etc. General Motors implemented the first industrial robot, called UNIMATE, in 1961 for die-casting at an automobile factory in New Jersey. By now, millions of robots are routinely employed and integrated throughout the world.

Robotics

The science and technology of designing, building, and applying robots, computer-controlled mechanical devices, such as automated tools and machines. Science

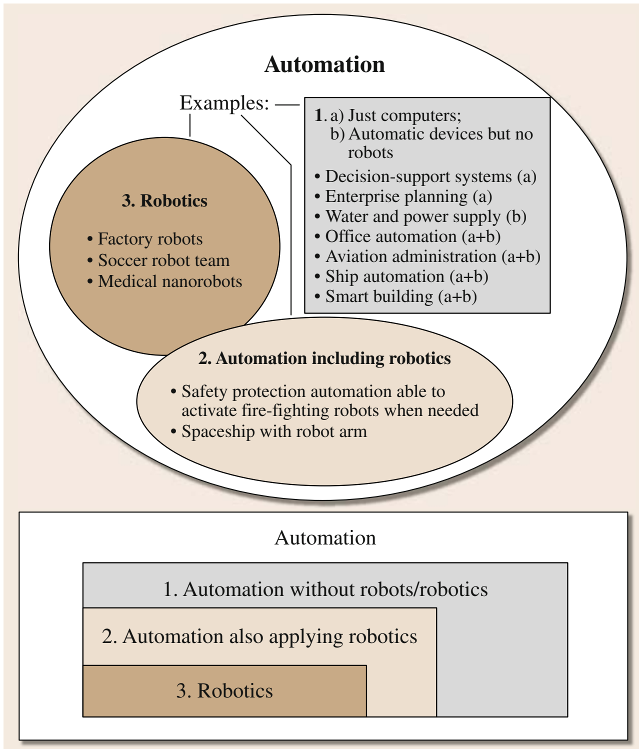

Fig. 3.2 The relation between robotics and automation: The scope of automation includes applications: (1a) with just computers, (1b) with various automation platforms and applications, but without robots; (2) automation including also some robotics; (3) automation with robotics

Table 3.4 Automation examples: modern and emerging

	Machine/system	Autonomous action/function	Autonomy: control/intelligence	Power source	Replacing	Process without human intervention
1.	Automatic door opener	Opening and closing of doors triggered by sensors	Automatic control	Compressed air or electric motor	Human effort	Doors of buses, trains, buildings open and close by themselves
2.	Elevators, cranes	Lifting, carrying	On-off; feedback; preprogrammed or interactive	Hydraulic pumps; electric motors	Human climbing, carrying	Speed and movements require minimal supervision
3.	Digital computers	Data processing and computing functions	Variety of automatic and interactive control and operating systems; intelligent control	Electricity	Calculations at speeds, complexity, and with amounts of data that are humanly impossible	Cognitive and decision-making functions
4.	Automatic pilot	Steering aircraft or boat	Same as (3)	Electrical motors	Human pilot	Navigation, operations, e.g., landing
5.	Automatic transmission	Switch gears of power transmission	Automatic control	Electricity; hydraulic pumps	Manual transmission control	Engaging/disengaging rotating gears
6.	Office automation	Document processing, imaging, storage, printing	Same as (3)	Electricity	Some manual work; some is practically impossible	Specific office procedures
7.	Multirobot factories	Robot arms and automatic devices perform variety of manufacturing and production processes	Optimal, adaptive, distributed, robust, self-organizing, collaborative, and other intelligent control	Hydraulic pumps, pneumatics, and electric motors	Human labor and supervision	Complex operations and procedures, including quality assurance

fiction author and scientist *Isaac Asimov* coined the term *robotics* in 1941 to describe the technology of robots and predicted the rise of a significant robot industry, e.g., in his foreword to [3.1]:

> *Since physics and most of its subdivisions routinely have the "-ics" suffix, I assumed that robotics was the proper scientific term for the systematic study of robots, of their construction, maintenance, and behavior, and that it was used as such.*

3.1.2 Robotics and Automation

Robotics is an important subset of automation (Fig. 3.2). For instance, of the 25 automation examples in Tables 3.1, 3.3 and 3.4, examples 4 in Table 3.1 and 7 in Table 3.4 are about robots. Beyond robotics, automation includes:

- Infrastructure, e.g., water supply, irrigation, power supply, telecommunication
- Nonrobot devices, e.g., timers, locks, valves, and sensors
- Automatic and automated machines, e.g., flour mills, looms, lathes, drills, presses, vehicles, and printers
- Automatic inspection machines, measurement workstations, and testers
- Installations, e.g., elevators, conveyors, railways, satellites, and space stations
- Systems, e.g., computers, office automation, Internet, cellular phones, and software packages.

Common to both robotics and automation are use of automatic control, and evolution with computing and communication progress. As in automation, robotics also relies on four major components, including a platform, autonomy, process, and power source, but in robotics, a robot is often considered a machine, thus the platform is mostly a machine, a tool or device, or a system of tools and devices. While robotics is, in a major way, about automation of motion and mobility, automation beyond robotics includes major areas based on software, decision-making, planning and optimization, collaboration, process automation, office automation, enterprise resource planning automation, and e-Services. Nevertheless, there is clearly an overlap between automation and robotics; while to most people a robot means a machine with certain automation intelligence, to many an intelligent elevator, or highly

Table 3.4 (cont.)

	Machine/system	Autonomous action/function	Autonomy: control/intelligence	Power source	Replacing	Process without human intervention
8.	Medical diagnostics (e.g., computerized tomography (CT), magnetic resonance imaging (MRI))	Visualization of medical test results in real time	Automatic control; automatic virtual reality	Electricity	Impossible otherwise	Noncontact testing and results presentation
9.	Wireless services	Remote prognostics and automatic repair	Predictive control; interacting with radio frequency identification (RFID) and sensor networks	Electricity	Practically impossible otherwise	Monitoring remote equipment functions, executing self-repairs
10.	Internet search engine	Finding requested information	Optimal control; multiagent control	Electricity	Human search, practically impossible	Search for specific information over a vast amount of data over worldwide systems

automated machine tool, or even a computer may also imply a robot.

Cybernetics

Cybernetics is the scientific study of control and communication in organisms, organic processes, and mechanical and electronic systems. It evolves from *kibernetes*, in Greek, meaning pilot, or captain, or governor, and focuses on applying technology to replicate or imitate biological control systems, often called today bioinspired, or system biology. *Cybernetics*, a book by Norbert Wiener, who is attributed with coining this word, appeared in 1948 and influenced artificial intelligence research. Cybernetics overlaps with control theory and systems theory.

Cyber

Cyber- is a prefix, as in cybernetic, cybernation, or cyborg. Recently, cyber has assumed a meaning as a noun, meaning computers and information systems, virtual reality, and the Internet. This meaning has emerged because of the increasing importance of these automation systems to society and daily life.

Artificial Intelligence (AI)

Artificial intelligence (AI) is the ability of a machine system to perceive anticipated or unanticipated new

Table 3.5 Definitions of automation (after [3.2])

Source	Definition of automation
1. John Diebold, President, John Diebold & Associates, Inc.	*It is a means of organizing or controlling production processes to achieve optimum use of all production resources – mechanical, material, and human. Automation means optimization of our business and industrial activities.*
2. Marshall G. Nuance, VP, York Corp.	*Automation is a new word, and to many people it has become a scare word. Yet it is not essentially different from the process of improving methods of production which has been going on throughout human history.*
3. James B. Carey, President, International Union of Electrical Workers	*When I speak of automation, I am referring to the use of mechanical and electronic devices, rather than human workers, to regulate and control the operation of machines. In that sense, automation represents something radically different from the mere extension of mechanization. Automation is a new technology. Arising from electronics and electrical engineering.*
4. Joseph A. Beirne, President, Communications Workers of America	*We in the telephone industry have lived with mechanization and its successor automation for many years.*
5. Robert C. Tait, Senior VP, General Dynamics Corp.	*Automation is simply a phrase coined, I believe, by Del Harder of Ford Motor Co. in describing their recent supermechanization which represents an extension of technological progress beyond what has formerly been known as mechanization.*
6. Robert W. Burgess, Director, Census, Department of Commerce	*Automation is a new word for a now familiar process of expanding the types of work in which machinery is used to do tasks faster, or better, or in greater quantity.*
7. D.J. Davis, VP Manufacturing, Ford Motor Co.	*The automatic handling of parts between progressive production processes. It is the result of better planning, improved tooling, and the application of more efficient manufacturing methods, which take full advantage of the progress made by the machine-tool and equipment industries.*
8. Don G. Mitchell, President, Sylvania Electric Products, Inc.	*Automation is a more recent term for mechanization, which has been going on since the industrial revolution began. Automation comes in bits and pieces. First the automation of a simple process, and then gradually a tying together of several processes to get a group of subassembly complete.*

Table 3.6 Automation domains

Domain	Accounting	Agriculture	Banking	Chemical process	Communication	Construction	Design
Example	Billing software	Harvester	ATM (automatic teller machine)	Refinery	Print-press	Truck	CAD (computer-aided design)
Education	**Energy**	**Engineering**	**Factory**	**Government**	**Healthcare**	**Home**	**Hospital**
Television	Power windmill	Simulation	AGV (automated guided vehicle)	Government web portals	Body scanner	Toaster	Drug delivery
Hospitality	**Leisure**	**Library**	**Logistics**	**Management**	**Manufacturing**	**Maritime**	**Military**
CRM (customer relations management)	Movie	Database	RFID (radio-frequency identification)	Financial analysis software	Assembly robot	Navigation	Intelligence satellite
Office	**Post**	**Retail**	**Safety**	**Security**	**Service**	**Sports**	**Transportation**
Copying machine	Mail sorter	e-Commerce	Fire alarm	Motion detector	Vending machine	Tread mill	Traffic light

conditions, decide what actions must be performed under these conditions, and plan the actions accordingly. The main areas of AI study and application are knowledge-based systems, computer sensory systems, language processing systems, and machine learning. AI is an important part of automation, especially to characterize what is sometimes called intelligent automation (Sect. 3.4.2).

It is important to note that AI is actually human intelligence that has been implemented on machines, mainly through computers and communication. Its significant advantages are that it can function automatically, i. e., without human intervention during its operation/function; it can combine intelligence from many humans, and improve its abilities by automatic learning and adaptation; it can be automatically distributed, duplicated, shared, inherited, and if necessary, restrained and even deleted. With the advent of these abilities, remarkable progress has been achieved. There is also, however, an increasing risk of *running out of control* (Sect. 3.6), which must be considered carefully as with harnessing any other technology.

3.1.3 Early Automation

The creative human desire to develop automation, from ancient times, has been to recreate natural activities, either for enjoyment or for productivity with less human effort and hazard. It should be clear, however, that the following six imperatives have been proven about automation:

1. Automation has always been developed by people
2. Automation has been developed for the sake of people
3. The benefits of automation are tremendous
4. Often automation performs tasks that are impossible or impractical for humans
5. As with other technologies, care should be taken to prevent abuse of automation, and to eliminate the possibilities of unsafe automation
6. Automation is usually inspiring further creativity of the human mind.

The main evolvement of automation has followed the development of mechanics and fluidics, civil infrastructure and machine design, and since the 20th century, of computers and communication. Examples of ancient automation that follow the formal definition (Table 3.1) include flying and chirping birds, sundial clocks, irrigation systems, and windmills. They all include the four basic automation elements, and have a clear autonomous process without human intervention, although they are mostly predetermined or predefined in terms of their control program and organization. But not all these ancient examples replace previously used human effort: Some of them would be impractical or even impossible for humans, e.g., displaying time, or moving large quantities of water by aqueducts over large distances. This observation is important, since, as evident from the definition surveys (Sect. 3.5):

1. In defining automation, over one-quarter of those surveyed associate automation with *replacing humans*, hinting somber connotation that humans are *losing* certain advantages. Many resources erroneously define automation as *replacement of human workers by technology*. But the definition is not about *replacing* humans, as many automation examples involve activities people cannot practically perform, e.g., complex and fast computing, wireless telecommunication, microelectronics manufacturing, and satellite-based positioning. The definition is about the autonomy of a system or process from human involvement and intervention during the process (independent of whether humans could or could not perform it themselves). Furthermore, automation is rarely disengaged from people, who must maintain and improve it (or at least replace its batteries).
2. Humans are always involved with automation, to a certain degree, from its development, to, at certain points, supervising, maintaining, repairing, and issuing necessary commands, e.g., *at which floor should this elevator stop for me?*

Describing automation, *Buckingham* [3.3] quotes Aristotle (384–322 BC): "When looms weave by themselves human's slavery will end." Indeed, the reliance on a process that can proceed successfully to completion autonomously, without human participation and intervention, is an essential characteristic of automation. But it took over 2000 years since Aristotle's prediction till the automatic loom was developed during the Industrial Revolution.

3.1.4 Industrial Revolution

Some scientists (e.g., *Truxal* [3.4]) define automation as applying machines or systems to execute tasks that involve more elaborate decision-making. Certain decisions were already involved in ancient automation, e.g., where to direct the irrigation water. More control sophistication was indeed developed later, beginning during the Industrial Revolution (see examples in Table 3.3).

During the Industrial Revolution, as shown in the examples, steam and later electricity became the main power sources of automation systems and machines, and autonomy of process and decision-making increasingly involved feedback control models.

3.1.5 Modern Automation

The term *automation* in its modern meaning was actually attributed in the early 1950s to D.S. Harder, a vice-president of the Ford Motor Company, who described it as a philosophy of manufacturing. Towards the 1950s, it became clear that automation could be viewed as substitution by mechanical, hydraulic, pneumatic, electric, and electronic devices for a combination of human efforts and decisions. Critics with humor referred to automation as *substitution of human error by mechanical error*. Automation can also be viewed as the combination of four fundamental principles: mechanization; process continuity; automatic control; and economic, social, and technological rationalization.

Mechanization

Mechanization is defined as the application of machines to perform work. Machines can perform various tasks, at different levels of complexity. When mechanization is designed with cognitive and decision-making functions, such as process control and automatic control, the modern term *automation* becomes appropriate. Some machines can be rationalized by benefits of safety and convenience. Some machines, based on their power, compactness, and speed, can accomplish tasks that could never be performed by human labor, no matter how much labor or how effectively the operation could be organized and managed. With increased availability and sophistication of power sources and of automatic control, the level of autonomy of machines and mechanical system created a distinction between mechanization and the more autonomous form of mechanization, which is automation (Sect. 3.4).

Process Continuity

Process continuity is already evident in some of the ancient automation examples, and more so in the Industrial Revolution examples (Tables 3.1 and 3.3). For instance, windmills could provide relatively uninterrupted cycles of grain milling. The idea of continuity is to increase productivity, the useful output per labor-hour. Early in the 20th century, with the advent of mass production, it became possible to better organize workflow. Organization of production flow and assembly lines, and automatic or semiautomatic transfer lines increased productivity beyond mere mechanization. The emerging automobile industry in Europe and the USA in the early 1900s utilized the concept of moving work continuously, automatically or semiautomatically, to specialized machines and workstations. Interesting problems that emerged with flow automation included balancing the work allocation and regulating the flow.

Automatic Control

A key mechanism of automatic control is feedback, which is the regulation of a process according to its own output, so that the output meets the conditions of a predetermined, set objective. An example is the windmill that can adjust the orientation of it blades by feedback informing it of the changing direction of the current wind. Another example is the heating system that can stop and restart its heating or cooling process according to feedback from its thermostat. Watt's flyball governor applied feedback from the position of the rotating balls as a function of their rotating speed to automatically regulate the speed of the steam engine. Charles Babbage analytical engine for calculations applied the feedback principle in 1840 (see more on the development of automatic control in Chap. 4).

Automation Rationalization

Rationalization means a logical and systematic analysis, understanding, and evaluation of the objectives and constraints of the automation solution. Automation is rationalized by considering the technological and engineering aspects in the context of economic, social, and managerial considerations, including also: human factors and usability, organizational issues, environmental constraints, conservation of resources and energy, and elimination of waste (Chaps. 40 and 41).

Soon after automation enabled mass production in factories of the early 20th century and workers feared for the future of their jobs, the US Congress held hearings in which experts explained what automation means to them (Table 3.5). From our vantage point several generations later, it is interesting to read these definitions, while we already know about automation discoveries yet unknown at that time, e.g., laptop computers, robots, cellular telephones and personal digital assistants, the Internet, and more.

A relevant question is: Why automate? Several prominent motivations are the following, as has been indicated by the survey participants (Sect. 3.5):

1. *Feasibility*: Humans cannot handle certain operations and processes, either because of their scale, e.g., micro- and nanoparticles are too small, the amount of data is too vast, or the process happens too fast, for instance, missile guidance; microelectronics design, manufacturing and repair; and database search.
2. *Productivity*: Beyond feasibility, computers, automatic transfer machines, and other equipment can operate at such high speed and capacity that it would be practically impossible without automation, for instance, controlling consecutive, rapid chemical processes in food production; performing medicine tests by manipulating atoms or molecules; optimizing a digital image; and placing millions of colored dots on a color television (TV) screen.
3. *Safety*: Automation sensors and devices can operate well in environments that are unsafe for humans, for example, under extreme temperatures, nuclear radiation, or in poisonous gas.
4. *Quality and economy*: Automation can save significant costs on jobs performed without it, including consistency, accuracy, and quality of manufactured products and of services, and saving labor, safety, and maintenance costs.
5. *Importance to individuals, to organizations, and to society*: Beyond the above motivations, service- and knowledge-based automation reduces the need for middle managers and middle agents, thus reducing or eliminating the agency costs and removing layers of bureaucracy, for instance, Internet-based travel services and financial services, and direct communication between manufacturing managers and line operators, or cell robots. Remote supervision and telecollaboration change the nature, sophistication, skills and training requirements, and responsibility of workers and their managers. As automation gains intelligence and competencies, it takes over some employment skills and opens up new types of work, skills, and service requirements.
6. *Accessibility*: Automation enables better accessibility for all people, including disadvantaged and disabled people. Furthermore, automation opens up new types of employment for people with limitations, e.g., by integration of speech and vision recognition interfaces.
7. *Additional motivations*: Additional motivations are the competitive ability to integrate complex mechanization, advantages of modernization, convenience, and improvement in quality of life.

To be automated, a system must follow the motivations listed above. The modern and emerging automation examples in Table 3.4 and the automation cases in Sect. 3.3 illustrate these motivations, and the mechanization, process continuity, and automatic control features.

Certain limits and risks of automation need also be considered. Modern, computer-controlled automation must be programmable and conform to definable procedures, protocols, routines, and boundaries. The limits also follow the boundaries imposed by the four principles of automation. Can it be mechanized? Is there continuity in the process? Can automatic control be designed for it? Can it be rationalized? Theoretically, all continuous processes can be automatically controlled, but practically such automation must be rationalized first; for instance, jet engines may be continuously advanced on conveyors to assembly cells, but if the demand for these engines is low, there is no justification to automate their flow. Furthermore, all automation must be designed to operate within safe boundaries, so it does not pose hazards to humans and to the environment.

3.1.6 Domains of Automation

Some unique meanings of automation are associated with the domain of automation. Several examples of well-known domains are listed here:

- *Detroit automation* – Automation of transfer lines and assembly lines adopted by the automotive industry [3.5].
- *Flexible automation* – Manufacturing and service automation consisting of a group of processing stations and robots operating as an integrated system under computer control, able to process a variety of different tasks simultaneously, under automatic, adaptive control or learning control [3.5]. Also known as flexible manufacturing system (FMS), flexible assembly system, or robot cell, which are suitable for medium demand volume and medium variety of flexible tasks. Its purpose is to advance from mass production of products to more customer-oriented and customized supply. For higher flexibility with low demand volume, stand-

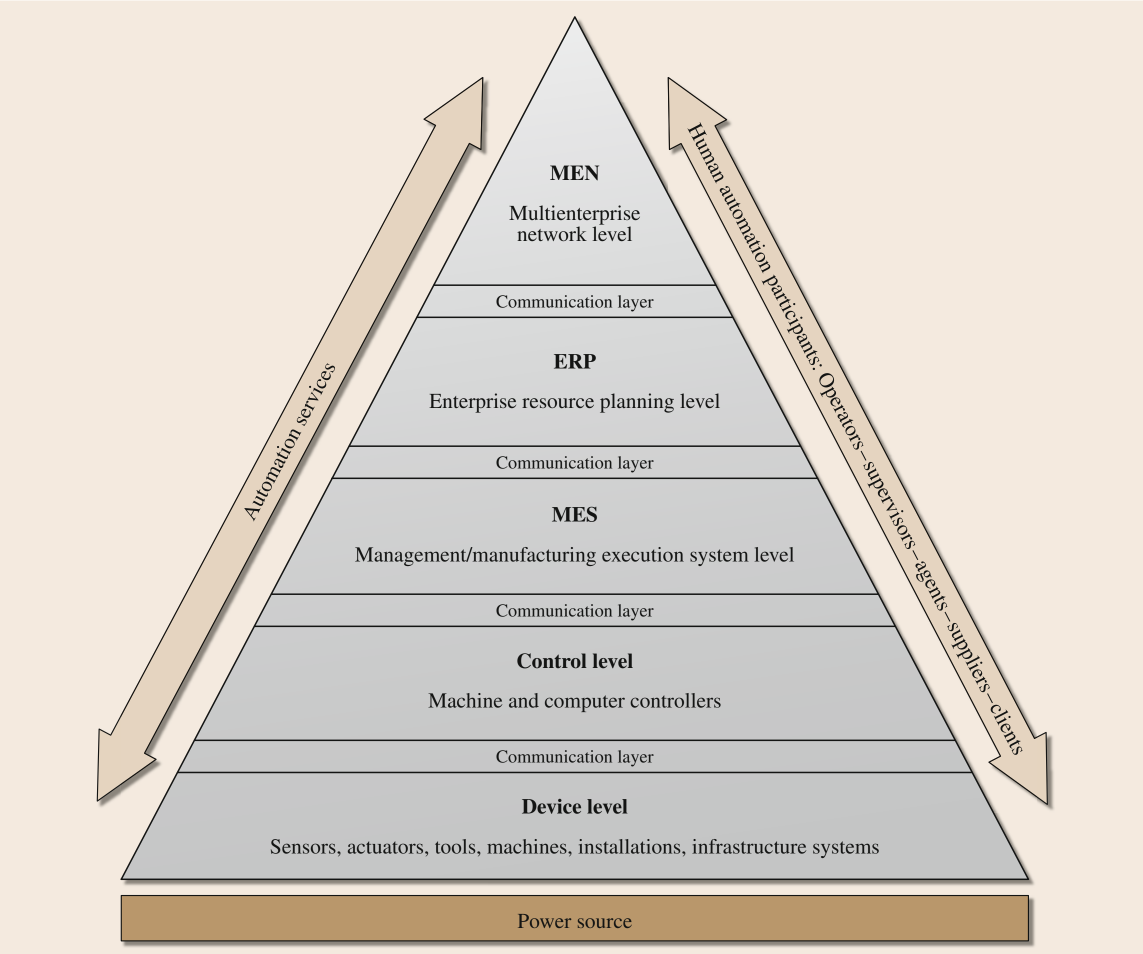

Fig. 3.3 The automation pyramid: organizational layers

alone numerically controlled (NC) machines and robots are preferred. For high demand volume with low task variability, automatic transfer lines are designed. The opposite of flexible automation is *fixed automation*, such as process-specific machine tools and transfer lines, lacking task flexibility. For mass customization (mass production with some flexibility to respond to variable customer demands), transfer lines with flexibility can be designed (see more on automation flexibility in Sect. 3.4).

- *Office automation* – Computer and communication machinery and software used to improve office procedures by digitally creating, collecting, storing, manipulating, displaying, and transmitting office information needed for accomplishing office tasks and functions [3.6, 7]. Office automation became popular in the 1970s and 1980s when the desktop computer and the personal computer emerged.

Other examples of well-known domains of automation have been factory automation (e.g., [3.8]), healthcare automation (e.g., [3.9]), workflow automation (e.g., [3.10]), and service automation (e.g., [3.11]). More domain examples are illustrated in Table 3.6.

Throughout these different domains, automation has been applied for various organization functions. Five hierarchical layers of automation are shown in the automation pyramid (Fig. 3.3), which is a common depiction of how to organize automation implementation.

3.2 Brief History of Automation

Table 3.7 Brief history of automation events

Period	Automation inventions (examples)	Automation generation
Prehistory	Sterilization of food and water, cooking, ships and boats, irrigation, wheel and axle, flush toilet, alphabet, metal processing	First generation: before automatic control (BAC)
Ancient history	Optics, maps, water clock, water wheel, water mill, kite, clockwork, catapult	
First millennium AD	Central heating, compass, woodblock printing, pen, glass and pottery factories, distillation, water purification, wind-powered gristmills, feedback control, automatic control, automatic musical instruments, self-feeding and self-trimming oil lamps, chemotherapy, diversion dam, water turbine, mechanical moving dolls and singing birds, navigational instruments, sundial	
11th–15th century	Pendulum, camera, flywheel, printing press, rocket, clock automation, flow-control regulator, reciprocating piston engine, humanoid robot, programmable robot, automatic gate, water supply system, calibration, metal casting	
16th century	Pocket watch, Pascal calculator, machine gun, corn grinding machine	Second generation: before computer control (BCC)
17th century	Automatic calculator, pendulum clock, steam car, pressure cooker	
18th century	Typewriter, steam piston engine, Industrial Revolution early automation, steamboat, hot-air balloon, automatic flour mill	
19th century	Automatic loom, electric motor, passenger elevator, escalator, photography, electric telegraph, telephone, incandescent light, radio, x-ray machine, combine harvester, lead–acid battery, fire sprinkler system, player piano, electric street car, electric fan, automobile, motorcycle, dishwasher, ballpoint pen, automatic telephone exchange, sprinkler system, traffic lights, electric bread toaster	
Early 20th century	Airplane, automatic manufacturing transfer line, conveyor belt-based assembly line, analog computer, air conditioning, television, movie, radar, copying machine, cruise missile, jet engine aircraft, helicopter, washing machine, parachute, flip–flop circuit	

Automation has evolved, as described in Table 3.7, along three automation generations.

3.2.1 First Generation: Before Automatic Control (BAC)

Early automation is characterized by elements of process autonomy and basic decision-making autonomy, but without feedback, or with minimal feedback. The period is generally from prehistory till the 15th century. Some examples of basic automatic control can be found earlier than the 15th century, at least in conceptual design or mathematical definition. Automation examples of the first generation can also be found later, whenever automation solutions without automatic control could be rationalized.

3.2.2 Second Generation: Before Computer Control (BCC)

Automation with advantages of automatic control, but before the introduction and implementation of the

Table 3.7 (cont.)

Period	Automation inventions (examples)	Automation generation
1940s	Digital computer, Assembler programming language, transistor, nuclear reactor, microwave oven, atomic clock, barcode	Third generation: automatic computer control (ACC)
1950s	Mass-produced digital computer, computer operating system, FORTRAN programming language, automatic sliding door, floppy disk, hard drive, power steering, optical fiber, communication satellite, computerized banking, integrated circuit, artificial satellite, medical ultrasonics, implantable pacemaker	
1960s	Laser, optical disk, microprocessor, industrial robot, automatic teller machine (ATM), computer mouse, computer-aided design, computer-aided manufacturing, random-access memory, video game console, barcode scanner, radiofrequency identification tags (RFID), permanent press fabric, wide-area packet switching network	
1970s	Food processor, word processor, Ethernet, laser printer, database management, computer-integrated manufacturing, mobile phone, personal computer, space station, digital camera, magnetic resonance imaging, computerized tomography (CT), e-Mail, spreadsheet, cellular phone	
1980s	Compact disk, scanning tunneling microscope, artificial heart, deoxyribonucleic acid DNA fingerprinting, Internet transmission control protocol/Internet protocol TCP/IP, camcorder	
1990s	World Wide Web, global positioning system, digital answering machine, smart pills, service robots, Java computer language, web search, Mars Pathfinder, web TV	
2000s	Artificial liver, Segway personal transporter, robotic vacuum cleaner, self-cleaning windows, iPod, softness-adjusting shoe, drug delivery by ultrasound, Mars Lander, disk-on-key, social robots	

computer, especially the digital computer, belongs to this generation. Automatic control emerging during this generation offered better stability and reliability, more complex decision-making, and in general better control and automation quality. The period is between the 15th century and the 1940s. It would be generally difficult to rationalize in the future any automation with automatic control and without computers; therefore, future examples of this generation will be rare.

3.2.3 Third Generation: Automatic Computer Control (ACC)

The progress of computers and communication has significantly impacted the sophistication of automatic control and its effectiveness. This generation began in the 1940s and continues today. Further refinement of this generation can be found in Sect. 3.4, discussing the levels of automation.

See also Table 3.8 for examples discovered or implemented during the three automation generations.

Table 3.8 Automation generations

Generation		Example
BAC before automatic control prehistoric, ancient		Waterwheel
ABC automatic control before computers 16th century–1940		Automobile
CAC computer automatic control 1940–present	*Hydraulic automation*	Hydraulic elevator
	Pneumatic automation	Door open/shut
	Electrical automation	Telegraph
	Electronic automation	Microprocessor
	Micro automation	Digital camera
	Nano automation	Nanomemory
	Mobile automation	Cellular phone
	Remote automation	Global positioning system (GPS)

3.3 Automation Cases

Ten automation cases are illustrated in this section to demonstrate the meaning and scope of automation in different domains.

3.3.1 Case A: Steam Turbine Governor (Fig. 3.4)

Source. Courtesy of Dresser-Rand Co., Houston (http://www.dresser-rand.com/).

Process. Operates a steam turbine used to drive a compressor or generator.

Platform. Device, integrated as a system with programmable logic controller (PLC).

Autonomy. Semiautomatic and automatic activation/deactivation and control of the turbine speed; critical speed-range avoidance; remote, auxiliary, and cascade speed control; loss of generator and loss of utility detection; hot standby ability; single and dual actuator control; programmable governor parameters via operator's screen and interface, and mobile computer. A manual mode is also available: The operator places the system in run mode which opens the governor valve to the full position, then manually opens the T&T valve to idle speed, to warm up the unit. After warm-up, the operator manually opens the T&T valve to full position, and as the turbine's speed approaches the rated (desirable) speed, the governor takes control with the governor valve. In semiautomatic and automatic modes, once the operator places the system in run mode, the governor takes over control.

3.3.2 Case B: Bioreactor (Fig. 3.5)

Source. Courtesy of Applikon Biotechnology Co., Schiedam (http://www.pharmaceutical-technology.com/contractors/process_automation/applikon-technology/).

Process. Microbial or cell culture applications that can be validated, conforming with standards for equipment used in life science and food industries, such as good automated manufacturing practice (GAMP).

Platform. System or installation, including microreactors, single-use reactors, autoclavable glass bioreactors, and stainless-steel bioreactors.

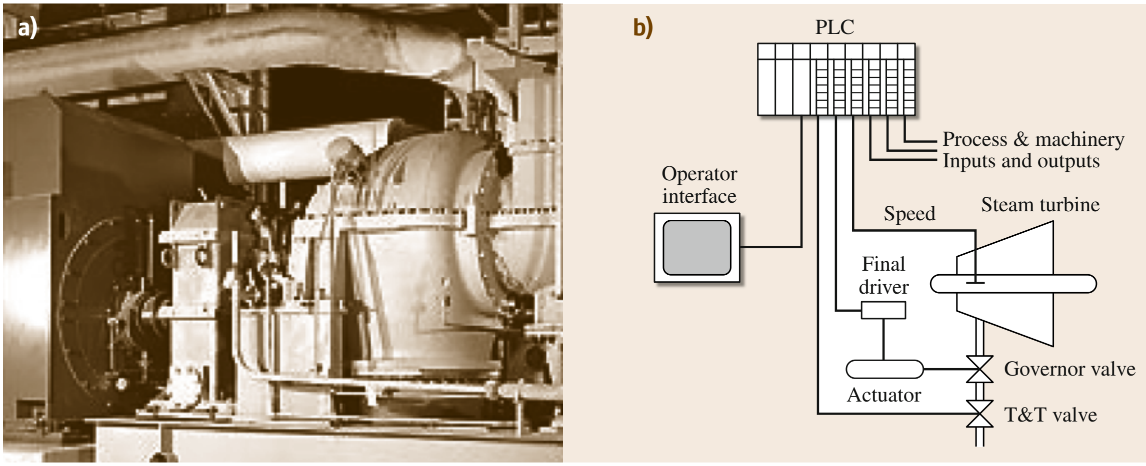

Fig. 3.4 **(a)** Steam turbine generator. **(b)** Governor block diagram (PLC: programmable logic controller; T&T: trip and throttle). A turbine generator designed for on-site power and distributed energy ranging from 0.5 to 100 MW. Turbine generator sets produce power for pulp and paper mills, sugar, hydrocarbon, petrochemical and process industries; palm oil, ethanol, waste-to-energy, other biomass burning facilities, and other installations (with permission from Dresser-Rand)

Autonomy. Bioreactor functions with complete measurement and control strategies and supervisory control and data acquisition (SCADA), including sensors and a cell retention device.

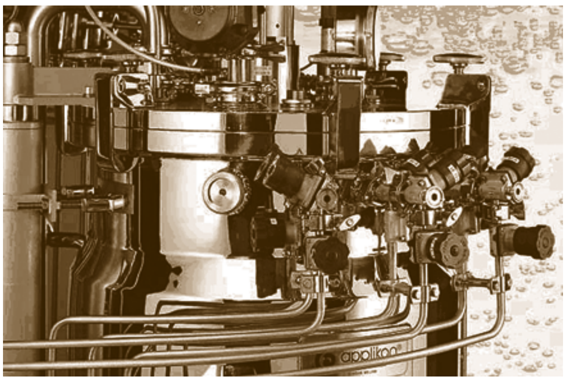

Fig. 3.5 Bioreactor system configured for microbial or cell culture applications. Optimization studies and screening and testing of strains and cell lines are of high importance in industry and research and development (R&D) institutes. Large numbers of tests are required and they must be performed in as short a time as possible. Tests should be performed so that results can be validated and used for further process development and production (with permission from Applikon Biotechnology)

3.3.3 Case C: Digital Photo Processing (Fig. 3.6)

Source. Adobe Systems Incorporated San Jose, California (http://adobe.com).

Process. Editing, enhancing, adding graphic features, removing stains, improving resolution, cropping and sizing, and other functions to process photo images.

Platform. Software system.

Autonomy. The software functions are fully automatic once activated by a user. The software can execute them semiautomatically under user control, or action series can be automated too.

3.3.4 Case D: Robotic Painting (Fig. 3.7)

Source. Courtesy of ABB Co., Zürich (http://www.ABB.com).

Process. Automatic painting under automatic control of car body movement, door opening and closing, paint-pump functions, fast robot motions to optimize finish quality, and minimize paint waste.

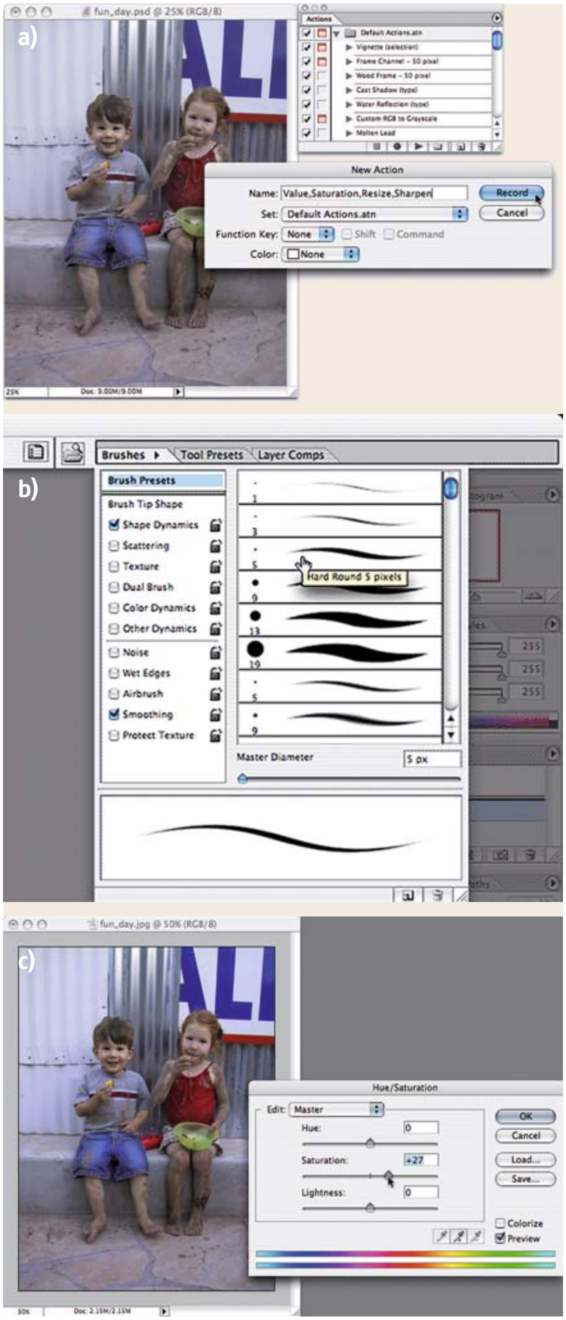

Fig. 3.6a–c Adobe Photoshop functions for digital image editing and processing: **(a)** automating functional actions, such as shadow, frame, reflection, and other visual effects; **(b)** selecting brush and palette for graphic effects; **(c)** setting color and saturation values (with permission from Adobe Systems Inc., 2008)

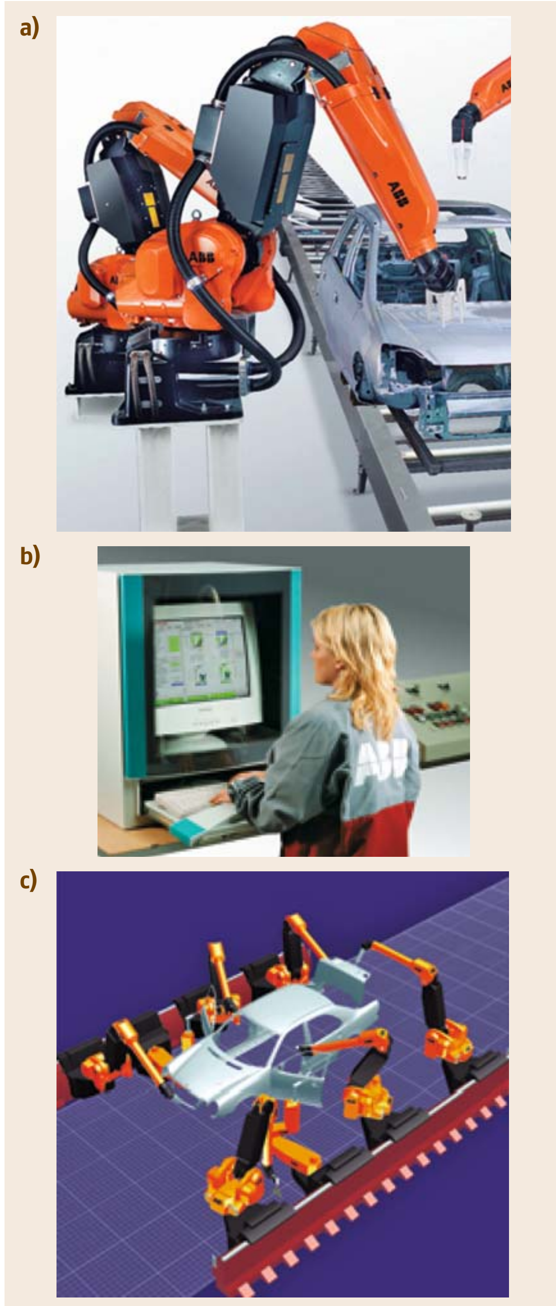

Fig. 3.7a–c A robotic painting line: **(a)** the facility; **(b)** programmer using interface to plan offline or online, experiment, optimize, and verify control programs for the line; **(c)** robotic painting facility design simulator (with permission from ABB)

Platform. Automatic tools, machines, and robots, including sensors, conveyors, spray-painting equipment, and integration with planning and programming software systems.

Autonomy. Flexibility of motions; collision avoidance; coordination of conveyor moves, robots' motions, and paint pump operations; programmability of process and line operations.

3.3.5 Case E: Assembly Automation (Fig. 3.8)

Source. Courtesy of Adapt Automation Inc., Santa Ana, California (www.adaptautomation.com/Medical.html).

Process. Hopper and two bowl feeders feed specimen sticks through a track to where they are picked and placed, two up, into a double nest on a 12-position indexed dial plate. Specimen pads are fed and placed on the sticks. Pads are fully seated and inspected. Rejected and good parts are separated into their respective chutes.

Platform. System of automatic tools, machines, and robots.

Autonomy. Automatic control through a solid-state programmable controller which operates the sequence of device operations with a control panel. Control programs include main power, emergency stop, manual, automatic, and individual operations controls.

3.3.6 Case F: Computer-Integrated Elevator Production (Fig. 3.9)

Process. Fabrication and production execution and management.

Platform. Automatic tools, machines, and robots, integrated with system-of-systems, comprising a production/manufacturing installation, with automated material handling equipment, fabrication and finishing machines and processes, and software and communication systems for production planning and control, robotic manipulators, and cranes. Human operators and supervisors are also included.

Autonomy. Automatic control, including knowledge-based control of laser, press, buffing, and sanding machines/cells; automated control of material handling and material flow, and of management information flow.

Fig. 3.8 Pharmaceutical pad-stick automatic assembly cell

3.3.7 Case G: Water Treatment (Fig. 3.10)

Source. Rockwell Automation Co., Cleveland (www.rockwellautomation.com).

Process. Water treatment by reverse osmosis filtering system (Fig. 3.10a) and water treatment and disposal ((Fig. 3.10b). When preparing to filter impurities from the city water, the controllers activate the pumps, which in turn flush wells to clean water sufficiently before it flows through the filtering equipment (Fig. 3.10a) or activating complete system for removal of grit, sediments, and disposal of sludge to clean water supply (Fig. 3.10b).

Platform. Installation including water treatment plant with a network of pumping stations, integrated with programmable and supervisory control and data acquisition (SCADA) control, remote communication software system, and human supervisory interfaces.

Autonomy. Monitoring and tracking the entire water treatment and purification system.

3.3.8 Case H: Digital Document Workflow (Fig. 3.11)

Source. Xerox Co., Norwalk (http://www.xerox.com).

Process. On-demand customized processing, production, and delivery of print, email, and customized web sites.

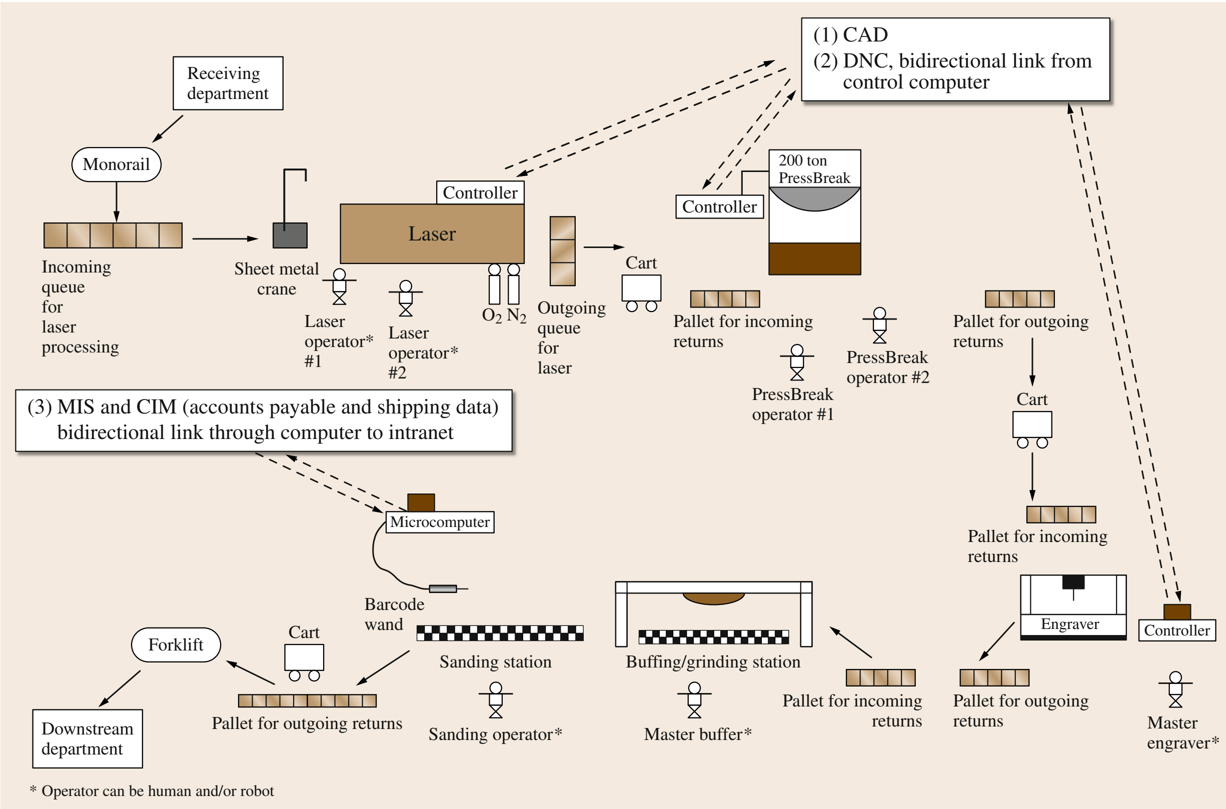

Fig. 3.9 Elevator swing return computer-integrated production system: Three levels of automation systems are integrated, including (1) link to computer-aided design (CAD) for individual customer elevator specifications and customized finish, (2) link to direct numerical control (DNC) of workcell machine and manufacturing activities, (3) link to management information system (MIS) and computer integrated manufacturing system (CIM) for accounting and shipping management (source: [3.12])

Platform. Network of devices, machines, robots, and software systems integrated within a system-of-systems with media technologies.

Autonomy. Integration of automatic workflow of document image capture, processing, enhancing, preparing, producing, and distributing.

3.3.9 Case I: Ship Building Automation (Fig. 3.12)

Source. [3.13]; Korea Shipbuilder's Association, Seoul (http://www.koshipa.or.kr); Hyundai Heavy Industries, Co., Ltd., Ulsan (http://www.hhi.co.kr).

Process. Shipbuilding manufacturing process control and automation; shipbuilding production, logistics, and service management; ship operations management.

Platform. Devices, tools, machines and multiple robots; system-of-software systems; system of systems.

Autonomy. Automatic control of manufacturing processes and quality assurance; automatic monitoring, planning and decision support software systems; integrated control and collaborative control for ship operations and bridge control of critical automatic functions of engine, power supply systems, and alarm systems.

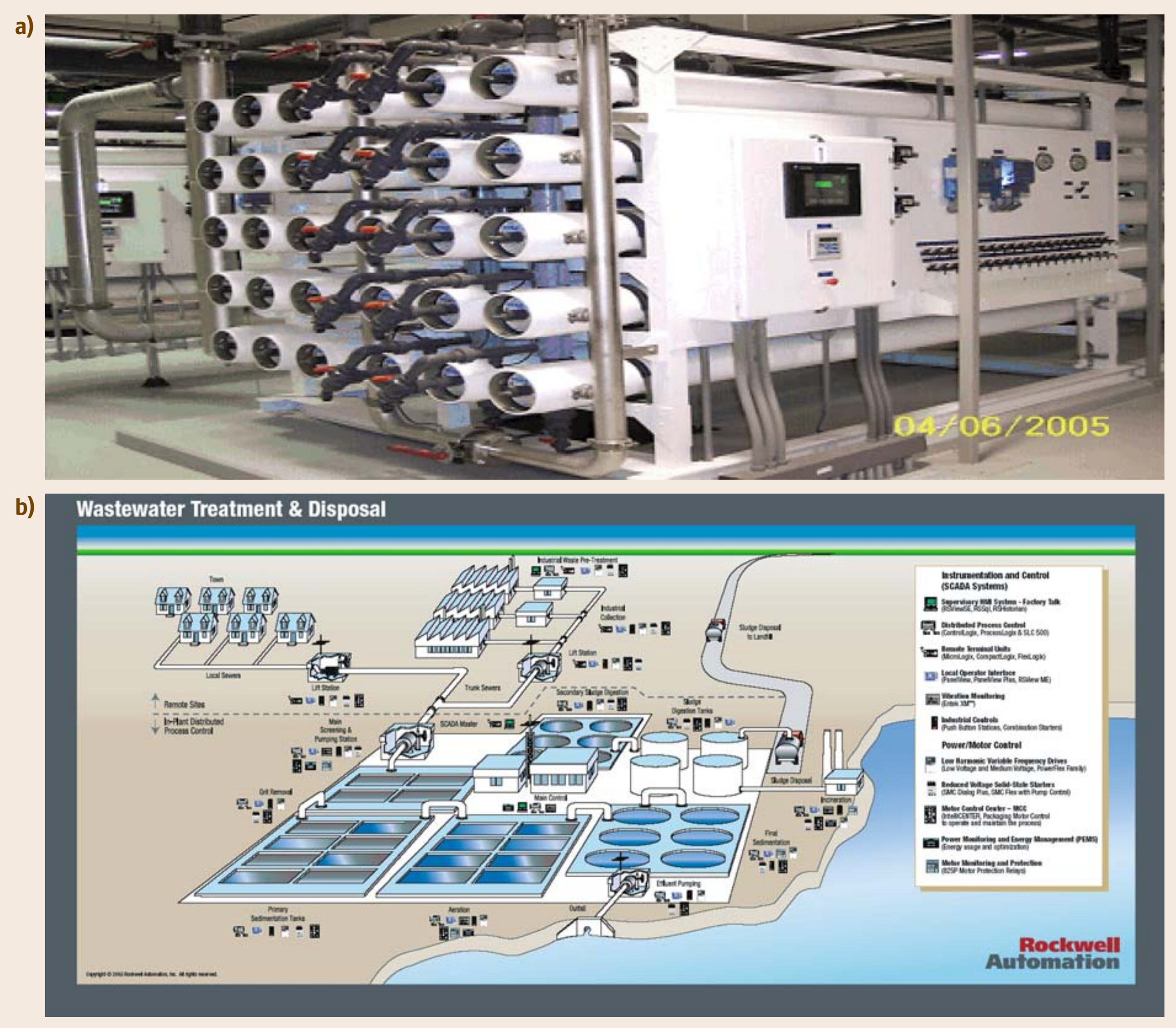

Fig. 3.10 **(a)** Municipal water treatment system in compliance with the Safe Drinking Water Federal Act (courtesy of City of Kewanee, IL; Engineered Fluid, Inc.; and Rockwell Automation Co.). **(b)** Wastewater treatment and disposal (courtesy of Rockwell Automation Co.)

3.3.10 Case J: Energy Power Substation Automation (Fig. 3.13)

Source. GE Energy Co., Atlanta (http://www.gepower.com/prod_serv/products/substation_automation/en/downloads/po.pdf).

Process. Automatically monitoring and activating backup power supply in case of breakdown in the power generation and distribution. Each substation automation platform has processing capacity to monitor and control thousands of input–output points and *intelligent electronic devices* over the network.

Platform. Devices integrated with a network of system-of-systems, including substation automation platforms, each communicating with and controlling thousands of power network devices.

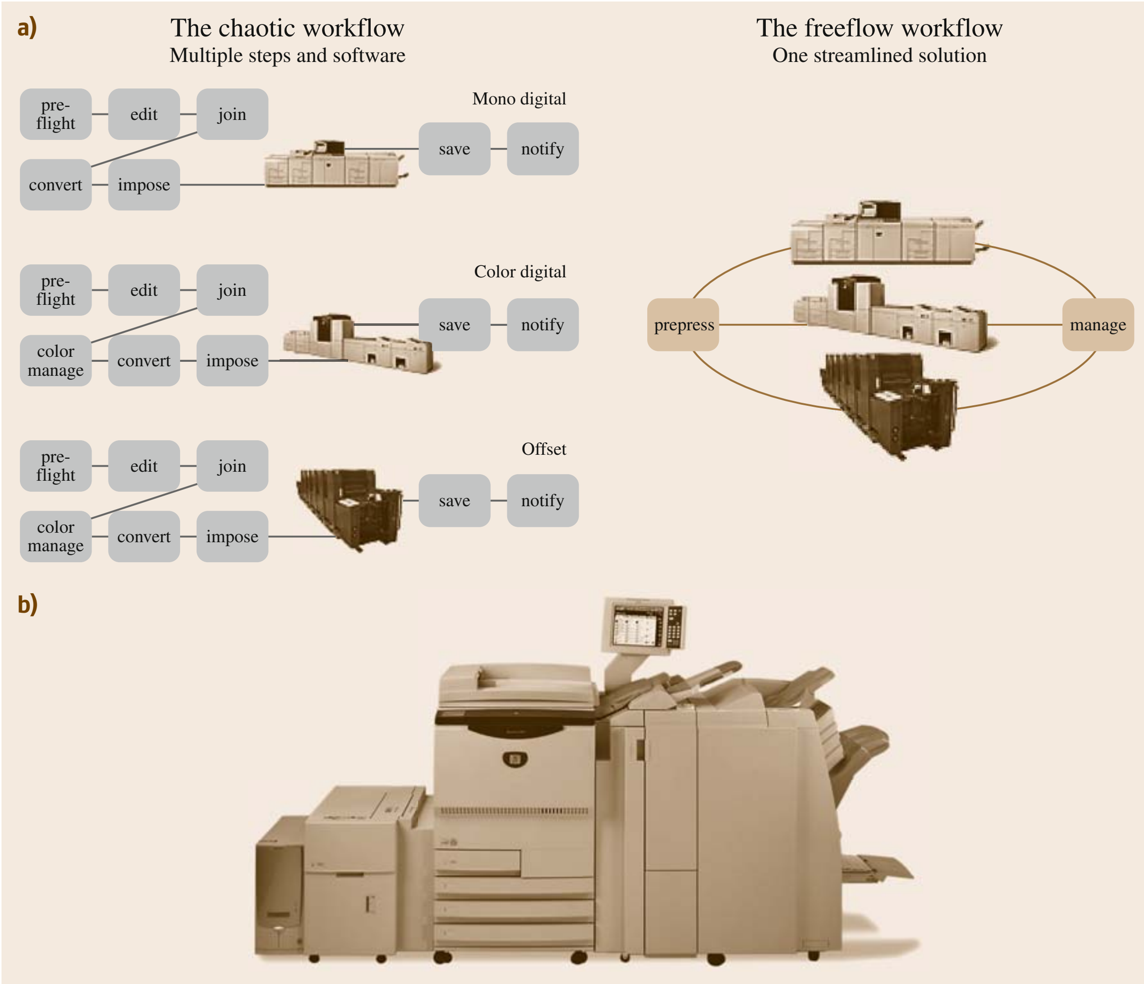

Fig. 3.11a,b Document imaging and color printing workflow: **(a)** streamlined workflow by FreeFlow. **(b)** *Detail* shows document scanner workstation with automatic document feeder and image processing (courtesy of Xerox Co., Norwalk)

Autonomy. Power generation, transmission, and distribution automation, including automatic steady voltage control, based on user-defined targets and settings; local/remote control of distributed devices; adjustment of control set-points based on control requests or control input values; automatic reclosure of tripped circuit breakers following momentary faults; automatic transfer of load and restoration of power to nonfaulty sections if possible; automatically locating and isolating faults to reduce customers' outage times; monitoring a network of substations and moving load off overloaded transformers to other stations as required.

These ten case studies cover a variety of automation domains. They also demonstrate different level of intelligence programmed into the automation application, different degrees of automation, and various types of automation flexibility. The meaning of these automation characteristics is explained in the next section.

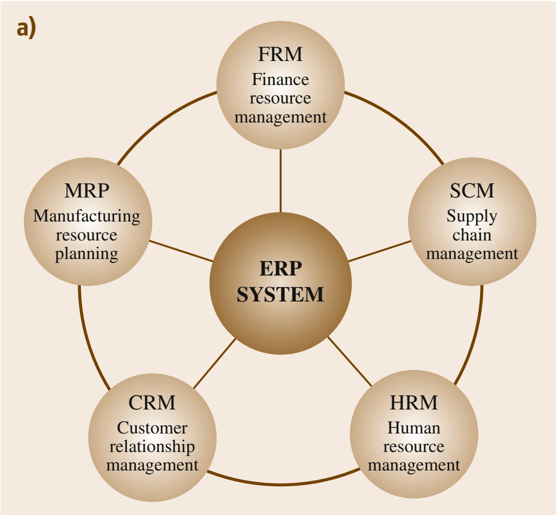

Fig. 3.12a–j Automation and control systems in shipbuilding: **(a)** production management through enterprise resource planning (ERP) systems. Manufacturing automation in shipbuilding examples: **(b)** overview; **(c)** automatic panel welding robots system; **(d)** sensor application in membrane tank fabrication; **(e)** propeller grinding process by robotic automation. Automatic ship operation systems examples: **(f)** overview; **(g)** alarm and monitoring system; **(h)** integrated bridge system; **(i)** power management system; **(j)** engine monitoring system (source: [3.13]) (with permission from Hyundai Heavy Industries)

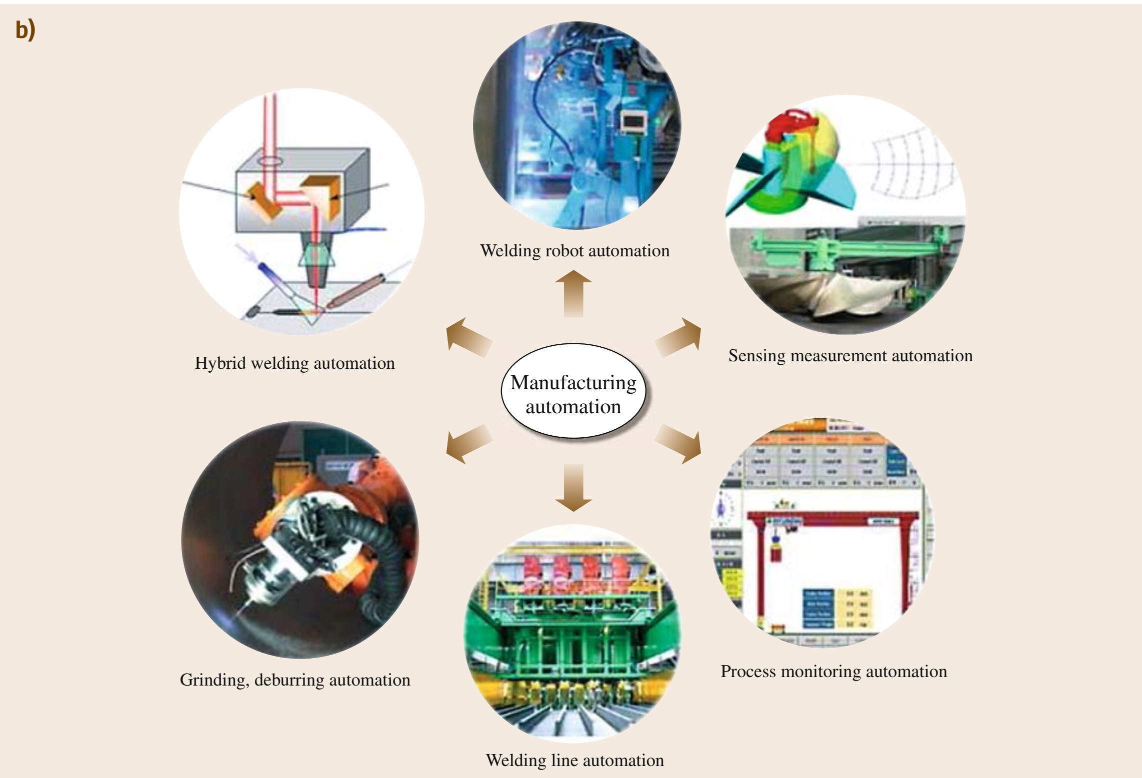

Fig. 3.12a–j (cont.)

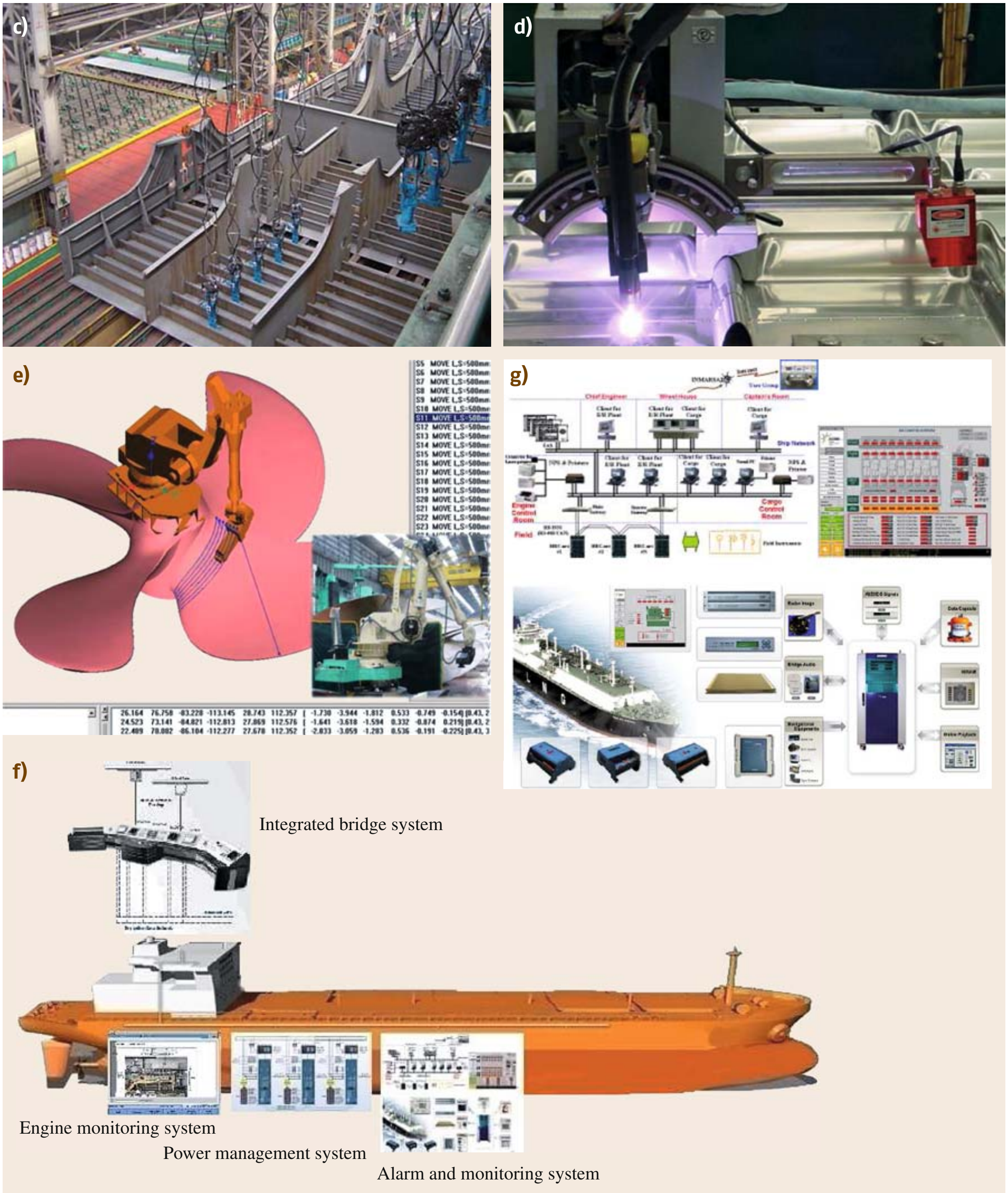

Fig. 3.12a–j (cont.)

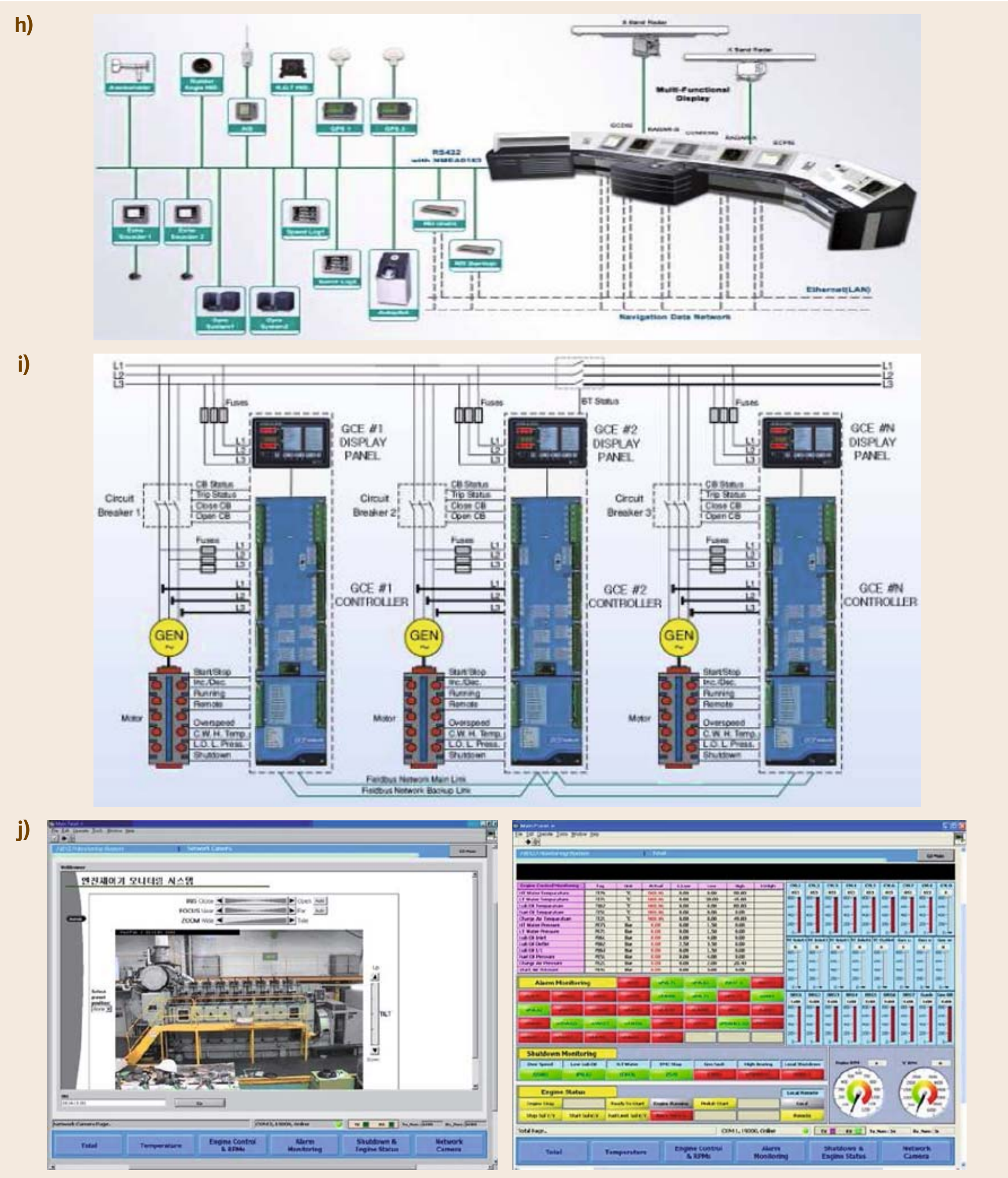

Fig. 3.12a–j (cont.)

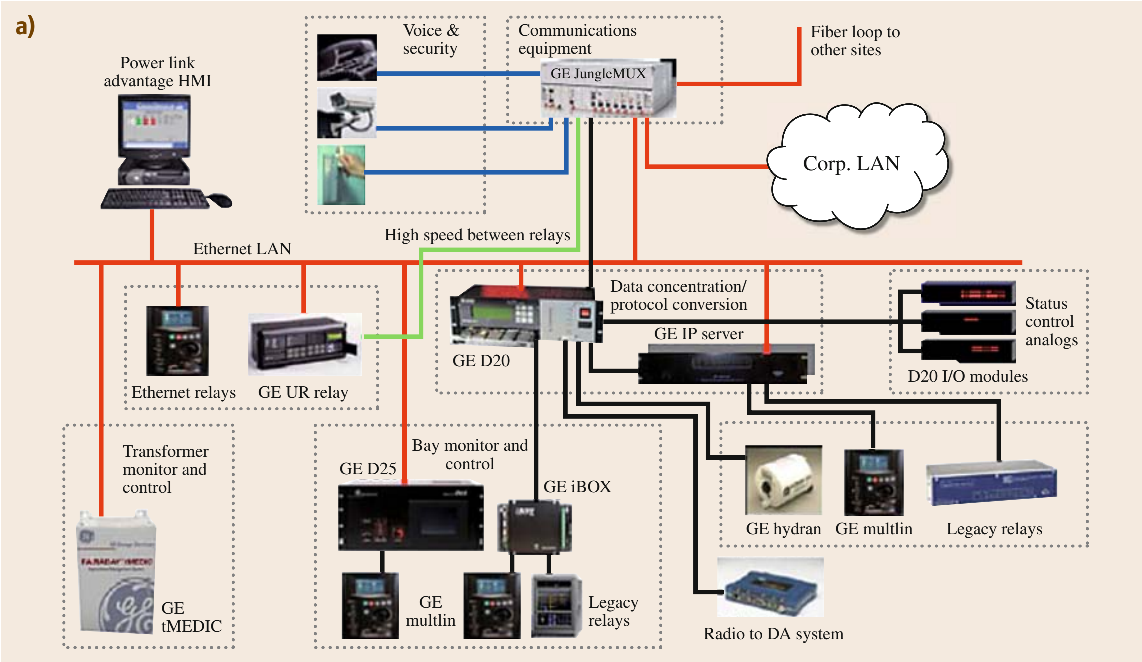

Fig. 3.13a,b Integrated power substation control system: **(a)** overview; **(b)** substation automation platform chassis (courtesy of GE Energy Co., Atlanta) (LAN – local area network, DA – data acquisition, UR – universal relay, MUX – multiplexor, HMI – human-machine interface)

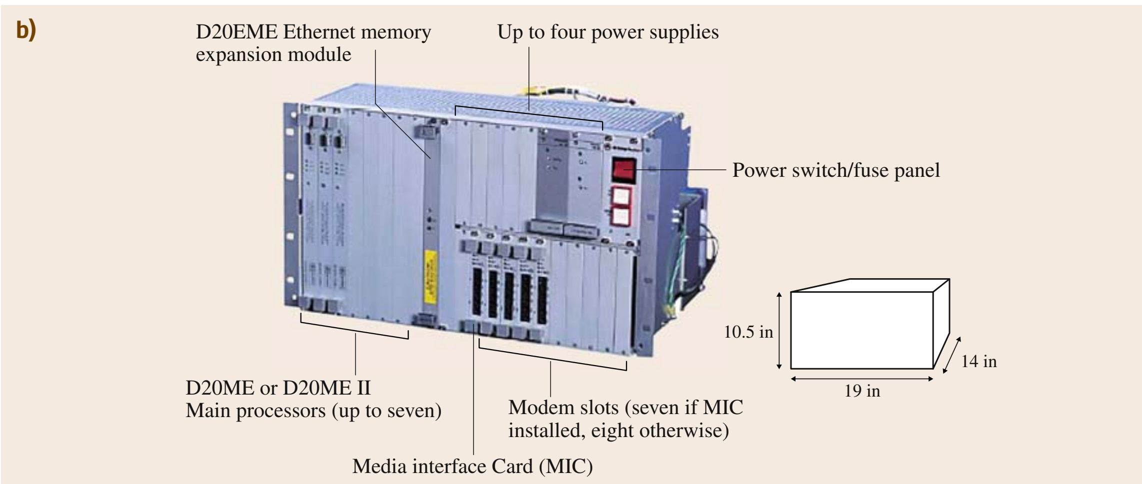

Fig. 3.13a,b (cont.)

3.4 Flexibility, Degrees, and Levels of Automation

Increasingly, solutions of society's problems cannot be satisfied by, and therefore cannot mean the automation of just a single, repeated process. By automating the networking and integration of devices and systems, they are able to perform different and variable tasks. Increasingly, this ability also requires cooperation (sharing of information and resources) and collaboration (sharing in the execution and responses) with other devices and systems. Thus, devices and systems have to be designed with inherent flexibility, which is motivated by the clients' requirements. With growing demand for service and product variety, there is also an increase in the expectations by users and customers for greater reliability, responsiveness, and smooth interoperability. Thus, the meaning of automation also involves the aspects of its flexibility, degree, and levels.

To enable design for flexibility, certain standards and measures have been and will continue to be established. Automation flexibility, often overlapping with the level of automation intelligence, depends on two main considerations:

1. The number of different states that can be assumed automatically
2. The length of time and amount of effort (setup process) necessary to respond and execute a change of state.

The number of different possible states and the cost of changes required are linked with two interrelated measures of flexibility: application flexibility and adaptation flexibility (Fig. 3.14). Both measures are concerned with the possible situations of the system and its environment. Automation solutions may address only switching between undisturbed, standard operations and nominal, variable situations, or can also aspire to respond when operations encounter disruptions and transitions, such as errors and conflicts, or significant design changes.

Application flexibility measures the number of different work states, scenarios, and conditions a system can handle. It can be defined as the probability that an arbitrary task, out of a given class of such tasks, can be carried out automatically. A relative comparison between the application flexibility of alternative designs is relevant mostly for the same domain of automation solutions. For instance, in Fig. 3.14 it is the domain of machining.

Adaptation flexibility is a measure of the time duration and the cost incurred for an automation device or system to transition from one given work state to another. Adaptation flexibility can also be measured only relatively, by comparing one automation device or system with another, and only for one defined change of state at a time. The change of state involves being in one possible state prior to the transition, and one possible state after it.

A relative estimate of the two flexibility measures (dimensions) for several implementations of machine tools automation is illustrated in Fig. 3.14. For generality, both measures are calibrated between 0 and 1.

3.4.1 Degree of Automation

Another dimension of automation, besides measures of its inherent flexibility, is the degree of automation. Automation can mean fully automatic or semiautomatic devices and systems, as exemplified in case A (Sect. 3.3.1), with the steam turbine speed governor, and in case E (Sect. 3.3.5), with a mix of robots and operators in elevator production. When a device or system is not fully automatic, meaning that some, or more frequent human intervention is required, they are con-

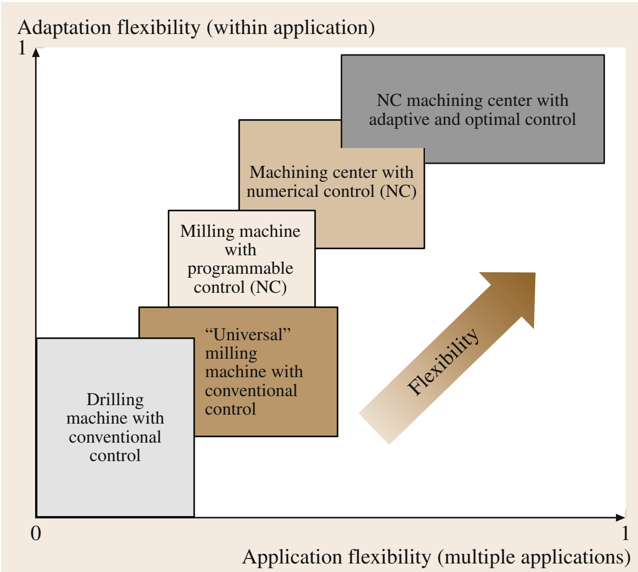

Fig. 3.14 Application flexibility and adaptation flexibility in machining automation (after [3.14])

sidered *automated*, or *semiautomatic*, equivalent terms implying *partial automation*.

A measure of the degree of automation, between fully manual to fully automatic, has been used to guide the design rationalization and compare between alternative solutions. Progression in the degree of automation in machining is illustrated in Fig. 3.14. The increase of automated partial functions is evident when comparing the drilling machine with the more flexible machines that can also drill and, in addition, are able to perform other processes such as milling.

The degree of automation can be defined as the fraction of automated functions out of the overall functions of an installation or system. It is calculated as the ratio between the number of automated operations, and the total number of operations that need to be performed, resulting in a value between 0 and 1. Thus, for a device or system with partial automation, where not all operations or functions are automatic, the degree of automation is less than 1. Practically, there are several methods to determine the degree of automation. The derived value requires a description of the method assumptions and steps. Typically, the degree of automation is associated with characteristics of:

1. Platform (device, system, etc.)
2. Group of platforms
3. Location, site
4. Plant, facility
5. Process and its scope
6. Process measures, e.g., operation cycle
7. Automatic control
8. Power source
9. Economic aspects
10. Environmental effects.

In determining the degree of automation of a given application, whether the following functions are also supposed to be considered must also be specified:

1. Setup
2. Organization, reorganization
3. Control and communication
4. Handling (of parts, components, etc.)
5. Maintenance and repair
6. Operation and process planning
7. Construction
8. Administration.

For example, suppose we consider the automation of a document processing system (case H, Sect. 3.3.8) which is limited to only the scanning process, thus omitting other workflow functions such as document feeding, joining, virtual inspection, and failure recovery. Then if the scanning is automatic, the degree of automation would be 1. However, if the other functions are also considered and they are not automatic, then the value would be less than 1.

Methods to determine the degree of automation divide into two categories:

- *Relative determination applying a graded scale*, containing all the functions of a defined domain process, relative to a defined system and the corresponding degrees of automation. For any given device or system in this domain, the degree of automation is found through comparison with the graded scale. This procedure is similar to other graded scales, e.g., Mohs' hardness scale, and Beaufort wind-speed scale. This method is illustrated in Fig. 3.15, which shows an example of the graded scale of mechanization and automation, following the scale developed by *Bright* [3.15].
- *Relative determination by a ratio between the autonomous and nonautonomous measures of reference*. The most common measure of reference is the number of decisions made during the process under consideration (Table 3.9). Other useful measures of reference for this determination are the comparative ratios of:
  - Rate of service quality
  - Human labor
  - Time measures of effort
  - Cycle time
  - Number of mobility and motion functions
  - Program steps.

To illustrate the method in reference to decisions made during the process, consider an example for case B (Sect. 3.3.2). Suppose in the bioreactor system process there is a total of seven decisions made automatically by the devices and five made by a human laboratory supervisor. Because these decisions are not similar, the degree of automation cannot be calculated simply as the ratio $7/(7+5) \approx 0.58$. The decisions must be weighted by their complexity, which is usually assessed by the number of control program commands or steps (Table 3.9). Hence, the degree of automation can be calculated as:

$$\begin{aligned}\begin{matrix}\text{degree of}\\ \text{automation}\end{matrix} &= \frac{\begin{pmatrix}\text{sum of decision steps made}\\ \text{automatically by devices}\end{pmatrix}}{(\text{total sum of decision steps made})}\\ &= 82/(82+178) \approx 0.32\,.\end{aligned}$$

Step-No.	Steps of the automation	Type of the machine reaction	Origin of the check	Energy source
1	Manual	Variable	From the worker	Manual
2	Manual hand tools			
3	Powered hand tools			
4	Machine tools, manual controlled			
5	Powered tool, fixed cycle, single function	Fixed in the machine	Through control-mechanism, testing determined work sequences	Mechanical (not done by hand)
6	Powered tool, programmed control with a sequence of functions			
7	Machine system with remote control			
8	Machine actuated by introduction of work-piece or material			
9	Measures characteristics of the execution	React to signals	Through variable influences in the environment	
10	Signals pre-selected values of measurement, includig error correction			
11	Registers execution			
12	Changes speed, position change and direction according to the measured signal	Reacts to the execution: Selects from determined processes		
13	Segregates or rejects according to measurements			
14	Identifies and selects operations			
15	Corrects execution after the processing	Reacts to the execution: Changes actions itself inside influences		
16	Corrects execution while processing			
17	Foresees the necessary working tasks, adjusts the execution			
18	Prevents error and self-optimizes current execution			

Fig. 3.15 Automation scale: scale for comparing grades of automation (after [3.15])

Now designers can compare this automation design against relatively more and less elaborate options. Rationalization will have to assess the costs, benefits, risks, and acceptability of the degree of automation for each alternative design.

Whenever the degree of automation is determined by a method, the following conditions must be followed:

1. The method is able to reproduce the same procedure consistently.
2. Comparison is only done between objective measures.
3. Degree values should be calibrated between 0 and 1 to simplify calculations and relative comparisons.

3.4.2 Levels of Automation, Intelligence, and Human Variability

There is obviously an inherent relation between the level of automation flexibility, the degree of automation, and the level of intelligence of a given automation ap-

Table 3.9 Degree of automation: calculation by the ratio of decision types

	Automatic decisions								Human decisions						Total
Decision number	1	2	3	4	5	6	7	Sum	8	9	10	11	12	Sum	
Complexity (number of program steps)	10	12	14	9	14	11	12	*82*	21	3	82	45	27	*178*	*260*

Table 3.10 Levels of automation (updated and expanded after [3.16])

Level	Automation	Automated human attribute	Examples
A_0	Hand-tool; manual machine	None	Knife; scissors; wheelbarrow
A_1	Powered machine tools (non-NC)	Energy, muscles	Electric hand drill; electric food processor; paint sprayer
A_2	Single-cycle automatics and hand-feeding machines	Dexterity	Pipe threading machine; machine tools (non-NC)
A_3	Automatics; repeated cycles	Diligence	Engine production line; automatic copying lathe; automatic packaging; NC machine; pick-and-place robot
A_4	Self-measuring and adjusting; feedback	Judgment	*Feedback about product*: dynamic balancing; weight control. *Feedback about position*: pattern-tracing flame cutter; servo-assisted follower control; self-correcting NC machines; spray-painting robot
A_5	Computer control; automatic cognition	Evaluation	Rate of feed cutting; maintaining pH; error compensation; turbine fuel control; interpolator
A_6	Limited self-programming	Learning	Sophisticated elevator dispatching; telephone call switching systems; artificial neural network models
A_7	Relating cause from effects	Reasoning	Sales prediction; weather forecasting; lamp failure anticipation; actuarial analysis; maintenance prognostics; computer chess playing
A_8	Unmanned mobile machines	Guided mobility	Autonomous vehicles and planes; nano-flying exploration monitors
A_9	Collaborative networks	Collaboration	Collaborative supply networks; Internet; collaborative sensor networks
A_{10}	Originality	Creativity	Computer systems to compose music; design fabric patterns; formulate new drugs; play with automation, e.g., virtual-reality games
A_{11}	Human-needs and animal-needs support	Compassion	Bioinspired robotic seals (aquatic mammal) to help emotionally challenged individuals; social robotic pets
A_{12}	Interactive companions	Humor	Humorous gadgets, e.g., sneezing tissue dispenser; automatic systems to create/share jokes; interactive comedian robot

NC: numerically controlled; non-NC: manually controlled plication. While there are no absolute measures of any of them, their meaning is useful and intriguing to inventors, designers, users, and clients of automation. Levels of automation are shown in Table 3.10 based on the intelligent human ability they represent.

It is interesting to note that the progression in our ability to develop and implement higher levels of automation follows the progress in our understanding of relatively more complex platforms; more elaborate control, communication, and solutions of computational complexity; process and operation programmability; and our ability to generate renewable, sustainable, and mobile power sources.

3.5 Worldwide Surveys: What Does Automation Mean to People?

With known human variability, we are all concerned about automation, enjoy its benefits, and wonder about its risks. But all individuals do not share our attitude towards automation equally, and it does not mean the same to everyone. We often hear people say:

- *I'll have to ask my grandson to program the video recorder.*
- *I hate my cell-phone.*
- *I can't imagine my life without a cell-phone.*
- *Those dumb computers.*
- *Sorry, I do not use elevators, I'll climb the six floors and meet you there!*

etc.

In an effort to explore the meaning of automation to people around the world, a random, nonscientific survey was conducted during 2007–2008 by the author, with the help of the following colleagues: Carlos Pereira (Brazil), Jose Ceroni (Chile), Alexandre Dolgui (France), Sigal Berman, Yael Edan, and Amit Gil (Israel), Kazayuhi Ishii, Masayuki Matsui, Jing Son, and Tetsuo Yamada (Japan), Jeong Wootae (Korea), Luis Basañez and Raúl Suárez Feijóo (Spain), Chin-Yin Huang (Taiwan), and Xin W. Chen (USA). Since the majority of the survey participants are students, undergraduate and graduate, and since they migrate globally, the respondents actually originate from all continents. In other words, while it is not a scientific survey, it carries a worldwide meaning.

Table 3.11 How do you define automation (do not use a dictionary)?

	Definition	Asia–Pacific (%)	Europe + Israel (%)	North America (%)	South America (%)	World-wide (%)
1.	Partially or fully replace human work [a]	6	43	18	5	27
2.	Use machines/computers/robots to execute or help execute physical operations, computational commands or tasks	25	17	35	32	24
3.	Work without or with little human participation	33	20	17	47	24
4.	Improve work/system in terms of labor, time, money, quality, productivity, etc.	9	9	22	5	11
5.	Functions and actions that assist humans	4	3	2	0	3
6.	Integrated system of sensors, actuators, and controllers	6	2	2	0	3
7.	Help do things humans cannot do	3	2	2	0	2
8.	Promote human value	6	1	0	0	2
9.	The mechanism of automatic machines	5	1	0	5	2
10.	Information-technology-based organizational change	0	0	3	0	1
11.	Machines with intelligence that works and knows what to do	1	1	0	5	1
12.	Enable humans to perform multiple actions	0	1	0	0	0

[a] Note: This definition is inaccurate; most automation accomplishes work that humans cannot do, or cannot do effectively
* Respondents: 318 (244 undergraduates, 64 graduates, 10 others)

Table 3.12 When and where did you encounter and recognize automation first in your life (probably as a child)?

First encounter		Asia–Pacific (%)	Europe + Israel (%)	North America (%)	South America (%)	World-wide (%)
1.	Automated manufacturing machine, factory	12	9	30	32	16
2.	Vending machine: snacks, candy, drink, tickets	14	10	11	5	11
3.	Car, truck, motorcycle, and components	8	14	2	0	9
4.	Automatic door (pneumatic; electric)	14	2	2	5	5
5.	Toy	4	7	2	5	5
6.	Computer (software), e.g., Microsoft Office, e-Mail, programming language	1	3	13	5	4
7.	Elevator/escalator	8	3	2	0	3
8.	Movie, TV	7	2	0	5	3
9.	Robot	1	4	3	11	3
10.	Washing machine	1	6	0	0	3
11.	Automatic teller machine (ATM)	1	1	3	5	2
12.	Dishwasher	0	4	0	0	2
13.	Game machine	4	1	2	0	2
14.	Microwave	0	3	2	0	2
15.	Air conditioner	0	1	2	5	1
16.	Amusement park	1	1	0	0	1
17.	Automatic check-in at airports	0	0	3	0	1
18.	Automatic light	0	1	2	5	1
19.	Barcode scanner	0	0	5	0	1
20.	Calculator	0	1	2	0	1
21.	Clock/watch	0	1	2	0	1
22.	Agricultural combine	0	1	0	0	1
23.	Fruit classification machine	1	1	0	0	1
24.	Garbage truck	0	1	0	0	1
25.	Home automation	0	0	3	5	1
26.	Kitchen mixer	0	1	0	0	1
27.	Lego (with automation)	0	1	0	0	1
28.	Medical equipment in the birth-delivery room	0	1	0	0	1
29.	Milking machine	0	2	0	0	1
30.	Oven/toaster	0	2	0	0	1
31.	Pneumatic door of the school bus	0	1	2	0	1
32.	Tape recorder, player	1	1	0	5	1
33.	Telephone/answering machine	0	1	3	5	1
34.	Train (unmanned)	3	0	0	0	1
35.	X-ray machine	0	2	0	0	1
36.	Automated grinding machine for sharpening knives	1	0	0	0	0
37.	Automatic car wash	0	1	0	0	0
38.	Automatic bottle filling (with soda or wine)	0	0	2	0	0
39.	Automatic toll collection	0	0	2	0	0
40.	Bread machine	0	1	0	0	0
41.	Centrifuge	0	0	2	0	0
42.	Coffee machine	0	1	0	0	0

Table 3.12 (cont.)

First encounter		Asia Pacific (%)	Europe + Israel (%)	North America (%)	South America (%)	World-wide (%)
43.	Conveyor (deliver food to chickens)	0	1	0	0	0
44.	Electric shaver	0	1	0	0	0
45.	Food processor	0	1	0	0	0
46.	Fuse/breaker	0	1	0	0	0
47.	Kettle	0	1	0	0	0
48.	Library	1	0	0	0	0
49.	Light by electricity	0	1	0	0	0
50.	Luggage/baggage sorting machine	0	1	0	0	0
51.	Oxygen device	0	1	0	0	0
52.	Pulse recorder	0	1	0	0	0
53.	Radio	0	1	0	0	0
54.	Self-checkout machine	0	0	2	0	0
55.	Sprinkler	0	1	0	0	0
56.	Switch (power; light)	0	1	0	0	0
57.	Thermometer	0	1	0	0	0
58.	Traffic light	0	1	0	0	0
59.	Treadmill	0	0	2	0	0
60.	Ultrasound machine	0	1	0	0	0
61.	Video cassette recorder (VCR)	0	1	0	0	0
62.	Water delivery	0	1	0	0	0

* Respondents: 316 (249 undergraduates, 57 graduates, 10 others)

The survey population includes 331 respondents, from three general categories:

1. Undergraduate students of engineering, science, management, and medical sciences (251)
2. Graduate students from the same disciplines (70)
3. Nonstudents, experts, and novices in automation (10).

Three questions were posed in this survey:

- How do you define automation (do not use a dictionary)?
- When and where did you encounter and recognize automation first in your life (probably as a child)?
- What do you think is the major impact/contribution of automation to humankind (only one)?

The answers are summarized in Tables 3.11–3.13.

3.5.1 How Do We Define Automation?

The key answer to this was question was (Table 3.11, no. 3): operate without or with little human participation (24%). This answer reflects a meaning that corresponds well with the definition in the beginning of this chapter. It was the most popular response in Asia–Pacific and South America.

Overall, the 12 types of definition meanings follow three main themes: How automation works (answer nos. 2, 6, 9, 11, total 30%); automation replaces humans, works without them, or augments their functions (answer nos. 1, 3, 7, 10, total 54%); automation improves (answer nos. 4, 5, 8, 12, total 16%).

Interestingly, the overall most *popular* answer (answer no. 1; 27%) is a partially wrong answer. (It was actually the significantly most popular response only in Europe and Israel.) *Replacing human work* may represent legacy fear of automation. This answer lacks the recognition that most automation applications are performing tasks humans cannot accomplish. The latter is also a partial, yet positive, meaning of automation and is addressed by answer no. 7 (2%).

Answer nos. 2, 6, 9, and 11 (total 29%) represent a factual meaning of how automation is implemented. Answer 10, found only in North America responses, addresses a meaning of automation that narrows it down to

Table 3.13 What do you think is the major impact/contribution of automation to humankind (only one)?

Major impact or contribution		Asia–Pacific (%)	Europe + Israel (%)	North America (%)	South America (%)	World-wide (%)
1.	Save time, increase productivity/efficiency; 24/7 operations	26	19	17	42	22
2.	Advance everyday life/improve quality of life/ convenience/ease of life/work	10	11	0	0	8
3.	Save labor	17	5	3	0	8
4.	Encourage/inspire creative work; inspire newer solutions	5	5	7	11	6
5.	Mass production and service	0	5	17	5	6
6.	Increase consistency/improve quality	5	5	2	16	5
7.	Prevent people from dangerous activities	7	2	7	5	5
8.	Detect errors in healthcare, flights, factories/ reduce (human) errors	8	2	2	5	4
9.	Medicine/medical equipment/medical system/ biotechnology/healthcare	0	8	2	0	4
10.	Save cost	7	2	5	0	4
11.	Computer	0	5	3	0	3
12.	Improve security and safety	0	7	2	0	3
13.	Assist/work for people	3	3	0	5	2
14.	Car	3	1	2	0	2
15.	Do things that humans cannot do	1	2	3	5	2
16.	Replace people; people lose jobs	2	2	2	0	2
17.	Save lives	0	4	0	0	2
18.	Transportation (e.g., train, traffic lights)	1	2	2	0	2
19.	Change/improvement in (global) economy	0	1	3	0	1
20.	Communication (devices)	0	1	5	0	1
21.	Deliver products/service to more people	1	1	0	0	1
22.	Extend life expectancy	0	1	0	0	1
23.	Foundation of industry/growth of industry	0	2	0	0	1
24.	Globalization and spread of culture and knowledge	0	0	3	0	1
25.	Help aged/handicapped people	3	1	0	0	1
26.	Manufacturing (machines)	1	1	2	0	1
27.	Robot; industrial robot	0	0	5	0	1
28.	Agriculture improvement	0	1	0	0	0
29.	Banking system	0	0	2	0	0
30.	Construction	0	0	2	0	0
31.	Flexibility in manufacturing	0	1	0	0	0
32.	Identify bottlenecks in production	0	0	2	0	0
33.	Industrial revolution	0	1	0	0	0
34.	Loom	0	0	2	0	0
35.	People lose abilities to complete tasks	0	1	0	0	0
36.	Save resources	0	1	0	0	0
37.	Weather prediction	0	0	2	0	0

* Respondents: 330 (251 undergraduate, 70 graduate, 9 others)

information technology. Answer nos. 4, 5, and 12 (total 14%) imply that automation means improvements and assistance. Finally, answer no. 8, promote human value (2%, but found only in Asia–Pacific, and Europe and Israel) may reflect cultural meaning more than a definition.

In addition to the regional response variations mentioned above, it turns out that the first four answers in Table 3.11 comprise the majority of meaning in each region: 73% for Asia–Pacific; 89% for Europe and Israel and for South America; and 92% for North America (86% worldwide). In Asia–Pacific, four other answer types each comprised 4–6% of the 12 answer types.

3.5.2 When and Where Did We Encounter Automation First in Our Life?

The key answer to this question was: automated manufacturing machine or factory (16%), which was the top answer in North and South America, but only the third response in Asia–Pacific and in Europe and Israel. The top answer in Asia–Pacific is shared by vending machine and automatic door (14% each), and in Europe and Israel the top answer was car, truck, motorcycle, and components (14%). Overall, the 62 types of responses to this question represent a wide range of what automation means to us.

There are variations in responses between regions, with only two answers – no. 1, automated manufacturing machine, factory, and no. 2, vending machine: snacks, candy, drink, tickets – shared by at least three of the four regions surveyed. Automatic door is in the top three only in Asia–Pacific; car, truck, motorcycle, and components is in the top three only in Europe and Israel; computer is in the top three only in North America; and robot is in the top three only in South America.

Of the 62 response types, almost 40 appear in only one region (or are negligible in other regions), and it is interesting to relate the regional context of the first encounter with automation. For instance:

- Answers no. 34, train (unmanned) and no. 36, automated grinding machine for sharpening knives, appear as responses mostly in Asia–Pacific (3%)
- Answers no. 12, dishwasher (4%); no. 35, x-ray machine (2%); and no. 58, traffic light (1%) appear as responses mostly in Europe and Israel
- Answers no. 19, barcode scanner (4%); no. 38, automatic bottle filling (2%); no. 39, automatic toll collection (2%); and no. 59, treadmill, (2%) appear as responses mostly in North America.

3.5.3 What Do We Think Is the Major Impact/Contribution of Automation to Humankind?

Thirty-seven types of impacts or benefits were found in the survey responses overall. The most inspiring impact and benefit of automation found is answer no. 4, *encourage/inspire creative work; inspire newer solutions* (6%).

The most popular response was: save time, increase productivity/efficiency; 24/7 operations (22%). The key risk identified, answer no. 16, was: replace people; people lose jobs (2%, but interestingly, this was not found in South America). Another risky impact identified is answer no. 35, people lose abilities to complete tasks, (1%, only in Europe and Israel). Nevertheless, the majority (98%) identified 35 types of positive impacts and benefits.

3.6 Emerging Trends

Many of us perceive the meaning of the automatic and automated factories and gadgets of the 20th and 21st century as outstanding examples of the human spirit and human ingenuity, no less than art; their disciplined organization and synchronized complex of carefully programmed functions and services mean to us harmonious expression, similar to good music (when they work).

Clearly, there is a mixture of emotions towards automation: Some of us are dismayed that humans cannot usually be as accurate, or as fast, or as responsive, attentive, and indefatigable as automation systems and installations. On the other hand, we sometimes hear the word *automaton* or *robot* describing a person or an organization that lacks consideration and compassion, let alone passion. Let us recall that automation is made *by people and for the people*. But can it run away by its own autonomy and become undesirable? Future automation will advance in micro- and nanosystems and systems-of-systems. Bioinspired automation and bioinspired collaborative control theory will significantly improve artificial intelligence, and the quality of robotics and automation, as well as the engineering of their safety and security. In this context, it is interesting to examine the role of automation in the 20th and 21st centuries.

3.6.1 Automation Trends of the 20th and 21st Centuries

The US National Academy of Engineering, which includes US and worldwide experts, compiled the list shown in Table 3.14 as the top 20 achievements that *have shaped a century and changed the world* [3.17]. The table adds columns indicating the role that automation has played in each achievement, and clearly, automation has been relevant in all of them and essential to most of them.

The US National Academy of Engineers has also compiled a list of the grand challenges for the 21st century. These challenges are listed in Table 3.15 with the anticipated and emerging role of automation in each. Again, automation is relevant to all of them and essential to most of them.

Some of the main trends in automation are described next.

3.6.2 Bioautomation

Bioinspired automation, also known as bioautomation or evolutionary automation, is emerging based on the trend of bioinspired computing, control, and AI. They influence traditional automation and artificial intelligence in the methods they offer for evolutionary machine learning, as opposed to what can be described as *generative methods* (sometimes called *creationist methods*) used in traditional programming and learning. In traditional methods, intelligence is typically programmed from top down: Automation engineers and programmers create and implement the automa-

Table 3.14 Top engineering achievements in the 20th century [3.17] and the role of automation

Achievement		Role of automation		
		Relevant		Irrelevant
		Essential	Supportive	
1.	Electrification	×		
2.	Automobile	×		
3.	Airplane	×		
4.	Water supply and distribution	×		
5.	Electronics	×		
6.	Radio and television	×		
7.	Agricultural mechanization	×		
8.	Computers	×		
9.	Telephone	×		
10.	Air conditioning and refrigeration	×		
11.	Highways		×	
12.	Spacecraft	×		
13.	Internet	×		
14.	Imaging	×		
15.	Household appliances	×		
16.	Health technologies	×		
17.	Petroleum and petrochemical technologies	×		
18.	Laser and fiber optics	×		
19.	Nuclear technologies	×		
20.	High-performance materials		×	

tion logic, and define the scope, functions, and limits of its intelligence. Bioinspired automation, on the other hand, is also created and implemented by automation engineers and programmers, but follows a bottom-up decentralized and distributed approach. Bioinspired techniques often involve a method of specifying a set of simple rules, followed and iteratively applied by a set of simple and autonomous manmade organisms. After several generations of rule repetition, initially manmade mechanisms of self-learning, self-repair, and self-organization enable self-evolution towards more complex behaviors. Complexity can result in unexpected behaviors, which may be robust and more reliable; can be counterintuitive compared with the original design; but can potentially become undesirable, out-of-control, and unsafe behaviors. This subject has been under intense research and examination in recent years.

Natural evolution and system biology (biology-inspired automation mechanisms for systems engineering) are the driving analogies of this trend: concurrent steps and rules of responsive selection, interdependent recombination, reproduction, mutation, reformation, adaptation, and death-and-birth can be defined, similar to how complex organisms function and evolve in nature. Similar automation techniques are used in genetic algorithms, artificial neural networks, swarm algorithms, and other emerging evolutionary automation systems. Mechanisms of self-organization, parallelism, fault tolerance, recovery, backup, and redundancy are being developed and researched for future automation, in areas such as neuro-fuzzy techniques, biorobotics, digital organisms, artificial cognitive models and architectures, artificial life, bionics, and bioinformatics. See related topics in many following handbook chapters, particularly, 29, 75 and 76.

3.6.3 Collaborative Control Theory and e-Collaboration

Collaboration of humans, and its advantages and challenges are well known from prehistory and throughout history, but have received increased attention with the advent of communication technology. Significantly better enabled and potentially streamlined and even optimized through e-Collaboration (based on communication via electronic means), it is emerging as one of the most powerful trends in automation, with telecommunication, computer communication, and wireless communication influencing education and research, engineering and business, healthcare and service industries, and global society in general. Those developments, in turn, motivate and propel further applications and theoretical investigations into this highly intelligent level of automation (Table 3.10, level A_9 and higher).

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Table 3.15 Grand engineering challenges for the 21st century [3.17] and the role of automation

Achievement		Anticipated and emerging role of automation		
		Relevant		Irrelevant
		Essential	Supportive	
1.	Make solar energy economical	×		
2.	Provide energy from fusion	×		
3.	Develop carbon sequestration methods	×		
4.	Manage the nitrogen cycle	×		
5.	Provide access to clean water	×		
6.	Restore and improve urban infrastructure		×	
7.	Advance health informatics	×		
8.	Engineer better medicines	×		
9.	Reverse-engineer the brain	×		
10.	Prevent nuclear terror	×		
11.	Secure cyberspace	×		
12.	Enhance virtual reality	×		
13.	Advance personalized learning	×		
14.	Engineer the tools of scientific discovery	×		

Interesting examples of the e-Collaboration trend include *wikis*, which since the early 2000s have been increasingly adopted by enterprises as collaborative software, enriching static intranets and the Internet. Examples of e-Collaborative applications that emerged in the 1990s include project communication for coplanning, sharing the creation and editing of design documents as codesign and codocumentation, and mutual inspiration for collaborative innovation and invention through cobrainstorming.

Beyond human–human automation-supported collaboration through better and more powerful communication technology, there is a well-known but not yet fully understood trend for collaborative e-Work. Associated with this field is collaborative control theory (CCT), which is under development. Collaborative e-Work is motivated by significantly improved performance of humans leveraging their collaborative automatic agents. The latter, from software automata (e.g., constructive *bots* as opposed to spam and other destructive bots) to automation devices, multisensors, multiagents, and multirobots can operate in a parallel, autonomous cyberspace, thus multiplying our productivity and increasing our ability to design sustainable systems and operations. A related important trend is the emergence of *active middleware* for collaboration support of device networks and of human team networks and enterprises.

More about this subject area can be found in several chapters of this handbook, particularly in Chaps. 12, 14, 26, and 88.

3.6.4 Risks of Automation

As civilization increasingly depends on automation and looks for automation to support solutions of its serious problems, the risks associated with automation must be understood and eliminated. Failures of automation on a very large scale are most risky. Just a few examples of disasters caused by automation failures are nuclear accidents; power supply disruptions and blackout; Federal Aviation Administration control systems failures causing air transportation delays and shutdowns; cellular communication network failures; and water supply failures. The impacts of severe natural and manmade disasters on automated infrastructure are therefore the target of intense research and development. In addition, automation experts are challenged to apply automation to enable sustainability and better mitigate and eliminate natural and manmade disasters, such as security, safety, and health calamities.

3.6.5 Need for Dependability, Survivability, Security, and Continuity of Operation

Emerging efforts are addressing better automation dependability and security by structured backup and recovery of information and communication systems. For instance, with service orientation that is able to survive, automation can enable gradual and degraded services by sustaining critical continuity of operations until the repair, recovery, and resumption of full services. Automation continues to be designed with the goal of preventing and eliminating any conceivable errors, failures, and conflicts, within economic constraints. In addition, the trend of collaborative flexibility being designed into automation frameworks encourages reconfiguration tools that redirect available, safe resources to support the most critical functions, rather that designing absolutely failure-proof system.

With the trend towards collaborative, networked automation systems, dependability, survivability, security, and continuity of operations are increasingly being enabled by autonomous self-activities, such as:

- Self-awareness and situation awareness
- Self-configuration
- Self-explaining and self-rationalizing
- Self-healing and self-repair
- Self-optimization
- Self-organization
- Self-protection for security.

Other dimensions of emerging automation risks involve privacy invasion, electronic surveillance, accuracy and integrity concerns, intellectual and physical property protection and security, accessibility issues, confidentiality, etc. Increasingly, people ask about the meaning of automation, how can we benefit from it, yet find a way to contain its risks and powers. At the extreme of this concern is the *automation singularity* [3.18].

Automation singularity follows the evident acceleration of technological developments and discoveries. At some point, people ask, is it possible that superhuman machines can take over the human race? If we build them too autonomous, with collaborative ability to self-improve and self-sustain, would they not eventually be able to exceed human intelligence? In other words, superintelligent machines may autonomously, automatically, produce discoveries that are too complex for humans to comprehend; they may even act in ways that we consider out of control, chaotic, and even aimed at damaging and overpowering people. This emerging trend of thought will no doubt energize future research on how to prevent automation from running on its own without limits. In a way, this is the 21st century human challenge of *never play with fire*.

3.7 Conclusion

This chapter explores the meaning of automation to people around the world. After review of the evolution of automation and its influence on civilization, its main contributions and attributes, a survey is used to summarize highlights of the meaning of automation according to people around the world. Finally, emerging trends in automation and concerns about automation are also described. They can be summarized as addressing three general questions:

1. How can automation be improved and become more useful and dependable?
2. How can we limit automation from being too risky when it fails?
3. How can we develop better automation that is more autonomous and performs better, yet does not take over our humanity?

These topics are discussed in detail in the chapters of this handbook.

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