LEARNING GOALS
After reading this supplement, you should be able to:

1. Describe several types of technologies that comprise computer-integrated manufacturing.
2. Discuss the advantages of these different technologies.

The popular press often writes about the factory of the future: a fully automated factory that manufactures a wide variety of products without human intervention. Although some “peopleless” factories do exist and others will be built, the major advances being made today occur in manufacturing operations where computers are being integrated into the process to help workers create high-quality products.

Computer-integrated manufacturing (CIM) is an umbrella term for the total integration of product design and engineering, process planning, and manufacturing by means of complex computer systems. Less comprehensive computerized systems for production planning, inventory control, or scheduling are often considered part of CIM. By using these powerful computer systems to integrate all phases of manufacturing, from initial customer order to final shipment, firms hope to increase productivity, improve quality, meet customer needs faster, and offer more flexibility. For example, McDonnell Douglas spent $10 million to introduce CIM in its Florida factory. The computer systems automatically schedule manufacturing tasks, keep track of labor, and send instructions to computer screens at workstations along the assembly line. Eliminating paperwork led to an increase of 30 percent in worker productivity. Less than 1 percent of U.S. manufacturing companies have approached full-scale use of CIM, but more than 40 percent are using one or more elements of CIM technology.
Computer-aided design (CAD) is an electronic system for designing new parts or products or altering existing ones, replacing drafting traditionally done by hand. The heart of CAD is a powerful desktop computer and graphics software that allow a designer to manipulate geometric shapes. The designer can create drawings and view them from any angle on a display monitor. The computer can also simulate the reaction of a part to strength and stress tests. Using the design data stored in the computer’s memory, manufacturing engineers and other users can quickly obtain printouts of plans and specifications for a part or product. CAD cuts the cost of product development and sharply reduces the time to market for new products. It is revolutionizing in-house design departments, from IBM to Rubbermaid and AT&T to Steelcase. CAD literacy is now a prerequisite for designers, and investments in it are growing rapidly. Many company budgets for CAD are three times what they were in 1990. The largest sums are going for software, with Pro-Engineer clearly approaching a national standard in the United States.

Analysts can use CAD to store, retrieve, and classify data about various parts. This information is useful in creating families of parts to be manufactured by the same group of machines. Computer-aided design saves time by enabling designers to access and modify old designs quickly, rather than start from scratch.

The component of CIM that deals directly with manufacturing operations is called computer-aided manufacturing (CAM). CAM systems are used to design production processes and to control machine tools and materials flow through programmable automation. For example, researchers at the Technology/Clothing Technology Corporation are developing a concept to enable clothing manufacturers to create “custom” clothing. The concept involves using a computer scan of a customer’s body and a computer-driven machine to cut the fabric to fit the customer perfectly. Automated custom clothing goes against established apparel industry procedures, whereby companies cut dozens of layers of cloth at the same time to hold down labor costs. However, labor costs account for only 11 percent of the cost of the garment delivered to the customer. Nonvalue-added handling (including inventory costs) after manufacture accounts for 27 percent, which is the cost category that this technology can reduce. It also has the advantage of fostering customization and speedy delivery as competitive priorities. For example, Levi Strauss is already using similar, although more cumbersome, technology for women’s jeans, and its customers are willing to pay a premium.

A CAD/CAM system integrates the design and manufacturing function by translating final design specifications into detailed machine instructions for manufacturing an item. CAD/CAM is quicker, less error prone than humans, and eliminates duplication between engineering and manufacturing. CAD/CAM systems allow engineers to see how the various parts of a design interact with each other without having to build a prototype. One of the more recent and stunning examples is the ability of Boeing to design and build its 777 wide-
body airframe without any prototype work at all. The first physical version was the actual plane that test pilots flew in 1994. Boeing’s engineers used Dassault Systemes’ software called CATIA, short for Computer Assisted Three-Dimensional Interactive Analysis. This French company is one of the most prominent of dozens of software suppliers. Another example is the K2 Corporation, the largest U.S. manufacturer of Alpine skis, which must continually redesign its products to meet changing customer needs. It produces about 20 different models in 12 different lengths. Its CAD and CAM workstations allow designers to convert the numerical descriptions for a new ski shape into drawings and tooling designs and to create machining instructions that can be used directly by the milling machines.

NUMERICALLY CONTROLLED MACHINES

Numerically controlled (NC) machines are large machine tools programmed to produce small- to medium-sized batches of intricate parts. Following a preprogrammed sequence of instructions, NC machines drill, turn, bore, or mill many different parts in various sizes and shapes. The technology was developed in the early 1950s at the Massachusetts Institute of Technology to find more efficient methods of manufacturing jet aircraft for the U.S. Air Force.

Currently, NC machines are the most commonly used form of flexible (programmable) automation. Early models received their instructions from a punched tape or card. Computerized numerically controlled (CNC) machines are usually stand-alone pieces of equipment, each controlled by its own microcomputer. Since the early 1980s, Japanese industry has spent twice as much money as North American or European industry on factory equipment, more than half of which went for CNC machines. NC and CNC machines rank just after CAD in terms of the most popular CIM technologies.

INDUSTRIAL ROBOTS

Robots are more glamorous than NC workhorses. The first industrial robot joined the GM production line in 1961. Industrial robots are versatile, computer-controlled machines programmed to perform various tasks. These “steel-collar” workers operate independently of human control. Most are stationary and mounted on the floor, with an arm that can reach into difficult locations. Figure F.1 shows the six standard movements of a robot’s arm. Not all robots have every movement.

The robot’s “hand,” sometimes called an end effector or tool, actually does the work. The hand (not shown) can be changed to perform different tasks, including materials handling, spot welding, spray painting, assembly, and inspection and testing. Second-generation numerically controlled (NC) machines
Large machine tools programmed to produce small- to medium-sized batches of intricate parts.

computerized numerically controlled (CNC) machines
Stand-alone pieces of equipment, each controlled by its own microcomputer.

FIGURE F.1
Robot and Its Standard Movements
robots equipped with sensors that simulate touch and sight have spawned new applications. For example, robots can wash windows, pick fruit from trees, mix chemicals in laboratories, and handle radioactive materials.

The initial cost of a robot depends on its size and function. Other potential costs include modifying both product and process to accommodate the robot, preparing the worksite, installing and debugging the robot, and retraining and relocating workers. Benefits from robot installation include less waste materials, more consistent quality, and labor savings. Robots are the drudges of the workforce, performing highly repetitive tasks without tiring, taking a lunch break, or complaining.

By the late 1980s, there were more than 20,000 robots in North America, 28,000 in Europe, and 80,000 in Japan. The conversion of U.S. industry to robots has fallen short of expectations: Less than 30 percent of manufacturers have even moderate experience with robots. One possible reason is that U.S. employers have not faced a labor shortage, whereas in Japan a limited supply of workers led the government to subsidize robots. Cincinnati Milacron, the last big U.S. robot maker, recently left the robot business and returned to making basic machine tools. Robotics is but one of many possible technologies that can be used to gain a competitive advantage.

AUTOMATED MATERIALS HANDLING

In both manufacturing and service industries, the choice of how, when, and by whom materials are handled is an important technological decision. Materials handling covers the processes of moving, packaging, and storing a product. Moving, handling, and storing materials cost time and money but add no value to the product. Therefore, operations managers are always looking for ways to reduce costs by automating the flow of materials to and from an operation.

Whether materials handling automation is justifiable depends on the process. When the process experiences low volumes and must provide a high degree of customization, job paths vary and there is little repeatability in materials handling. Such variability means that workers must move materials and equipment in open-top containers, carts, or lift trucks. However, when the process experiences high volumes, line flows, and high repeatability, handling can be automated. In addition, other types of flexible automation are now available for processes that fall between these two extremes. Let’s look at two such technologies: automated guided vehicles and automated storage and retrieval systems.

AGVS

An automated guided vehicle (AGV) is a small, driverless, battery-driven truck that moves materials between operations, following instructions from either an onboard or a central computer. Most older models follow a cable installed below the floor, but the newest generation follows optical paths and can go anywhere with aisle space and a relatively smooth floor.

The AGV’s ability to route around problems such as production bottlenecks and transportation blockages helps production avoid expensive, unpredictable shutdowns. Furthermore, AGVs enable operations managers to deliver parts as they are needed, thus reducing stockpiles of expensive inventories throughout the plant. The automotive industry now uses AGVs in some plants as mobile assembly stands, primarily for heavy loads. Workers prefer them to inflexible conveyors because the AGVs do not leave until the workers have done the job correctly at their own pace. NCR Corporation installed a $100,000 AGV system in one of its electronics fabrication facilities. Machines run along a 3,000-foot guidepath at 1.5 miles per hour, ferrying parts between the stockroom, assembly stations, and the automated storage and retrieval system.

AS/RS

An automated storage and retrieval system (AS/RS) is a computer-controlled method of storing and retrieving materials and tools using racks, bins, and stackers. With support from AGVs, an AS/RS can receive and deliver materials without the aid of human hands. For example, IBM’s new distribution center in Mechanicsburg, Pennsylvania, ships 105,000 spare computer parts and related publications each day—a staggering volume—using an AS/RS and 13 AGVs. Computer control assigns newly arrived materials to one of 37,240 storage locations. If optical sensors confirm that the materials will fit, the automated system moves them along to the proper location. Production at this highly automated facility has increased 20 percent, and accuracy of filled orders has reached 99.8 percent.
A **flexible manufacturing system (FMS)** is a configuration of computer-controlled, semi-independent workstations where materials are automatically handled and machine loaded. An FMS is a type of flexible automation system that builds on the programmable automation of NC and CNC machines. Programs and tooling setups can be changed with almost no loss of production time for moving from production of one product to the next. Such systems require a large initial investment ($5 to $20 million) but little direct labor to operate. An FMS system has three key components:

1. several computer-controlled workstations, such as CNC machines or robots, that perform a series of operations
2. a computer-controlled transport system for moving materials and parts from one machine to another and in and out of the system
3. loading and unloading stations

Workers bring raw materials for a part family to the loading points, where the FMS takes over. Computer-controlled transporters deliver the materials to various workstations where they pass through a specific sequence of operations unique to each part. The route is determined by the central computer. The goal of using FMS systems is to synchronize activities and maximize the system’s utilization. Because automation makes it possible to switch tools quickly, setup times for machines are short. This flexibility often allows one machine to perform an operation when another is down for maintenance and avoids bottlenecks by routing parts to another machine when one is busy.

Figure F.2 shows the layout of a typical FMS, which produces turning and machining centers. Specific characteristics of this FMS include the following:

- The computer control room (right) houses the main computer, which controls the transporter and sequence of operations.
- Three CNC machines, each with its own microprocessor, control the details of the machining process.
- Two AGVs, which travel around a 200-foot-long oval track, move materials on pallets to and from the CNCs. When the AGVs’ batteries run low, the central computer directs them to certain spots on the track for recharging.

**FIGURE F.2**  |  A Flexible Manufacturing System

*Source: Courtesy of Vincent Mabert. Reprinted by permission.*

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1We are indebted to Vincent Mabert for much of the information about this FMS, including Figure F.2.
Indexing tables lie between each CNC and the track. Inbound pallets from an AGV are automatically transferred to the right side of the table, and out-bound pallets holding finished parts are transferred to the left side for pickup.

A tool changer located behind each CNC loads and unloads tool magazines. Each magazine holds an assortment of tools. A machine automatically selects tools for the next specific operation. Changing from one tool to another takes only 2 minutes.

Two load and unload stations are manually loaded by workers; loading takes 10 to 20 minutes.

An automatic AS/RS (upper right) stores finished parts. The AGV transfers parts on its pallet to an indexing table, which then transfers them to the AS/RS. The process is reversed when parts are needed for assembly into finished products elsewhere in the plant.

This particular system fits processes involving medium-level variety (5 to 100 parts) and volume (annual production rates of 40 to 2,000 units per part). The system can simultaneously handle small batches of many products. In addition, an FMS can be used a second way: At any given time, an FMS can produce low-variety, high-volume products in much the same way that fixed manufacturing systems do. However, when these products reach the end of their life cycles, the FMS can be reprogrammed to accommodate a different product. This flexibility makes FMS very appealing, especially to operations where life cycles are short.

Since the first FMS was introduced in the mid-1960s, the number installed worldwide has grown to almost 500, with about half of them either in Japan or the United States and the other half in Europe. A much more popular version of flexible automation is the **flexible manufacturing cell (FMC)**, which is a scaled-down version of FMS that consists of one or a very small group of NC machines that may or may not be linked to a materials handling mechanism.

**DISCUSSION QUESTIONS**

1. Through widespread use of robots, an automobile manufacturer improved its global competitiveness and economic success. Much of the savings resulted from reducing its workforce from 138,000 to 72,000. There was a human cost of displaced workers, however, and displaced employees had a difficult time finding new jobs. Was the automation decision defensible on ethical grounds? What steps can a firm take to be a responsible and ethical employer when cutbacks are necessary?

2. “The central problem of America’s economic future is that the nation is not moving quickly enough out of high-volume, standardized production. The extraordinary success of the half-century of the management era has left the United States a legacy of economic inflexibility. Thus, our institutional heritage now imperils our future.”

**SELECTED REFERENCES**


