OPERATIONS TECHNOLOGY

Vol. IV "Quality Product and Process Design at Detroit Diesel"

Much of the recent growth in productivity has come from the application of operations technology. In services this comes primarily from soft technology—information processing. In manufacturing it comes from a combination of soft and hard (machine) technologies. Given that most readers of this book have covered information technologies in services in MIS courses, our focus in this supplement is on manufacturing.

TECHNOLOGIES IN MANUFACTURING

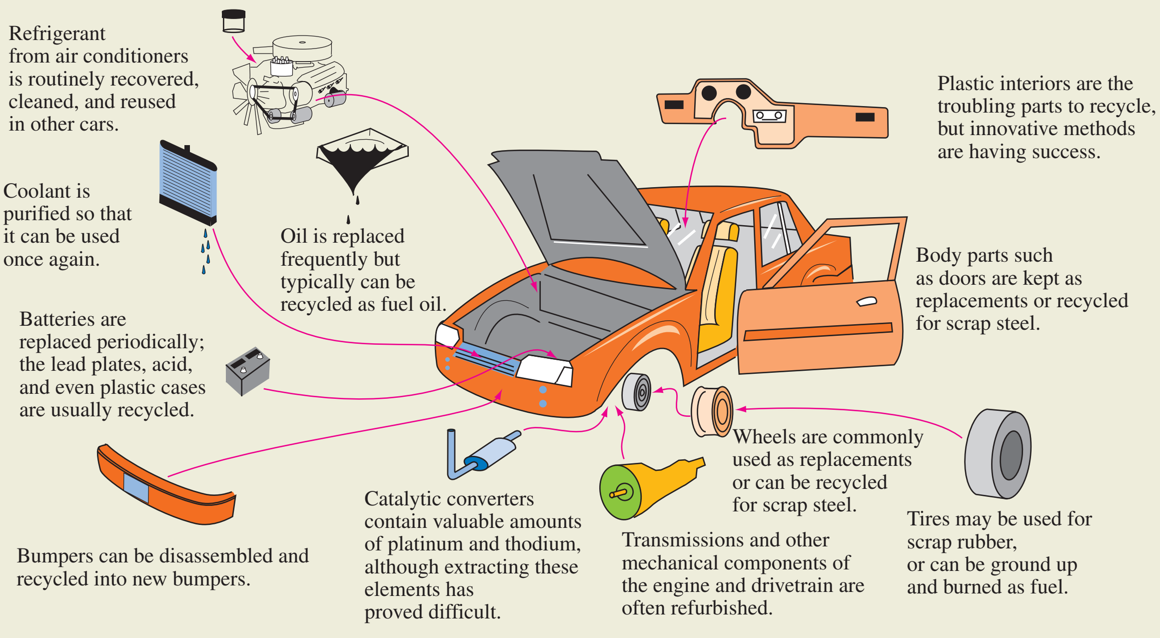
Although technological changes have occurred in almost every industry, many may be unique to an industry. For instance, a prestressed concrete block is a technological advance unique to the construction industry. Major developments in the design of automobiles will result in cars that are made from recyclable parts. (See Exhibit SC.1 for a description of the materials and process technologies that are being developed.)

Some technological advances in recent decades have had a significant, widespread impact on manufacturing firms in many industries. These advances, which are the topic of this section, can be categorized in two ways: hardware systems and software systems.

Hardware technologies have generally resulted in greater automation of processes; they perform labor-intensive tasks originally performed by humans. Examples of these major types of hardware technologies are numerically controlled machine tools, machining centers, industrial robots, automated materials handling systems, and flexible manufacturing systems. These are all computer-controlled devices that can be used in the manufacturing of

EXHIBIT SC.1

Automobile Recycling



Automobile recycling is one of the most successful examples of reuse of manufactured product. About 75 percent of a typical car can be recycled in the form of refurbished parts, useful fluids and scrap materials. This process can, however, be taken further. New methods to separate and recycle plastic components, for example, offer the possibility of removing even more material from the waste stream and returning it to the manufacturing cycle.

FIGURE FROM R. A. FROSCH, "THE INDUSTRIAL ECOLOGY," *SCIENTIFIC AMERICAN*, SEPTEMBER 1995, P. 18. ILLUSTRATION © 1995 BY KARL GUDE. USED WITH PERMISSION.

products. Software-based technologies aid in the design of manufactured products and in the analysis and planning of manufacturing activities. These technologies include computer-aided design and automated manufacturing planning and control systems. Each of these technologies will be described in greater detail in the following sections.

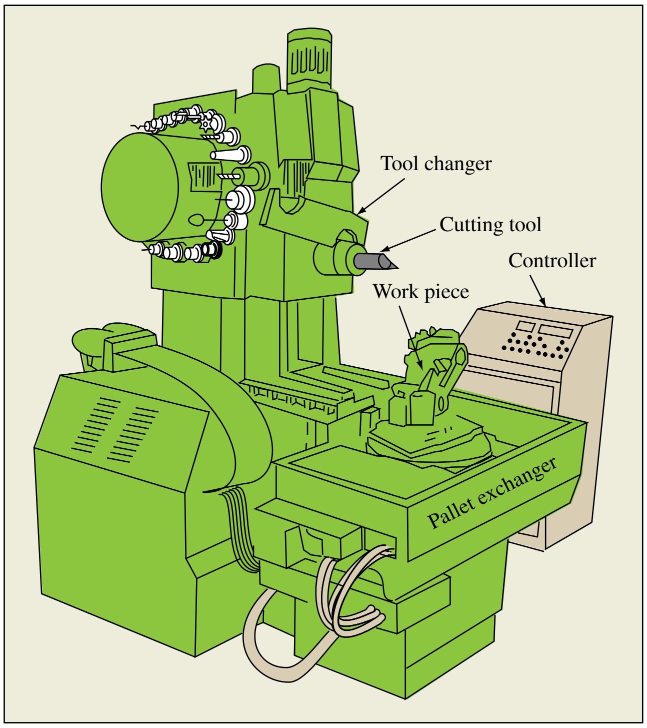
Hardware Systems *Numerically controlled (NC) machines* are comprised of (1) a typical machine tool used to turn, drill, or grind different types of parts and (2) a computer that controls the sequence of processes performed by the machine. NC machines were first adopted by U.S. aerospace firms in the 1960s, and they have since proliferated to many other industries. In more recent models, feedback control loops determine the position of the machine tooling during the work, constantly compare the actual location with the programmed location, and correct as needed. This is often called *adaptive control.*

Machining centers represent an increased level of automation and complexity relative to NC machines. Machining centers not only provide automatic control of a machine, they may also carry many tools that can be automatically changed depending on the tool required for each operation. In addition, a single machine may be equipped with a shuttle system so that a finished part can be unloaded and an unfinished part loaded while the machine is working on a part. To help you visualize a machining center, we have included a diagram in Exhibit SC.2.

Industrial robots are used as substitutes for workers for many repetitive manual activities and tasks that are dangerous, dirty, or dull. A robot is a programmable, multifunctional machine that may be equipped with an end effector. Examples of end effectors include a gripper to pick things up, or a tool such as a wrench, a welder, or a paint sprayer. Exhibit SC.3 examines the human motions a robot can reproduce. Advanced capabilities have been designed into robots to allow vision, tactile sensing, and hand-to-hand coordination. In addition,

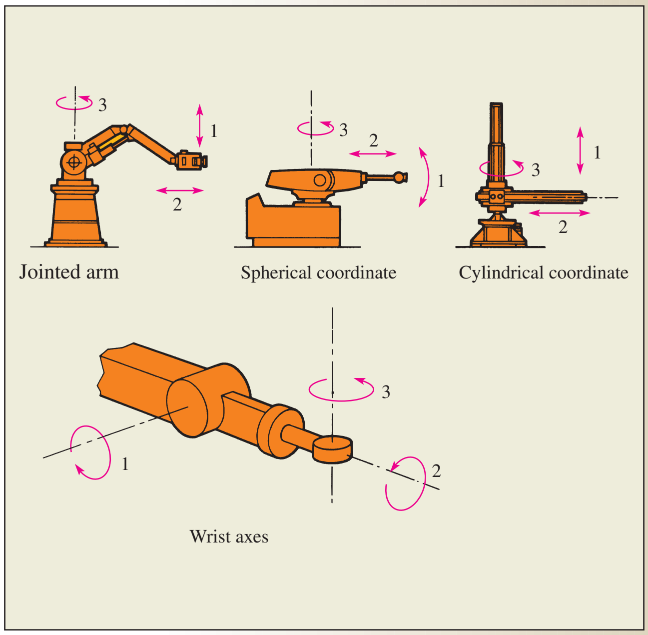
EXHIBITS SC.2 & 3

SC.2—The CNC Machining Center

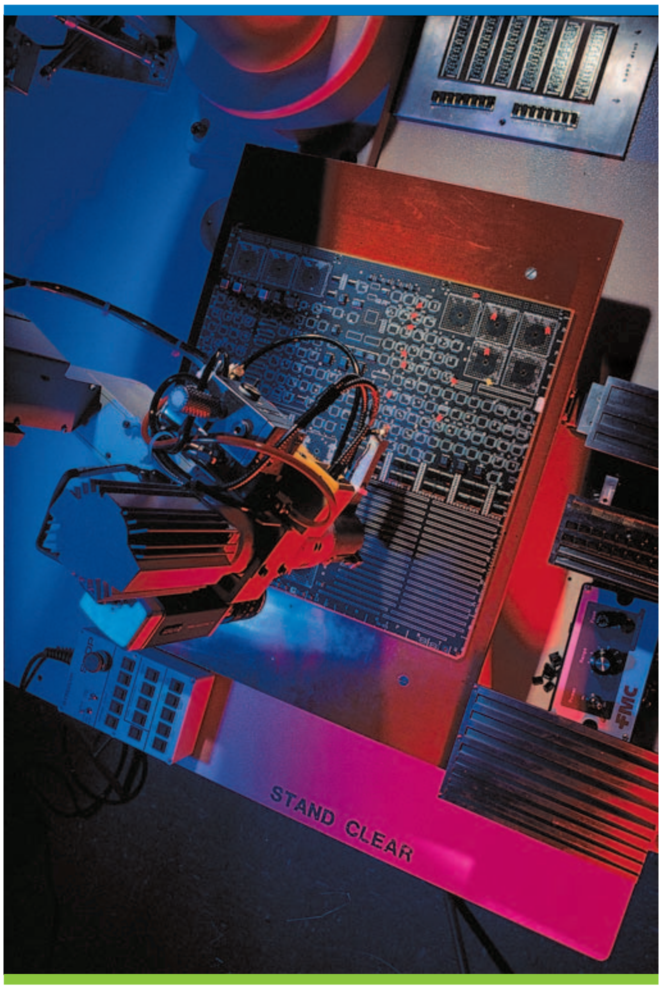


SOURCE: J. T. BLACK, *THE DESIGN OF THE FACTORY WITH A FUTURE* (NEW YORK: MCGRAW-HILL, 1991, P. 39), WITH PERMISSION OF THE MCGRAW-HILL COMPANIES.

SC.3—Typical Robot Axes of Motion



SOURCE: L. V. OTTINGER, "ROBOTICS FOR THE IE: TERMINOLOGY, TYPES OF ROBOTS," *INDUSTRIAL ENGINEERING*, NOVEMBER 1981, P. 30.



some models can be "taught" a sequence of motions in a three-dimensional pattern. As a worker moves the end of the robot arm through the required motions, the robot records this pattern in its memory and repeats it on command. As shown in the box "Formula for Evaluating a Robot Investment," robots are often justified based on labor savings.

Automated materials handing (AMH) systems improve efficiency of transportation, storage, and retrieval of materials. Examples are computerized conveyors and automated storage and retrieval systems (AS/RS) in which computers direct automatic loaders to pick and place items. Automated guided vehicle (AGV) systems use embedded floor wires to direct driverless vehicles to various locations in the plant. Benefits of AMH systems include quicker material movement, lower inventories and storage space, reduced product damage, and higher labor productivity.

These individual pieces of automation can be combined to form *manufacturing cells* or even complete *flexible manufacturing systems (FMS).* A manufacturing cell might consist of a robot and a machining center. The robot could be programmed to automatically insert and remove parts from the machining center, thus allowing unattended operation. An FMS is a totally automated manufacturing system that consists of machining centers with automated loading and unloading of parts, an automated guided vehicle system for moving parts between machines, and other automated elements to allow unattended production of parts. In an FMS, a comprehensive computer control system is used to run the entire system.

A good example of an FMS is the Cincinnati Milacron facility in Mt. Orab, Ohio, which has been in operation for over 20 years. Exhibit SC.4 is a layout of this FMS. In this system, parts are loaded onto standardized fixtures (these are called "risers"), which are mounted on pallets that can be moved by the AGVs. Workers load and unload tools and parts onto the standardized fixtures at the workstations shown on the right side of the diagram. Most

FORMULA FOR EVALUATING A ROBOT INVESTMENT

Many companies use the following modification of the basic payback formula in deciding if a robot should be purchased:

$$P = \frac{I}{L - E + q(L + Z)}$$

where

P = Payback period in years

I = Total capital investment required in robot and accessories

L = Annual labor costs replaced by the robot (wage and benefit costs per worker times the number of shifts per day)

E = Annual maintenance cost for the robot

q = Fractional speedup (or slowdown) factor

Z = Annual depreciation

Example:

I = $50,000

L = $60,000 (two workers × $20,000 each working one of two shifts; overhead is $10,000 each)

E = $9,600 ($2/hour × 4,800 hours/year)

q = 1.5 (robot works 150 percent as fast as a worker)

Z = $10,000

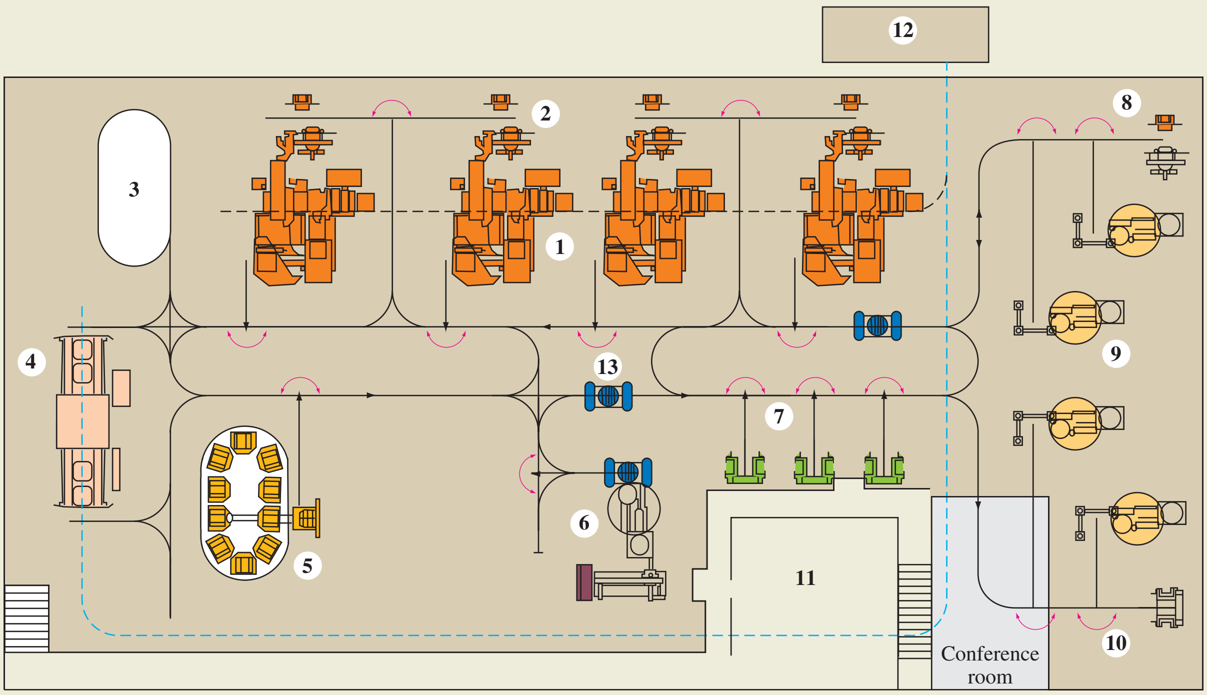
then

$$P = \frac{\$50{,}000}{\$60{,}000 - \$9{,}600 + 1.5(\$60{,}000 + \$10{,}000)}$$

$$= 1/3 \text{ year.}$$

EXHIBIT SC.4

The Cincinnati Milacron Flexible Manufacturing System



Key:

1 Four Milacron T-30 CNC Machining Centers.
2 Four tool interchange stations, one per machine, for tool storage chain delivery via computer-controlled cart.
3 Cart maintenance station. Coolant monitoring and maintenance area.
4 Parts wash station, automatic handling.
5 Automatic Workchanger (10 pallets) for online pallet queue.
6 One inspection module—horizontal type coordinate measuring machine.
7 Three queue stations for tool delivery chains.
8 Tool delivery chain load/unload stations.
9 Four part load/unload stations.
10 Pallet/fixture build station.
11 Control center, computer room (elevated).
12 Centralized chip/coolant collection/recovery system (----flume path).
13 Three computer-controlled carts, with wire-guided path.
Cart turnaround station (up to 360° around its own axis)

SOURCE: TOUR BROCHURE FROM THE PLANT.

ONE OF THE FOUR LARGE MACHINING CENTERS (SEE EXHIBIT SC.4) THAT ARE PART OF THE FLEXIBLE MANUFACTURING SYSTEMS AT CINCINNATI MILACRON'S MT. ORAB, OHIO, PLANT.

of this loading and unloading is done during a single shift. The system can operate virtually unattended for the other two shifts each day.

Within the system there are areas for the storage of tools (Area 7) and for parts (Area 5). This system is designed to machine large castings used in the production of the machine tools made by Cincinnati Milacron. The machining is done by the four CNC machining centers (Area 1). When the machining has been completed on a part, it is sent to the parts washing station (Area 4), where it is cleaned. The part is then sent to the automated inspection station (Area 6) for a quality check. The system is capable of producing hundreds of different parts.

Software Systems *Computer-aided design (CAD)* is an approach to product and process design that utilizes the power of the computer. CAD covers several automated technologies, such as *computer graphics* to examine the visual characteristics of a product and *computer-aided engineering (CAE)* to evaluate its engineering characteristics. Rubbermaid used CAD to refine dimensions of its ToteWheels to meet airline requirements for checked baggage. CAD also includes technologies associated with the manufacturing process design, referred to as *computer-aided process planning (CAPP).* CAPP is used to design the computer part programs that serve as instructions to computer-controlled machine tools, and to design the programs used to sequence parts through the machine centers and other processes (such as the washing and inspection) needed to complete the part. These programs are referred to as *process plans.* Sophisticated CAD systems are also able to do on-screen tests, replacing the early phases of prototype testing and modification.

CAD has been used to design everything from computer chips to potato chips. Frito-Lay, for example, used CAD to design its O'Grady's double-density, ruffled potato chip. The problem in designing such a chip is that if it is cut improperly, it may be burned on the outside and soggy on the inside, be too brittle (and shatter when placed in the bag), or display other characteristics that make it unworthy for, say, a guacamole dip. However, through the use of CAD, the proper angle and number of ruffles were determined mathematically; the O'Grady's model passed its stress test in the infamous Frito-Lay "crusher" and made it to your grocer's shelf.

CAD is now being used to custom design swimsuits. Measurements of the wearer are fed into the CAD program, along with the style of suit desired. Working with the customer, the designer modifies the suit design as it appears on a human-form drawing on the computer screen. Once the design is decided upon, the computer prints out a pattern, and the suit is cut and sewn on the spot.

Automated manufacturing planning and control systems (MP&CS) are simply computer-based information systems that help plan, schedule, and monitor a manufacturing operation. They obtain information from the factory floor continuously about work status, material arrivals, and so on, and they release production and purchase orders. Sophisticated manufacturing and planning control systems include order-entry processing, shop-floor control, purchasing, and cost accounting.

COMPUTER-INTEGRATED MANUFACTURING (CIM)

Vol. I "Computer Integrated Manufacturing"

All of these automation technologies are brought together under *computer-integrated manufacturing (CIM).* CIM is the automated version of the manufacturing process, where the three major manufacturing functions—product and process design, planning and control, and the manufacturing process itself—are replaced by the automated technologies just described. Further, the traditional integration mechanisms of oral and written communication are replaced by computer technology. Such highly automated and integrated manufacturing also goes under other names: *total factory automation* and the *factory of the future.*

All of the CIM technologies are tied together using a network and integrated database. For instance, data integration allows CAD systems to be linked to *computer-aided manufacturing (CAM),* which consists of numerical-control parts programs; and the manufacturing planning and control system can be linked to the automated material handling systems to facilitate parts pick list generation. Thus, in a fully integrated system, the areas of design, testing, fabrication, assembly, inspection, and material handling are not only automated but also integrated with each other and with the manufacturing planning and scheduling function.

EVALUATION OF TECHNOLOGY INVESTMENTS

Modern technologies such as flexible manufacturing systems or computerized order processing systems represent large capital investments. Hence, a firm has to carefully assess its financial and strategic benefits from a technology before acquiring it. Evaluating such investments is especially hard because the purpose of acquiring new technologies is not just to reduce labor costs but also to increase product quality and variety, to shorten production lead times, and to increase the flexibility of an operation. Some of these benefits are intangible relative to labor cost reduction, so justification becomes difficult. Further, rapid technological change renders new equipment obsolete in just a few years, making the cost–benefit evaluation more complex.

But never assume that new automation technologies are always cost-effective. Even when there is no uncertainty about the benefits of automation, it may not be worthwhile to adopt it. For instance, many analysts predicted that integrated CAD/CAM systems would be the answer to all manufacturing problems. But a number of companies investing in such systems lost money in the process. The idea was to take a lot of skilled labor out of the process of tooling up for new or redesigned products and to speed up the process. However, it can take less time to mill complex, low-volume parts than to program the milling machine, and programmer time is more expensive than the milling operator time. Also, it may not always be easy to transfer all the expert knowledge and experience that a milling operator has gained over the years into a computer program. Only recently has CAD/CAM integration software become available that can be cost-effective even in high-variety, low-volume manufacturing environments.

BENEFITS OF TECHNOLOGY INVESTMENTS

The typical benefits from adopting new manufacturing technologies are both tangible and intangible. The tangible benefits can be used in traditional modes of financial analysis, such as discounted cash flow, to make sound investment decisions. Specific benefits can be summarized as follows:

COST REDUCTION

Labor costs. Replacing people with robots, or enabling fewer workers to run semi-automatic equipment.

Material costs. Using existing materials more efficiently, or enabling the use of high-tolerance materials.

Inventory costs. Fast changeover equipment allowing for JIT inventory management.

Quality costs. Automated inspection and reduced variation in product output.

Maintenance costs. Self-adjusting equipment.

OTHER BENEFITS

Increased product variety. Scope economies due to flexible manufacturing systems.

Improved product features. Ability to make things that could not be made by hand (e.g., microprocessors).

Shorter cycle times. Faster setups and change-overs.

Greater product output.

Risks in Adopting New Technologies Although there may be many benefits in acquiring new technologies, several types of risk accompany the acquisition of new technologies. These risks have to be evaluated and traded off against the benefits before the technologies are adopted. Some of these risks are described next.

TECHNOLOGICAL RISKS

An early adopter of a new technology has the benefit of being ahead of the competition, but he or she also runs the risk of acquiring an untested technology whose problems could disrupt the firm's operations. There is also the risk of obsolescence, especially with electronics-based technologies where change is rapid and when the fixed cost of acquiring new technologies or the cost of upgrades is high. Also, alternative technologies may become more cost-effective in the future, negating the benefits of a technology today.

OPERATIONAL RISKS

There could also be risks in applying a new technology to a firm's operations. Installation of a new technology generally results in significant disruptions, at least in the short run, in the form of plantwide reorganization, retraining, and so on. Further risks are due to the delays and errors introduced in the production process and the uncertain and sudden demands on various resources.

ORGANIZATIONAL RISKS

Firms may lack the organizational culture and top management commitment required to absorb the short-term disruptions and uncertainties associated with adopting a new technology. In such organizations, there is a risk that the firm's employees or managers may quickly abandon the technology when there are short-term failures or will avoid major changes by simply automating the firm's old, inefficient process and therefore not obtain the benefits of the new technology.

ENVIRONMENTAL OR MARKET RISKS

In many cases, a firm may invest in a particular technology only to discover a few years later that changes in some environmental or market factors make the investment worthless. For instance, in environmental issues auto firms have been reluctant to invest in technology for making electric cars because they are uncertain about future emission standards of state and federal governments, the potential for decreasing emissions from gasoline-based cars, and the potential for significant improvements in battery technology. Typical examples of market risks are fluctuations in currency exchange rates and interest rates.

CONCLUSION

Technology has played the dominant role in the productivity growth of most nations and has provided the competitive edge to firms that have adopted it early and implemented it successfully. Although each of the manufacturing and information technologies described here is a powerful tool by itself and can be adopted separately, their benefits grow exponentially when they are integrated with each other. This is particularly the case with CIM technologies.

With more modern technologies, the benefits are not entirely tangible and many benefits may be realized only on a long-term basis. Thus, typical cost accounting methods and standard financial analysis may not adequately capture all the potential benefits of technologies such as CIM. Hence, we must take into account the strategic benefits in evaluating such investments. Further, because capital costs for many modern technologies are substantial, the various risks associated with such investments have to be carefully assessed.

Implementing flexible manufacturing systems or complex decision support systems requires a significant commitment for most firms. Such investments may even be beyond the reach of small to medium-sized firms. However, as technologies continue to improve and are adopted more widely, their costs may decline and place them within the reach of smaller firms. Given the complex, integrative nature of these technologies, the total commitment of top management and all employees is critical for the successful implementation of these technologies.

REVIEW AND DISCUSSION QUESTIONS

1 Do robots have to be trained? Explain.
2 How does the axiom used in industrial selling "You don't sell the product; you sell the company" pertain to manufacturing technology?
3 List three analytical tools (other than financial analysis) covered elsewhere in the book that can be used to evaluate technological alternatives.
4 The Belleville, Ontario, Canada, subsidiary of Atlanta-based Interface Inc., one of the world's largest makers of commercial flooring, credits much of its profitability to "green manufacturing" or "eco-efficiency." What do you believe these terms mean, eh? And how could such practices lead to cost reduction?
5 Give two examples each of recent process and product technology innovations.
6 What is the difference between an NC machine and a machining center?
7 The major auto companies are planning to invest millions of dollars in developing new product and process technologies required to make electric cars. Describe briefly why they are investing in these technologies. Discuss the potential benefits and risks involved in these investments.

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