mainframe computers employed at various levels of the plant to perform functions ranging from process control and data acquisition to data management and interactive scientific computation (*34*). At each level, the computer performs its own function, reports to and receives instructions from the level above it, and receives data from and sends instructions to the level below it. Microcomputers operate at the local level to control process loops and extract and display data. Several microcomputers report to a single minicomputer, which is responsible for decision-making for that segment of the plant. The minicomputer may also be responsible for tracking, analyzing, and reporting results for analytical samples. The number of tiers will depend on the number of tasks to be performed and how the work load is to be distributed. At the highest level, a large computer receives data from the minicomputers and performs scientific and business computing functions. This multitiered approach minimizes the effects of shutdown of any single component, provides stand-alone capabilities for alarm checking, and provides a clear path for modular system expansion.

Modern refining control systems (*35*, *36*) tend to replace the traditional control panel and analog displays by operator consoles with cathode-ray tubes. Process units now have standard control packages, including start-up and shutdown procedures.

### References


1. L. B. Evans, *Science* **195**, 1146 (1977).
2. R. J. Fowles, paper presented at the Paper Industry Management Association Meeting, Washington, D.C., June 1980.
3. C. Hudson, *Science* **215**, 818 (1982).
4. S. Kahne, I. Lefkowitz, C. Rose, *Sci. Am.* **240**, 78 (June 1979).
5. E. J. Kompass, *Control Eng.* **28**, 4 (August 1981).
6. H. M. J. M. Dortmans, *J. Phys. E* **14**, 777 (July 1981).
7. R. Allan, *Electronics* **53**, 101 (July 1980).
8. S. Ohr, *Electron. Des.* **28**, 59 (September 1980).
9. N. Andreiev, *Control Eng.* **28**, 50 (February 1981).
10. P. Bradshaw, *ibid.* **27**, 57 (February 1980).
11. G. P. Edwards, *Electron. Des.* **28**, 137 (February 1980).
12. M. E. Hoff and M. Townsend, *Elektronik* **28**, 37 (July 1979).
13. L. Lowe, *Electronics* **5**, 171 (May 1980).
14. J. G. Posa, *ibid.* **4**, 100 (April 1980).
15. R. E. Holm and J. S. Rittenhouse, "Implementation of a scanning spectrum analyzer using the 2920 signal processor," *Intel Appl. Note AP-92* (1980).
16. H. M. Morris, *Control Eng.* **28**, 65 (March 1981).
17. S. J. Bailey, *ibid.* **27**, 64 (January 1980).
18. This is a measurement of signal power loss. A value of 3 dB/km indicates a 50 percent loss in the power of the signal in traveling.
19. J. Bolles, A. J. Broderich, H. R. Wampler, Jr., paper presented at the 1977 AIME Annual Meeting, Atlanta, Ga., March 1977; Society of Manufacturing Engineers preprint 77-B-47 (1977).
20. R. Davies, *Am. Lab.* **6**, 73 (December 1973); *ibid.* (January 1974), p. 78; *ibid.* (February 1979), p. 82.
21. *Chem. Market. Rep.* (8 September 1980), p. 66.
22. J. C. Flynn, *Pap. Trade J.* **165**, 27 (July 1981).
23. J. H. Rogers, S. C. Vespa, C. Mills, D. J. Butler, N. D. Legault, *Pulp Pap. Mag. Can.* **81**, T277 (October 1980).
24. R. V. Byrd, *Pulp Pap.* **54**, 100 (May 1980).
25. R. P. Powell, *Tappi* **62**, 21 (December 1979).
26. R. S. MacWilliams and K. Robe, *Chem. Process.* **43**, 40 (April 1980).
27. R. L. Smallwood, *Pulp Pap.* **52**, 98 (February 1978).
28. ———, *ibid.* **54**, 101 (February 1980).
29. E. C. Frost, in *Proceedings of the 1979 Spring Annual Conference* (American Institute of Industrial Engineers, New York, 1979), p. 375.
30. *Iron Steel Eng.* **58**, 69 (June 1981).
31. C. H. Trapp, in *Proceedings of the 1981 Spring Annual Conference and World Productivity Congress* (American Institute of Industrial Engineers, New York, 1981), p. 507.
32. J. A. Jordan and J. Dejnecki, *Iron Steel Eng.* **58**, 33 (April 1981).
33. *Iron Steel Eng.* **58**, 32 (August 1981).
34. J. H. Taylor, J. A. Johnson, W. J. Barton, R. Wang, *Chem. Eng. Prog.* **77**, 41 (August 1981).
35. W. J. Baker, *Chem. Process.* **42**, 16 (mid-April 1979).
36. K. L. Hopkins, in *Proceedings of the 1977 Symposium on Instrumentation and Process Control for Fossil Demonstration Plants* (ANL-78-7, Argonne National Laboratory, Argonne, Ill., 1977), p. 287.
37. AccuRay Corporation, Paper 8, September 1980.


38. We acknowledge the support of many members of the IITRI staff, but in particular we express our appreciation to W. A. Davison, R. DeLa-Pena, and G. J. Yucuis for their assistance in the preparation of this article.


# Computers in Manufacturing


C. A. Hudson


While the United States remains among the most productive nations in the world, other industrialized countries are quickly closing the gap. In Japan manufacturing productivity is currently growing at the rate of 4.1 percent a year. France and Germany have manufacturing productivity growth rates of 4.9 and 5.0 percent a year, respectively. Meanwhile, in the United States the rate of growth in manufacturing productivity has fallen sharply. From 1969 to 1973, output per man-hour increased at a compound rate of 2.9 percent. From 1973 to 1979, the gains dwindled to 1.6 percent a year (*1*).

In the United States the program to significantly reverse this productivity pattern must rely on the continued development of advanced technology and its application. Perhaps the most important element in this reliance on innovation is increased factory automation and a growing use of computers and microprocessor technology in manufacturing. Today, we are on the technological and sociological edge of a dramatic increase in the use of computers in our factories. This will have a profound impact on the nation's productivity growth in the next decade.

Within the next 10 to 15 years, four evolutionary trends will meet on the factory floor: (i) the increasing power and simplification of computers, (ii) a widespread appreciation of the practicality of computerized manufacturing and robotic applications, (iii) a new realization of the impact of computers on people and of people on computers, and (iv) a growing awareness of the urgent need for manufacturing innovation in our society.

Many computerized factory systems exist today as islands of automation. The immediate task of the scientific and technical communities is to use the increased power and simplicity of computers to link these elements into an integrated system. Making use of low-cost computer hardware to perform more and more jobs will make such an integrated factory system economically viable.

Some difficult technical problems remain. We must develop generally accepted, standardized interfaces between computerized design engineering and computerized manufacturing, between individual machines and machining centers, and between computers and the people using them. We must also refine the present state of application technology and reduce the cost of the factory automated system through the increased use of computers. Advances in factory automation are dependent on advances in computer technology.


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*Summary.* Computers are now widely used in product design and in automation of selected areas in factories. Within the next decade, the use of computers in the entire spectrum of manufacturing applications, from computer-aided design to computer-aided manufacturing and robotics, is expected to be practical and economically justified. Such widespread use of computers on the factory floor awaits further advances in computer capabilities, the emergence of systems that are adaptive to the workplace, and the development of interfaces to link islands of automation and to allow effective user communications.

## Computer Evolution

The technological changes in the computer field during the past several years clearly equal any technological change that has occurred in our society over the past 100 years. The introduction of high-performance, low-cost microprocessor and storage technology has dramatically improved and enhanced the functions and capabilities of computer software and hardware. With today's increased power, manufacturing computer systems can be made more adaptable to the manufacturing environment, thus cutting systems engineering costs and time per installation.

The cost of computer hardware itself has been steadily declining. This trend will continue with the introduction of new technologies such as very high performance microprocessor chips based on very large scale integration (VLSI). On the other hand, the cost of the human and software resources for systems engineering and programming has gone up. In 1955, 85 percent of the total cost for processing information was hardware. It is estimated that by 1985 hardware will account for only 15 percent of this total cost. To improve manufacturing productivity we must reverse this trend by optimizing the use of our human resources and take advantage of the increased computer power and reduced hardware costs (*2*).

The need to make increased use of available computer power is heightened by the decline in available technical manpower. The National Science Foundation found the annual growth rate of scientific and R & D personnel between 1954 and 1969 to be 5.9 percent. Some 556,000 employees were involved in technical work in 1969, but the number fell to 517,000 in 1973 and then grew to only 610,000 by last year—a rate of only 2.8 percent annually (*1*).

The increased capability of computer technology and broad availability of application software packages, including the expanded use of problem-oriented languages and database software, can reduce the cost of program development and maintenance by a factor of 10. The graphics capabilities of engineering computers can link integrated design and drafting systems to manufacturing systems. With these "user-friendly" approaches to provide a bridge between man and computer, the user can interact directly with the manufacturing system without traditional interfaces and jargon-heavy manuals.

Computers and the applications they support can now be considered for functions or activities that only recently were impractical. The opportunity for the application of this technology, for all practical purposes, is unlimited.

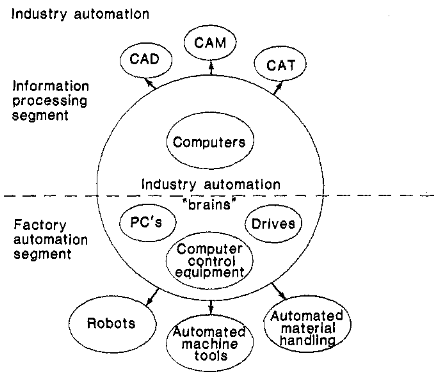


Fig. 1. Industry automation. CAD/CAM unifies the range of advanced computer technologies in the factory.

## Manufacturing Automation

Advances in the two primary elements of factory computerization—computer-aided design (CAD) and computer-aided manufacturing (CAM)—will create a new industrial revolution. By integrating design with manufacturing, we can not only turn out new product designs much faster but also program the computer to make sure the designs provide quality and reliability as well as the lowest possible manufacturing costs. CAD/CAM is the integrated use of advanced computer technology in engineering and manufacturing (Fig. 1). It is a common database of part and product geometry and related information which makes it easier to translate a creative idea into a final product at a reduced cost.

With CAD, a user can define a part shape, analyze stresses and other factors, check mechanical actions, and automatically produce engineering drawings from a graphics terminal. When CAD is combined with the CAM system, the user can also manipulate nongraphic data such as bills of material, shop information, and cost factors. The end result is greater design flexibility and what is referred to as designing to cost.

The CAD functions can be grouped in four categories: design and geometric modeling, engineering analysis, kinematics, and drafting.

1) In design and geometric modeling, the designer describes the shape of a structure with a geometric model constucted graphically on a cathrode-ray tube (Fig. 2). The computer converts this picture into a mathematical model, which is stored in the computer database for later use. Many other design functions depend heavily on the model. It can, for example, be used to create a finite-element model for stress analysis, serve as input for automated drafting to make a drawing, or be used to create numerical control tapes for the factory.

2) After the geometric model has been created, the engineer can easily calculate such things as weight, volume, surface area, moment of inertia, or center of gravity of a part. But the most powerful method of analyzing a structure is probably finite-element analysis. In this technique, the structure is broken down into a network of simple elements that the computer uses to determine stresses, deflections, and other structural characteristics. The designer can see how the structure will behave before it is built and can modify it without building costly physical models and prototypes. This procedure can be expanded to a complete systems model, and the operation of a product can be simulated.

3) With computer kinematics, the user can examine the effects of moving parts on other parts of the structure or design and analyze more complex mechanisms.

4) Finally, the CAD system automatically drafts drawings for use in manufacturing.

Computer-aided design is a good example of the transition of expensive, state-of-the-art computer technology to a commercial, economically justifiable system. Recent advances in CAD technology have increased the productivity and effectiveness of design engineering

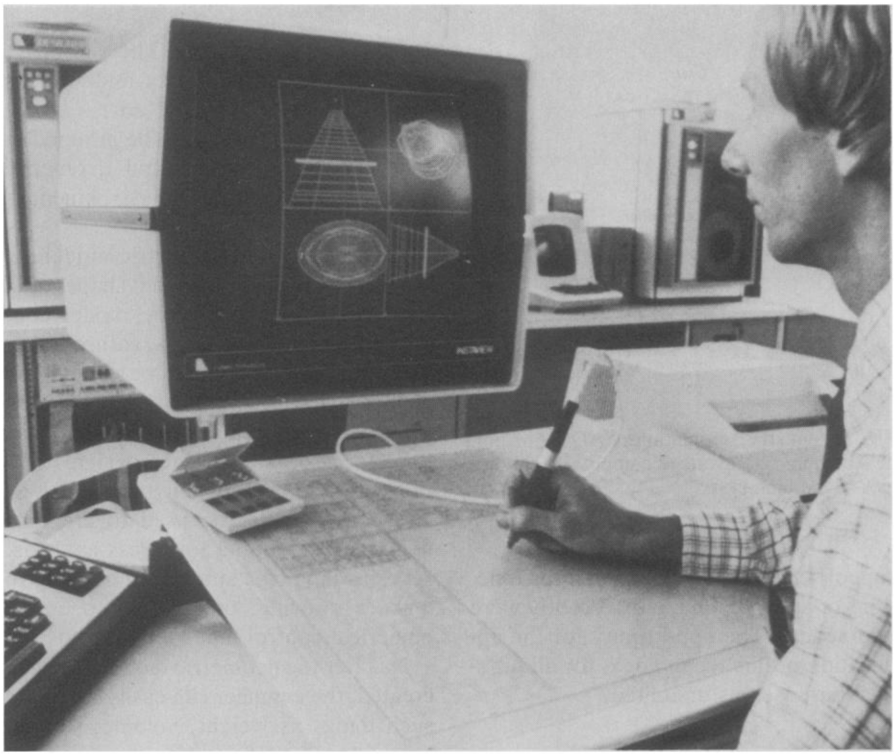

Fig. 2. Computer-aided design. Graphic design already makes extensive use of the computer's ability to simulate complex activities.

groups. Such systems will be even more common in the next 5 to 10 years.

Manufacturing groups can draw on the geometric and numerically coded description produced by CAD to create numerical control tapes, which allow direct computer control of shop machines, determine process plans and scheduling, instruct robots, computerize testing, and in general improve the management of plant operations.

Computer-aided manufacturing has five main functions: tool design, machine control, process and materials planning, robotics, and factory management.

1) Manufacturing engineering and tool design deals with the machines and fixtures needed to make a new product. In effect, the set of machines, tooling, and fixtures is a new product, and all the techniques of CAD are used in fashioning it. The CAD techniques are then used to simulate plant operation and the integration of machines and materials handling.

2) Machine automation consists of a chain of increasingly sophisticated control techniques. At the lower end of the spectrum are fixed automation with relays or cams and programmable controllers, where relays have been replaced by electronics. Moving up the spectrum, numerical control (NC) refers to controlling a machine with prerecorded, numerically coded information to fabricate a part. In this case, the machine is hard-wired and not readily reprogrammed. In computer numerical control (CNC) the machine is directly controlled by a minicomputer, which stores the machining instructions as software that is relatively easy to reprogram. Because of the computer control, CNC has the advantages of much higher storage capability and increased flexibility. Virtually all numerical control is computer-based, yet only 10 years ago CNC was an expensive exception.

3) Process planning considers the detailed sequence of production steps from start to finish. The process plan describes the state of the workpiece at each work station. An important element in process planning is group technology, in which similar parts are organized into families to allow standardized fabrication steps; this permits significant savings by avoiding duplicate tooling and systems engineering. Most automated process-planning systems use a retrieval technique based on part families and existing databases for standard tooling and fabrication processes. Materials planning or manufacturing resource planning is concerned with the precise flow and timing of manpower, materials, and processes; it is a detailed look at how everything comes together. The ultimate goal is to have continuous use of all production equipment, no bottlenecks, and a minimum inventory.

4) Because they are widely applicable, robots have a distinct advantage over specialized, highly engineered manufacturing systems. The economic advantage of a mass-produced, readily adaptable robot over a one-of-a-kind system with a great deal of engineering content is obvious. Robots are now being used to perform materials-handling functions in CAM systems. They can select and position tools and workpieces for NC or CNC tools, operate tools such as drills and welders, or perform test and inspection functions. Through visual or tactile sensors, the robot can manipulate objects. Through its computer intelligence, it can inspect the object and provide the machine with corrective feedback or actually reprogram the machine or change the tooling.

5) Factory management coordinates the operations of an entire plant. Factory management systems tie together individual machine tools, test stations, robots, and materials-handling systems into manufacturing cells and the cells into an integrated whole. An integrated CAM system of this sort is usually hierarchical, with microprocessors handling specific machining functions or robot operation, middle-level computers controlling the operation and work scheduling of one or more manufacturing cells, and a large central computer controlling the overall system (*3*).

Reliability is greatly improved by structuring the control system correctly. Local, distributed control (with defined responsibilities) reports up to a supervisory control that, in turn, is linked to a managerial computer. This parallels the structure of the typical industrial organization.

Ultimately, the digital output from the CAD computer will be simply plugged into the CAM system to reprogram the plant's manufacturing computers. In such an integrated system, the databases will be organized in a way that avoids redundancy and reformatting of information. And any change in one part of the system will automatically revise dependent or related information in other parts of the system.

Bridging the CAM and CAD systems will be one of our major jobs in the future. A fundamental difference that has to be reconciled is that CAD makes use of a pictorial, graphics-oriented computer database while CAM involves a great deal of text-oriented information. In other words, we need to find a way for the computer doing the drawing to speak the same language as the computer directing the manufacturing plant.

Layering is one way to link these systems. Layering is a particular technique for structuring the CAD and CAM databases. It enables various people to input data without losing control of the overall design and manufacturing process. Equally important, it enables shop people to see information that is meaningful to them without having to sort through and understand the rest of the information that is normally included in a drawing.

To do this, all information is organized in an arrangement resembling layers, or slices, inside the database. The engineer or users in other departments of an organization can provide pertinent information or examine any or all layers of information according to their particular needs. As an example, a printed circuit board may have 250 to 300 layers of information. A manufacturing engineer inputs layers of information that deal with fabrication and assembly. In turn, machine operators concerned with the details of the drilling and cutting configuration may access layers dealing with this part of the drawing. Other layers provide information pertinent to the needs of the purchasing department or component assemblers.

Another major effort to integrate computer systems is an Air Force program called ICAM (integrated computer-aided manufacturing). This is a practical attempt to greatly shorten the time span for the implementation of compatible and standardized computer-manufacturing techniques and to provide a unified direction for industry. The ICAM program provides seed money for the establishment, within private industry, of modular subsystems designed to computerize and tie together various phases of design, fabrication, and distribution processes and their associated management hierarchy. As appropriate, these mutually compatible modules will be combined to demonstrate a comprehensive control and management package capable of continual adjustment as production needs and the state of the art change.

The ICAM program is divided into five major parts:

1) Defining the manufacturing architecture. This permits a concentration on problems of generic scope and wide applicability as the basis for later projects in integration, support, and application systems and demonstrations.

2) Developing integration methodology. This activity provides a bridge between industry and ICAM for the transfer of ICAM technology for the integrated factory of tomorrow. The projects addressed include establishing factory simulation techniques, ICAM implementation techniques, configuration management, modeling tools, software integration simulation, automated systems engineering methodology, and various system analysis and design capabilities.

3) Establishing support systems. This is concerned with the portion of the ICAM system involving computer operations, including both software and hardware and both operational and managerial aspects of computerized manufacturing.

4) Establishing application systems. This includes such items as manufacturing cost and design guides, the design-manufacturing interface, manufacturing standards, group technology concepts, and scheduling and process planning. Under an ICAM contract, the National Bureau of Standards considered standards in computer communications, languages, and networks to identify potential conflicts within an integrated manufacturing environment. Other areas of concern include robotics, prototype integrated production cells, integrated materials-handling and storage systems, and

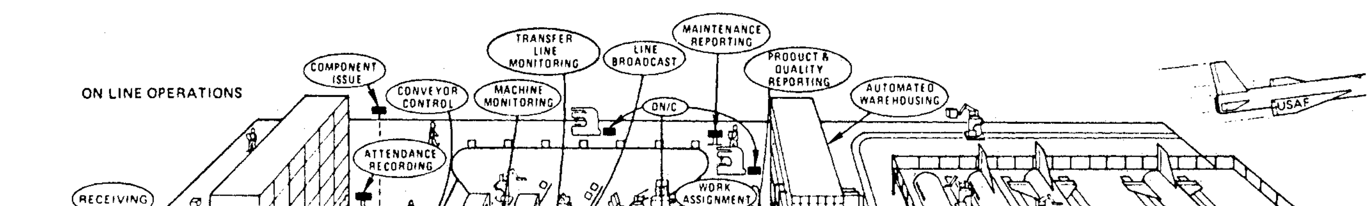


Fig. 3. Factory of tomorrow. The Air Force's ICAM program attempts to integrate manufacturing systems through the capabilities of the computer.

integrated manufacturing control and material management.

5) Demonstrating the ICAM program. The ultimate goal in ICAM is the use of totally integrated manufacturing systems by industry in the completely automated factory (Fig. 3) (*4*).

## Robotics

The problems encountered in trying to integrate advanced computer concepts, new manufacturing technologies, and the shop floor are clearly evident in the evolution of robotics. Robots are classified according to the way we provide them with information and the amount of self-adaptability they possess. The most comprehensive categorization of robots is provided by Japan's Industrial Robot Association (*5*):

1) Manual manipulators are worked by an operator.

2) A fixed-sequence robot has a manipulator that repetitively performs successive steps of an operation according to a predetermined sequence which cannot be easily changed.

3) A variable-sequence robot is similar to the fixed-sequence robot except that the set information can be easily changed.

4) A playback robot reproduces, from its computer memory, operations that were originally executed under human control.

5) An NC robot is a manipulator whose tasks are programmed by using numerical control tapes or cards.

6) An intelligent robot, using sensory perception, detects changes in the work environment and proceeds accordingly, using its decision-making capability.

Industry today is focusing on the development of NC and intelligent robots. There has been a growth in the number of firms that manufacture and sell such robots which is reminiscent of the proliferation of minicomputer companies in the 1960's.

Basically, robots are microprocessor-controlled mechanical devices that perform a function or provide an intelligent interface between machines and processes. They can be intelligent enough to make on-the-spot manufacturing "decisions." But for robots to become practical, we must reduce their size, mechanical complexity, and installed cost—primarily through the expanded use of computer and control technology.

Robots can duplicate human manipulative skills with accuracy and precision. Their flexibility and versatility, as opposed to hard automation, make robots ideally suited to the kinds of small batch jobs that constitute the bulk of industry's manufacturing activity. Today, robots are freeing people from jobs that present serious health hazards, are mundane, or are highly repetitive. In most cases their use is justified for noneconomic reasons.

In the United States industry has been slow to adopt robotics. This reluctance appears to be due primarily to the large initial investment and the general availability of relatively inexpensive manual labor. Why install a $100,000 or $150,000 robot to perform a $25,000-a-year job? Also, the majority of today's robots are monsters: bulky, unwieldy mixtures of hydraulic and mechanical contraptions with a machine tool heritage.

This situation is changing. Robots are becoming more streamlined and, when they are manufactured in large quantities, will rapidly decline in cost. Many technologically innovative firms are entering the business. Equally important, system engineering, which represents as much as two-thirds of the cost of a robotic application, is being greatly reduced. It is not difficult to imagine that in a short time the cost of a typical robotic system will be paid back in 1 or 2 years. In the next decade the cost of a robot is likely to be down to $10,000 to $20,000, while skilled labor costs might easily be $25 or $30 an hour. When this economic threshold is reached, there will be a virtual flood of robotic applications.

When this happens, robots will play an important part in the totally integrated factory of the future. Most of our plants will have a direct numerical control supervisory computer that coordinates the activities of several NC and CNC machines or hardwired machining centers and robots and connects all the machines into a system. The robot interface will handle the transfer of material and, with newly developed sensory capabilities, will also perform the in-line inspection of parts. For the near future, however, our factories will be some particular mix of machines, robots, and people that makes the most economic sense.

Eventually—in a decade or so—robots will fill a void in the supply of skilled labor. There has been a shift in the labor force from blue-collar to white-collar workers and from production jobs to service jobs. Currently, about two-thirds of our work force and 85 percent of all college graduates are employed in a service-related activity. The total service-oriented labor force is expected to increase by 20 percent in the 1980's—to about 85 million people. This shift to a service economy, coupled with the slowdown in the growth of the U.S. population, suggests that many businesses will find factory labor in short supply; this is already the case in Sweden today.

At a leading university in Japan, there is a robot with human-type hands and legs, TV-camera eyes, artificial ears and mouth, and with touch and joint sensing. These technologies are combined to provide the robot with some of the capabilities of a 2- or 3-year-old child. For example, when ordered to fetch an item in the room, the robot looks around the room and finds the article, walks to it, picks it up, and brings it back. If the robot does not understand a command, it speaks up.

Such robots are essentially showcase examples; they are not appropriate for the majority of industrial applications. In fact, a universal person-like robot would make little sense except for very limited, specialized applications. At present, the major applications for robotics are in arc welding and material transfer. In the future, the major application will be in assembly. Artificial intelligence is a worthwhile goal, but for the moment industry has more than enough applications for "dumb" robots. Employment of robots in these applications is actually limited by the extensive engineering required to put them to use.

It is estimated that by 1990, two-thirds of the robots sold to industry will be off-the-shelf, modular units rather than specially designed systems. Looking at automated systems generally, by the end of the decade, 30 percent of our systems will consist of hard automation, about 20 percent will be adaptive control, and the remaining 50 percent will be systems of a universal programmable nature.

Respondents to a study conducted by the Society of Manufacturing Engineers ranked the technical and performance barriers constraining the rapid utilization of robots in U.S. industry (*6*). The leading technical barriers were mechanical manipulation, vision systems, tactile systems, sensory systems, programming, and control systems. The primary performance barriers included accuracy, speed, and the ratio of capacity to size.

Robots will have a much greater impact in manufacturing when their total installed cost is reduced and they are more easily programmed. As with CAD and CAM systems, the most difficult thing about putting in a robot is interfacing it with the factory—both the machines and the people.

Research today is focused on the development of (i) equipment that will make greater use of computer technology to cut the cost of systems engineering and power electronics, improve servo-motor technology, and rapidly move from hydraulics to electrics and (ii) sensors that will enable robots to perform more reliably and with greater precision and adaptability.

A good overview of sensor types has been provided by Bejczy (*7*):

"The nonvisual sensor information is used in controlling the physical contact or near-contact of the mechanical arm/hand with objects in the environment. It is obtained from proximity, force-torque, and touch-slip sensors integrated with the mechanical hand. These sensors provide the information needed to perform terminal orientation and dynamic compliance control with fine manipulator motions. . . .

"Terminal orientation and dynamic compliance control are essential and intricate elements of manipulation. Soft and adaptive grasp of objects, gentle load transfer in emplacing objects, assembling or disassembling parts with narrow tolerances, and performing geometrically and dynamically constrained motions (like opening or closing a latch or fitting two parts together) are typical examples of manipulator control problems that challenge both sensor and control engineering. . . ."

Vision systems close the control loop and allow the robot to interact in a dynamic, changing environment. A second use of vision will be for the critical inspection of the batch-produced parts. The position and orientation of the part can be used in advanced automation systems to direct a robot manipulator to pick up the part for an assembly or transfer operation.

The Robotics Laboratory at Westinghouse is working on state-of-the-art applications in many of these areas. Systems and development engineers are working on the integration of controls, tooling, processes, computer, and other elements of the automated factory. Specialists in robotics are concentrating on developing and applying high-speed vision systems, tactile and force feedback sensors, high-performance electric servo systems, adaptable programmable assembly techniques and computer control, and artificial intelligence.

One of these projects is called APAS (automated programmable assembly system). Funded in part by the National Science Foundation, APAS is a pilot program in which robots are used to assemble components into the end bells of the Westinghouse line of fractional-horsepower motors. It is a development project intended to transfer newly developed technology to the factory. The fractional-horsepower motors are currently assembled in batches averaging 600 units at a time. There is a 20-second assembly time per motor to put together 30 different parts, and there are 13 changeovers a day to handle 450 different motor styles.

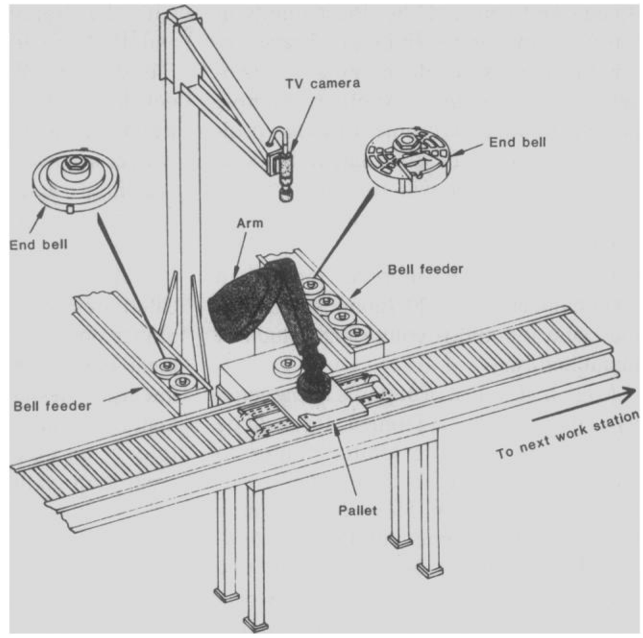


Fig. 4. Section of the APAS assembly line. A robot with an advanced vision system quickly performs a complex assembly operation (*8*).

The first section of the line (Fig. 4) puts parts on the motor end bells. To start the 15-second subassembly operation, a vision system in conjunction with a five-axis PUMA (programmable universal machine for assembly) robot inspects the end bells to make sure they are the style currently being assembled. The end bell is then oriented and placed on a pallet. The next step in the assembly is the insertion of the uppermost components: a thrust washer, a bearing cap, and a felt washer. An auto-place robot picks up the parts and loads them onto an anvil. The end bell is moved into the station, and the parts are passed on. At the same time a semisolid lubricant is injected.

At the next station, four screws, a plastic plug, and a contact point are inserted. Following this there is a complicated assembly procedure. In order to assemble all the different styles of end bells, several styles of certain parts are required. More precisely, six styles of mounting rings and three styles of dust caps are needed. Programmable feeders are used to accomplish the feeding and orienting of all these parts. At this station, a PUMA robot picks up a mounting ring, dust cap, and felt washer on an oil finger from the programmable feeder and places them on an insertion device, where they are fitted onto the end bell.

At the final station, a vision system and a PUMA robot are used to perform the final inspection of the end bell, pick it up from the pallet, and remove it from the system.

The computer control and sensory parts of APAS are the most revolutionary elements of the application. A distributed microprocessor system is needed to handle many simultaneous tasks in the short 15-second assembly time, and a visual sensory system is required to provide orientation and feedback (Fig. 5). One master microprocessor controls the entire system. Under its control are three types of smaller microprocessors for vision control, local process control, and robot path control. All these controllers work in conjunction with the master computer to coordinate the inspection and assembly procedures. The vision system on this project recognizes randomly oriented parts on an assembly line after a multipass learning cycle controlled by an operator. It can also be used to rotate the part to any given angle (*8*).

## Fostering Innovation

The technology exists in many parts of the world to achieve significant advances in many areas of factory automation. Many European countries are working on numerical control, process planning, and group technology approaches rather than the graphics approach emphasized in the United States. They are well advanced in integrating CAD and CAM systems.

In Japan, major advances are achieved through the efforts of the Ministry of International Trade and Industry (MITI). For example, hundreds of millions of dollars and some of the finest minds in business and universities are being applied to the task of developing a fourth-generation computer. Another example is a $60 million government-funded project to develop a flexible machining system. This system will use high-energy lasers to manufacture small batches of machined parts with assembly line efficiency. The project involves more than 500 engineers from 20 Japanese companies, and it could revolutionize much of manufacturing.

MITI makes use of Japan's homogeneity and organizational milieu. It would be inappropriate for the United States to adopt the same methods to foster manufacturing innovation. However, we must recognize the urgency of the problem. The United States is one of the few major industrialized nations in the world without a significant coordinated industry-government-university program directed at improving manufacturing technology. We need a national strategy for productivity improvement that brings together government, business, labor, and academia in a cooperative, rather than adversary, relationship. We will have to remove many of the disincentives to innovation and find new ways to capitalize on our diversity and our proven creative and inventive abilities. Just as MITI capitalizes on Japan's homogeneity, we must find new ways to foster, encourage, and channel our innovative diversity.

At present, Westinghouse is working with the National Science Foundation and the universities of Rhode Island, Florida, and Wisconsin on technology development programs. Along with the Robotics Institute of Carnegie-Mellon University, we are developing "seeing," "feeling," and "thinking" robotic systems for several of our factories. We are also very interested in the Air Force's ICAM program to coordinate sophisticated design and manufacturing techniques now used by industry on a piecemeal basis. This program attempts to integrate design, analysis, fabrication, materials handling, and inspection and to develop hardware and software demonstration manufacturing cells in selected aerospace plants.

## Human Factors Engineering and Sociological Impact of Automation

The easier it is for people to use computers, the broader will be their applications in manufacturing. We are moving away from the airplane-cockpit approach, with rows of complex devices, to create simple computer tools. Compare the ease with which we use personal computers today with the way we approached computers in the early 1970's. The same changes will occur in manufacturing.

The computer has three language levels: machine language, programming language such as COBOL or FORTRAN, and user interface or problem-oriented language. Designing the computer so that it can be quickly used by someone familiar with a problem—but not with computers—is the most difficult of all programming tasks. Today, computers "converse" with users in pictures, in ladder diagrams, or in the secretarial language of word processing. Voice recognition systems will free workers' hands to perform other tasks and make it even easier for them to use computers. In the future, when research efforts begin to pay off in systems with some understanding of natural language and with "commonsense," communications with computers may become as simple as talking to a 3-year-old.

An important area of concern in manufacturing is worker safety. Automated systems and robots must be able to work side by side with humans. Major developments are taking place in the sensor area, particularly with proximity detectors and ultrasonic sensors, to make robots more suitable for inclusion in existing factories.

The application of automated systems in manufacturing will have several major affects on the people involved in production. It will make our jobs more interesting and challenging, it will enhance job security, and it will multiply the productivity increases.

Workers today are looking for greater job satisfaction through greater involvement and increased sophistication. New technologies provide this added dimension to the workplace. For instance, draftsmen use CAD today to perform work that was normally performed by engineers just 5 or 10 years ago. Engineers, in turn, are freed to delve into even more technically sophisticated areas. As a peripheral advantage, the critical need for technical manpower is partially satisfied.

To manage technological change, we must manage our human resources better. For example, we must commit ourselves to ensuring that none of our workers are laid off because of technological changes, as long as they are willing to be retrained and accept new job assignments. Our experience at Westinghouse has been that employees displaced by robots normally move up to better, more challenging work. We should also rethink who can do what job. For instance, there is a tremendous potential for productivity improvement if the person who knows the machine better than anyone else also has the skills to program the machine while it is working on another job and the skills to debug the programs on the spot.

In Westinghouse, by putting the pro-

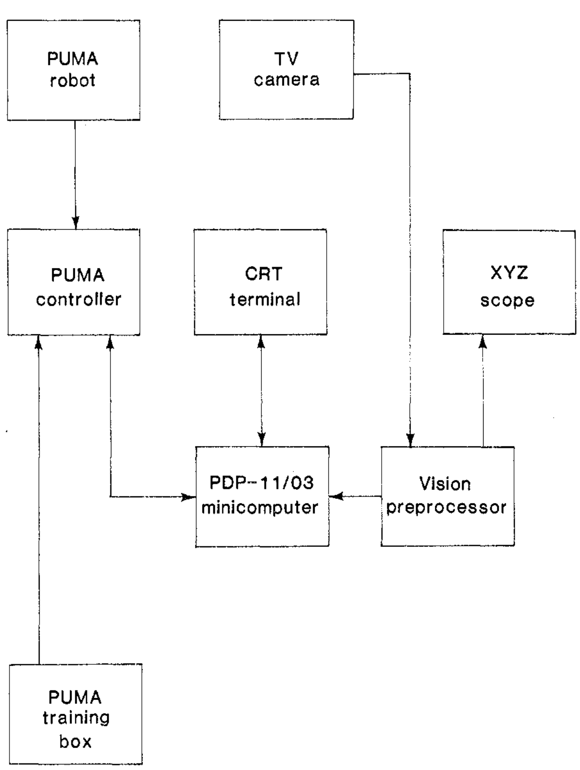

Fig. 5. Distributed microprocessor system used to control an APAS robot (*8*).

grams for people first, we expect to multiply the productivity improvements that are gained through technology and capital investments. With participative management, for instance, employees welcome advanced technology because they feel in charge of it. Only when these programs are in place will we emerge from the showcase and token automation phase that manufacturing is presently in.

Today, scientific work in the application of computers to factory automation is in the embryonic stage. We are on the verge of seeing the cost of NC, CNC, and robotics become low enough for these systems to be economically justifiable for many more applications. The cost will continue to decline as application problems are resolved and the computer becomes an understood and respected partner in the manufacturing environment. When this happens, our nation's productivity will be greatly enhanced.

**References and Notes**

1. "The reindustrialization of America," *Business Week*, 30 June 1980, p. 9.
2. "Information systems planning guide," unpublished internal manuscript, Westinghouse Electric Corporation.
3. J. K. Krouse, "CAD/CAM—bridging the gap from design to production," *IEEE Trans. Prof. Commun.* **PC-33**, 191 (1980).
4. "ICAM program prospectus, manufacturing technology," U.S. Air Force, September 1979.
5. "A report on robotics in Japan," *Robotics Today* **3**, 26 (Fall 1981).
6. Delphi Study, Society of Manufacturing Engineers, Dearborn, Mich., 1981.
7. A. K. Bejczy, *Science* **208**, 1327 (1980).
8. R. Sugarman, *IEEE Spectrum* **17**, 53 (September 1980).

# Japan–U.S. Competition: Semiconductors Are the Key

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*Summary.* Japan appears to have achieved a breakthrough with its success in selling the 16K random access memory chip. The rivalry between Japan and the United States over integrated circuits could make the 1980's crucial years in the contest for the lead in the world electronics trade.

The United States continues to dominate world trade in electronics. In 1980, the U.S. balance of trade surplus in electronics was \$6.8 billion on exports of \$20.1 billion and imports of \$13.3 billion—up 38 percent from the previous year (Table 1) (*1*). In bilateral trade with Japan in 1980, however, the United States imported nearly \$4 billion more in electronics than it exported (Table 2). And trends in Japan–U.S. trade have given rise in this country to concern that the long-held American lead in the high-technology sector of electronics is eroding. The perception is growing here that what is at stake is not simply first place in a rapidly expanding international market, but world primacy in technology.

What prompts this view is the phenomenon, described in this issue, of the widening application of microelectronics to manufacturing and communications and to the infusion of information technology into virtually every aspect of commerce and technology. In this decade, a decisive contest is foreseen between Japanese and American industry for superiority in integrated circuits, the key constituent of the smart machines of tomorrow.

Governments of industrial countries are increasingly acting on the view that maintenance of a viable electronics industry is essential to economic well-being and military security. Several Western European countries are following the example of Japan in fashioning national policies designed to assist their electronics industries to achieve competitive positions in world markets.

The rivalry in electronics is occurring against a background of inflation, recession, and unemployment in Western industrial nations. In the United States, microelectronics is seen as offering an effective counter to declining technological innovation and industrial productivity. At the same time, however, there is apprehension that microelectronics-driven automation will cause greater loss of jobs and social dislocation. For all these reasons, protectionist sentiment toward foreign trade is mounting in the United States and Western Europe.

Protectionist feeling in this country is directed most strongly against Japan; the United States faces an expected trade deficit of \$28 billion overall for 1981 (*2*) and a deficit of \$15 billion in trade with Japan. Resentment is sharpened by a general perception that Japan has used tariff and nontariff barriers to shelter its own industry.

While trade relations are receiving considerable notice, the broader dimensions of the Japanese challenge are attracting attention in industry and government; comparisons are increasingly being made of the structure of industry, financial systems, and social organization in the two countries.

Supremacy in microelectronics is equated with the holding of a commanding position in the sales of semiconductors and computers. The United States retains a world lead in both categories. The Japanese, however, have recently won a round in the semiconductor competition that some informed observers see as presaging the kind of success they scored earlier with textiles, footwear, steel, shipbuilding, consumer electronics, and, most recently and conspicuously, automobiles.

## Breakthrough for Japan

The Japanese surge came with sales of the 16K random access memory (RAM) chip, widely used in multiples for computer memories. The 16K RAM was introduced by American companies in the mid-1970's, but the supply of American-made 16K chips fell short of demand. Opinion is somewhat divided on why the shortfall occurred. Some observers attribute it to an underestimate of demand. Others note that unexpected difficulties in production were encountered. A more general view, however, is that, in the recession that followed the oil crisis of 1974, U.S. industry failed to

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