RESEARCH INITIATIVES

In modern times the discipline of engineering has become heavily computer oriented. Computer-aided design (CAD) (1,2), computer-aided manufacturing (CAM) (3,4), computer-integrated manufacturing (CIM) (5,6), computer-based simulations (CBS), and virtual machines (VM) have become common in various fields of engineering, and even more so in the areas of electrical and computer engineering. An integration has evolved in the classical and sequential phases of research, design, and product development; product testing and evaluation; and next-generation product projections. With the continuous enhancements in technological innovations and new scientific inventions, engineering management (EM) has become an important layer in the engineering discipline. EM's range of activity is much wider than simply the management of human engineering resources. In a larger sense, present-day engineering management has to deal with hardware and/or software resources and cost-effective integration schemes; continuous software and hardware upgrades; integrating technological innovations and dealing with technology transfers; direct design and simulation methodologies suitable for manufacturing; and continuous emphasis on learning, from research into technology, by the personnel involved and those in the associated technology training programs. Also, one of the primary tasks of the engineering management team is to predict accurately the reliability of their engineering product and expend every possible effort to develop and manufacture a reliable and fully functional product. This should prevent the waste of resources caused by releasing the product in stages and with upgrades.

With the explosion of the aforementioned technologies, it is not practical for every institution to maintain a complete, in-house technology research unit. Instead, engineering management should explore various avenues available for collaboration with the technology and industrial specialists in associated disciplines. In this context, it becomes increasingly important to identify research initiatives and funding resources for centralized technology development schemes and to manage the resources efficiently and cost effectively. This article addresses some of these issues with applicable engineering case studies. It also provides objective technology growth patterns from the ever-growing fields of electronics, semiconductors, and computer systems.

The primary concerns in the field of electrical, electronics, and computer engineering are (1) how to manage the human, software, hardware, and technology resources efficiently and cost effectively to develop a reliable and marketable product; (2) how to deal with the explosion in the technology and integrate the ongoing technological innovations into products; (3) how to minimize product development and evaluation time and implement designs for manufacturing the product; (4) how to protect the confidentiality of the product design, especially if distributed intelligence is used; (5) how to motivate, challenge, and encourage the involved personnel to upgrade their technical and engineering knowledge continuously; (6) how to optimize the organizational, financial, and other resources by obtaining external funding support and guidance from the leaders in the field; and (7) how to integrate the principles of expert systems with real systems to make them modular, adaptable, and expandable.

This article explores the appropriate research initiatives to account for the aforementioned concerns in engineering management dealing with electrical, electronics, and computer engineering. Some of these initiatives are equally applicable for other engineering disciplines. While it is certainly desirable to obtain external funding to conduct research, it is more important to identify the problem areas in the engineering disciplines and accordingly identify the research procedures to address the problem areas. There are no simple solutions to ever-demanding consumer satisfaction of electronic systems. However, it is the general belief that if an engineering prouct is user friendly and reliable, most consumers seem happy and are supportive of a given engineering product.

The explosion in communications technology, such as the globalization of the Internet, the World Wide Web (WWW), and emerging Intranet schemes make teletraining and teleconsulting very attractive in the software and hardware aspects of computer, control, communication, and other engineering systems. This article also discusses associated research initiatives in the area of telecommunications and networking.

TYPICAL INDUSTRIAL ENVIRONMENT

The electronics industry is oriented toward entertainment and education, computers and networks, communication and information transfers, control and manufacturing operations, security, health, and government organizations. Electronics is either directly or indirectly involved in every discipline. Figure 1 shows an engineering management perspective of a typical electronics-oriented industrial-type environment. The sales department interfaces with the customer and translates the customer's requirements into product specifications to be given to the design engineer. Thus, design engineering is removed from the customer. Any misinterpretation of the customer's needs by the sales department can have devastating effects on design. By the same token, if the design engineering group directly interfaces with the customer, the designs may be too conservative and expensive; even if the resulting product is an engineering marvel, it may be a disaster at the market level. Thus the engineering management team has to balance cost, requirements, and design scope. There is a research initiative to optimize the product designs based on the customers' current and projected needs. Some of the ideas may be used to develop a dynamic database of the types of questions customers would ask regarding servicing of the existing product so that the next-generation product can be well predicted, projected, and designed (5,6).

Product Reliability

The design data and the component specification from the design groups need to be filtered by industrial engineering groups, taking into consideration availability, inventory con-

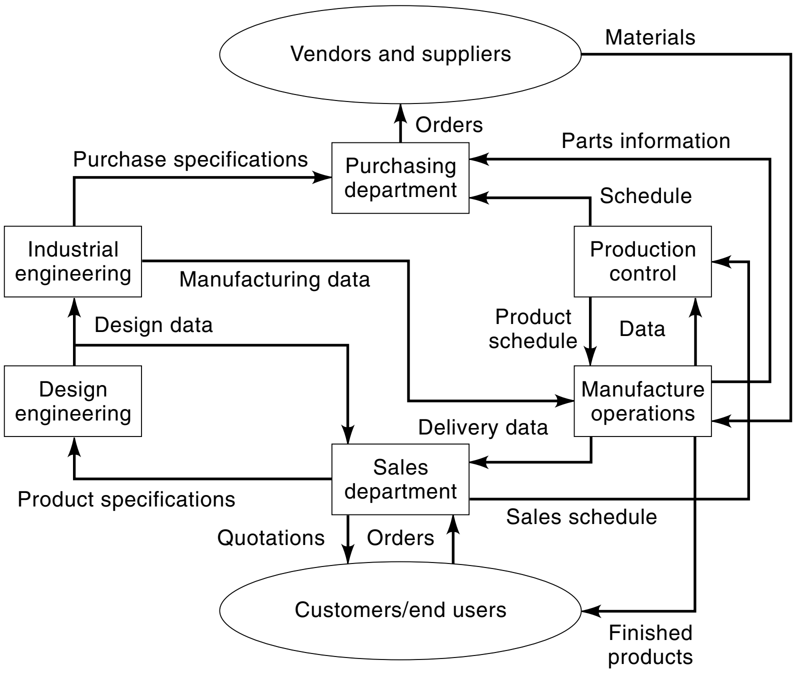

Figure 1. Typical information flow in an industrial environment.

trol, and manufacturing. The purchasing department always looks for the lowest bidder and sometimes may not understand the concepts of reliability. The modern control system is usually some kind of microprocessor based on memory and support logic. Consider a microcontroller system as shown in Fig. 2. The component or subsystem reliability $R(t)$ is specified in terms of the failure rate such as one failure in 10^{12} events for the microcontroller unit. This seems to indicate a high reliability. However, the customers and engineers are more interested in the performance and the mean time between failures (MTBF), rather than these one in one trillion failures.

Suppose the microcontroller is running at 60 MHz clock frequency and has a throughput of 20 million instructions per seconds (MIPS). That is, the microcontroller executes 20 million instructions per second. An event may be considered as an execution of an instruction. Due to noise on the signal lines, power supply, or other variations, if the microcontroller executes a wrong code or accesses a wrong memory location, it results in an error and ultimate failure condition. Thus, for the present case, the MTBF may be computed as (7).

MTBF of microcontroller

$$= [\text{time per instruction as an event}] \cdot [R(t)]$$
$$= [1/20 \cdot 10^6)] \cdot [10^{12}] = 50,000\,\text{s} = 13.9\,\text{h}$$

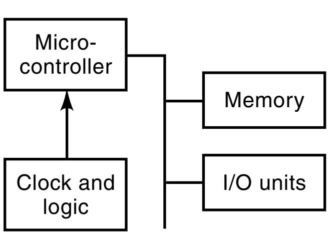

Figure 2. Typical microcontroller driving memory and I/O.

This translates into a statistical failure rate of once every 13.9 h of operation. This is certainly not a very reliable system, and especially in a production or manufacturing environment such a system is surely undesirable. Thus there should be ample care taken in ordering and procuring the components with the highest reliability specification rather than from the lowest bidder.

In reality, a microcontroller would be driving several input output (I/O) modules, and most of the I/O modules are mechanical in nature. The failure rate of an I/O module is higher than that of a microcontroller. Thus, the system MTBF would be smaller than that of the microcontroller itself.

Certainly, the scope exists to improve the reliability of operation of the system as a whole, and one of the research initiatives would be to search for ways of improving the performance and the reliability of the system while being cost effective. Perhaps self-checking and error-correcting schemes for electronic and other components should be explored.

Concurrent Engineering and Product Development (8,9)

From Fig. 1 it can be clearly inferred that various engineering, sales, and purchasing groups need to work in concurrence. Also, software for the end product should be developed in concurrence with hardware development (10). In earlier years of product development, such a scheme was not practical and possible. However, with modern software, system configuration, and networks, it is possible to emulate a system using software methodologies. Software development can take place based on the emulated results of a virtual machine. A VM can be defined as a nonexisting hardware system the specifications and characteristics of which can be emulated by software. Such a scheme can be very useful in the overall product development.

Most of the present-day electronic systems tend to be digital in nature. In the earlier days, digital engineers designed the systems using logic gates, flip flops, registers, etc. These

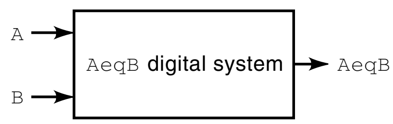

Figure 3. VHDL-based design concept and system realization.

systems had to be built in the laboratory with specific devices and then tested out for design modifications. Also, the reliability of the system could only be tested after the field data became available.

Modern software design and simulation packages, such as VHDL (Very High Speed Integrated Circuit Hardware Description Language), have become available. With these VHDL tools, any complex digital circuit and system can be designed and simulated for logic and timing accuracy. Semiconductor vendors have come up with actual hardware devices, such as CPLD (Complex Programmable Logic Devices) and FPGA (Field Programmable Gate Arrays), that accept VHDL-generated design code and accordingly synthesize a real digital system. Current FPGA devices from companies like Cypress Corporation far exceed 4000-gate complexity, and a complete system can be easily synthesized in a single device. For example, the VHDL statement

```
AeqB = 1 when A = B else 0;
```

specifies a logic comparison circuit, where two digital words `A` and `B` are compared and an output `AeqB` is provided that takes a logical value of 1 if `A = B`, and takes a logical value of 0 if `A` is not equal to `B`. This is shown conceptually in Fig. 3.

If the digital word `A` is 11100111 and the digital word `B` is also 11100111, then only the system output `AeqB` would take on a logic 1 value. The VHDL code thus generates the needed logic design. Also, the system response can be easily tested with simulation design tools such as VHDL and computer simulations. Together they provide a decent virtual machine environment for product development (11,12).

The research initiative here would be to educate and train engineering personnel in the area of system design, using software methodologies and contemporary hardware description languages such as VHDL and VARILOG, and to develop the virtual machine realizations using the simulated results. This would greatly enhance the scope of product development on the software and hardware tracks (12,13).

COMPUTER-AIDED ACTIVITIES

Almost any industrial organization uses some kind of computer-based activity in its operations. It may be simple word processing in an office environment, computer-aided design in a distributed design environment, computer-aided manufacturing in a production environment where computers are used for data acquisition and process adjustment, or computer-integrated manufacturing, in which computers are directly involved in running the production machines in a synchronous or asynchronous environment.

In all the aforementioned phases, the computer is the underlining factor. With the innovations in computer communications using PSTN (public switched telephone networks) and high-speed communications using satellites and fiber optics, almost any computer anywhere in the world can be connected. In addition, with the explosion of internet-based multimedia-type information transfers, there is ample scope in distributed processing and design environments.

Virtual Design Centers

For computer-aided design, it is no longer necessary to have all the software and human resources available at the same location. The high-speed data transfers along with the multimedia information transfers either on PSTN or the Internet would help distributed computerized design environments. Such a scheme would lead to the virtual design center (VDC) concept, as shown in Fig. 4 (14,15).

Several computer stations and individuals connected to the network can share and exchange the same information on the screens, thus performing combined designs. Research initiatives in this area would be cost effectively sharing the multiple screens using PSTN technologies such as ISDN (Integrated Services Digital Network) and would have the following advantages: bandwidth on demand schemes, where more channel capacity would be added depending on the information traffic; adaptability of the system for basic rate interface (BRI) ISDN, consisting of two B channels each at 64 kb/s and a D channel at 16 kb/s; coupling of several BRI ISDN lines for increased throughput in increments of 64 kb/s; adaptability for primary rate interface (PRI) ISDN with 23 B channels at 64 kb/s each and a D channel at 64 kb/s; and fault-tolerant schemes using sampled B channel data on the D channel and other associated methodologies.

For high-speed multimedia information transfers, other technologies, such as frame relay, SMDS (switched megabit digital service), and ATM (asynchronous mode of transfer), and the cost effectiveness and reliability of transfers should be researched.

Computer-Aided Manufacturing

In the computer-aided manufacturing environment, proper electronic and other sensors provide information about the manufacturing operations to the semicentralized computer system. The system then makes proper decisions and activates the subsystems at critical manufacturing nodes in order to perform distributed, but definitely coordinated, operations. Most of the semi-intelligent operational manufacturing nodes are some type of robot, as shown in Fig. 5 (16,17).

In a real manufacturing environment, several robotic units similar to that in Fig. 5 would have to be coordinated by the computer system. The sensing information about the pulleys, robotic belts, and loading of the robotic arm has to reach the

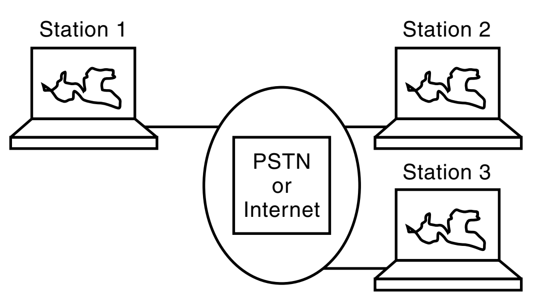

Figure 4. Virtual design center concept with multiple locations sharing the design activity.

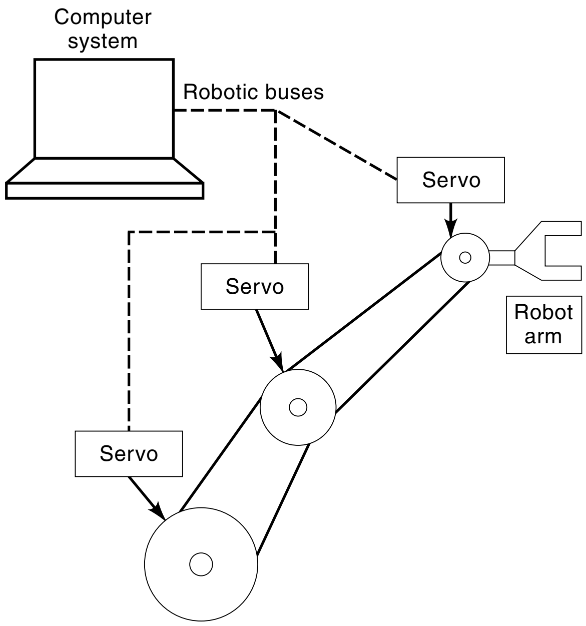

Figure 5. Computer-driven robotic arm in a CAM environment.

computer accurately and quickly in order for the computer to respond and control the process. Also, there should be adequate protection against the robotic arm failing due to overload, heat, or normal wear and tear (17).

The computer system may be physically away from the production floor environment. So the information transfers between the robots and the computer should be accurate and fault correcting. Research initiatives in this area are to find the coding and information redundancy mechanisms, such as the overlapping parity, to correct any data transmission errors; expert system principles to make the CAM adaptive; real-time digital signal processing (DSP) methodologies to calculate the robotic positioning; and thermal and vibration management in a production environment (18,19).

Learning Technology Research

Due to the explosion of technology in all engineering and software disciplines, it is almost impossible to learn about state-of-the-art research only by reading journals or magazines. Generally, an engineer spends more than 50 h per week on job-related activities, and it has become difficult to devote the needed time and effort to learn about new concepts and technological breakthroughs. Additionally, technological information is updated daily. Therefore, the only feasible way to obtain current information is by accessing file servers of various organizations containing descriptions of their technologies, research activities, and products. The World Wide Web is a major tool for accomplishing this.

Often an individual needs to be reeducated on a continuous basis. Also, the learning capabilities of several employees in an organization working on a given project may not be the same. As such, there should be a way to learn things on an asynchronous basis with the help of remote accessed material through computer systems. This leads to the concept of computerized teletraining. Testing is an integral part of any learning process. There is an immediate need to promote and make a reality the interactive learning process using computer systems and remote file servers. The research initiatives in this area would be developing interactive and self-teaching methodologies using computers and possible WWW servers; finding ways to motivate engineers, scientists, and other personnel to use computers move in the learning process rather than being intimidated by the computerized learning process; and finding other ways to synthesize what must be learned rather than spending long periods of time obtaining expertise in the necessary technologies.

With the memory and speed of present-day personal computers (PC) becoming increasingly efficient, several artificial intelligence and expert system concepts can be integrated in the engineering management environment.

Expert System Principles

The concepts of expert systems are not new. However, the memory and speed efficient computer systems can be used effectively to implement expert system principles in the day-to-day operations of an organization. Expert system principles can be used to predict the behavior of a system or operation and thus can prevent failures and undesirable events. Figure 6 shows a forward chaining rule-based expert system concept in a production environment. If the speed of production belt motors needs to be increased or decreased, the speed will be adjusted accordingly. The expert system will also compute the associated oil pressure and temperature variations of the production control unit. If there is a projected possibility of danger when speed is increased or decreased, the expert system will respond to provide the necessary warnings and protect the system (20).

It can be seen from Fig. 6 that the knowledge-based expert system with adaptive databases always computes and accordingly adjusts the interface displays and warning systems. This kind of expert system can be made more user friendly

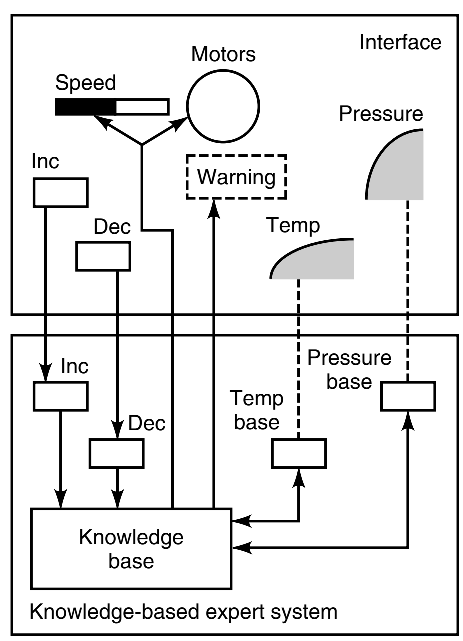

Figure 6. Forward chaining rule-based expert system in production environment.

and can be implemented as a real unit. Several research initiatives exist in this area: applicability of backward or forward chaining rule-based expert systems for production and office environments; integration of the certainty theory for near practical expert systems; applications of fuzzy logic and neural network principles for the implementation of the expert systems; and applicability of frame-based expert systems in a learning environment (20,21).

DESIGN FOR MANUFACTURE

As mentioned earlier, the product development cycle will have to follow the principles of concurrent engineering due to time and resource restrictions. The product will have to be marketed rather quickly but should be highly reliable. The classical cycle of laboratory model development, test, and evaluation cycles is merging with design aspects (22,23).

One of the worst things that could happen is for the design not to match the manufacturing requirements. Any design that does not take into consideration the component tolerances, variations of the specifications as functions of temperature, humidity, vibrations, and aging would create manufacturing and reliability problems. Also, a design that uses too many different-valued components and nonstandard values will increase the production and manufacturing costs, thereby forcing a high customer cost. Such a product will not provide good returns. A perpetual engineering management problem is to match the designs for manufacturing ease and product reliability (22,23).

Effects of Tolerance on System Response

Due to the automatic insertion of electronic components into electronic printed circuit boards, mechanical tolerances are extremely important. If an integrated circuit package does not properly get inserted into the socket on a printed circuit board, the device will not properly make contact and the system will not function correctly. By the same token, if the integrated circuit package is damaged due to excessive pressure, with a break in one of the internal bonding wires, the circuit would not function. Thus, extreme care should be exercised in mechanical specifications. It has become customary to observe the MIL standards for almost all mechanical and electrical specifications.

Effects of *LC* Properties of Printed Circuit Boards

Most of electronic systems are based on printed circuit boards. The conductor runs on a typical printed circuit board that has the properties of inductance and capacitance. A typical 8 in $\times$ 8 in printed circuit board can have two adjacent conductor paths that run parallel to each other for almost the same length of 8 in or approximately 20 cm. For a two-layer board, the inductance L of a 20 cm conductor can be as high as 10 nH. Similarly, the interconductor capacitance C between two adjacent conductors running for 20 cm can be as high as 10 pF. This LC combination forms a series resonant circuit with a natural frequency f given by

$$f = 1/(2 \cdot \pi) \cdot (LC)^{-0.5} = 500\,\text{MHz}$$

This natural frequency of oscillation manifests itself as the ringing frequency. If the system is running on a clock signal, the signal should not make a transition until the ringing oscillations die down. Allowing about five ringing cycles to reach a steady-state condition, a stable operation can be obtained if either the clock half-time period is larger than the time for five ringing cycles, or the clock frequency is not more than one-tenth of the ringing frequency. Thus for the aforementioned printed circuit board, the maximum reliable frequency of operation should not exceed 50 MHz.

If the circuit broad is predesigned (which should not exceed 50 MHz operation) and is used on systems exceeding the 50 MHz operation, the system will not function reliably and may break into oscillations. Such a design flaw renders this type of printed circuit board incompatible with high-speed circuits.

Effects of Component Tolerances

Almost every intelligent computer system uses an RS 232 serial interface to drive asynchronous I/O systems such as printers and modems. The serial data are sent at a given baud rate by the transmitting clock. At the receiving end, a receiving clock samples the incoming serial bit stream and reconstructs the 1 and 0 logic pattern. The concept is shown in Fig. 7. Inexpensive RC circuits are used for transmit and receive clocks. Each receiving bit is sampled at the center of bit time.

If the transmit and receive clocks are fully synchronized and there are no component variations, each bit would be properly sampled and recovered at the receiving end. A typical RS 232 serial frame would be 11 bits long. (One start, seven data, one parity, and two stop bits are typical.) Suppose the receiver clock were running slower than the transmitter clock. This implies that the received bits would be sampled farther and farther away for each additional bit. The maximum allowed deviation would be a half bit time over an 11 bit frame (otherwise synchronization will fail, and data sampling will be corrupted).

Maximum deviation between transmit and receive clocks = 1/(2)(11) = 0.045 = 4.5%. If the R&C values are 10% tolerant components in the manufacturing environment, the respective transmit and receive clock variations will be much more than the allowed 4.5% variation, the data would be wrongly sampled, and faults would occur. The problem is 2-fold: (1) The tolerances have been ignored, and (2) the system reliable response has not been analyzed in terms of the tolerance of the components.

The research initiatives in this type of manufacturing design should be rather obvious: (1) how to analyze the system response in terms of the component variations; (2) the physical properties of the communicating media, such as the

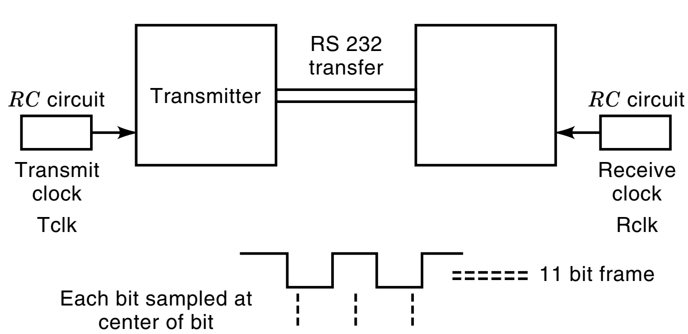

Figure 7. Effect of component variations on RS 232 type serial interface.

printed circuit boards; and (3) a clear understanding of the cumulative effects of the inductive and capacitance properties associated with the wiring and connections in the electronic systems. It is conceivable that the *LC* properties of the internal conductive paths of high-speed and high-density integrated circuits, such as current microprocessors and memories, may be giving rise to performance uncertainty. Certainly, another research initiative would be to probe such *LC* phenomena in high-speed integrated circuits.

TECHNOLOGY TRANSFER, INNOVATION, AND PUSH

With the current complex and ever-changing technology base, it is impractical, inefficient, and uneconomical to conduct in-house technology research. In addition, some foreign countries, especially in Europe and Asia, have a technological edge. It may be more beneficial and economical to obtain technology from the leaders rather than to develop it in-house.

Technology Transfer

When a technology transfer between two countries is involved, the respective governments are involved. For example, in the United States, the Department of Commerce is the responsible agency. This governmental role should include protection against monopolizing the technology base and against unauthorized technology transfers (24,25). The legal, ethical, and moral obligations of the technology transfers are detailed in the Department of Commerce publications on technology transfers (26). In addition, certain organizations specialize in technology transfer operations among corporations, but it is beyond the scope of this article to analyze those types of organizations.

Technology Push

While Motorola and Intel have been very successful in marketing digital technologies, such as microprocessors and microcontrollers, and IBM has promoted computer technology, the government has much more power in advocating technologies. The space program, initiated and funded by the U.S. government in the mid-1960s, has set the tone for the NASA program and the associated growth in the aeronautics and electronics industries. Similarly, technology promotion of a network scheme by the Department of Defense (DOD) and the National Science Foundation has resulted in the Internet. It is conceivable that the present technological emphasis of the U.S. government on the information superhighway will result in a massive multimedia communication system on the Internet. There are several instances in which involvement by government agencies has helped respective technologies mature and gain widespread acceptance. For example, microminiaturization of electronic circuits has been due to the involvement of the Departments of Defense and State in requiring and promoting low-power portable vigilance devices. Similarly, the explosive growth in communication technology is partly due to demand by U.S. law enforcement agencies (26,27).

Technology Innovation

Traditionally, technological innovations have occurred in academic institutions and in research organizations such as Bell Laboratories. Most of the innovative research work has been conducted by faculty and other research personnel, with the help of state and federal governments. After the Second World War, the United States took the lead in technological innovations. During the last few years, the federal government has been encouraging multidisciplinary and consortium-based research in the United States. It is the author's belief that such collaborative research will bring innovative talent together with astounding results. Technological innovation has always been an open-ended activity for the great benefit of participating institutions and individuals (28).

FUNDING

Most of the technology, research, and product-oriented funding in the United States comes from federal agencies. The agencies most involved in such funding are as follows (24–30):

NSF:	National Science Foundation
DOD:	Department of Defense
DOT:	Department of Transportation
DOE:	Department of Energy
DARPA:	Defense Advance Research Project Agency
	Department of Education
NASA:	National Aeronautical and Space Administration

The *Federal Register* publication and the relevant Web sites provide details of funding mechanisms and proposal submission details.

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RESEARCH POLICY. See PUBLIC POLICY TOWARDS SCIENCE AND TECHNOLOGY.

RESERVED CAPACITY USING PUMPED STORAGE. See PUMPED-STORAGE POWER STATIONS.