Chapter 8

Research and Development

Contents

Tables

Figures

Chapter 8

Research and Development

Summary

A wide variety of research and development (R&D) efforts, ranging from very basic, long-term research to market-oriented, short-term product development, are applicable to programmable automation (PA). The principal fields which contribute to such R&D are computer science; electrical, mechanical, industrial, and manufacturing engineering; and metallurgy.

Both government and industry are major funders of R&D in automation technologies. The Federal Government budgeted approximately $80 million of work in this area in fiscal year 1984. This work is undertaken in industry, university, and government laboratories.

The bulk of Federal funding for automation R&D (roughly $64 million) comes from the Department of Defense (DOD), primarily through its Manufacturing Technology (ManTech) Program. This work is aimed at facilitating technologies that would improve defense production. Other agencies in DOD fund work with potential applications for both defense manufacturing and the battlefield. While DOD's funding of automation technology R&D has had some benefits for civilian manufacturing, its programs are not aimed at technological developments that would have wide applications outside of defense neds. In addition, the technologies developed through DOD tend to be some of the most complex, usefd largely in the advanced aerospace and electronics industries.

Civilian agency programs in automation R&D are relatively small. The National Aeronautics and Space Administration (NASA) funds work primarily in robotics-related tools for use in space, much of which, like DOD's programs, is at the very sophisticated end of the technology spectrum and has limited commercial spinoffs. The National Science Foundation (NSF) funds a wide range of more basic work related to programmable automation, as well as helping to establish centers for university-industry cooperation. The National Bureau of Standards' (NBS) laboratory is the Government's primary in-house performer of R&D for manufacturing. Their work includes a largescale test arena for computer-integrated manufacturing (CIM) techniques and interface standards, known as the Automated Manufacturing Research Facility (AMRF).

Industry funding for R&D in this area, though hard to gauge precisely, seems to be healthy and escalating rapidly, especially as the market for programmable automation devices becomes more competitive. The perception among technology researchers seems to be that industry is "where the action is" for automation R&D. Industry spending in the machine tool, CAD, and robotics industries alone amounted to approximately $250 million to $400 million in 1983. There is also evidence of a proliferation of industry-university cooperative research.

Foreign industries and cooperative industry-government laboratories are also pursuing very active PA research programs. Japan, West Germany, and Sweden-and to a lesser extent the United Kingdom and France-have significant research efforts in this area. The traditional U.S. lead in development of these technologies has been eroded, although the United States is still a strong leader in many technical areas. However, Japan has been more active than either the United States or Western Europe in application of the technologies.

Introduction

The aim of this chapter is to assess the context for R&D in programmable automation. The chapter begins with general background on R&D and its funding, and examines in detail Federal funding of R&Din programmable automation. Industry R&D efforts are outlined, and a final section brings forth some of the highlights in international comparisons in R&D.*

"R&D" is often used as a catch-all term for a wide variety of activities which range from the most esoteric science (far at the "R" end of the range) to the most down-toearth product development efforts (pure "D"). And because programmable automation draws on such a wide variety of science and engineering fields-computer science; manufacturing, electrical, mechanical, and industrial engineering; and metallurgy, to name just the primary ones—it can be difficult to isolate those efforts which should be considered relevant.

NSF offers the following definitions:

- In basic research the objective of the sponsor is to gain fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without having specific applications toward processes or products in mind.
- In applied research the objective of the sponsor is to gain knowledge or understanding necessary for determining the means by which a recognized and specific need may be met.
- Development is systematic use of the knowledge or understanding gained from research, directed toward the production of useful materials, devices, systems, or methods, including design and development of prototypes and processes. It excludes quality control, routine product testing, and production.[1]

Classification of individual R&D efforts into such categories is often not completely straightforward, and involves a great deal of judgment. Moreover, this distinction has become increasingly less clear-cut in recent decades. Science and technology have become harder to differentiate, and universities have more actively sought industrial funding. R&D efforts at all three levels—those considered basic research, applied research, and development—are important for programmable automation.

As figure 33 indicates, the Federal Government and industry are the two dominant contributors to R&D spending in the United States. Universities, State and local governments, and other nonprofit institutions make a small addition of their own funds. In 1983, out of a total R&D pool of $86.5 billion, the Federal Government spent almost $40 billion, or 46 percent. Industry contributed $44.3 billion, or 51 percent. NSF estimates that total R&D funding will be $97 billion for 1984. Industry overtook the Government in spending for R&D in 1980, according to NSF data (see fig 34). While the Federal Government's spending for R8zD has remained relatively constant in 1972 dollars, industry's share grew substantially in real dollars in the 1970's and early 1980's.

Industry is also the dominant performer of R&D, receiving 74 percent of the total of $86.5 billion in 1983. Universities received 9 percent of those funds, and Federal agencies or R&D centers 14 percent.

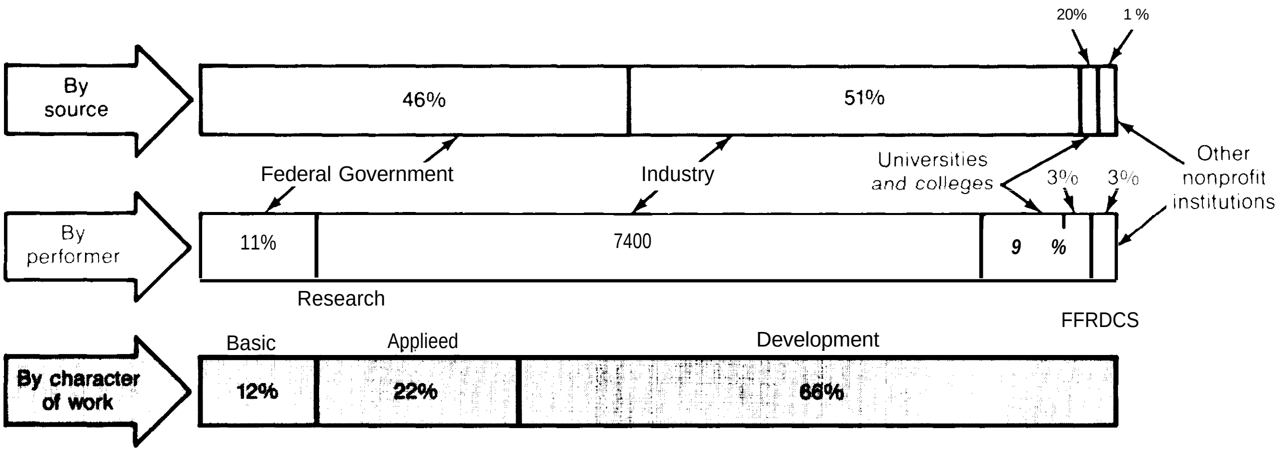
Within the Federal Government, tables 63 and 64 show that defenserelated R&D is the single largest and fastest growing component

*ChapMr 9 Covers foreign R&D mechanisms and institutions. The content of foreign R&D in automation will be outlined at the end of this chapter.

[1] National Science Foundation, *Federal Funds for Research and* Development: Fiscal Years 1981, 1982, and 1983 (Washington, D. C.: National Science Foundation, 1982), p. 1.

Figure 33.—The Nationai R&D) Effort

Expenditures for R&D = $97 billion, 1984 (est)



SOURCE National Science Foundation, Preliminary figures from National Pattern of Science and Technology Resources, 1983, in press

of Federal R&D funding. Nondefense R&D spending by the Federal Government has de clined in real terms under the Reagan administration, primarily due to dramatic reduction in nondefense applied research, development, and demonstration activities. Basic research has been relatively healthy, albeit with a few shifts in priorities. Defense-related R&D is estimated at $30.2 billion in 1984, accounting for 66 percent of Federal spending for R&D.[2]

[2]W. C. Boesman, "U.S. Civilian and Defense Research and Development Funding: Some Trends and Comparisons With selected Industrialized Nations," Congressional Research Service, Report No. 83-183, Aug. 29, 1983; and American Association for the Advancement of Science, *AAAS Report IX: Research & Development, FY 1985* (Washington, D. C.: AAAS, 1984).

The United States has historically spent far more than its allies on R&D. However, figure 35 shows that foreign expenditures for R&D have grown faster than those in the United States. In addition, both Japan and West Germany have exceeded the United States in nondefense R&D as a percentage of gross national product (GNP)[3] (see fig. 36).

'Ibid.

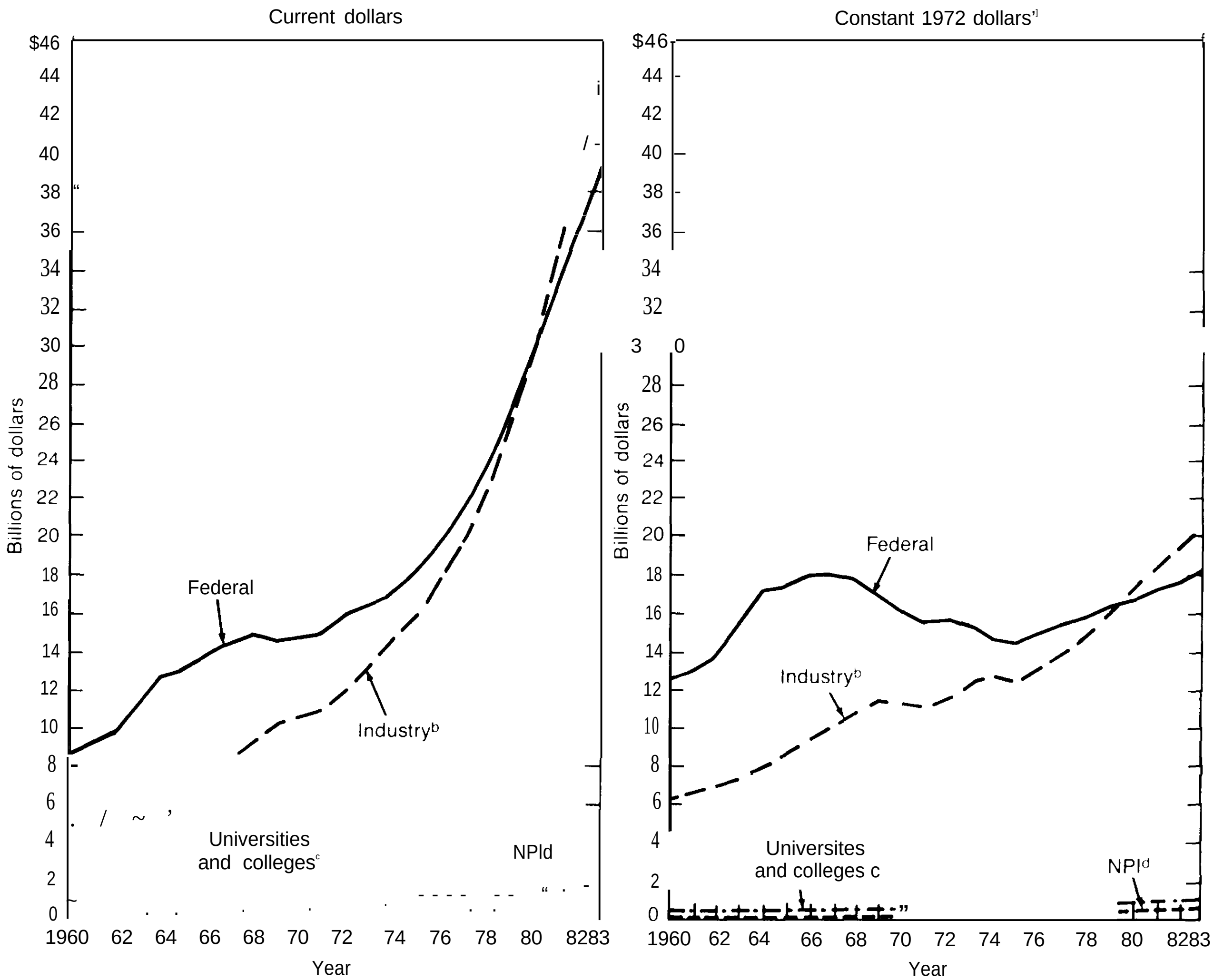
Funding and Performers of R&D in Programmable Automation

Overview

For purposes of this study, R&D in programmable automation is work which *is* centrally concerned with one or more of the technologies identified in table 5 in chapter 3. Industry and the Federal Government are the primary sources of funding for such work in the United States, although universities and State governments have 'made small contributions.

Figure 37 is a rough map of the performers of R&D related to programmable automation. The Federal Government's interest in such work comes from several agencies, each with

Figure 34.—National Expenditures for R&D by Source



[a]GNP implicit price deflators used to convert current dollars to constant 1972 dollars
[b]Data are not available on industry resources for research in the psychological and social sciences
[c]Includes State and local government sources
[d]Other nonprofit institutions

SOURCE National Science Foundation, ***Science Indicators—1982*** (Washington, D.C.: National Science Board, 1983).

Table 63.—Major Components of Federal Funding for R&D[a] (budget authority in billions)

	Fiscal year 1967 actual	Fiscal year 1972 actual	Fiscal year 1982 actual	Fiscal year 1983 actual	Fiscal year 1984 estlmate	Fiscal year 1985 budget
Current dollars:						
Defense[b]	$88	$92	$229	$256	$302	$379
Non-Defense'	8.3	79	158	144	157	164
Space[l]	47	27	36	17	19	23
Health{ '	13	20	4.1	4.5	5.1	52
Energy[l]	06	06	35	29	28	27
General sclence	05	07	15	16	19	22
All other	12	19	31	37	40	40
Total R&D	$171	$171	$387	$400	$459	$543
Constant fiscal year 1972 *dollars:*						
De fense[P]	$12.4	$9.2	$9.8	$104	$11.9	$142
Non-Defense'	$117	$79	$72	$64	$66	$66
Space"	66	27	17	08	08	09
Health"	18	20	19	20	22	21
Energy'	08	06	16	13	12	11
General science[g]	07	07	07	07	08	09
All other	1.7	1.9	14	16	17	16
Total R&D	$240	$171	$17.0	$16.8	$18.5	$208

[a]Includes conduct of R&D and R&D facilities
[b]Includes DOD and defense activities in DOE
Includes all R&D in defense
[d]Reflects AA AS' est I mates for NASA less space appl ications and aeronaut ical research
'For fiscal years 19821985 Includes health research in H HS, VA Education and EPA Fiscal year 1967 and 1972 based on OM B data for health research in al I Federal , agencies
Includes NRC EPA energy research and DOE less defense act ivities and general science
[g]Includes NSF and DOE general science

SOURCE American Assoc iation for the Advancement of Science, *AAAS Report IX Research & Development FY 1985* (Washington DC AAAS 1984\ AAAS estimates based on data from OMB and agency budget justifications Conversion to constant FY 1972 dollars by AAAS based on OMB deflators

Table 64.—R&D in Selected Agencies[a] (budget authority in millions)

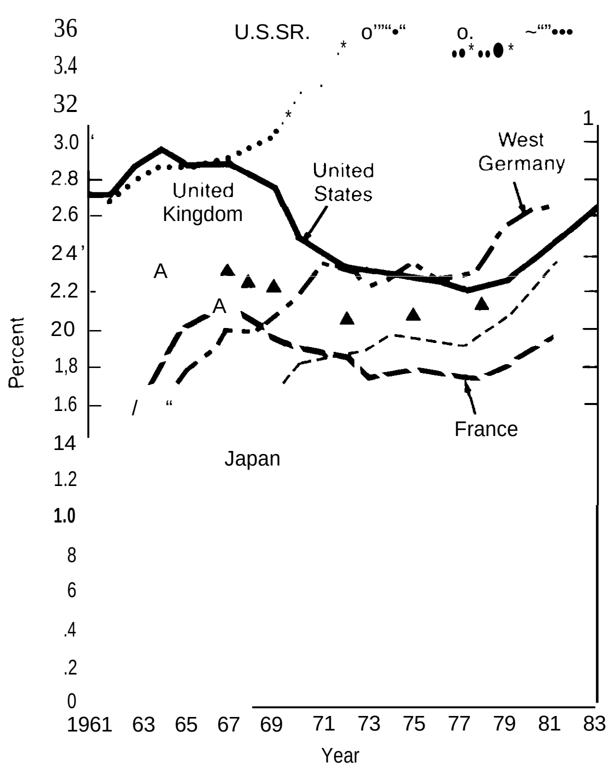
	Fiscal year 1983 actual	Fiscal year 1984 estimated	Fiscal year 1985 budget (proposed)	Percent change: Fiscal year 1984-85 Current dollars	Percent change: Fiscal year 1984-85 constant dollars
DOD	$23,673	$27,876	$35,336	+ 26.80/o	+ 20.90/o
DOE-defense	1,975	2,286	2,522	+ 10.30/0	+ 5.3%
(Total defense)	(25,648)	(30,162)	(37,858)	(+ 25.50/o)	(+ 19.80/o)
DOE-general science	568	639	745	+ 16.50/o	+ 11 .3%
DOE-energy	2,622	2,610	2,499	– 4.3	–8.50/o
NASA	2,735	2,971	3,466	+ 16,70/o	+ 11 .4%
NSF	1,059	1,247	1,427	+ 14.40/0	+ 9.20/o
NIH	3,814	4,264	4,356	+ 2.2%	–2.40/o
Other HHS	557	613	597	– 2.70/o	– 7.0%
USDA	885	923	926	+0.40/0	–4.1%
EPA	234	248	280	+ 12.70/o	+ 7.6 0/0
Education	102	111	107	–3.30/0	– 7.5%
NOAA	213	240	167	– 30,40/0	– 33.50/0
NBS	94	95	103	+ 8.2 0/0	+ 3.5%
USGS	149	162	148	– 8.6%	– 12.70/o
Bureau of Mines	97	87	69	–21.O5	–24.50/o
All other	1,265	1,533	1,555	+ 1 .5%	– 3.0%
(Total nondefense)	(14,393)	(15,743)	(16,444)	(+4.4%)	(–0.30/0)
Total	$40,042	$45,905	$54,301	+ 18.30/o	+ 12.70/o

a Includes conduct of R&D and R&D faclilties

SOURCE American Association for the Advancement of Science, *AAAS Report IX Research & Development. FY 1985* (Washington, D C AAAS 1964), using 'OMB Data for Special Analysis K," as revised, and agency budget justifications

25-452 O - 84 - 21 : QL 3

Figure 35.— National Expenditures for Performance of R&D. as a Percent of Gross National Product by Country

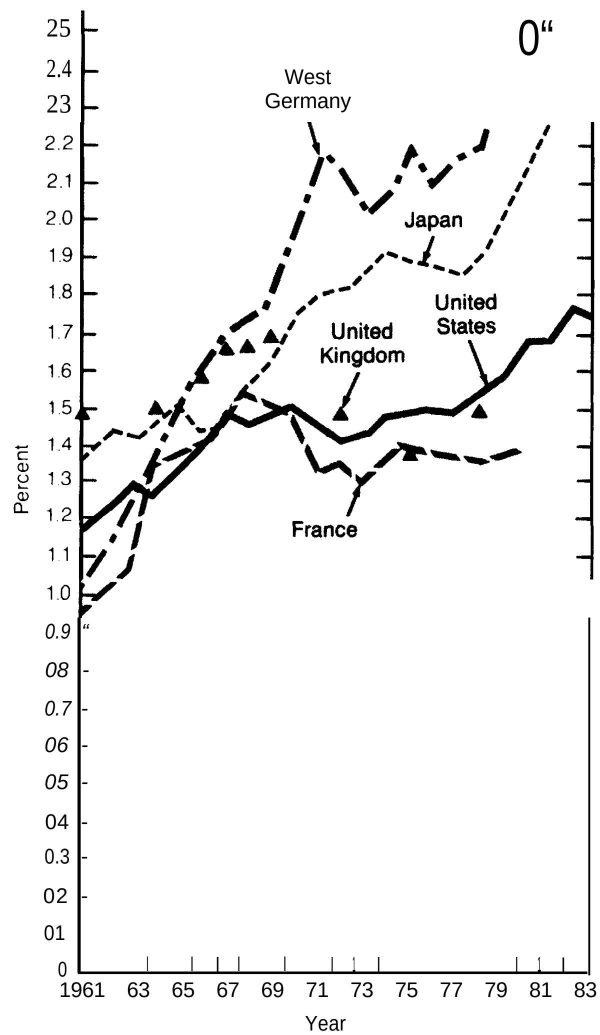


[a]Gross expenditures for performance of R&D including associated capital expenditures, except for the United States where total capital expenditure data are not available. Estimates for the period 1972-80 show that their inclusion would have an impact of less than one-tenth of 1 percent for each year.

NOTE: The latest data may be preliminary or estimated

SOURCE National Science Foundation, *Science Indicators— 1982* (Washington, D.C.: National Science Board, 1983).

Figure 36.— Estimated Ratio of Civilian R&D Expenditures to Gross National Product for Selected Countries

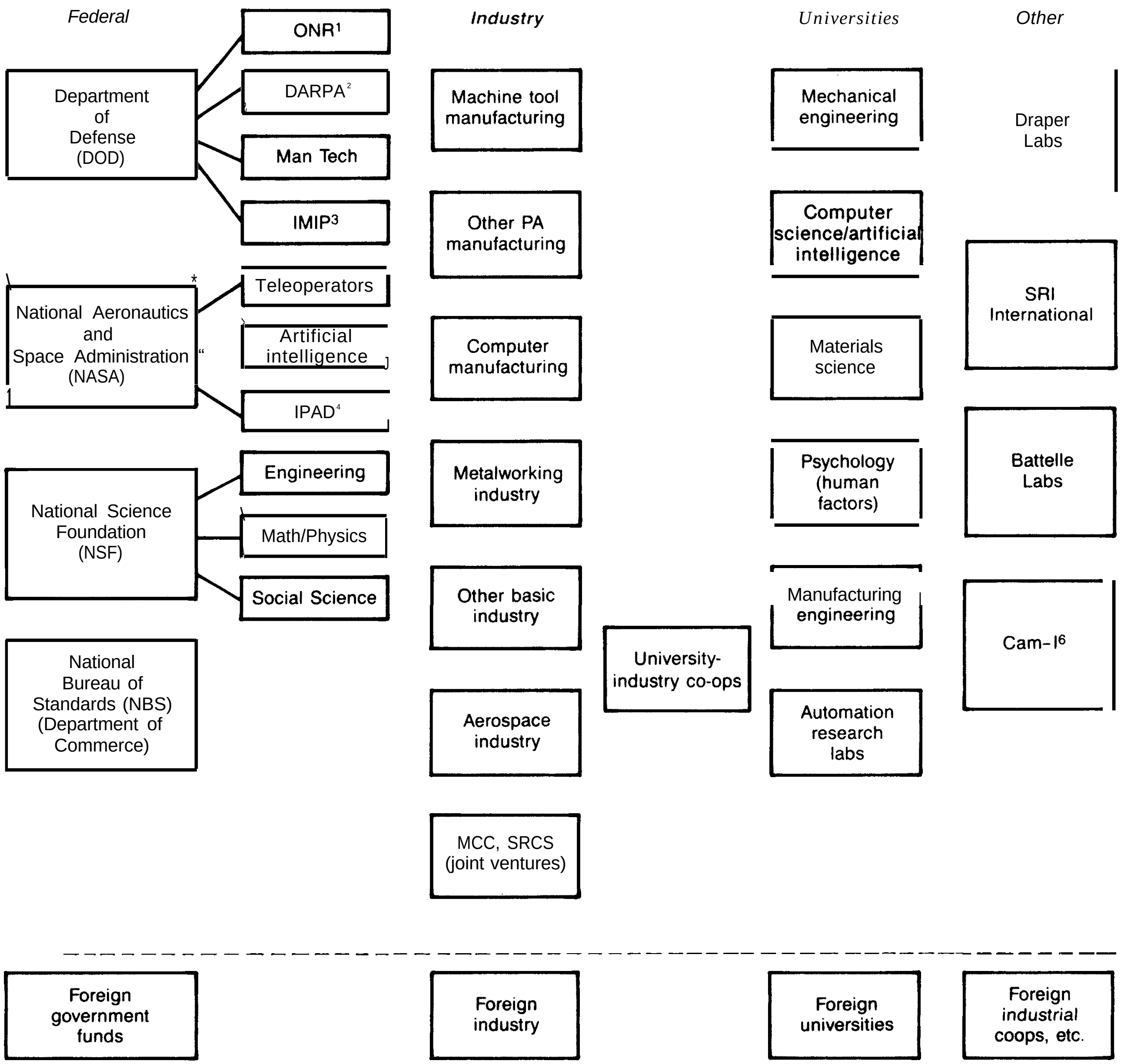


a National expeditures exculding Government funds for defense and space R&D

SOURCE' National Science Foundation, Science Indicatetors-1982 (Washington, D C : National Science Board, 1983).

different approaches and goals. DOD funds very substantial amounts of R&D in automation technology-primarily in industry labs—both to save the Government money on its purchases of manufactured goods, and to develop technologies which may have applications for manufacturing or in battlefield situations. NBS, under the auspices of the Department of Commerce, pursues automation research because of the standards and measurement issues involved, and as a result of a longstanding mandate to investigate various aspects of computer technology. NASA looks to automation technologies to help plan and conduct space missions. NSF funds a broad range of automation research, primarily at universities, as part of its general mandate to support work in science and engineering and encourage technology transfer to industry. And finally, an assortment of other agencies are exploring robotics, primarily for non-manufacturing applications such as maintenance in nuclear powerplants.

Figure 37.—The Range of Programmable Automation Research and Development



Key:
1 ONR = Office of Naval Research
2 DARPA = Defense Advanced Research Projects Agency.
3 IMIP = Industrial Modernization Incentive Program
4 IPAD = Integrated Program for Aerospace Vehicle Design
5 MCC = Microelectronics & Computer Corp.
SRC = Semiconductor Research Corp
6 CAM-I = Computer Aided Manufacturing International

SOURCE: Office of Technology Assessment

As the second column of figure 37 displays, the major players in R&D in industry are those who make automation technology and those who use it, categories which have merged to some extent (see ch. 7). In addition, cooperative interindustry research efforts play a small, though perhaps increasing, role. As will be discussed below, industry spending on automation R&D is hard to gauge accurately because some privately held firms do not divulge the information; other, larger companies do not disaggregate the portion of their R&D budget spent for programmable automation.

Universities (column 3) pursue automation research through a handful of traditional departments, and in some cases through new automation research labs and/or cooperative efforts with industry. They are still the centers of basic research, although they are increasingly working on applied research and even de velopment topics.

Finally, several other independent laboratories (column 4) have played key roles in automation R&D, and one association of various industry, government, and foreign interests—Computer Aided Manufacturing-International (CAM-1)–funds research projects at university and industry labs, and in some cases serves as a forum for technology transfer between companies or from universities to industry.

The remainder of this section describes in more detail the particular programs and levels of funding undertaken by the primary sponsors of programmable automation R&D—government and industry.

Federally Funded R&D Efforts

The Department of Defense

Manufacturing Technology.-The bulk of DOD's automation technology research is conducted under its Manufacturing Technology, (ManTech) Program, which is funded at $200 million in fiscal year 1984. The Army, Navy, and Air Force's allocations within ManTech have been somewhat unstable over the past few years,* although DOD plans a substantial increase in all ManTech funding within the next few years (see table 65). The goal of the program is to develop and apply productivity-enhancing manufacturing technologies, primarily to military contractors. ManTech also attempts to actively transfer manufacturing technologies to industries not necessarily involved in military work.**

Although the Pentagon has been involved in manufacturing technology for several decades, the current ManTech program essentially began in 1960. It has helped develop and apply several historically significant technologies, including numerically controlled machine tools and the APT language for those tools, as well as calculators using integrated circuits.

ManTech projects aim for a grey area be tween applied research, development, and application. Although the program purports not to "develop" technology, it nonetheless contributes to that process. The standards of the program require that the projects are technically feasible, generically applicable, and have a level of cost and risk such that private industry cannot or will not fund the work.

ManTech contracts with industry to (in its terms) "procure" a manufacturing process

*In particular, the Army's ManTech program suffered a substantial cut in 1983 funds when the House Appropriations Subcommittee on Defense decided that Army ManTech did not belong in the procurement budget, but rather in R&D. The subcommittee cut the entire amount ($1 10 million) requested in the procurement category, but later restored $50 million in R&D funds. Pentagon officials argue that although ManTech does look like R&D in some respects, it is better for the program to be administered in procurement, where managers are more likely to be familiar with manufacturing. As of early 1984, the subcommittee had persuaded DOD to put the bulk of ManTech Funding in R&D. There is some worry that R&D funding may be more unstable, however. (Lloyd Lehn, ManTech Program Officer, The Pentagon, personal communications.)

**The General Accounting Office (GAO) has criticized the ManTech program for having inadequate documentation of the effectiveness of its technology transfer efforts ("Manufacturing Technology-A Cost Reduction Tool at the Department of Defense That Needs Sharpening, " September 1979). As the Pentagon concedes, ManTech staff often do not know to what extent industries pick up technologies developed under the program. GAO plans to publish an update of that report in the spring of 1984.

Table 65.—Funding for the DOD Manufacturing Technology Program[a] (in millions)

	Fiscal year					
	1980	1981	1982	1983	1984	1985 (preliminary)
Army	68	76	95	41	86	81
Navy	14	12	29	32	57	68
Air Force	56	66	86	59	57	62
Total	138	154	210	132	200	211

[a]As of January 1984

SOURCE Department of Defense

that enhances particular DOD manufacturing applications. For example, the Air Force ManTech staff might decide that soldering of particular printed circuit boards could be automated if someone would apply existing soldering and computer control technologies and build an interface between the computer and soldering machines. The Air Force would request competitive bids to do this work, and would then establish a contract and a schedule with a particular firm. (ManTech did, in fact, fund the automation of a wave soldering machine for printed circuit boards used in several weapons systems. The new process is claimed to save $1.1 million per year; ManTech's investment was $450,000.)[4]

Of $200 million in fiscal year 1984 funding for ManTech, $56 million is concerned with computer-aided manufacturing. Other technical areas funded by ManTech include electronics, inspection and test techniques, production of metal and nonmetal parts, and ammunition production. Pentagon directors of the program estimate that the vast majority of ManTech funds are spent for R&D in private industry–100 percent of Air Force ManTech funds, 75 percent of Navy funds, and 50 percent of the Army's. Roughly 400 to 500 projects are active at a time, covering an extraordinary range of subjects from rocket nozzle improvements to ambitious efforts to integrate programmable automation devices.

The latter are the most relevant to this study. The Air Force began its Integrated Computer-Aided Manufacturing (ICAM) program in 1978. It is the largest single expenditure in ManTech, funded at $18 million in 1983. It is also one of the most prominent and broad-based efforts in programmable automation systems R&D. ICAM has developed "architectures" for the structure and control of automated manufacturing, and it has funded a variety of work on the foundations of CIM. ICAM is being phased out as a separately budgeted line item in the Air Force ManTech program, though the program's directors intend to continue work in integrated manufacturing.

The Army's ManTech program has a similar project clearly related to programmable automation: Electronics Computer-Aided Manufacturing (ECAM). It is similar in concept to ICAM although newer and much less ambitious in scope. It aims to develop CAM techniques for electronics, specifically for the small batch sizes of electronic devices which are often needed in a military environment.

The Navy has been slower to pursue automated manufacturing technologies, in part because of the immense product size and often custom-production environment in shipbuilding operations. However, there has been substantial progress in recent years, particularly in robotic welding in shipbuilding.[5]

The Army, Navy, and Air Force ManTech programs are coordinated by a Manufacturing Technology Advisory Group (MTAG), which has representatives from each of the Services, the Pentagon, other Government

[4]L. R. Allen and L. L. Lehn, *Technology Area Description of the Manufacturing Technology Program,* June 30, 1983 (a Pentagon publication).

[5]See, *An Assessment of Maritime Trade and Technology* (Washington, D. C.: U.S. Congress, Office of Technology Assessment, October 1983), and R. Brooks, "Navy ManTech to Focus More on Shipbuilding," *American Metal Market/Metalworking News,* Mar. 12, 1984.

agencies, and defense-related industries. MTAG and its subcommittees suggest areas for ManTech projects, help avoid duplication of effort, and conduct conferences and demonstrations which help transfer ManTech-developed technologies to industry. In addition, MTAG serves as an informal coordinating and information-gathering body for automation R&D in other Government agencies and industry. Beyond its function for DOD, it is the only established forum in which key representatives fromn defense-related industry and Government agencies meet regularly to discuss automation R&D. As such, it facilitates some of the informal networking and development of consortia that occurs among Government and industry programmable automation experts. Approximately 200 representatives serve on MTAG and its subcommittees, roughly 80 percent from DOD and the military services, and 10 percent each from other Government agencies and industry.

Until fiscal year 1982, DOD conducted a program within ManTech which helped manufacturers pay for implementing new manufacturing technologies, including many of those developed in ManTech projects. This Technology Modernization (TechMod) program-used primarily by the Air Force—has now been relabeled the Industrial Modernization Incentives Program (IMIP), and separated from ManTech funding. (The removal of TechMod from ManTech was one of the reasons for the dip in ManTech funding in fiscal year 1983, along with disagreements described in footnote, p. 314). Some in industry have argued that many of the technologies explored in ManTech are rather esoteric, while those involved in the TechMod or IMIP efforts seem to be more practical.

IMIP is used to supplement cost-reimbursable contracts—procurement agreements with no fixed dollar amount; the firm bills DOD for its materials and services. Such contracts are used for most major procurements at DOD to insulate industry from the unpredictability of building massive weapons systems. Under IMIP, DOD helps pay for installing new manufacturing technology because it expects to reap the benefits downstream in lower reimbursable costs. Although all three services have a mandate to use IMIP, the Air Force continues to be the primary user of the program, with $83 million budgeted in 1984.[6]

Other DOD Programs.-Two other agencies within DOD fund longer term, more basic research efforts related to automation technologies. The Defense Advanced Research Projects Agency (DARPA) has a program in Intelligent Task Automation (ITA), which funds robotics research with both manufacturing and military (i.e., maintenance, logistics, and weapons) uses in mind. Three major initiatives are under way:[7]

- DARPA and the Air Force materials lab are jointly funding a "Systems Integration and Demonstration" project, in which two competing teams of contractors are performing applied R&D that may "lead to quantum jumps" in robotics technology. One team, headed by Honeywell, is attempting to develop a coordinated dual-arm robot-i. e., not two robots operating in sequence, as is already found in industry, but dual arms that can work together much like human arms. Another team, headed by Martin Marietta, is working on a programmable assembly robot which would make extensive use of sensors, enabling it to cope with relatively disordered manufacturing situations such as bins of parts. These projects are 27-month efforts funded at $1.6 million (total) in 1984. DARPA aims to evaluate the research in early 1985 and to continue more intensive work with one of the two teams.
- DARPA budgeted $1.3 million in 1984 for work in sensory control. This includes work on 3-dimensional vision sensing at Carnegie-Mellon University, and ultrasonic imaging at Rockwell International. The latter is intended primarily for nonmanufacturing military needs. For example,

[6] D. Reeves, staff engineer, IMIP Program, The Pentagon, personal communication, Feb. 10, 1984.
[7] W.Isler, ITA program officer, DARPA, interview, Sept. 2, 1983.

vision systems are of little use in smoke, fog, or darkness on a battlefield, but a sound-based system could construct images based on the way objects reflect sound waves. A third project in this category involves tactile sensing at Case Western Reserve University, where researchers hope to combine conventional touch sensors with what they call a haptic sensor, which would send feedback to the robot controller about the state of "elbow" and "shoulder" joints.

- Finally, $600,000 is budgeted in 1984 for work in advanced mechanical design of robots. This primarily involves developing lightweight, flexible structures (most like ly from composite fiber materials), as well as control systems and sensors which would allow controllers to direct the motion of such arms without backlash, and establish the position of flexible arms under various loads.

Aside from these projects in the ITA program, DARPA has been the dominant funder of general artificial intelligence (AI) research, and has proposed an extensive new program called "Strategic Computing" for R&D in AI and advanced computer architectures. Congress has appropriated $50 million for the pro gram in fiscal year 1984, and DARPA plans to spend $600 million total between 1984 and 1988. The program aims for advanced applications of AI techniques (weapons systems in particular) and also includes some development of "supercomputers, machines like the CRAY and CDC Cyber which can process more than 100 million instructions per second. Though this work is not aimed specifically at manufacturing, it may ultimately (in future decades) have some applicability for all computerized systems.

There may be some uses for supercomputers in manufacturing, although currently only CAD and, to some extent, machine vision, need substantially more processing power. Other automation systems may, as their sophistication increases, also require more computer power, but the supercomputer is not likely to be the answer for many of these problems because of its multimillion-dollar price tag and because hierarchical organization of factory computer systems is more likely than reliance on one huge machine. Supercomputers currently cost roughly $5 million to $15 million.

The second DOD agency funding automation research is the Office of Naval Research (ONR), whose manufacturing science program has two components:[8]

- ONR has awarded grants to Stanford, North Carolina State, Purdue, and the University of Maryland (totaling roughly $1.2 million per year) for work in precision engineering. These projects respond to an increasing need for precision in machining and high-quality surfaces, especially for weapons systems and optical instrumentation. There are also a few nonmilitary applications, such as manufacturing of computer disk drives. In general, this research aims to develop machine tools and other devices which can position and shape part surfaces within a tolerance of less than one ten-thousandth of an inch.
- Four other research efforts are under way, at a total funding level of approximateiy $600,000 per year, in a variety of topics, including 3-dimensional vision, adaptive control of grinding and polishing tools, and automated process planning.

ONR also supports:

- A "special focus program in robotics, " spending about $1 million per year total on a variety of topics, and emphasizing "intelligent robot" projects similar to DARPA's.
- Feasibility studies and plans for flexible manufacturing systems, at $800,000 per year.
- Man-machine interaction research, at roughly $500,000 per year. This work, aimed at optimizing computer systems' power and ease of use for *humans, in*cludes use of videodisks and multimedia presentations, advanced color graphics,

[8]E. Glauberson and A. Meyerowitz, ONR, interview, Aug. 10, 1983.

and improvements in ease of use for CAD geometric modeling systems.
- General AI research, at about $2.5 million per year.

The Navy has also begun a robotics program at its Naval Surface Weapons Center in Maryland. That program, budgeted at approximately $4 million per year, is aimed at robotics uses for the military, such as maintenance, testing and support of Navy equipment. *

summary *and Conclusions:* DOD.–Table 66 summarizes DOD funding of programmable automation R&D. It is clear that DOD supports a substantial amount of R&D efforts related to programmable automation. While DOD's involvement in this area has had significant spinoffs and has led industry to pursue certain aspects of automation, it would be misleading to conclude that DOD's involvement in this area constitutes a focal point in the Federal Government for generic R&D in automation technologies.

First, DOD's projects are mission-oriented in ways that limit their applicability to nondefense manufacturing. The vast majority of ManTech projects, for example, are designed to produce a very specific technology to improve a particular defense manufacturing process. Many of these manufacturing applications, especially those involving ammunition, weapons, or armored vehicles, are unique to DOD. Some ManTech-developed technologies can be modified for commercial use, although there is some question about the effectiveness of DOD*S attempts to promote such technology transfer.[8]

Likewise, most of DOD's more basic work, such as that funded by DARPA and ONR, is oriented toward military applications. A DARPA official explained, "We don't have a mandate to be pushing manufacturing. . . YOU don't have to be a wild-eyed Strangelove to see the possibilities [for use of robots in battlefield support]. " In many cases there are commonalities between military and commercial applications of automation technologies: A robot that could navigate a battlefield could also make its way through a cluttered factory; a machine tool that can make very precise parts for weapons systems can also make very precise parts for computer disk drives. Nevertheless, R&D oriented toward military applica-

*Tom McKnight, Naval Surface Weapons Center, Personal communication, Feb. 10, 1984.

'General Accounting Office report, op. cit.

Table 66.–Summary: DOD R&D in Programmable Automation, Fiscal Year 1984 (in millions)

Manufacturing Technology (ManTech):		
Army, Navy, and Air Force including $20 million for Air Force's ICAM program		$56.0'
Defense Advanced Research Projects Agency (DARPA):		
Intelligent Task Automation Program:		
Systems integration and demonstration	1.6	
Sensory control	1.3	
Advanced mechanical design	0.6	
DARPA total		3.5
Office of Naval Research (ON R):		
Manufacturing Science Program:		
Precision engineering	1.2	
Other topics	0.6	
Special focus program in robotics	1.0	
Man-machine interaction	0.5	
Flexible manufacturing systems	0.8	
ONR total		4.1
DOD total		$63.6

a NOte. The total M'nTeCh budget for fiscal year 1984 is approximately $200 MlilOn Of that tOtFd, CKJPrOXlMat81Y $fi m III ion funded work in **PA.**

SOURCE Department of Defense, Defense Advanced Research Projects Agency, Office of **Naval** Research.

tions has a much higher payback for defense than for nondefense commercial applications. Transfer of computer-related technologies from DOD to civilian applications is increasingly the exception rather than the rule.

Finally, there is a set of DOD-sponsored activities, such as ICAM and ECAM, which are neither directed toward a very specific defense manufacturing process, nor exclusively oriented toward military applications. These have helped develop substantial automation techniques of fairly generic applicability. However, these programs, like most of the ManTech, DARPA, and ONR projects, tend to apply to, and be useful for, only the most sophisticated of current manufacturers. In a manufacturing sector which has only a small fraction of its machine tools equipped with numerical control, ICAM's hierarchical architecture for an integrated, automated factory may seem to some like science-fiction. Moreover, because of DOD's close relationship with certain supplier firms, technologies developed under programs like ManTech tend to be transferred to the sophisticated aerospace and electronics industries.

In summary, DOD's R&Din programmable automation serves several distinct purposes. It purports to save the Government a substantial amount of money in procurement funds; it makes advances in certain technologies available for commercial exploitation, primarily for high-end users; and it advances the state of automation technology for many military purposes, with some side benefits for nonmilitary industry. DOD has had a significant impact on the directions for automation R&Din civilian industry, and ManTech's MTAG group also serves as a coordination and information-dissemination forum for industry and Government. However, DOD's involvement in this area is not, nor is it intended to be, a general-purpose avenue for widely applicable R&D in programmable automation.

Civilian Agency Programs

Three civilian agencies have substantial research interests related to automation technologies: NBS, NSF, and NASA.

National Bureau of Standards. -Under the auspices of the Department of Commerce, NBS Center for Manufacturing Engineering conducts a considerable amount of automation-related research. As table 67 indicates, NBS' work in automation has grown rapidly over the past few years, to a $7.55 million program in 1984. The budget for automation research is a small part of NBS' total budget of $120 million, and it is also small compared with DOD's budget for automation efforts. NBS has two labs, one in Maryland and another in Colorado, working on issues ranging from fire and construction codes to evaluating computer systems for Federal purchase.

NBS' mandate for involvement in programmable automation R&D is threefold. First, it is intended to be a catalyst for standards-de velopment activities in industry. Standards for computerized devices-in particular for ~-terfaces between such devices—are some of the most prominent issues in the standards area in this decade.

Second, NBS is keeper of the standards for measurement—the agency still keeps the official yardstick and thousands of other official measurement standards in its vault. As part of this role, NBS has also become involved in R&D for such PA devices as programmable "coordinate measuring machines" and other electronic measurement devices that are increasingly used for quality control. NBS must have the capability to certify the accuracy of such machines, and it therefore performs R&D on methods of measurement and methods of using the measurements to improve quality in production. NBS officials believe that the ultimate trend in manufacturing, facilitated by programmable automation, is toward factories which "cannot make a bad part. " That

Table 67.—Automation Research, National Bureau of Standards

Year	Appropriation	Reimbursable [a]	Total	Staff (FTE)[b]
1979	$1,150,000	$ 100,000	$1,250,000	12
1980	1,850,000	100,000	1,950,000	19
1981	2,450,000	100,000	2,550,000	25
1982	3,850,000	66,000	3,916,000	39
1983	4,716,000	2,475,000	7,191,000	65
1984 (estimate)	3,850,000	3,700,000	7,550,000	75
1985 (preliminary)	3,900,000	4,800,000	8,700,000	75

a R&D contracted by Other Federal agenctes, primarily the Department of Defense
[b]Full-time equivalent.
SOURCE National Bureau of Standards

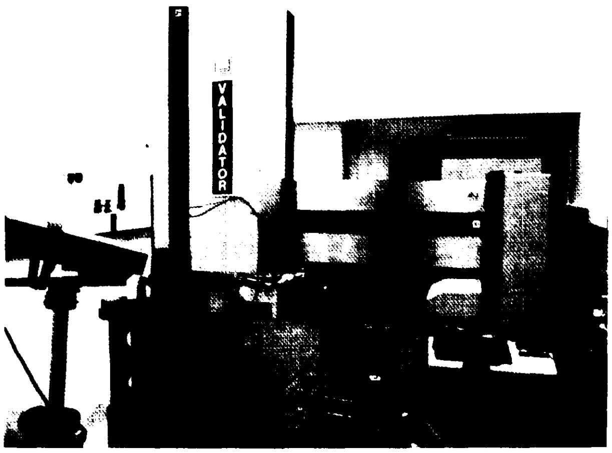


Photo credit. *National Bureau of Standards*

A coordinate measuring machine undergoes calibration at the National Bureau of Standards

is, with various electronic measurement devices present in the production process and connected electronically to PA control computers, the production line could sense minor variations in dimensions before they became a defect, and the control computers could send a signal to the production machines to correct the variation, or shut down the machine for maintenance.

Third and finally, the Department of Commerce was mandated by Congress in 1965 to recommend standards for the Federal Government's procurement and use of computers and to carry out supporting research in the science and technology of automated data processing. Acting on those mandates, NBS began work in the early 1970's on computer interfaces, including those involved with computer-controlled systems such as robots. Subsequently, this latter work became part of a program on factory automation technologies.l"

Among the highlights of NBS' automation R&D:

. In 1979, NBS received funding from the Air Force ICAM and other sources to de velop a set of standards so that different brands of computer-aided design systems could communicate with one another. The standards, called IGES (Initial Graphic Exchange Standards), specify a common format for geometric data, essentially a lowest common denominator for CAD systems. Typically, the operator of a CAD system can command his/her system to translate a drawing from the proprietary storage format of the CAD manufacturer to the IGES format and record the IGES data on a magnetic disk, which can then be read by a different CAD system and reconverted to the second system's proprietary format.

IGES was released in a preliminary form in 1980, and was adopted by CAD manufacturers in record time, according to NBS researchers. They speculate that the reason for this rapidity was that the CAD industry was "hurting" for a standard-that is, customer complaints and dissatisfaction about the inability to exchange drawings between CAD systems hurt sales and limited possible applications.11

[10]Robert Hocken, chief, Automated Production Technology Division, NBS, personal communication, Oct. 5, 1983.

[11]Robert Hocken, Chief, Automated Production Technology Division, NBS; OTA Automation Technology Workshop. A second and third version of IGES have been launched, building

- With funding assistance from the Air Force and Navy, NBS researchers are designing and assembling an Automated Manufacturing Research Facility (AM RF) to serve as a laboratory for various kinds of CIM R&D. The facility is being constructed in a portion of the NBS machining shop in Gaithersburg, Md., which produces roughly $2.5 million worth of parts annually for use by NBS researchers. PA equipment manufacturers have donated several key pieces of equipment for the project that are, in some cases, more advanced than commercially available products. In this project, as in others in NBS automation R&D efforts, industry has loaned technical staff to work at NBS for a fixed period of time. In return, the firm gets firsthand knowledge of NBS R&D and enhanced opportunities to transfer technologies developed at NBS to their own labs. The AMRF is constructed from "off-the-shelf" hardware (i.e., the machine tools, robots, and other devices are bought from or donated by manufacturers from their product lines) because NBS argues that it is software and interface systems, not hardware, which need to be developed further to enhance possibilities for automated manufacturing. In addition, NBS officials working with the AMRF are emphasizing the possible applications of automated technology for the large number of small machine shops which fabricate parts in batches too small for conventional automation, but large enough to enable the use of PA. *
- NBS researchers also pursue a wide *range* of R&D related to specific PA technologies, including important work in the use of structured light for 3-D vision perception, simulation of factory operations, and control systems for automated factories.

on the initial version, and makers of 30 CAD systems have announced that they subscribe to IGES. (" IGES Version Accommodates Modelers, " *America Metal Market/Metalworking News,* Dec. 13, 1982).

*OTA site visits, AM RF/NBS, Apr. 18, 1983, and Nov. 14, 1983.

NBS staffers also contribute to standards efforts by serving on and helping to coordinate the many private sector standards committees working on automation issues.

National Science Foundation.–NSF also plays a significant role in funding of automation research. Because of its interdisciplinary nature, several different parts of the agency contribute to this work. Table 68 highlights some of the programs within NSF which fund PA research. NSF has tried to rationalize and coordinate its funding in this area by establishing in 1981 a Coordinating Committee on Research on Intelligent Robotic Systems, and by issuing in 1983 a "Program Announcement in Intelligent Robotics Systems and Automated Manufacturing, " which sets forth the possible avenues for funding.

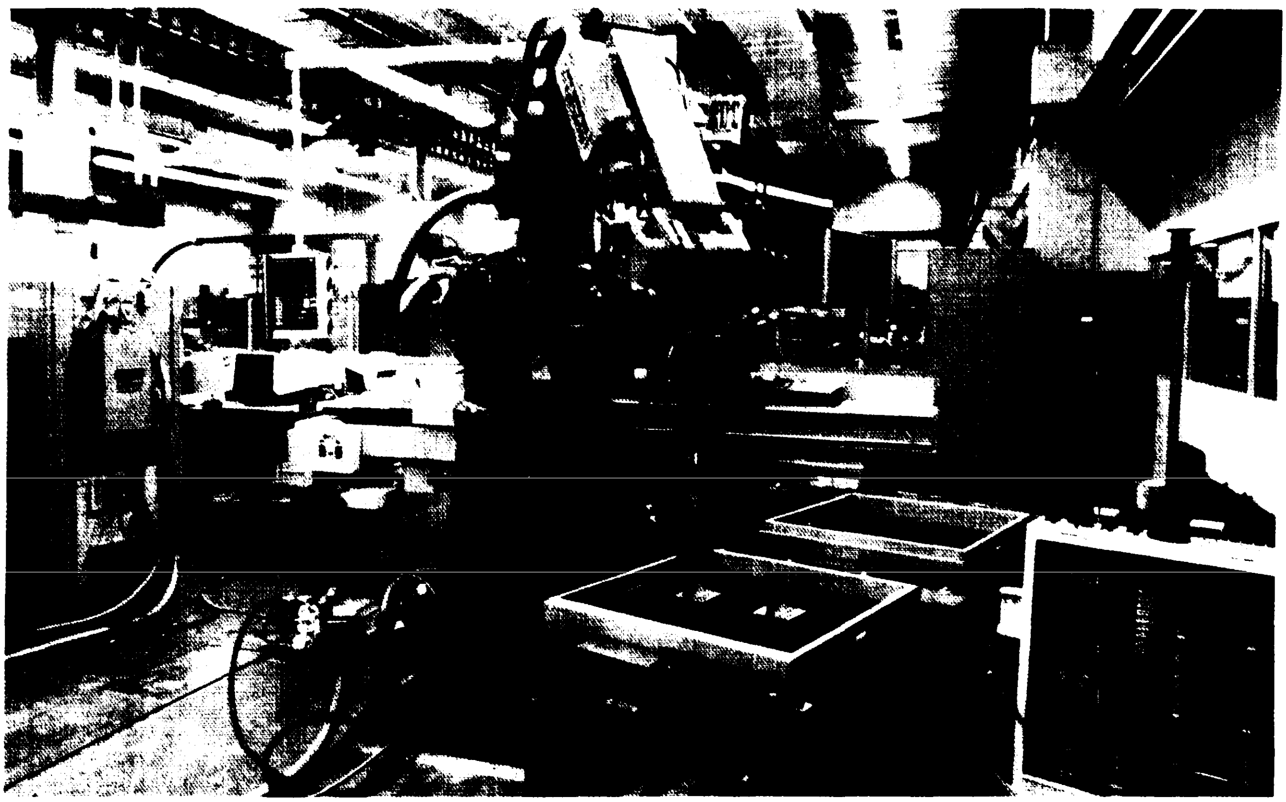
The Production Research Program in the Engineering Directorate* is directly focused on programmable automation for discrete manufacturing. This program has grown rapidly in the past 5 years-from $2.3 million in 1980 to $4.6 million in 1984—but is still relatively small. Although exact figures are not available, NSF officials estimate that the funding for PA research from all programs at NSF might be 1.5-2 times as much as the budget of Production Research, or roughly $7 to $9 million in 1984. In fiscal year 1983, the Production Research Program included 17 projects in CAD, 47 projects in various aspects of computer-aided manufacturing technologies, and 11 projects in computer-aided testing. Production research, in collaboration with NSF's Industry-University Cooperative Research Program, also provided seed money for two new industry-university research centers, one in robotics at the University of Rhode Island, and one in materials handling at Georgia Tech.**

*NSF is divided into six directorates (administration; astronomical, atmospheric, earth, and ocean sciences; biological, behavioral, and social sciences; engineering; mathematical and physical sciences; and scientific, technological, and international affairs). Each directorate has four or five divisions.

**For example, General Electric (GE) reported that its recently released "BinVision" system was based on machine vision research conducted at the University of Rhode Island. GE is one of 27 companies, in addition to NSF, which fund the center. "Vision Sensors Expanding Industrial Robot Flexibility, " *Aviation Week and Space Technology,* May 30, 1983, p. 139.

red

S m m M R g N B
G g M



red

m M gR
m g

Table 68.—Selected NSF Programs Which Fund Automation"Related Research

Program	Aspects of automation
Automation, bioengineering, and sensing systems	Touch and vision sensors, control systems
Computer engineering	Robot programing languages, computer architectures, human-computer interface
Electrical and optical communications	Communication networks, integrated optics for vision sensors
Industry/university cooperative research	Seed funds for cooperative industry/university research centers
Mechanical systems	Mechanical aspects of robots, CAD
Production research	All aspects of factory automation for discrete manufacturing
Quantum electronics, waves and beams	Sensors and processes using lasers
Small business innovation	Incentive grants for research in small high technology firms
Solid state and microstructure engineering	Fabrication of miniature devices for sensing and control
Systems theory and operation research	Large-scale systems control, scheduling, organization

SOURCE National Science Foundation, "Program Announcement in Intelligent Robotics Systems and Automated Manufactunng, " No 3145-0058, 1983

A new initiative for fiscal year 1985 aims to provide $10 million as seed funds to establish 5-10 centers for cross-disciplinary engineering research. It is likely that one or more of these centers will be focused on automation.

Other programs at NSF which fund work related to PA include Automation, Bioengineering, and Sensing Systems; Computer Engineering; Electrical and Optical Communications; Mechanical Systems; and Systems Theory and Operation Research. In addition, programs in social sciences and policy analysis include a small amount of work on the social effects of new technologies such as progr ammable automation.

The primary funding machanism at NSF is grants made in response to unsolicited research proposals, which are evaluated by NSF staff and external reviewers. Few if any strings are attached regarding the nature or direction of the work. However, NSF is also mandated to encourage transfer of science and technology to industry, and several programs which fund PA research take an active role in facilitating such transfer. Three staff members from the Industrial Science and Technological Innovation Division, for example, in collaboration with eight other experts, recently studied the diffusion process and called for more coherent and supportive government policy in this area:[12]

> Taking advantage of advanced manufacturing capabilities is a process which will require considerably more, and more systematic, attention to the phenomenon of deployment than has heretofore been generally in evidence in U.S. industry.

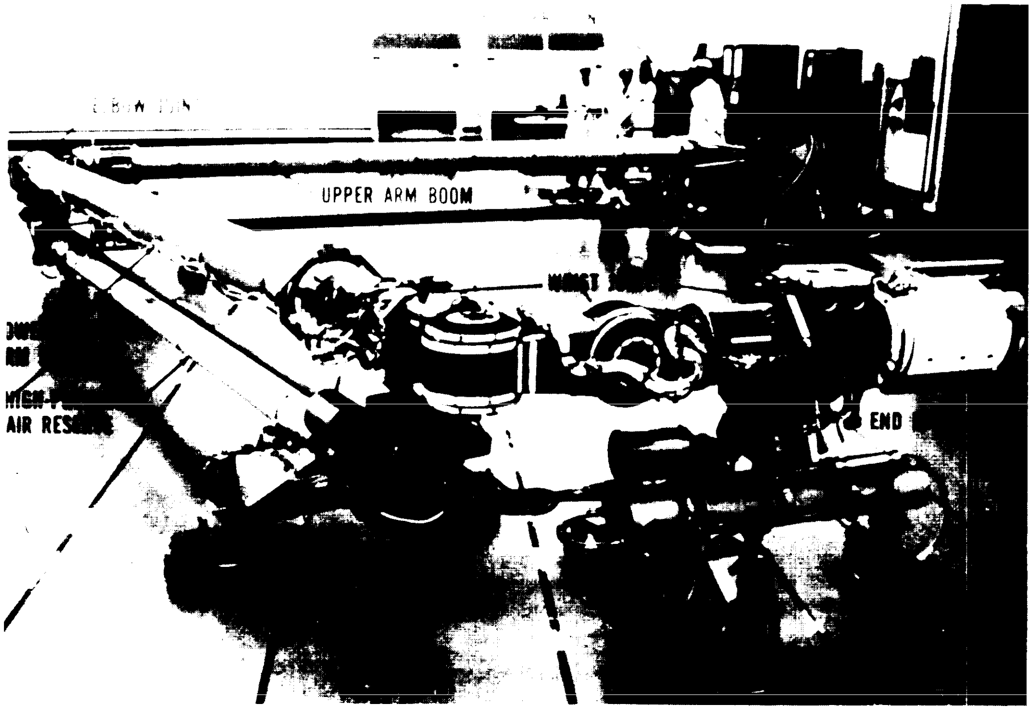
This and related Government policy issues will be examined in Chapter 10.

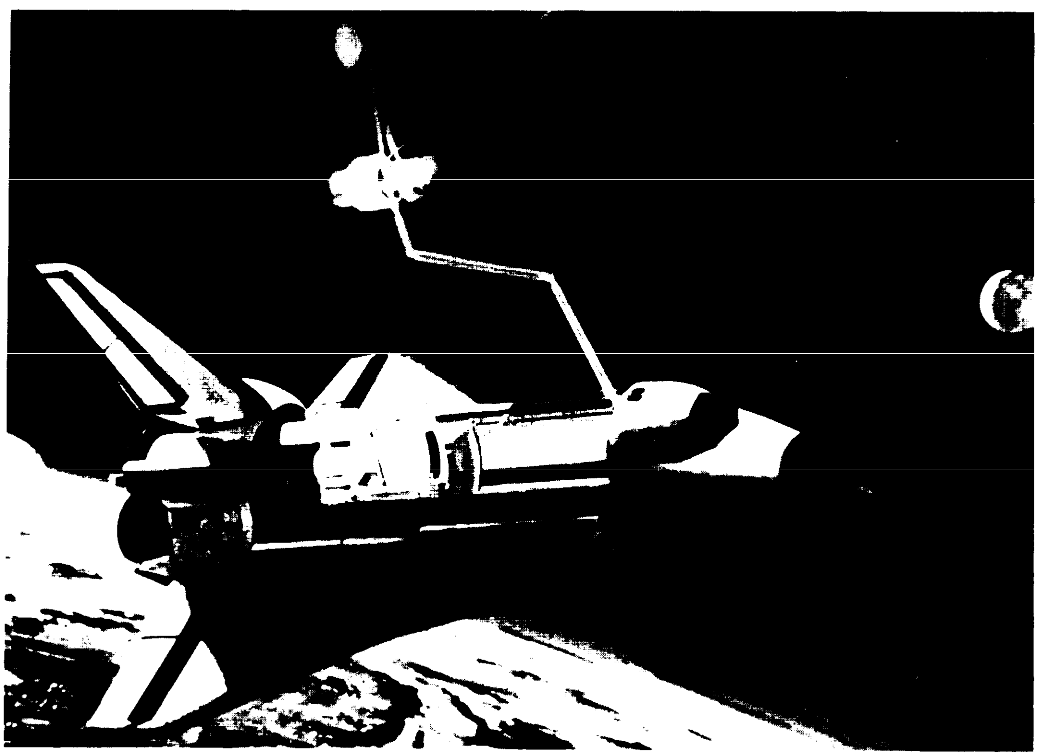
National Aeronautics and Space Adminstration.—NASA pursues three general types of progr ammable automation R&D. They are summarized in table 69.

The first is robotics and teleoperator research to develop manipulators for applications on space missions. Near-term NASA uses will involve teleoperators rather than robots. Their movements will be controlled more or less directly by a human, who is either in space or on the ground. For example, the Space Shuttle's well-known Remote Manipulator System, which reaches into the shuttle's cargo bay to extract and manipulate satellites, is controlled by the shuttle's flight crew. Because of the relatively direct human control of the teleoperator, human factors research to develop the most effective combinations of man and machine is very prominent in the pro gram. NASA researchers expect people to remain in direct control of these devices for some time because of the complexity of the tasks.

The robotics and teleoperator work is now focused on a "Remote Orbital Servicing Systern, " an unmanned space vehicle that would be capable of servicing satellites by ground

[12]L. G. Tornatzky, W. A. Hetzner, and J. D. Eveland (National Science Foundation, Division of Industrial Science and Technological Innovation), "Fostering the Use of Advanced Manufacturing Technology, " *Technology Review, in* press, 1984.





Phofo credit Natlonal Aeronautics and Space Adm/n/strat/on

Top, the space shuttle's manipulator arm in a laboratory. Bottom, an artist's conception of the manipulator as it deploys a satellite from the shuttle

Table 69.—NASA Automation Research (dollars in thousands)

	Fiscal year					
	1980	1981	1982	1983	1984	1985 (prelim.)
Automation research program:						
Robotics/teleoperators		$ 538	$ 245	$1,600	$1,600	$1,600	$1,600
Artificial intelligence/corn puter-aided planning	1,048	1,017	1,065	2,000	2,000	2,000
Integrated program for aerospace vehicle design (IPAD)[a]	NA	5,000	2,100	2,300	2,300	2,500
Total	NA	6,262	3,765	5,900	5,900	6,100

NA—Not available

Note Figures do not Include salaries of NASA personnel which are budgeted separately

[a]IPAD figures include NASA funds only The Navy also contributes to the program, and plans to spend an additional $2 million for IPAD in 1985

SOURCE National Aeronautics and Space Adminlstratlon

control commands to its manipulator arm.[13] For the future, NASA is exploring machine vision and AI systems which would allow a servicing vehicle to conduct repairs somewhat autonomously. Most of this research is conducted in-house at the Jet Propulsion Laboratory and at Langley Research Center. NASA also supports research work at the University of Illinois and Stanford University.

The second major area of NASA's involvement in programmable automation R&D is the development of an advanced computer-aided planning system called "Deviser," developed at the Jet Propulsion Laboratory in response to the complicated and sometimes conflicting needs for scheduling NASA's recent unmanned scientific missions (the Voyager series). The Voyager craft is radioed signals to direct its trajectory, aim its telescopes and cameras, and manipulate other scientific equipment. Dozens of NASA scientists request the attention of the satellite for particular experiments, and according to one NASA researcher, it takes hundreds of man-years to develop efficient plans and tell the spacecraft what to do.[14] Deviser uses sophisticated programing techniques to juggle the capabilities of the satellite and the demands of the scientists, resulting in an order-of-magnitude increase in productivity, according to NASA officials.

[13]A. J. Meintel, Jr. and R. L. Larsen, "NASA Research in Teleoperation and Robotics," paper presented at the Society of PhotoOptical Instrumentation Engineers Conference, Aug. 23-27, 1982.

[14]R. L. Larsen, Computer Science and Electronics Office, NASA, personal communication, Aug. 25, 1983.

The final area of NASA's involvement in automation R&D is an effort called Integrated Programs for Aerospace Vehicle Design (IPAD), which was begun in 1976. It is a joint NASA/industry program whose goal is to integrate computer-aided design and engineering systems used in the design of aerospace vehicles, and to link them with powerful software systems which could help manage the tremendous amount of information involved in designing such a complex product. Boeing Commercial Airplane Co. is the prime contractor for the IPAD R&D effort.

Other Federal Agencies.-Severa-l other Federal agencies fund small R&D efforts, primarily in robotics for nonmanufacturing applications. These include the Department of Energy, which is interested in the use of robots to service nuclear power facilities. The Department of Agriculture has also recently been investigating use of robotics for various agricultural applications. The Department of Transportation's Transportation Systems Center has conducted R&D in robotics for motor vehicle manufacture in the past, but the current administration views such work as the responsibility of industry.

Summary and Conlusion-Civilian Agencies. —Table 70 summarizes the programmable automation R&D supported or conducted by Federal civilian agencies. The three Federal agencies primarily concerned with PA each have very different roles. NBS plays a unique role in three respects:

1. Support of standards efforts for PA devices, and relevant research to determine

Table 70.—Summary: Federal Civilian Agency R&D in Programmable Automation, Fiscal Year 1984 (In millions)

National Bureau of Standards (at NBS labs in Gaithersburg, Md.):		
NBS-funded work	3.85	
Work sponsored by other Federal agencies (primarily Navy and Air Force funding for automated manufacturing research facility)	3.70”	
NBS Total		3.85
National Aeronautics and Space Administration (approximately two-thirds is conducted in NASA’s in-house labs, and one-third is grants/contracts to non-NASA labs):		
Teleoperator research	1.60	
Artificial intelligence/corn puter-aided planning	2.00	
IPAD	2.30	
IPAD work funded by Navy	1,875a	
NASA total		5.90
National Science Foundation (all grants/contracts to universities and nonprofit labs):		
Production Research Program	4.60	
Other NSF grants centrally concerned with PA from a variety of programs (estimate)	2.30-4.60	
NSF total		6.90-9.20
Total for civilian agencies		**16.65-18.95**

[a]Not included in civilian **total**

SOURCE National Bureau of Standards, National Aeronautics and Space Administration, National Science Foundation

how best to construct standards, particularly for interfaces between PA devices.

z. Development of the AMRF, perhaps the only full-scale test bed for integrated PA research using some of the most advanced technologies that have been developed.
3. Serving as a resource to other Federal agencies and to the private sector on a range of issues related to PA.

NSF is the Government’s only avenue for support of generic research on a broad range of subjects related to PA, although available funds are limited. Hence, NSF supports longer term research in many areas which might not receive funding horn mission-oriented agencies such as DOD or NASA. In addition, NSF funds provide crucial support to universities for building the foundation of automation R&D–maintaining technical expertise in the universities and helping to train new technical experts through students’ involvement in research work.

NASA’s aims for automation R&D are complex and specialized. However, these efforts could have substantial spinoffs in the longer term.

Industry-Funded R&D

The amount of money and effort which industry as a whole spends on programmable automation R&D is hard to gauge. Statistics about R&D tend to be either protected by pro prietary concerns or muddled by inconsistent definitions of R&D and industry classifications. With increasing Federal tax incentives for R&D activities, many firms seem to have broadened the set of activities and expenditures to which they attach the label, “R&D.” Is

Nevertheless, several agencies and research firms have made estimates of R&D expenditures in various classes of industry, including computers, and mechanical manufacturing (see table 71). No similar effort has been undertaken for PA vendors as a group. However, examinations of R8zD in information technology-related industries tend to reveal a pattern of fairly consistent and comparatively high spending for R&D as a proportion of gross sales. By combining estimates of gross sales in automation industries with industry ana-

“National Science Foundation, science *Resources Studies Highlights,* Sept. 9, 1982.

Table 71 .–Company R&D Expenditures as a Proportion of Sales, By Industry

	NSF[a] 1980	*Business Week*[b] 1980	1981	1982
Machinery	4.8			
Office, computing, accounting	10.0	4.3-6.4	5.0-6.4	5.1-7.2
Other machinery, except electrical	2.3	1.6	1.9	2.6
Electrical equipment	3.9	2.8	2.9	2.8
Radio and TV receiving equipment	1.6			
Communication equipment	5.2			
Motor vehicles	4.3	4.0	3.7	4.0
Motor vehicles parts and equipment		1.9	2.0	2.3

[a]National Science Foundation, "Research and Development in Industry, 1980. " Data are based on a survey of approximatel Y 11,500 companies, conducted by the Bureau of the Census

[b]*Business Week*, "R&D Scoreboard, " July 6, 1981, July 5, 1982, and June 20, 1983. Data are based on the amount of R&D spending reported to the Securities and Exchange Commission on Form 1O-K Companies included are those reporting sales for the year of $35 million or more and R&D expenses amounting to at least $1 million or at least 1 percent of sales Industry classifications used by Business Week are similar, but not identical to those used by NSF. Hence the two sets of data are not strictly comparable

lysts' assessment of the percentage of gross sales spent on R&D, one can arrive at an estimated range for automation industry spending on R&D (table 72).

Such estimates are possible only for the pro grammable automation technologies that comprise an industry-notably CAD, robotics, and machine tools. Table 72 shows that R&D spending in just these three industries was approximately $264 million to $400 million in 1983. This is roughly 3 to 5 times as much as the approximately $80 million spent by Federal agencies for the whole range of programmable automation R&D. PA-industry spending for R&D has increased rapidly in the past few years, in parallel with high industry growth rates particularly for robots and CAD. (See ch. 7 for further detail.) However, robots industry analysts expect the proportion of gross sales spent on R&D in that industry to decline from an estimated 12 to 18 percent to 10 to 12 percent as sales in the industry accelerate.

Only a few companies conduct substantial work in more long-range basic or applied PA research, as opposed to relatively short-term product development (although it should be noted that such product developments provide important feedback to more long-term re search efforts regarding productive directions for R&D). These more long-range efforts include IBM's research, primarily in robotics and sensing technologies; GE's work in robotics, sensing, computerized controllers, and CIM; GM's research in robotics; Cincinnati Milacron's efforts in robotics, machine tools, automated materials handling, and flexible manufacturing systems; Unimation's (now owned by Westinghouse) robotics research; and Computervision's CAD explorations. It

Table 72.—Estimated R&D Expenditures in PA Industries, 1983 (in millions)

	Industry sales	Estimated percent of sales spent on R&D	Estimated level of R&D spending
CAD	$1,600	12-18	$192-$288
Robots	$ 235	12-18	$ 28-$42
Machine tools	$1 ,750[a]	2.5-4.0	$ 44-$ 70
Total			$264-$400

a National Machines Tool Builder's Association. Note that the U S machine tool industry has been experiencing dramatic changes in level Of sale For example, Shipments in 1982 totaled $3.7 million, while those in 1981 totaled $51 million

SOURCE Interviews and compilation of material from industry analysts

25-452 0 - 84 - 22 : QL 3

should be noted that users of automation technologies, particularly large firms such as GM and GE, are playing important roles in R&D and have in many cases become vendors themselves (see ch. 7).

In addition, some of the large consulting and research firms have played key roles in development of programmable automation technologies. SRI International has been a pioneer in machine vision and robotics research; Draper Laboratories has conducted robot and FMS research, and consults with industry on implementation of automation systems; other "think tanks" such as Battelle Laboratories and Arthur D. Little have played key roles in both research on the technologies and assisting in implementation.

There is also evidence of more extensive interaction in the past few years between industry and academia on manufacturing automation research. Many universities have set up cooperative research centers in which firms contribute funds to support manufacturing-related research efforts. These centers vary in the extent to which industry has a say in the research agenda and control over the results.

One kind of university-industry cooperative program is the Manufacturing Engineering Applications Center (MEAC) at the Worcester Polytechnic Institute (WPI). Here, professors and students work with staff from companies to develop specific applications of automated equipment. Emhart Corp. helped to establish and was the first to work with WPI on such a project. For Emhart, the goals of the program were to obtain:[16]

1. assistance in conducting practical, short-term applications research that would adhere to industrial time lines and result in completed projects delivered to Emhart within 1 year;
2. a situation that would promote technology transfer-(i.e., that would help the firms receiving the systems to understand the development processes and the operations of the systems themselves); and
3. provision of laboratory and office space on the campus for Emhart engineers to enable them to work in an environment free from production pressures and responsibilities.

MEAC'S liaison with Emhart resulted in several applications developed for the company's factories, and MEAC has now expanded to include two other firms.

Another form of industry-university effort is the Industrial Affiliates program at Carnegie-Mellon University's Robotics Institute. Various industrial sponsors (Westinghouse is one of the largest) contribute more than $2 million per year.[17] The institute includes labs in flexible assembly, flexible manufacturing, intelligent systems, vision, mobile robots, smart sensors, automatic programing, and social ~. pacts analysis. The sponsors, however, do not have control over research agendas, but rather have priority in obtaining the research results and are entitled to limited consulting service from the Institute faculty. This more limited impact on research agendas is generally the norm at top engineering schools with similar programs, such as MIT and Stanford.

Industry-university cooperative research centers are spreading rapidly. Though it is not feasible to list all of them, other universities which undertake PA research in cooperation with industries include the [University of Rhode Island, Georgia Institute of Technology (both discussed earlier in the NSF section), Purdue, the University of Florida, and the University of Maryland. *

One of the most dramatic industry moves to support university PA research was IBM's donation of $50 million in cash and equipment in 1983 to support manufacturing education. The grants were given to about two dozen schools—$10 million was allocated to universities to implement new manufacturing-

[16] Education and Training case study.

[17] "The Robotics Institute, CarnegieMellon University, "The Industrial Affiliates Program."

*Others the growing list include the University of Michigan, Brigham Young University, and the University of Utah.

systems curricula at the master's degree level, while $40 million in CAD and other computer equipment was donated to support research and education in manufacturing using state-of-the-art tools.

Finally, there are several interfirm cooperative research efforts relevant to programmable automation.* CAM-I, based in Arlington, Tex., has eight active research groups in which members pool funds to support research in areas of interest. The groups are Sculptured Surfaces, Process Planning, Geometric 'Modeling, Advanced NC, Factory Management, Electronics Automation, Quality Assurance, and Robotics Software. CAM-I was a spinoff from DOD's early efforts to develop NC machine tools. Now independent of DOD, the membership of CAM-I includes American and foreign com-panics as well as some universities and Goverment agencies. The members pay a fee for each of the seven research groups in which they choose to participate, ranging from $8,000 to $10,000.** In return they have a voice in the direction of research and receive copies of all the reports, documentation, and software produced in the research group. CAM- I does not actually conduct the-research in-house, but contracts for research efforts in industry and private laboratories.

Microelectronics and Computer Corp. (MCC) is a controversial collective research effort formed in 1982, and aimed at research on advanced semiconductor and computer architecture technologies. Based in Austin, Tex., MCC performs much of its research in-house with about 50 researchers. It has a $75 million annual budget contributed by 13 medium-sized electronics manufacturers. Another group, the Semiconductor Research Corp., consists of 19 electronics firms. It has already granted more than $8 million to support university research that would advance the technology of integrated circuit manufacture."[18]

The issue of cooperative research efforts has been hotly debated over the past 2 to 3 years. In some cases, industry executives have argued that the ability of foreign companies, particularly in Japan, to form R&D collectives (sometimes with government assistance) gives them an unfair advantage over American firms. Often, the perceptions of what antitrust law will permit do not mesh with the law itself. In general, collective research is permitted under current U.S. law, though there may be legal difficulties if, for example, the firms involved are those which dominate an industry or if they wish to restrict access to the results of the effort.[19]

The issue of what constitutes an appropriate area for collective R&D is not at all clear. Some industry observers argue that the advantages of collective R&D are, by and large, illusory-while Japanese cultural habits encourage group efforts of all kinds, American companies perform better in mutual competition.[20]

In any case, there seem to be at least three advantages in principle to some collective R&D endeavors: First, a collective effort may be useful if there are high costs and risks involved, with uncertain and long-term paybacks. Certain problems in programmable automation fit this description. R&D in computer-integrated manufacturing, for example, requires an immense investment in equipment and tremendous labor costs because of the complexity of running and modifying such a system. Second, CIM is clearly an interdisciplinary problem, and a collective effort could be useful in bringing together expertise from, for example, a machine tool manufacturer, a computer manufacturer, a materials handling system manufacturer, and so forth. And finally, collective research efforts can afford smaller companies the opportunity to enter or stay in a market where R&D costs would be pro-

* of the consortia which pursue integrated manufacturing R&D came together, either formally or informally, through DOD. For example, several parts of the Air Force's ICAM program brought together a variety of industry contractors and subcontractors.

** CAM-I brochures.

[18]" High-Tech Companies Team Up in the R&D Race, " *Business Week,* Aug. 15, 1983, pp. 94-95.

[19]"U.S. Department of Justice, Antitrust Division, *Antitrust Guide Concerning Research Joint Ventures* (Washington, D. C.: Department of Justice, November 1980). OTA'S forthcoming study, *Information Technology Research and Development,* will discuss joint ventures in R&D in more detail.

[20]WTA Automation Technology Workshop, May 29, 1983.

hibitively high if they were conducting such work independently. Nevertheless, a great deal of R&D in programmable automation is taking place without collective efforts, and promotion of such efforts may not be necessary in this area. *

Other Sources of Funding for R&D

In addition to the Federal Government and industry, a small portion of R&D funds are provided by State and local governments, nonprofit organizations or foundations, and by universities. Often this funding is in conjunction with efforts to setup local high-technology centers, for the purpose of attracting or revitalizing local industry, or for retraining local workers. Such centers are proliferating rapidly throughout the country.

Michigan, for example, has established an "Industrial Technology Institute" to help ease the State's adoption of advanced manufacturing technologies. The institute has received grants from the Dow Foundation ($10 million), the Michigan Economic Development Authority ($17.5 million), and the Kellogg Foundation ($40 million).[21] The State of Rhode Island has proposed "Industrial Greenhouses" to capitalize, in part, on robotics technology developed at the University of Rhode Island. Even the State of Hawaii has made a $50,000 grant to the University of Hawaii to launch a Pacific International Center for High Technology Research.[22]

These are only a few examples of the many local centers which have been proposed or established. The proliferation of such centers is evidence that many States and regions believe that computerized manufacturing automation technologies are "the wave of the future. " However, only a finite number of such centers for robotics, for example, can operate effectively. And establishing such a center always involves tradeoffs with other local priorities. *

*Futher, current research efforts in automat8d manufacturing, for example at NBS and GE, suggest that the scale of effort required for integrated manufacturing research is not as massive as that in, for example, the development of new aircraft engines. Such initiatives may require R&D expenditures on the order of $1 billion. (See, for example, R. Witkin, "7 Companies to Spend $1 Billion on Jet Engine, " *The New York Times, Nov.* 1, 1983, p. D1.)

[21]" Smith Heads High-tech Group Pushing Advanced Factories, " *Automotive News,* July 11, 1983.

[22]A. A. Smyser, "Low Performance on Hi-Tech, " *Honolulu Star-Bulletin,* Aug. 9, 1983. This decision was relatively controversial in Hawaii. State senator Mary George lambasted the program, asking, "What are we doing in this world-class competition when we are basically a sand-lot team?"

*For mom information on this and related issues, see the recent OTA studies, *Census of State Government Initiatives for High-Technology Industrial Development* (May 1983) and *Encouraging High-Technology Development* (February 1984). Both of the aforementioned are background papers for the forthcoming OTA study, *Technology, Innovation, and Regional nomic Development.*

International Comparisons in R&D

Foreign R&D efforts in PA are tremendously varied. This analysis will elucidate certain themes in the content of foreign R&D, and point out strengths in particular foreign research programs. Institutional issues concerning foreign R&D (e.g., research cooperatives and government R&D support), are addressed in the International Comparisons chapter (ch. 9).

In order to analyze international R&D, the level of R&D must be treated separately from the level of application of automation technologies. Hence, while certain other countries exceed the United States in use of PA (see chs. 7 and 9) the vast majority of R&D in programmable automation has taken place in the United States. Japan, West Germany, and Sweden, and to a lesser extent France and

Great Britain, have also become important contributors to automation R&D.

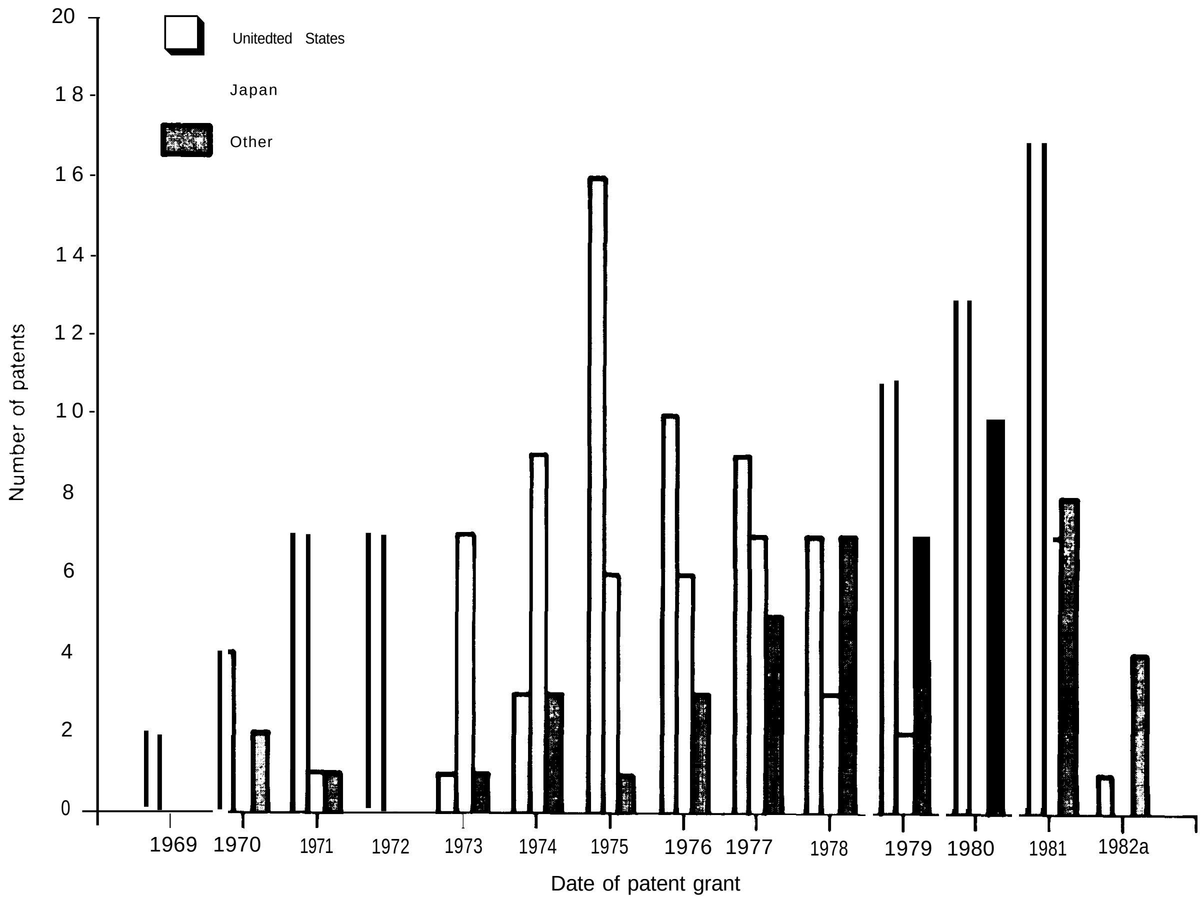
One indicator of the relative contributions of different countries to this technology is the number of patents that residents of each country hold. Patents are not a good index of quality of innovation, nor is it assured that foreign innovations that are not marketed here will be patented in the United States (and therefore available as statistics). However, it may nevertheless be instructive to examine the intemational distribution of U.S. patents. A 1982 study by the U.S. Patent and Trademark Office showed that U.S. residents hold 51 Dercent of the U.S. patents for robotics, while-the Japanese hold 24.5 percent and residents of other countries (largely West Germany, Sweden, France, and Italy) hold the remainder.[2s] Figure 38 shows that U.S. dominance in U.S. robotics patents has been erratic but generally strong.

Moreover, automation technology researchers believe, almost unanimously, that the United States is still in the lead or at least equivalent in level of sophistication in virtually all areas of R&D.[24] A typical comment

23 U.S. Patent and Trademark Office, U.S. Department of Commerce, *Industrial Robots: A Survey of Foreign and Domestic U.S. Patents* (Washington, D. C.: Department of Commerce, August 1982).

“OTA Automation Technology Workshop, various personal communications.

Figure 38.— Patent Activity by Country Comparison



[a]January 10 March 1982

SOURCE U S Patent and Trademark Office, Industrial Robots *A* Survey of Foreign *and Domestics US. Patents,* August 1982 is this one from an Army technical officer's Japan trip report: "No equipment was seen during the trip that lead (sic) me to beieve the Japanese had any sort of technology edge in the robotics area. In fact, much of their recent work in the machine vision area owes a technology debt to R&D performed by such firms as SRI International. "[25] This position is often voiced defensively by U.S. technology experts as foreign government efforts, particularly in Japan, have received increased attention.

Japan. -It is by now a cliche that Japan's fundamental strength has been in applying technologies, rather than in more fundamental innovations. There is a moderate consensus on this point, though there is not a consensus on its significance. Some argue that it is sensible for a country to emphasize applications when another country (the United States) is a strong leader in technical areas. In any case, the Japanese have taken steps to bolster their capacity in areas which they have not heretofore emphasized, including software and more fundamental research. A 1982 Japanese White Paper explains:[26]

> . . . It has also been said that Japanese technology has for the most part been introduced from other industrially advanced nations, and that only a few innovations have been created by Japanese scientists and engineers.
>
> Meanwhile, prevailing situations seem to suggest that the once active creation of new technologies by foreign countries has lost its glamour at the moment; in addition, there are many instances in which foreign countries and business corporations appear reluctant, as a strategic measure, to transfer the limited scope of remaining technological know-how to Japan. Given these circumstances, it has become absolutely necessary for Japan to de velop creative technologies on her own if she is to maintain her economic viability among the world's industrially advanced nations.

The Japanese plan for bolstering innovative capacity involves establishing long-range R&D efforts, setting up various new programs for researchers, promoting public understanding of the issue, and pursuing active international cooperation in science and technology development.

This plan is one of several wide-ranging efforts that the Japanese have announced in the past few years. Others include development plans for the "fifth generation" computer project and the "Flexible Machining Complex Equipped with Laser (FMC/laser). " The Japanese seem to have a propensity for establishing plans and goals which far exceeds that of many other countries, even those such as the United States whose research in these areas is extensive. This has led one U.S. computer expert to complain, "We're being out-brochured. '[27]

Many of these ambitious efforts have not yet shown substantial results. The FMC/laser project is a good example. Begun in 1977 with a budget of approximately $6 million a year in government money and significant private sector support, the project was designed to produce an advanced, "metamorphic" (i.e., easily changed) machining cell which would use a laser both for cutting metal and for measurement. However, the result of the project is neither advanced nor flexible, according to an NBS official, and the use of a laser was more a political decision than a technical one (i.e., it brought the electrical engineering community in Japan into the project).

> The program has broken little new technical ground. It has had to retreat from the most ambitious technical goals of the program. When asked about these apparent technical failures, the MITI people responded that this did not matter, that the true goal of the program was to create a national team to work on automated manufacturing and that this goal was accomplished.[28]

---

[25] C S. Shoemaker, Special Projects Office, U.S. Army Human Engineering Laboratory, "OCONUS Trip Report," dates of travel: Oct. 4-17, 1981. Many similar sentiments were expressed at the OTA Automation Technology Workshop, May 29, 1983.

[26] "In Pursuit of Creativity in Science and Technology: Outline of White Paper on Science and Technology 1982, " *Science and Technology in Japan,* vol. 2, Apr. 1, 1983, pp. 18-23.

[27] Neil Lincoln, Control Data Corp., OTA Workshop on Advanced Computer Architecture, July 14, 1983.

[28] J. A. Simpson, director, Center for Manufacturing Engineering, NBS, "FMC/Laser vs. AMRF: A Comparison, " speech to Manufacturing Studies Board of the National Academy of Engineering, 1982. Simpson arranged an exchange between the

The product of the FMC/laser project turned out to be considerably simpler than its goals implied, somewhat like a mass-production line which can be easily reconfigured. Whether or not this was intended, the notion of simplicity seems to be an underlying theme in several Japanese automation products and development efforts. Japanese FMSS, for example, tend to be substantially smaller and simpler, without the complex recovery methods for worn tools and bypass-loops in material-handling tracks which characterize U.S. designs. An engineer for Niigata Engineering Co. explained to one reporter, "Complex systems are prone to failures . . . we don't want our systems to stop, not more than a few times a year. "[29]

Further, Japanese FMSS seem to place lower emphasis on the goal of completely unmanned production, instead replacing "some work slots where logical"30 and leaving other jobs for human workers. These principles may seem to contradict reports of unmanned pro duction at certain Japanese factories, particularly the well-known Fanuc factory near Mt. Fuji. However, even this plant, upon closer examination, reveals a reliance upon human workers and relatively simple processes. At night, NC machining takes place without direct human supervision, although a worker monitors the production floor from a control room. Workers are still key features of the pro duction equipment during the day. Each NC machine tool has an operator who is primarily responsible for its performance.[3,]

FMC/laser project and NBS' AMRF staff. Japan's MITI has announced that the product of the FMC/laser project will be made part of a new test plant for computerind, unmanned operation, scheduled to be completed in 1984. (M. Inaba, "MITI Builds Laser+quipped Flexible Manufacturing System, " *American Metal Market/Metal working News, Nov.* 21, 1983.)

[29]M. Inaba, "In FMS, Simplicity Governs: Japan's PhiloscF phy of Design Differs Somewhat From the U.S. Approach, " *American Metal Market/Metalworking News, Japanese Machine Tools Supplement,* July 11, 1983.

'Ibid.

[`]See N. Usui, "Untended Machines Build Machines, " *American* Machinist, June 1982, pp. 142-145. There have been conflicting reports on the number of workers at the plant. In addition, several other portions of the plant use human workers extensively, notably for asaembly.

The Japanese are very active in R&Don industrial robots. A recent JIRA survey notes that the number of government and university robot R&D facilities in Japan has doubled over the past 3 years.[32] The number of robot research facilities in Japan, according to JIRA, exceeds the number existing in the United States, but such a claim has not been verified.[33] Until 1982, private industry had shouldered the major responsibility for Japanese R&D in the robotics field. According to a JIRA survey in 1979, over two-thirds of robot manufacturers had conducted some form of in-house robot research. Private research has concentrated mainly on application-i. e., on speed, miniaturization, computer control, weight reduction, and development of interchangeable robots.[34]

Other International Comparisons.-For historical, social and political reasons, countries have different strengths and weaknesses in R&D areas. There are many areas in which the United States is a strong international leader. These include:

- Long-range basic science research, where the U.S. university system is unmatched in size and effectiveness.
- Artificial intelligence, where the most important centers for AI work have long been in the United States (MIT, Stanford, CMU, and SRI International; the University of Edinburgh, Scotland, is also a historically important center but somewhat less prominent today).
- Software as a whole, which appears to stem from American dominance of the computer field. CAD and computer graphics in particular are American strengths. The United Kingdom recently has developed a very good reputation and

[32]Mutsuko Murakami, "Japan Stresses R&D in High-Performance Robots, " *Amen"can **Metal** Market,* July 11, 1983, p. 9A.

[33]Eij i **Nakano**, "Potentialities of Japanese Robot Industry, " *Journal of Japanese Trade and Industry,* published by Japan Economic Foundation, January 1982, p. 7.

[34]P. Aron, **Daiwa** Securities **America**, "Robots Revisited: One Year Later, " Report No. 25, July 28, 1981.

market in software as well. Japan is apparently attempting to catchup in software by pooling R&D efforts. In 1982, for example, 25 Japanese corporations entered into a joint agreement with the University of Tokyo to develop software for mechanical design.35
- Systems of computerized devices (includtig programmable automation) are in general more sophisticated in the United States than in other countries.

However, there are several areas in which other countries are leaders:

- The field of manufacturing engineering has undergone a slump in the United States in the past decade, according to many observers, with the best engineers avoiding work that was considered less intellectually exciting and "dirtier" than more theoretical efforts. Although this slump has occurred in other countries as well, West Germany's industries and technical universities have maintained a very strong program of production research and manufacturing engineering. Research, although partly funded by the government, is conducted autonomously through industry/university consortia. West Germany and Sweden have been very strong in precision machine tools and robots, in part because of the understanding of mechanical processes obtained from these institutes.
- Two foreign research efforts, one a joint Norwegian-West German program and the other under Hitachi in Japan, are pur" suing ambitious work in developing more fully integrated CIM, starting with the geometric modeling of the product. Both projects aim to produce preliminary products in the next 2 years. At this time it is unclear how these projects compare with similar integration work, particularly at GE, IPAD and ICAM, and NBS.
- European countries in general are stronger in research relating to the effect of automation technologies on the work environment. This work is particularly emphasized in Sweden, where the Swedish Work Environment Fund administers research funded by the government and industry. Chapter 5 covers these efforts in more detail.

35Industry and Trade Strategies, unpublished paper prepared for OTA, April 1983,

There is significant interest in programmable automation in Eastern Bloc countries, although there is limited information on their efforts. One U.S. robotics researcher, after a tour of the U. S. S. R., wrote:36

> Overall, I must conclude that the robotics technology in Russia is at least a decade behind that in the United States. They have ap parently recognized this fact and now have a national program in this emerging technology.

Another titer described very substantial development efforts, particularly for FMS, in East Germany, Czechoslovwia and the U. S. S.R.[97] East Germany has a well-developed machine-tool industry and an extensive program on robotics development. Bulgaria and Poland have factories which produce manipulators.[38] On the whole, evidence seems to indicate that the Eastern Bloc countries are a few years behind the West, though there are concerted efforts in these countries to correct this situation. Reliable data and descriptions of programs in Eastern Bloc countries are rarely avalable.

[36]D. Tesar, director, Center for Intelligent Machines and Robotics, University of Florida, personal communication, Aug. 3, 1981.

"''CAM: An International Comparison,' *American Machinist,* November 1981, special report 740. (The section on Eastern Europe was written by **Jozsef Hatvany** of the Hungarian Academy of Sciences).

[38]B. Roth, Stanford University, personal communication, October 1983.