Chapter 7

Programmable Automation Industries

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Summary

The principal programmable automation (PA) industries grew slowly in their early years. Development of the robot industry was dominated by entrepreneurs. The U.S. Government, through programs aimed at improving military procurement, contributed to the launch of other major PA industries, including computer-aided design (CAD) and numerical control (NC). Since the mid- to late 1970's, PA industries have grown rapidly even during the past recessions; they are expected to continue to do so throughout this decade. These industries are largely separate at this time, but a unified computer-integrated manufacturing (CIM) industry may emerge in the future.

Markets for programmable automation are strongly international, and various forms of interfirm cooperation blur distinctions among firms by nationality. Further, PA suppliers are providers of services as well as goods; the role of hardware and of manufacturing among these industries is considered much less strategically important than the role of software, controls, and various forms of customer support.

OTA'S evaluation of PA industries reveals several broad themes. These are: 1) there has been a discrepancy between vendor and buyer views of needs and capabilities; 2) systems planning and other services are key features of PA supply, while manufacturing itself plays a smaller role; 3) vendors are likely to package and/or distribute hardware and software elements made by several firms; 4) both large and small firms have played distinctive roles in the development of PA markets; and 5) governments have had a major influence on PA market development.

Introduction

CAD, robots, NC machine tools, flexible manufacturing systems (FMS), and other programmable automation equipment and systems are supplied by industries that are currently more or less separate. Of the principal PA industries, the NC industry is the oldest and largest, dating from the 1950's. While CAD and robots were available by the 1960's, significant markets for these technologies did not emerge until the 1970 's. These industries are now growing quickly.

The previously slow and uneven growth seen in markets for automation goods and services reflects a persistent mismatch between commercially available technologies and the willingness and ability of users to purchase them. This may now be changing. Recent technological and economic trends—including improvements in computer control, improvements in equipment interfacing, cost reductions, and a growing interest in manufacturing productivity—have fueled rapid growth in PA sales during the last few years. These trends also have blurred some of the distinctions among automation industries. They suggest that a single market encompassing CIM may eventually emerge. Whether or not this happens, industry analysts forecast that the combined PA market may grow from under $5 billion in sales today to $20 billion to $30 billion by 1990.*

*Note that published market estimates ~rary enormous].y. in part because of different approaches to market definition. The Arthur D. Little consulting firm, for example, contends that the 1982 market was over $24 billion, including $11.5 billion in "computing technology', " $6.26 in "CAM, " $6.1 billion in "automated materials handling, " and $0.26 billion in robots. This estimate appears to use very broad categories that may apply to nonprogrammable automation products. *American Metal Market/Metalworkjng News,* Sept. 26, 1983.

This chapter focuses on the producers and sellers of PA equipment and systems, who comprise the various PA industries. The discussion provides perspective on their roles as: 1) so-called "high-technology" enterprises, and 2) sources of employment. Insights into the current and potential role of these businesses in the U.S. economy is provided by describing their industrial structure (trends in the number and types of firms), competitive conduct (e.g., product strategies), and their financial performance. This task is made difficult by the uneven quality and availability of industry data; some industry data (e.g., for robots) are available only through trade associations and are questioned even by trade association staff.[1] Since automation industries are growing and changing, descriptions of current characteristics offer only a snapshot. Consequently, the chapter addresses changes in automation industries over time. *

Although automation industries are growing relatively rapidly, much of their impact on the economy will be realized indirectly. This is because their principal customers are other businesses, which adopt automation to use in producing consumer and other producer goods, from appliances to construction equipment. The direct contributions of these customers to the gross national product (GNP), the balance of trade, and other indicators of national economic well-being will thus derive in part from the use of automated equipment and systems; the size of those contributions may reflect the extent and success of PA applications. This is one of the reasons why many analysts believe that programmable automation will be increasingly important to the Nation's industrial base and, ultimately, to national security.

[1]See Jake Kirchner, "Government Must Support Robotics, Says RIA President," *American Metal Market/Metalworking News*, Sept. 19, 1983. By contrast, note that data on equipment production and use in Japan appear to be much more thorough and accurate.

*Because PA industries are evolving relatively quickly, it is hard to describe current conditions in enduring terms. Data presented in this report reflect information available up to late March 1984.

The broader the customer base for programmable automation, the greater the direct economic contribution of automation businesses. For reference, it should be pointed out that the machine-tool industry, a principal supplier of capital goods to metalworking manufacturing industries, is very small in terms of output and its own employment (under 70,000 employees in 1983 and under 80,000 employees in 1982, down from about 100,000 in 1980; about two-thirds are production workers).[2] By contrast, the computing equipment industry, which is less labor-intensive than the machine tool industry and which serves both industrial and consumer markets, is much larger (employing about 3,420,000 in 1982).[3] PA producers come from both of these industries and from others.

The ultimate growth and size of domestic programmable automation industries will be constrained because automation markets are and always have been international. Although the United States initiated the production and use of many types of PA, these technologies were adopted relatively quickly abroad. Japan, the United Kingdom, France, Italy, West Germany, Sweden, and Norway are each significant sources of at least one type of programmable automation. This parallel development of industries may be due, in part, to foreign government support for automation development and use, although it is difficult to evaluate the effectiveness of such government support actions (see ch. 9). At present, U.S. producers dominate U.S. markets for programmable automation. They also export automation products, and some U.S. firms have invested in the production of PA equipment and systems abroad. For example, Unimation (now part of Westinghouse) has a robot plant in Telford, England, and Cincinnati Milacron has several European machine tool plants. Unless governments restrict access to national markets, international competition in automation markets will continue to be strong.

[2]National Machine Tool Builders Association, 1983-84 *Economic Handbook of the Machine Tool Industry*.

[3]Electronic Industries Association, 1983 *Market Data Book*.

Near-term growth of domestic programmable automation industries will depend on whether domestic economic conditions are favorable to investment. The recent recessions eroded the dramatic growth rates observed for automation sales toward the end of the last decade. Nevertheless, industry analysts commonly forecast rapid PA market growth for the decade. For example, Predicasts, Inc., has forecast that the combined market for "manufacturing computers, ' CAD systems, machine tools and controls, and robots will grow over 15 percent annually between 1982 -1987.[4] Sales will double, according to that analysis, attaining almost $15 billion by 1987. The analysis assumes a GNP growth rate in real terms of 3.8 percent per year. A more sluggish economy would therefore mean lower PA sales.

Industry growth will also depend on the ability of American managers to justify investments in programmable automation and to become adept at using it. Inability to do both has limited the diffusion of PA technologies. * In the future, attitudinal obstacles are likely to be lower because widespread concern (sometimes bordering on hysteria) about international competitiveness, as well as trade association activities, technical and trade publications, and various informal networking activities are all familiarizing growing numbers of businessmen with PA's nature and potential benefits and costs. Conferences sponsored by the Society of Manufacturing Engineers (SME) and other professional and trade associations during the early 1980's have included numerous sessions on financial analysis and other activities designed to help engineers persuade upper management to support automation. Meanwhile, anecdotal evidence suggests that in a number of companies upper management is demanding programmable automation, even before specific applications are identified.

The remainder of this chapter addresses the development of the CAD, NC (with FMS), and robotics industries; characterizes related industrial activity; examines the potential for a CIM market; and derives conclusions about key traits of PA industries. Contrasts between countries are examined to the extent that data permit.

[4]"Robots, CAD/CAM to Lead 1980's Automation Surge, Says Predicasts," *The* Battery *Man*, November 1983.

*While indirect production costs tend not to vary with choices of conventional equipment, they can vary enormously for PA. Conventional methods of investment analysis have been unable to capture all changes in costs. Also, the conventional emphasis on investments with quick paybacks overlooks the long-term benefits of flexibility conveyed by PA.

Principal Programmable Automation Industries: Evolution and Outlook

CAD

History

The first CAD systems were developed by users. In the late 1950's and early 1960's, aircraft and automobile companies, whose products are very complex, developed their own software to aid in product design and engineering. Pioneer users, such as GM and Boeing, were necessarily large firms because early CAD and engineering required the use of expensive mainframe computers. The diffusion of CAD during the 1960's was slow, limited by the cost of hardware and the requirements for extensive engineering and software support. Most early users were defense contractors in the aerospace and electronics industries, where the U.S. Department of Defense (DOD) supported CAD development and use.

A formal market for the purchase and sale of CAD emerged during the 1970's, due in part to improvements in computer hardware and in operating systems which enabled more firms to afford computers for increasingly powerful work. Using microprocessors, mini- and microcomputers made many tasks, including basic two-dimensional computer-aided drafting, possible without a mainframe computer. The electronics industry, from component manufacturers to computer makers, provided a growing market for CAD systems. Compared to mechanical manufacturing firms, electronics firms were more comfortable with computer-based technology. Their integrated-circuit (and circuit-board) design applications were fundamentally two-dimensional, and therefore well-suited to early CAD. Also, the growing complexity of integrated circuits made computer assistance in design increasingly necessary; manual design would require exorbitant amounts of time and manpower. Another early commercial application was in two-dimensional drafting for mechanical design.

During the 1970's, improvements in software for two- and especially three-dimensional CAD fueled a market expansion into mechanical and mapping as well as architecture, engineering, and construction (AEC) applications. Some of these advances stemmed from Government-funded efforts, which emphasized aerospace and electronics applications for CAD and the integration of CAD and CAM.*

Between 1973 and 1981, the CAD system market grew from under $25 million in annual sales to over $1 billion.[5] Hardware and software makers entered the CAD market with specific applications and packaged systems. Firms that entered the CAD market to fill an applications niche typically grew by increasing the variety of CAD applications they could serve. Turnkey vendors, who assembled and installed systems from components made by various sources, also provided training, support, and both standard and custom software. These vendors, led by Computervision, dominated the market. They were successful because their customers lacked the technical sophistication to assemble their own systems (but knew when a turnkey system would work for them), and because their typical reliance on external sources for hardware and other inputs allowed them to incorporate new technology relatively quickly. Accordingly, in addition to system vendors, the CAD industry grew to include groups of hardware and software producers serving both turnkey firms and users directly.

During the mid-tolate 1970's, the Japanese and European markets (especially those in England, France, Sweden, and Norway) grew rapidly, and markets in less developed countries began to emerge (primarily for mapping applications). U.S. firms dominated the CAD market, both within the United States and abroad, largely because of their perceived software and systems engineering strengths.

Recent and Contemporary

The size of the worldwide CAD market is currently about $1.6 billion in annual sales.[6] Five U.S. vendors account for about 80 percent of the market,[7] although many firms have entered the CAD market recently and others may soon enter. In total, there are perhaps 100 vendors today. Table 56 shows recent market development as a function of application. Table 57 shows recent market share estimates.

The current CAD market contains segments distinguished by type of computerization: mainframe, minicomputer, and microcomputer/workstation. From this perspective, mainframe-based systems are the most sophisticated, microcomputer-based systems the least. The market can also be segmented by discipline of application, although there is substantial overlap among disciplines: mechanical (e.g., design of components for future fabrication); electronics (e.g. wiring, printed circuit-board design, integrated circuit design); and

*Government-sponsored programs, such as the DOD ICAM and NASA I PAD programs, are described in ch. 8.

[5]see Roger Rowand, "Manufacturing Makes a Move Into the Future," *Automotive News* (Detroit: Automotive News Extra, May 23, 1983). Note that most published sales estimates refer to turnkey systems sales and associated revenues.

[6]Thomas Kurlak, "CAD/CAM: Review and Outlook," Merrill Lynch Capital Markets, October 1982.

[7]Ibid.

Table 56.—Estimated Worldwide CAD Market (Turnkey) by Application (dollars in millions)

	1980	Percent growth	1981	Percent growth	1982	Percent growth	Est. 1983	Percent growth	Est. 1984	Percent growth
Mechanical	$235	+84	$380	+62	$ 460	+21	$ 552	+20	$ 825	+49
Electronic	177	+81	235	+33	310	+32	430	+39	645	+50
Architecture and engineering	87	+50	138	+59	210	+52	335	+60	485	+45
Mapping	13	+128	111	+52	154	+39	190	+23	240	+26
Other	20	+11	30	+50	73	+43	93	+27	140	+51
Total	592	+77	894	+51	$1,207	+35	$1,600	+33	$2,335	+46

SOURCE Thomas P Kurlak Merrill Lynch Capital Markets

AEC (e.g., piping, architectural drafting). Mechanical applications, especially those using 3-D modeling, tend to be more complex than the others. The so-called high end of the market involves larger computers and more sophisticated software, sold as systems costing several hundreds of thousands of dollars. Software alone may amount to anywhere between 25 to 50 percent of system cost. The low end is comprised of workstations and simpler software packages. These systems are available for under $100,000, and some (based on Apples and other small computers) cost as little as $10,000 (or less).[8] One commercial study has estimated that sales of CAD systems costing under $100,000 will grow from the 5 percent share of total CAD sales reached in 1981 (580 systems valued at $36 million) to 20 percent by 1986 (10,600 systems valued at $544 million).[9]

Two changes in computing hardware have had a big impact on the CAD industry. First, in the late 1970's, the introduction of 32-bit minicomputers (with virtual-memory operating systems), offering improvement over the 16-bit standard, changed the competitive ranking within the industry and broadened the market. The first firm to offer 32-bit CAD systems, Intergraph, increased its market share significantly. More importantly, the increase in computing power made minicomputers competitive with mainframes across a variety of CAD applications, such as simulation and solid modeling. This development opened the market to customers who could not have purchased mainframe-based systems.

Second, the introduction of low-cost, microcomputer-based CAD systems in 1981 also broadened the CAD market. While these CAD systems—generally stand-alone workstation units—are less powerful than systems with larger computers, they make basic CAD available to a larger group of customers, including small manufacturers and, particularly, AEC firms. Microcomputer-based systems have thus enlarged the portion of the CAD market serving nonmanufacturing firms, potentially increasing the overlap between CAD and other computer and computer-graphics applications. One study has predicted that the installed base of microcomputers and workstations for scientific and engineering applications will grow from under 9,000 units in 1983 to more than 275,000 in the next 10 years.[10] Others anticipate even higher growth rates.

Although hardware is the largest cost element for CAD systems, current competition in the CAD market centers on software. This is because software determines what a system can do, while hardware largely determines how fast a task can be done. Moreover, because CAD system vendors deliver up to 500 to 600 systems a year, it tends to be uneconomical for them to produce their own hardware.* In-

[8] For example, the CAD-1 package for use with Apple Computers, designed for architects and engineers, is available for about $ 1.000, (Bob Schwabach, "Computer paints a pretty picture," St. Paul *Dispatch, Nov'. 16,* 1953.)

[9] Eric Teicholz and Peggy Kilburn, "Low-Cost CADD at Work," *Datamation,* Jan. 1983.

[10] "CAE Terminals in Demand," *Computerworld,* May *23, 1983.* Another important hardware development is the growing use of raster display terminals.

*Computervision has been an exception; it has produced its own CPU—although it has recently decided to buy and resell large IBM computers–and it also markets Sun Microsystems workstations. See: Ed Scarnell, "IBM CAD CAM Thrust Linked to Remarketers," *Computerworld,* Aug. 22, 1983.

Table 57.—Estimated Turnkey CAD Market Shares

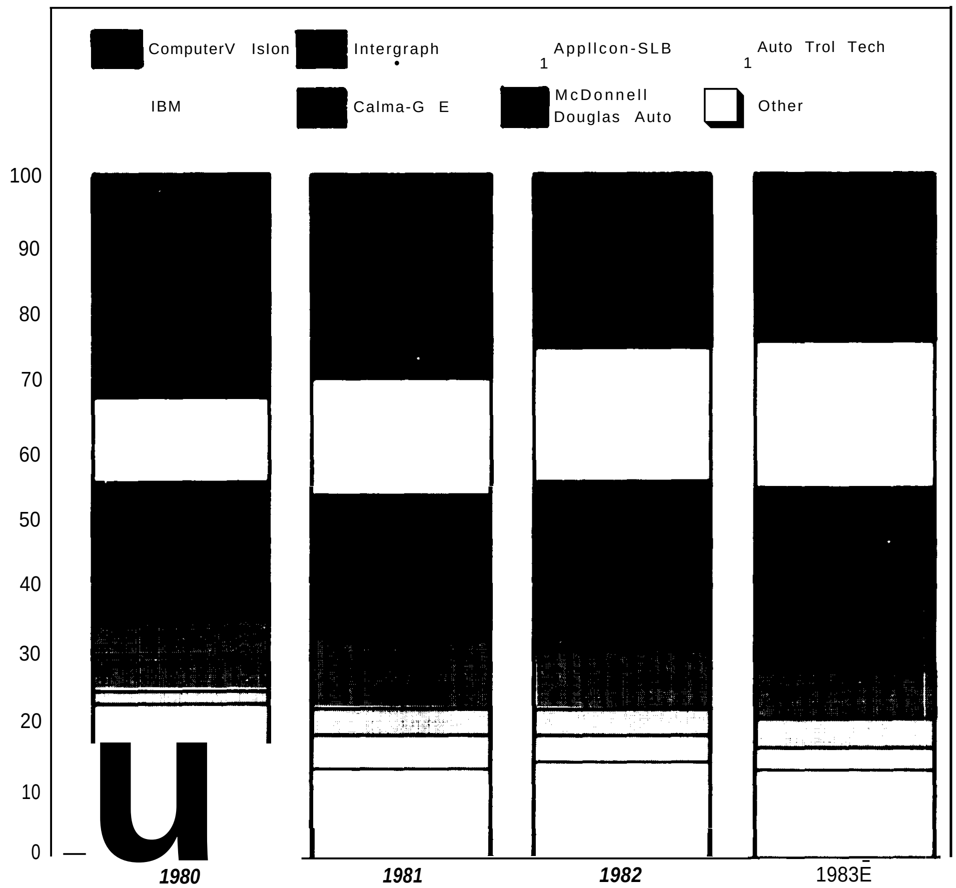
	1980	Percent	1981	Percent	1982	Percent	1983 (est.)	Percent
Cornputervision	$191	32	$271	30	$ 325	27	$ 395	25
IBM	71	12	145	16	225	19	340	;!1
Intergraph	56	9	91	10	156	13	246	15
Calma-G. E.	62	10	100	11	140	12	195	12
Applicon-SLB	68	11	84	9	96	8	100	6
McDonnell Douglas Auto	14	2	35	4	46	4	60	4
Auto-trol Technology	51	9	48	5	44	4	49	3
OtheF’	79	13	120	13	175	14	215	13
Totals	$592	l(x)°\o	$894	1000/o	$1,207	loOO/o	$1,600	100 ”/0
Growth			+51 0/0		35 ”/0		33 ”/0	

acₒₜ,l Data, prime, Digital Equipment, Data General, Sanders, Gerber Sclentlfic, etc

Note Control Data revenues estimated at $61 million for 1982, $76 million for 1983, $108 milllon for 1984 Service estimated at 60°/0 for 1983, 40°i0 for 1984 Turnkey sales ($30 milllon for 1983) from workstations and 600 series

SOURCE Thomas Kurlak. Merrill Lynch Capital Markets

Estimated Turnkey CAD Market Shares



NOTE Control data revenues est ı mated at $61 m{ I for 1982 $76 rn ı I for 1983 $106 m ı l I lon for 1984 Service est ı mated at bO °, for 1983 40, for 1984 Turnkey sales ($30 rml for 1983) from workstations and 800 ser(es

SOURCE Thornas Kurlak, Merrill Lynch Capital Markets stead, they rely on a few mass-producing hardware vendors for their equipment. * CAD vendors' contributions to the product come from software development, systems integration, applications engineering, and other support activities—they produce services that accompany the goods they sell. The costs of replicating software, compared to hardware, are negligible. The principal fixed costs born by turnkey vendors are for R&D and for software development, which may range from tens to hundreds of thousands of dollars. R&D tends to run at 10 to 12 percent of sales for major CAD vendors; this compares with an average of about 8 to 10 percent for major firms in the data-processing industry."

A variety of firms have entered the CAD market or expanded their involvement through merger and acquisition, product licensing, and product innovation. Many computer vendors (e.g., DEC, Sperry Univac, Honeywell, Harris, Prime, Data General, Perkin-Elmer, and Hewlett-Packard) have entered the CAD market, often by selling systems with software licensed from other firms. IBM, for example, offers its hardware with Lockheed's CADAM software; it has recently moved to provide its hardware through other software developers acting as so-called value-added remarketer. Large diversified companies (e.g., GE and Schlumberger) have also entered the CAD market, principally through the acquisition of smaller CAD or software firms. GE, for example, bought Calma; Schlumberger bought Applicon.

In addition, independent software suppliers have proliferated to meet special applications needs and to meet the growth in demand associated with the spread of micro-based systerns. ** One group of specific applications served by software firms is computer-aided engineering. In this area, MacNeal-Schwendler Corp. and Swanson Analysis offer widely used finite-element analysis packages (MSC/Nastran and ANSYS, respectively). Such specific applications software is typically supplied as part of system packages, or sold directly to users. Software for microcomputers, however, tends to be sold in higher volumes and at lower costs, using networks of distributors and dealers. Other participants in the broader CAD market include producers of such related items as documentation and microfilm generators. These items have come into demand as CAD users developed or perceived new needs associated with CAD. At least four technical publishing companies, for example, started up during the first half of 1983 alone.

A growing but hard-to-measure factor in the CAD market is the participation of CAD users who have developed their own systems—although their role remains small. External sale of internally developed CAD systems allows users to gain an additional return on their investments in software development. Historically, users who developed their own systems did not enter the CAD market for several reasons: Their applications tend to be highly customized; it is difficult and costly to prepare for external marketing; and users may prefer to retain their systems to enhance their own profitability. Lockheed, for example, found meeting divergent market needs to be a major challenge during its first 15 years selling CADAM. IBM is known to have developed its own CAD software, but markets CADAM software instead (it also markets less sophisticated software of its own design).

Ford recently decided to market, through Prime Computer, a 3-D wire frame design and drafting system it developed and has used for the past 10 years; it generalized the system from automotive applications to design of structures, mechanical components, and systems.1' And Chrysler plans to develop with Control Data advanced mechanical CAD and CAM software, which Chrysler would use for vehicle design and development and Control Data

*The Digital Equipment Corp. VAX line has been particularly popular for CAD systems.

"Personal communication Terence Carleton, analyst, Kidder, Peabody & Co.

**The market research firm I DC estimates that annual sales of microcomputer software overall will grow from $965 million in 1982 to nearly $7.5 billion in 1987. Independent firms now supply about 50 percent of that software, and their share may grow to 57 percent by 1987. *Computerworld, March 14, 1983.*

[12] *Computerworld*, June 6, 1983.

would market as part of a line of computer goods and services.[15] Other user-producers include McDonnell Douglas (Unigraphics), the French firm Dassault (CATIA), and Northrop (NCAD).

U.S. firms continue to dominate both U.S. and foreign markets for CAD systems. Ninety percent of the U.S. CAD market is served by U.S. firms. Major CAD vendors operate overseas facilities to serve foreign markets. Intergraph, for example, has a customer support center in the Netherlands that serves customers in Europe and the Middle East. The center carries out repair, training, and other customer support activities. U.S. CAD systems are generally sold in Japan through Japanese distributors."

The international market appears to be experiencing a substantial degree of international merger, acquisition, and especially licensing activity. European firms have developed important CAD software, but Europe lacks significant suppliers of CAD hardware. Consequently, European software has been licensed to U.S. firms (e.g., Evans and Sutherland, Prime, Computervision) that package CAD systems, and U.S. firms have purchased foreign companies. For example, Evans and Sutherland bought Shape Data (United Kingdom), and ComputerVision bought Cambridge Interactive Systems (United Kingdom) and Grado (West Germany). Such "cross-fertilization" is a typical means of entry into foreign markets.

The Japanese role in the CAD market remains limited and focused on hardware. Japanese vendors tend to be computer firms, rather than turnkey companies; they sell systems providing American software under license, although they are developing their own software internally and through a government-sponsored consortium.

Likely Change

The CAD market will remain relatively dynamic for the next several years. Industry analysts predict that it will grow at rates between 30 and 50 percent per year; some forecasts for the CAE sub-market anticipate even higher rates of growth. While industry spokesmen believe that most of the Fortune 500 companies already use CAD, growth will come from both existing and new customers. Factors such as expected improvements in system capabilities, especially for 3-D modeling; greater ease of use; and reductions in costs for given capabilities will widen the range of customers by size, industry, and application area. These trends will create new niches and ancillary-product markets, and they will change patterns of competition. Most analysts expect that mechanical applications and CAE systems will become more prominent in the CAD market, reflecting both technological development and the expected spending growth of manufacturers as they recover from the recent recessions. One source expects that mechanical design will comprise about half of CAD applications, and that CAE will account for about 20 percent of the workstation market, by 1987. Mapping and facilities management applications are also expected to grow, serving government, utility, and natural resource development customers.

CAE has been a major factor in the growth of the custom microchip market.[17] Expected growth in the microchip market overall and the custom share will spur CAE sales. In the mechanical area, future use in forging-die design, for example, will be encouraged by an Air Force project to develop a generic forging-die CAD/CAE system for aerospace applications. The project involves a consortium of firms.[18]

While the market is expected to grow rapidly, the number of vendors may stabilize or

[13] "Control Data and Chrysler to Make Software, *Automotive News*, Dec. 12, 1983.

[14] OTA Automation Industries Workshop.

[15] Jack Thornton and Tsukasa Furukawa, "GE, Japanese Plan Automation Venture," *American Metal Market/Metalworking News, Nov.* 1, 1982.

[16] "1987 CAD Market Estimated at $6.9 Billion," *American Metal Market/Metalworking News,* Dec. 5, 1983.

[17] Bohdan 0, Szuprowicz, "Microelectronics Here Showing Massive Growth," *Computerworld,* Dec. 5, 1983.

[18] Bruce Vernyi, "Shultz Steel Selected by Air Force to Develop Forging Die CAD System," *American Metal Market/Metalworking News,* Jan. 30, 1984.

fall. Consolidation is occurring already, as both turnkey firms and computer companies acquire software houses and expand their offerings. Computervision, for example, recently arranged to buy the Organization for Industrial Research, a privately held CAD software firm with strength in group technology. IBM's growing involvement in the CAD market, particularly at the high end but potentially in low-cost systems, is also likely to promote consolidation.

One trend that may affect sales is the growth in firms offering CAD services and/or related facilities to manufacturers, usually small companies which cannot afford CAD on their own or companies of any size that cannot meet extraordinary needs. These businesses resemble computer time-sharing service bureaus that provide general-purpose computing services. Danly Machine Corp., for example, will sell CAD services through its CAD/Share Service Center to automotive suppliers. In particular, it will provide authorized tool and part vendors with computerized design data to enable them to use CAD in bidding for contracts and performing design and production work for the Buick division of GM. It will also provide CAD training and consulting services.[19]

Some CAD service bureaus provide complementary manufacturing "services." For example, Camax Systems, Inc., sells time on computers to customers designing prototype tools, which it will also manufacture for them.[20] NCR and Control Data Corp. have developed an electronic CAD design center that allows integrated circuit makers and systems houses to design at engineering workstations, have access to a supercomputer, use semicustom circuit "cells," check circuit performance, and arrange for chip fabrication.1

As the installed base of CAD systems grows, the role of vendor services (e.g., software updates, related training) will grow. This growth will reflect in part the growth in sales to smaller firms, which traditionally buy a variety of services they cannot afford to perform themselves. Already (although in part because the recession damped new system sales) Computervision has seen its share of revenues from services to existing customers rise significantly in the last few years.[22] Also, CAD vendors contacted by OTA appear to be increasing their efforts in the area of training, corresponding in part to growth or change in software offerings. The growing role of services parallels the experience in the computer industry, where service activities and their proportional contribution to revenues increased with the spread of computer systems.

The extent to which CAD vendors will address the broader problems of computer-based integration of manufacturing is a key uncertainty for the future of the industry. Compared to other types of firms, especially industrial machinery vendors, CAD vendors may be especially well-positioned to link CAD to CAM. The design-to-production chain begins with CAD, and CAD firms are already developing systems for modeling production activities and communicating production instructions to other equipment. Computervision, for example, offers systems that program NC machine tools, robots, and coordinate-measuring machines; design and model manufacturing cells; design tooling, molds, and dies; and perform computer-aided process planning. It offers multifunction systems, such as a system for plant design, engineering, construction, and management. Prime Computer will market a British computer-aided process planing system which can be integrated with CAD; while McAuto purchased Insight Technology, which developed a CAD system terminal that can be linked to NC machine tools.

As the above examples suggest, many vendors are broadening their lines through acquisitions. Also, some vendors are developing

"⁴' Danly Sets Up CAD/CAM Office for Auto Industry, " *American Metal Market/Metalworking News*, Nov. 7, 1983.

""'Firm Sells CAD/CAM Computer Time to Clients, " *American Metal Market, 'Metalworking News*, Sept. 26, 1983.

"*See CAE*, November–December 1983.

[22]Jack Thornton, "Turnkey CAD/CAM Producers Confront a Difficult Year, *"Amen"can Metal Market/Metalworking News*, Jan. 3, 1983.

their own software to facilitate CAD and CAM links. McAuto, for example, is developing expert systems for evaluating robot system configurations.[23]

Some vendors (e.g., Apollo) are moving away from dedicated CAD terminals in favor of general-purpose engineering/professional workstations. These workstations would accommodate not only drafting and design, but also research, software development, and "office automation" functions; they would thus facilitate shifts in customer activities and software preferences and lower the risk of hardware obsolescence. Multifunction workstations could facilitate manufacturing integration, especially when combined with sophisticated data communication systems linking engineering, production, and general corporate databases. An alternative approach is to market low-cost, dedicated CAD workstations which can be linked to mainframe computers for other functions that use a common database. Some analysts expect sales of such low-cost microcomputer workstations to grow at the expense of minicomputer-based systems, a development that could pose problems for turnkey vendors.[24]

For other CAD vendors, the term "CAD/CAM vendor" will continue to be misleading, since their products serve only design or drafting purposes. Because a market for basic CAD will remain to serve small manufacturers and nonmanufacturing customers, the division of the market between small, "niche" firms and low-cost CAD firms on the one hand, and large, integrated system-oriented firms on the other is likely to deepen. Also, firms not seeking to integrate CAD and CAM may be subsumed by the larger business graphics market, depending on the complexity of their systems.

International competition and trade trends for CAD will depend on how CAD products and markets develop abroad and whether protectionist measures are invoked.* A major uncertainty is the future role of the Japanese in the CAD market. The delayed entry of Japan into this market makes it hard to forecast Japanese competition in CAD, although there are now major efforts under way in Japan to develop CAD software and Japanese companies are actively involved in producing graphics peripherals (e.g., displays, printers, and plotters). However, the Japaneses could concentrate on gaining benefits from the use of sophisticated CAD systems in designing integrated circuits and other products, rather than from the the sale of CAD systems.

[23] Lauri Griesen, "McAuto Working to Add Dynamic Parameters, Expert Systems to Robot Programming Software, *American Metal Market/Metalworking News,* Dec. 26, 1983.

[24] Thomas Kurlak, "CAD/CAM: Follow-Up to Opinion on Changes, " Merrill Lynch Capital Markets, Dec. 7, 1983.

*For example, a Norwegian firm, Kongsberg, is doing very well in the European CAD market.

Numerical Control and Flexible Manufacturing Systems

History

Numerical control (NC) is the oldest of the programmable automation technologies and markets. DOD underwrote the development of the technology in the 1940's and 1950's, and required its use by principal aerospace contractors, thereby assuring the launch of NC production. It also fostered the adoption of APT as the standard NC programing language, and it continues to purchase machine tools through prime contractors as part of the procurement process.

The NC market is a subset of the broader machine-tool market, which contains two principal divisions: metal-cutting machine tools (e.g., lathes, and boring, milling, and grinding machines-SIC 3541) and metal-forming machine tools (e.g., presses, and boring, punching, shearing, and bending machines-SIC 3542). * However, the market for NC machine tools can be treated separately from the overall machine-tool market. inasmuch as customers do not consider NC and conventional machine tools to be alternatives.** This has been increasingly the case: As NC technology has improved, as the cost of controls has fallen, as computerization has improved, and

*other components of the machine tool industry include makers of special dies, tools, jigs and fixtures (SIC 3544), machine-tool accessories (SIC 3545), and other, not-elsewhere-classified metalworking machinery (SIC 3549).

**Note that available data do not always make clear what pertains to NC production and what to machine tools overall.

as applications have grown more complex and costly, many machine tool buyers have come to prefer NC equipment to conventional equipment. Also, customers have grown to understand how and why NC and conventional costs differ, becoming more willing to bear the higher initial cost of adopting NC. *

The "machine-tool industry" has historically referred to builders of machine-tool bodies.** The high cost of developing controllers (estimated to be between $1 million and $5 million) and the tendency for controller cost to fall with high-volume production generally deterred machine-tool builders from building their own controllers. Instead, they bought controllers from firms serving both machine-tool builders and other groups of customers. In 1981, 22 companies made positioning-type (direct data entry) NC controls, 16 companies made continuous path-type (computerized data entry) controls, and 23 made dial or plugboard-type controls. Shipments in 1982 exceeded $192 million; 1981 shipments exceeded $273 million."

The machine-tool industry has had a large number of firms, given the small sales volume of the industry. Many of these firms are small. The 1963 Census of Manufactures counted 1,146 companies with 1,167 establishments, only 415 of which had 20 or more employees. The 1977 Census of Manufactures counted 1,343 establishments, 469 with at least 20 employees. 'e More recent data indicate that there are 1,285 companies with 1,345 establishments, twothirds of which have fewer than 20 employees. The 20 largest companies account for 55 percent of industry shipments; the 50 largest account for 75 percent."

Because NC hardware was relatively expensive, and because its use required access to computers and special support personnel, training, and maintenance, early production and use of NC was concentrated among relatively large firms. Although some smaller aerospace subcontractors did adopt NC in the 1960's, small firms were very slow to adopt NC. The diffusion of NC accelerated in the late 1960's. Between 1964 and 1968, unit shipments of (U. S.) NC machine tools virtually doubled; although unit shipments fell briefly in the early 1970's, they about doubled again in the period 1968-78, and rose over 150 percent between 1978 and 1981.28 During this period, the variety of NC equipment also grew. Sales of NC machining centers (multifunction machine tools made possible by NC technology and the advent of automatic tool changers) grew by over 300 percent between 1970 and 1980.[29] Nevertheless, by 1978 only 2 percent of machine tools in use were numerically controlled; by 1983, that proportion was 4.7 percent.[30] 3]

Meanwhile, growth in demand for industrial equipment fell overall in the 1970's compared to the 1960's, and the relative importance of machine tools in particular also declined. Key metalworking markets grew slowly or shrank in the 1970's due to changes in customer sales patterns, closing of less efficient factories, and increased offshore production. Although booming investment by commercial aerospace and automobile industries caused sales to surge in the late 1970's, the principal machine tool buyers were the dominant firms in different metalworking industries, who could afford major modernization efforts.[32] The decline in

* In some Cases customers retrofit or rebuild older machines to add NC capability; this is usually cheaper than buying new NC equipment. However, machine performance tends to be lower than that provided by new NC equipment.

**However, machinee tools are often sold by nommmufacturer distributors.

"U.S. Department of *Commerce*, Report No. MA-36A.

"National Machine Tool Builders Association, 1983-84 *Handbook of the Machine Tool Industry.*

[27]Eli Lustgarten, Vice President, Paine, Webber, Mitchell, Hutchins, personal communication.

[28]National Machine Tool Builders Association, *1983-84 Handbook of the Machine Tool Industry,* and U.S. Department of Commerce; latest data are incomplete, to avoid disclosure.

'National Machine Tool Builders Association, *1983-84 Handbook of the Machine Tool Industry.*

"'The 13th American Machinist Inventory of Metalworking Equipment 1983, " *American Machinist,* November 1983.

"National Machine Tool Builders Association, 1983-84 *Handbook of the Machine Tool Industry.*

[32]Garry J. Schinasi, "Business Fixed Investment: Recent Developments and Outlook, " *Federal Reserve Bulletin,* vol. *69,* January 1983; John Duke and Horst Brand, "Cyclical Behavior of Productivity In the Machine Tool Industry, *Monthly Labor Review,* November 1981.

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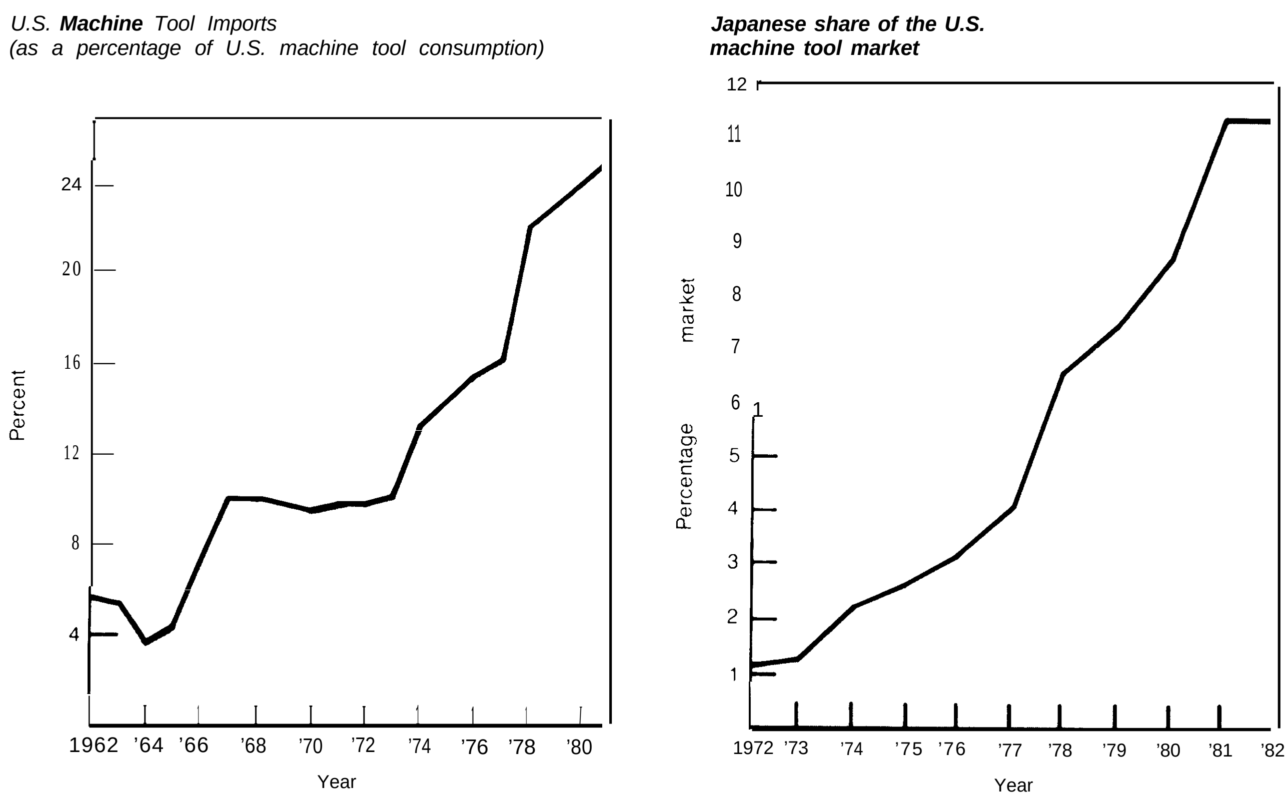
the machine-tool proportion of total expenditures for equipment appears to be due in part to the increase in productivity of individual machine tools (reflecting improvements in cutting tools and other changes as well as the implementation of NC and CNC); productivity improvements allow customers to buy fewer (albeit sometimes more expensive) machines to do a given amount of work. The decline in the machinetool proportion also reflects changes in product design and composition that lower the amount of machining performed. The long-term market decline exacerbates the impact of import competition; it also makes sales to smaller firms and other new categories of customers more important.

The development of CNC, which essentially built computer capability into the machine tool, made NC technology more accessible to smaller firms. However, while the CNC market grew during the 1970's, major U.S. producers tended to neglect the small-firm market. This happened because the large-firm market was strong during the mid to late 1970's. Also, small firms were considered relatively unreliable customers, particularly sensitive to machine-tool market cycles and lacking in technological sophistication.

During the 1970's, the Japanese increased their share of the U.S. NC machine-tool market. They quickly dominated the U.S. market for small NC lathes and machining centers (see fig. 28). The import success of the Japanese has been attributed to several factors, including the inadequacy of domestic capacitv (which has led delivery times to rise to between 1.5 and 2 years), the Japanese strategy of concentrating on selling a few products to assure competitive advantage, * and favor-

*BY focusing on a few products, Japanese Producers gained scale economies, allowing more flexibility in pricing.

Figure 28.—Machine Tool Import Trends



SOURCE National Match Tool Builders Association on able exchange rates, which gave the Japanese a price advantage relative to U.S. firms. Other factors, discussed below, include the slowness of U.S. machine-tool firms to adopt new technology and differences in U.S. and Japanese market characteristics (and related government policies).

The U.S. machine-tool industry has historically been slow to adopt new technology. Because of relatively low levels of capital investment, the average age of equipment used in the machine tool-producing industry has been relatively high and the level of equipment sophistication relatively low. Old equipment appears to be a factor in the poor productivity performance of the industry in the past (productivity growth in machine tools peaked in 1966, subsequently declined, and rose again in the late 1970' s).[83] The machine-tool industry has tended to rely more on skilled labor than on advanced equipment in production. This pattern developed because of the complexity and low production volumes of machine tools; the prominence of small, small-batch producers with limited ability to invest in new equipment; and the high levels of financial risk in the industry. * The machine-tool business is considered financially risky because of its sensitivity to changes in the business cycle and in the buying patterns of major customer groups including DOD, other equipment producers, and makers of consumer durables. Prior to the recent pair of recessions, business declined severely for the industry in 1956-58, 1969-71, and 1974-75.

Characteristics of the U.S. NC industry may have undermined its competitiveness. Three dimensions for comparison are interfirm communication, relative specialization, and attention to small firms. According to some analysts, compared to Japanese firms, U.S. producers of machine tools, controllers, and semiconductors have not communicated well with each other. To improve the match between machine tools and controls, major machinetool builders attempted to produce their own controllers during the 1970's; most failed to do so successfully. In contrast, Japanese producers of semiconductors, controllers, and machine tools appear to have communicated well, and they have participated in cooperative R&D and product development efforts. Cooperative efforts and communication appear to have been encouraged by the Japanese Government (see ch. 9). * These collaborations may have contributed to their rapid domination of the small machine tool market.

The different patterns of interaction among firms in the two countries are due, in part, to different industrial structures. In Japan, the major producers of machine tools and controls are highly specialized, although they are linked as "independent" subsidiaries to producers of related products. For example, the leading Japanese control builder, a monopolist, is also linked to related businesses: Fuji, a leading electronics firm, spawned Fujitsu, a leader in industrial controls, which in turn spun off Fanuc, a specialist in NC controllers. Most Japanese machine-tool companies have standardized their products to use Fanuc controls. By contrast, in the United States, GE once dominated the NC control market but lost its shares to competitors such as Allen-Bradley because it failed to keep pace with market and technological developments. (This may have happened because GE does not focus exclusively on the machine-tool market, or because of bad managerial judgment, or both.) While the Japanese pattern of specialization may have facilitated early production and use of NC, its value in more complex areas-such as

[83]John Duke and Horst Brand, "Cyclical Behavior of Productivity in the Machine Tool Industry, " *Monthly Labor Review*, November 1981.

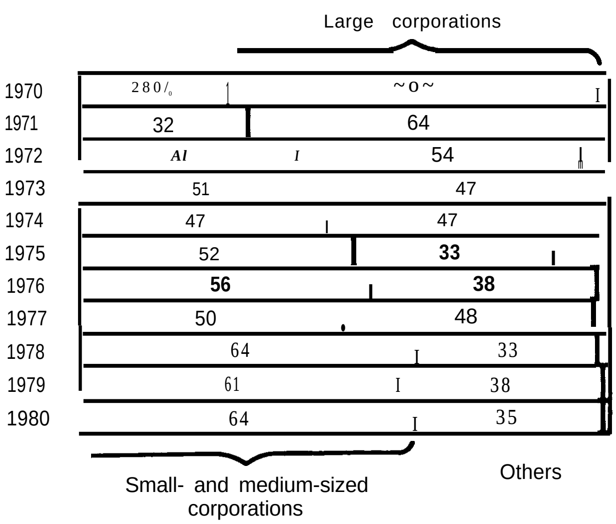
*on the other hand, some critics of the industry—in particular, the industry leaders–charge that management became overly interested in new technology. David Noble, for example, argues that the machine-tool industry has suffered from "unreasonable technical enthusiasm and a shift away from the shop floor as a repository of innovative and practical ideas toward the laboratories . . . ." David Noble, "An Outsider's View of Machine Tool Industry, " *American Metal Market Metalworking News,* Aug. 8, 1983.

*They have also been cited in recent industry appeals for U.S. Government intervention, including the 1982 petition by Houdaille to deny investment tax credits to purchasers of Japanese NC machining centers and punching machines, and the 1983 petition by the National Machine Tool Builders' Association for restriction of machine tool imports on national security grounds.

machining cells or FMS—that draw on electronics and mechanics is less clear.

Finally, Japanese import penetration built successfully on the unmet demands of smaller firms for NC equipment. Japanese production and use of smaller NC equipment was relatively well-established before exports were significant. About two thirds of NC equipment in Japan is bought by small-and medium-sized firms (see fig. 29). Smaller firms have historically been a focus of Japanese Government support and interest (a legacy of the relatively recent transition of the Japanese economy away from an agricultural base). Unlike the U.S. Government, the Japanese Government focused its support for NC diffusion on commercial/civilian use, especially by small and medium-sized firms. Also, ties between final customers and producers appear to be stronger in Japan, another factor that may have hastened NC diffusion in Japan. The expertise gained by Japanese machine-tool builders in smaller NC installations helped them to serve the small-user niche in the U.S. market, while the increase in production volume afforded by sales to markets in two countries lowered costs.

Figure 29.— Breakdown of Japanese Numerically Controlled Machine Tool Shipments by Size of End Users (percent)



SOURCE Japan Machine Tool Builders Association Reproduced in Machine Tool Industry The Long Road to Recovery" by Eli Lustgarten, Paine Webber Mitchell, Hutch Ins, Aug 8, 1983

Recent and Contemporary

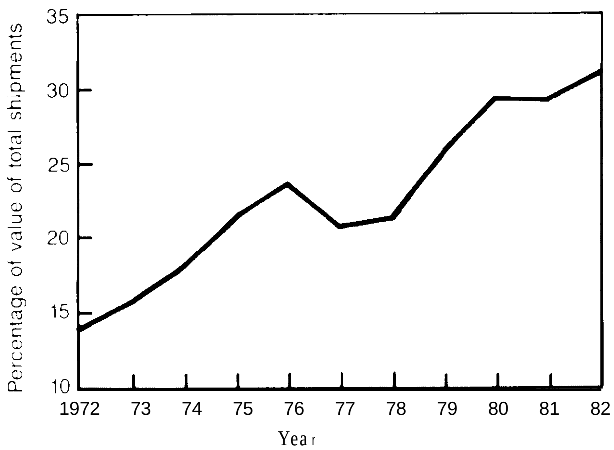
The NC industry in the United States has become more competitive as declining costs have allowed more companies to produce equipment for small customers. The fact that NC machine-tool builders continue to be larger, on average, than non-NC firms is a legacy of the past, when only large firms could bear the expense and risk of NC production. Financially, the machine-tool industry as a whole has been suffering. New orders peaked in 1979 at $5.62 billion, declining 75 percent to $1.5 billion in 1982 and continuing at 1982 levels through the first half of 1983. The decline of orders has been sharper than the previous decline in 1973-75, and the reduction in capacity utilization has been aggravated by the fact that capacity had expanded in response to the late-1970's surge in demand.[34]

U.S. NC producers have been selling higher proportions of NC equipment relative to total machine-tool volume. By 1982, NC accounted for nearly 35 percent of total machine-tool shipments (see fig. 30). Producers also are broadening their product offerings to include not only NC equipment aimed at smaller users, but also machines for processing other materials such as plastics, as well as flexible manufacturing systems (FMS) which link individual machine tools and materials handling equipment and are computer-controlled.

FMS, as a cornerstone of so-called horizontal integration of production, provides a vehicle for machine-tool builders to expand their activity in selling integrated programmable automation. These systems also help machine tool builders serve new groups of batch-production customers whose output (10 to 50 parts per hour) is less than that required to justify transfer lines but more than that which single pieces of equipment can handle. Aerospace firms appear to be particularly interested in FMS.

[34]Eli Lustgarten, "Machine Tool Industry: The Long Road to Recovery, " status report, Paine Webber Mitchell Hutchins, Aug. 8, 1983.

Figure 30.–Value of U.S. Shipments of Numerically Controlled Machine Tools as a Percentage of Value of Total U.S. Machine Tool Shipments (for machines valued over $1,000 1972-77 and over $2,500 1978.82)



NOTE. 1982 data are for first three quarters

SOURCE U.S. Department of Commerce, "Current Industrial Reports. Series MQ-35W, Metalworking Machinery" (quarterly and annual summaries)

Although the market for FMSS is relatively small and existing FMSS have been largely experimental, machine-tool firms appear eager to supply FMSS and even to underprice bids.” The leading FMS vendor is Keamey & Trecker (part of Cross& Trecker), which has sold about half of the FMSS installed in the United States. Other vendors include Cincinnati Milacron, WhiteSundstrand, Ingersoll Milling Co., Mazak Machinery Co. (Yarnazaki), and Giddings & Lewis Machine Tool Co.

The association with advanced technology afforded by FMS offerings can be helpful to producers for marketing purposes. For similar reasons, some machine-tool builders (e.g., Cincinnati Milacron and Textron/Bridgeport) are beginning to sell robots. Also, U.S. firms may emphasize “high-technology” capital goods as a competitive strategy, telling customers that higher prices relative to the Japanese reflect a technology premium. Finally, support for FMS development (and purchase by aerospace firms) is provided by DOD projects promoting the design and use of integrated manufacturing systems. While FMS offers users the potential for savings in production time, direct labor, floorspace, and work-in-process inventory, the number of customers is low because existing systems are expensive, require extensive planning and support, and prove relatively difficult to operate successfully (at least at first).

Trade trends, especially imports, remain a salient feature of the contemporary NC and overall machine-tool industries. The U.S. balance of trade in machine tools became negative in 1977 and has steadily worsened. Japan is the principal source of U.S. machine tool imports. Other major import sources are West Germany, the United Kingdom, Taiwan, Switzerland, and Italy. The decline in domestic production in 1983 contributed to growth in the percentage of imports relative to 1982 levels, from 28 to about 37 percent for metalcutting machine tools and from 22 to almost 36 percent for metal forming machine tools.[36] The Japanese share of the U.S. market for some machine-tool products exceeds 50 percent. It is greatest for NC lathes and machining centers, which are the fastest growing markets in the United States and abroad.” Because of the recession, Japanese machine-tool exports declined significantly from their 1981 peak in 1982 and 1983.[38] Various government and trade groups are currently examining whether the Japanese have engaged in unfair competition and debating whether the machine-tool industry in the United States has a special claim to the public interest for national security reasons. *

“AS of late 1983, Kearney and Trecker reported about $250 million worth of proposals with high likelihood of becoming orders. “Machinery Capital Goods Industry: Flexible Manufacturing Systems, Kidder, Peabody, & Co., Inc., Sept. 30, 1983.

[36] U.S. Department of Commerce *1984* U.S. *Industrial Outlook* (Washington, D. C.: U.S. Government Printing Office) January 1984.

[37] See Eli Lustgarten. “Machine Tool Industry: The Long Road to Recovery, ” status report, Paine Webber Mitchell Hutchins, Aug. 8, 1983.

[38] Mark Sfiligoj, "Imports from Japan Fall, *American Metal Market 'Metalworking* News, Japanese Machine Tools Supplement, July 11, 1983.

*The National Academy of Sciences, the International Trade Commission, the Department of Commerce, and Congress have actively considered machine-tool industry issues during the past 2 years.

U.S. exports have also been declining, due to worldwide recession and to longer term, noneconomic reasons. During the late 1970's, changes in foreign policy curbed shipments to Eastern Europe and the U. S. S. R., while durin the early 1980's, the nationalization and/ or government-imposed consolidation of machine-tool industries in such countries as France, Spain, and the United Kingdom have effectively closed these exports markets to the United States. *

Some companies based abroad have begun to produce machine tools in the United States. Mazak (a subsidiary of the Japanese firm, Yamazaki) has established a highly automated facility in Kentucky for producing NC lathes and machining centers. Other firms, such as LeBlond-Makino, Hitachi Seiki, and Scharmann Gmbh., are only assembling foreign-designed equipment in the United States. And some foreign firms, such as Mitsubishi Heavy Industries and Toyoda Machine Works, have licensed machine designs for production by U.S. firms.

Likely Change

During the next two decades there may be a resurgence in machine-tool demand as part of a broader trend toward industrial modernization. Several analysts anticipate such a trend, since about a third of machine tools in use in the United States are at least 20 years old.[39] Indeed, recent research shows that older, Midwestern plants are among the principal buyers of new machining technology .40 The Department of Commerce has forecast relatively rapid business growth for the machine-tool industry during 1984, but it expects shipments to remain below the 1982 level.[41]

Structurally, the overall U.S. machine-tool industry is likely to continue to contract. This should happen because of the persistence of heavy financial losses during the early 1980's, because of the movement of the U.S. firms away from domestic production of hardware, and because import competition appears to have eroded U.S. market share permanently. Also, lack of experience in manufacturing systems and limited capability to develop software are likely to restrict entry into FMS and related businesses. It is possible that only the largest companies may be able to develop the extensive software and electronics expertise needed to succeed in the systems market.

While the machine-tool industry as a whole contracts, the NC share of the industry will continue to grow. This will be hastened by the anticipated rapid decline in the cost premium of NC relative to conventional machine tools. It will also reflect market withdrawal of small and medium-size firms unable to afford to modernize their products and facilities. Increasing sophistication of NC products and increased emphasis on integrating NC equipment into manufacturing systems, both of which entail an ongoing infusion of computer/ electronics technology, may make the future machine-tool industry more of a "high-technology" industry than it has been, How the industry will evolve depends on several factors which bear on the competitiveness of the industry, such as new product and market (segment) development and increased efficiency.

Major machine-tool builders have begun modernizing their own facilities, resorting in many cases to greater use of programmable automation. For example, the Wickes Machine Tool Group, Inc., has arranged to purchase a CAD system to help it compete with larger firms; Kearney and Trecker (Cross & Trecker) is installing one of its own FMSS; Brown & Sharpe Manufacturing Co. uses CAD to design new products and to translate plans for 3-D products into 2-D patterns for sheet metal processing; and Ingersoll Milling Machine Co. has used CAD to develop a new FMS.[42] But

*The French program began in December 1981 and tires to double French machinetool production, raising it to about $995 million by 1986. One of the program's goals is to halve the 60 percent import penetration of 1980 by the middle of the decade. *American Metal Market/Metalworking News,* July 25, 1983.

[39] "The 13th American Machinist Inventory of Metalworking Equipment 1983, " *American Machinist,* November 1983.

[40] John Rees, et al., "The Adoption of New Technology in the American Machinery Industry," Occasional Paper No. 71, Maxwell School of Citizenship and Public Affairs, Syracuse University, August 1983.

[41] "Commerce Department Foresees Metalworking Gains, " *American Metal Market/Metalworking News,* Jan. 2, 1984.

[42] *"Amen"can Metal Market/Metalworking News,* various issues.

the costs of modernizing in the context of strong import competition and a sluggish market may lead other firms to withdraw from the market. Machine-tool builders have also contemplated cooperative research ventures, and several companies have recently built new research facilities. For example, Cincinnati Milacron, Inc., has completed a new research center; Ex-Cell-O has a new technology center; Monarch Machine Tool is forming a new engineering development lab; and South Bend Lathe is adding a new engineering group for its research division.[43]

Rather than improve domestic plant ancl equipment, there is already evidence of a growing reliance by U.S. firms on foreign companies, or on their own production facilities, abroad, for the hardware they sell. As one machine-tool industry executive explained to the International Trade Commission:

> It is essential to distinguish between the future prosperity of American companies that trade in machine tools and the future prosperity of the domestic machine tool building industry. Cross & Trecker is committed to the business of machine tools, but it is not committed to build in the United States all or any specific portion of the machine tools it sells here.[44]

Bendix, before deciding early in 1984 to divest its industrial automation operations, planned to introduce new products while shifting the production of other products (small CNC lathes and chuckers) to Japan, where it participated in a joint venture with Murata Machinery Co. Also, it had invested in the Italian firm Comau, which could have provided it with hardware; and it had arranged to be the exclusive distributor of Toyoda Machine Works NC machine tools in the United States and Canada. Acme-Cleveland and Cross a Trecker have forged agreements with foreign firms to supply equipment to replace or add to products already made and sold in the United States. Another firm, Sulzer, has recently chosen to enter the U.S. market by selling Italian equipment under license. On the other hand, Cincinnati Milacron officials have stated that they plan to continue to produce commodity machinery, in part because advances in machine-tool technology make control over the design of both hardware and controls important.[45] Yet some of their equipment may be produced in their European facilities. Interestingly, the willingness of leading U.S. machine-tool builders to move offshore suggests that they do not believe that PA technology alone would sufficiently lower their own production costs.

Three principal areas of new product development that may benefit the domestic industry are products for processing nonmetal materials, products aimed at smaller users, and manufacturing integration. Products for processing nonmetal materials include machinery for processing plastics, especially composite materials (used increasingly by the aerospace industry). The growing substitution of plastics for metals in the aircraft, motor vehicle, and appliance industries, among others, is feeding long-term growth in plastics machinery sales. Cincinnati Milacron, for example, not only makes computer-controlled plastics molding machinery but offers robotic cells for plastics production and equipment for producing and inspecting items made with composites. Other equipment may be aimed at processing ceramics, used increasingly by the auto and aerospace industries, in particular.

There are several reasons why machine-tool firms may aim to serve smaller customers. One is that the huge automotive and commercial aerospace purchases of the late 1970's are not likely to be repeated; thus, defense spending and small firms may become key forces in the market. * An argument for growth in small-user demand is increased competition among

“*Amen”can Metal Market/Metalworking News*, June 12, 1983; NMTBA Pet. Supp.

[44]Rosanne Brooks, “Tool Builders Consider Offshore Sites, ” *Amen”can Metal MarketMetalworking News*, July 4, 1983.

“Bruce Vernyi, “ Machine Builders Look to New Technology Products: Some Concede Standard Lines to Foreign Firms, ” *American Metal Market/Metalworking News*, June 13, 1983.

*Note that offset, coproduction, and other agreements are increasing the foreign production component of U.S. civil and military aircraft, a trend that adversely affects U.S. parts suppliers and presumably constrains U.S. machinery demand.

smaller metalworking firms for business, a trend indicated both by OTA case studies and by other evidence. The benefits of NC in terms of improved production reliability, better cost estimation, and faster production time may & come increasingly attractive to smaller users facing high competition for machining work. On the other hand, since small manufacturers were the principal victims of the past recessions, their spending capacity is uncertain.

Other motivations include the possibility of tighter links between prime manufacturers and subcontractors in the automobile and aerospace industries. These links are associated with such inventory-control strategies as the just-in-time system, which tends to be accompanied by singlie-sourcing of supplies, and with the spread of programmable automation itself, which encourages direct computer links between manufacturers and suppliers. The National Tooling and Machining Association (NTMA), for example, has arranged seminars between major auto producers and metalworking suppliers to facilitate the transition to PA. The possibility of closer links with their customers may spur metalworking and other suppliers to modernize their facilities; in effect, such a requirement may be imposed on them.

Though smaller users offer a potential for market expansion, the primary U.S. competitive strength continues to be in larger, more complex systems. This is one reason why machine-tool builders may seek to procure smaller products from foreign sources. Lodge and Shipley, for example, has begun to market small CNC lathes from Italy. Strength in large systems is also a reason why major NC producers are likely to further emphasize inte~ati manufacturing, through supply of manufacturing cells, FMS, and other integrated systems, and through the production of robots. Cross & Trecker, for example, recently formed a division to produce automated materials-handling devices. It also acquired Bendix' operations for industrial controls, machine tools, and robots.

Machine-tool builders may continue to expand into robot production because, among other reasons, robots can complement machine tools or accessories (e.g., loaders, changers) within FMS or other settings. Also, transfer lines and other special machine-tool products are expected to be more flexible and capable of producing small lots and component families economically. They will include advanced computer control and monitoring, sensors, and automated functions for stock delivery, gauging, loading, and removal of broken tools.[46]

While NC producers may supply integrated systems by making key components and s~ftware themselves, it is also possible that they may adopt a turnkey approach, assembling components made by a variety of companies. As NC machine-tool builders become better able to match machine tools with controls, and as users seek to standardize the controls they use, machine-tool builders may become increasingly willing and able to offer their equipment with a variety of options for controls.[47] Turnkey operation is also more likely if NC firms continue to diminish their domestic production and focus more on machine-tool distribution. On the other hand, machine-tool builders may establish links with such firms as IBM, GE, or Westinghouse, supplying hardware which those firms would package for sale with engineering services, controls, and software.

Control makers themselves are already involved in the integration field. Allen-Bradley, for example, offers an "area control " system to integrate management and operation functions. It is working with 3M and Western Digital to develop a broadband local area network that would allow a wide range of manufacturing devices to communicate. Both systems would accommodate equipment from different vendors, making integration more accessible to users.

Regardless of how much hardware NC suppliers build themselves, their nonproduction activities will continue to increase. This trend

[48]A1 Wrigley, "Versatile Transfer Lines, " *American Metal Market/Metalworking News,* Aug. 15, 1983. Lauri Giesen, "Transfer Line Design is Changing Rapidly, *American Metal Market/Metalworking News,* Aug. 15, 1983.

[47]See, for example, "Bridgeport Shows Tools, " *American Metal Market/Metalworking News,* Sept. 20, 1982.

is due in part to the large need for support activities associated with the design and implementation of complex systems like FMS. Such systems require extended (2 to 5 years) planning by users, whether for retrofit or new-facility installations. NC producers have begun to establish service units that advise customers in the planning for and design of automated systems. For example, several firms, including Cincinnati Milacron and Allen-Bradley, now have automation consulting units.

Future trade trends in the NC industry are difficult to predict, although the status of the U.S. market as the largest machine-tool market in the world (followed by the U. S. S. R., West Germany, and Japan) suggests that foreign competition will persist. Key factors bearing on U.S.-Japan competition are the prospects for protectionist action by the United States and of voluntary export curbs initiated by the Japanese, although the Japanese already have large inventories positioned in the United States. More generally, other factors affecting trade patterns include the development of foreign markets, and changes in U.S. customer demand. For example, Ford's shift from turning to milling of crankshafts offers new opportunities to foreign machine-tool firms, which already produce for this application (unlike U.S. firms) .48 Other changes in customer products and processes may also affect the competitive balance. Finally, competition in NC will depend on the relative similarity of national preferences. For example, Japanese vendors and users appear to prefer relatively simple FMSS, while U.S. companies appear to prefer more sophisticated systems. " If NC sales, including FMS, become increasingly oriented toward integrated systems, the traditional U.S. strength in software and systems technologies may prove to be an enduring advantage.

[48] Jack Thornton, "Ford Engine Plant to Mill Rather Than Turn Cranks, " *American Metal Market' Metalworking News*, Sept. 20, 1982.

[49] "In FMS, Simplicity Governs, " *American Metal Market-working News*, Japanese Machine Tool Supplement, July 11, 1983.

Robots

History

The role of entrepreneurs, and the absence of a major government role, distinguish the early development of the robotics industry from that of other PA technologies. After Unimation installed the first commercial robot in 1961 in the auto industry, sales were negligible for about a decade. With a virtual monopoly, Unimation had sold only 200 robots by 1970.[50] One other firm, Versatran (now part of Prab Robots), also sold a few robots during that first decade. Several other firms investigated robotics technology during the 1960's without entering the market.

By the mid-1970's, robot sales in the United States had risen to about $15 million. Cincinnati Milacron and DeVilbiss (machine-tool builders), Autoplace (Copperweld Robotics, until sold in early 1984), Prab Conveyors (a materials handling equipment maker, which bought out Versatran and became Prab Robots), and Swedish-owned ASEA had become significant vendors, although Unimation remained the leader. Cincinnati Milacron and ASEA developed their own robots, but they also licensed technology from Unimation,[51] while DeVilbiss sold robots licensed from Trallffa (of Norway). The automobile industry was the principal customer, buying robots for applications such as spot welding and spray painting. Figure 31 shows market growth trends.

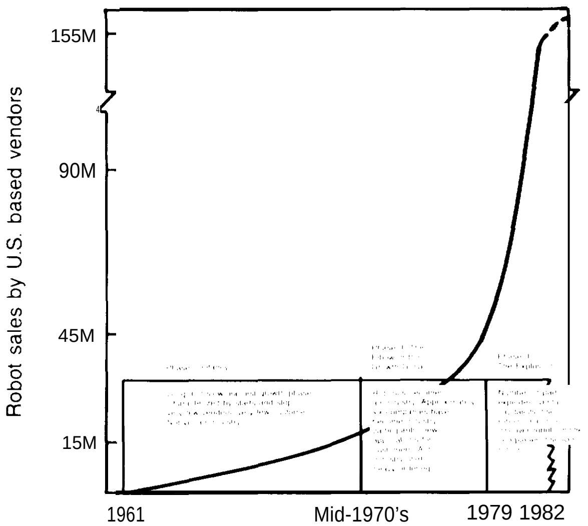
Major investment programs by automobile manufacturers led the growth in demand for robots in the late 1970's. Although the auto industry was already heavily automated, volatile consumer demand and variable production runs created a growing problem of premature obsolescence of plant and equipment. These factors, plus foreign competition, generated pressure to reduce costs as well as increase flexibility and quality in production.

[50] "Tackling the Prejudice Against Robots, "Business *Week*, Apr. 26, 1976.

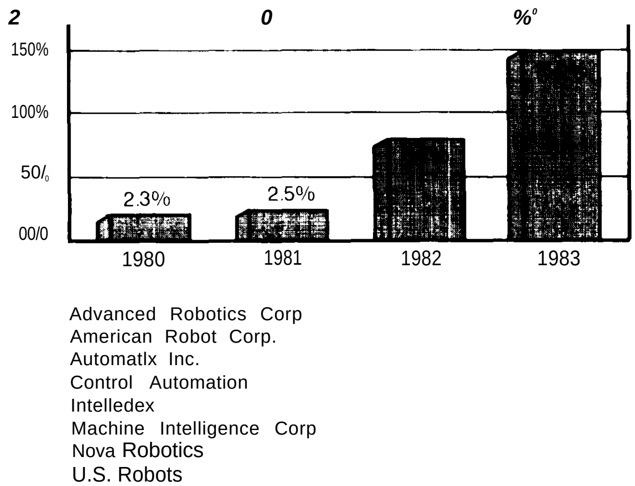
[51] " Robot Makers Still Waiting for Promised Big Markets, *Electronic Business*, October 1980.

Figure 31.—Robot Market Trends

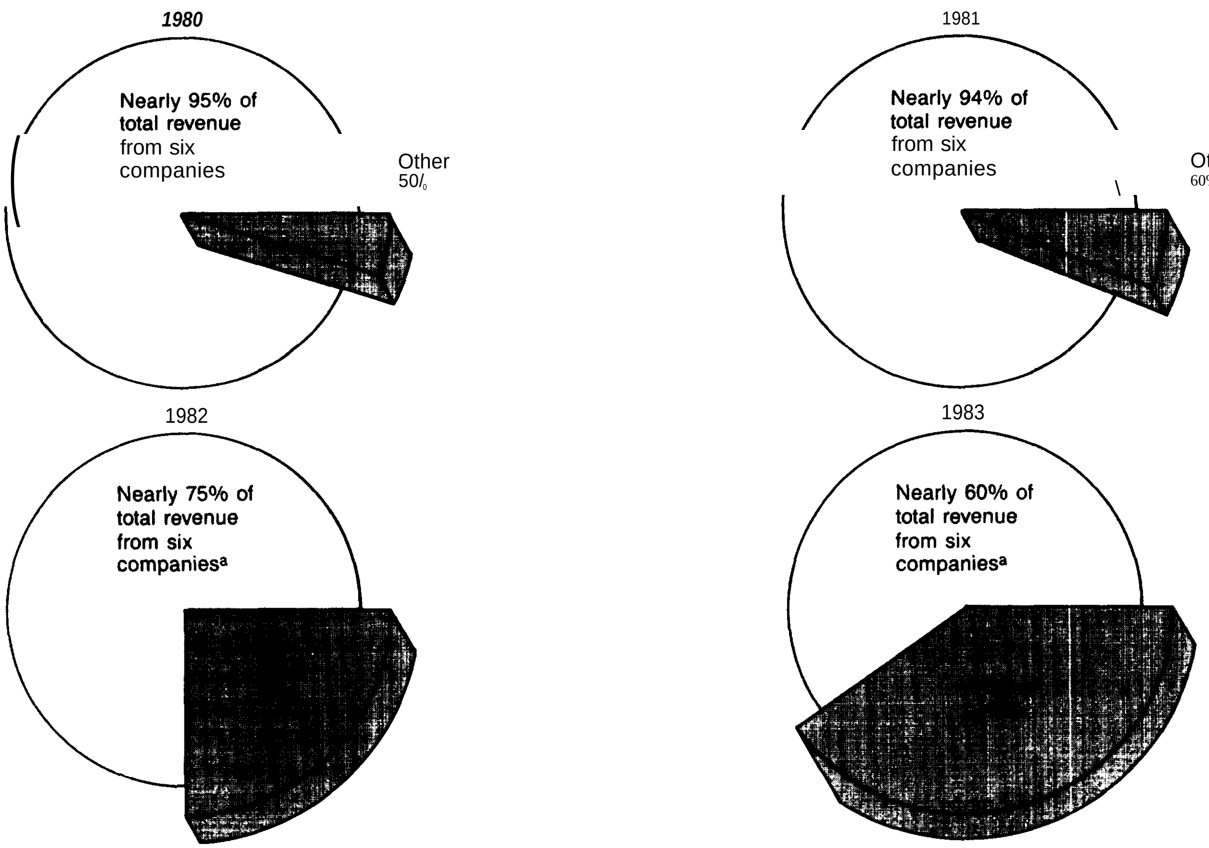
The phases of the *robot industry*



Market share: startup companies only; 1980-83



Changes in market share composition, 1980-83



[a] Unimation, Cincinnati Milacron, DeVilbiss, Asea Inc., Prab Robots Inc., Copperweld Robotics

SOURCE: Prudential Bache Securities Inc.

Substitution for less flexible equipment, and the reduction of labor costs, were both major motivations for automotive use of robots. By late 1980, 1,400, or nearly half of the 3,200 robots Unimation had installed, were for spot-welding applications.[62]

The potential market for robots in the aerospace and electronics industries was also explored during the 1970's. The aerospace industry, unlike the automobile industry, contained relatively few obvious applications, because aircraft are very high-precision products produced in small batches; early robots tended to be insufficiently precise and relatively expensive to adapt for each use. During the mid to late 1970's, DOD programs (e.g., ICAM) aimed at improving defense procurement motivated the evaluation, perfection, and adoption of robots by large aerospace firms working in conjunction with government and university researchers (see ch. 8). Although DOD technology-diffusion programs also evaluated the use of robots for electronics applications, the electronics industry was largely responsible for developing its own early applications. Firms such as Texas Instruments and IBM developed robots and applications in such broad areas as materials handling and simple assembly.

Foreign firms have participated in robot markets since the 1960's. The Japanese industry grew bigger and at a faster rate than the U.S. industry.* This happened in part because the Japanese Government encouraged robot use by small and medium-sized firms, through such measures as a robot leasing program (see ch. 9). The typically close links between major Japanese manufacturers and their suppliers also served to promote growth in smaller firm use of robots. In 1968, Kawasaki licensed robot technology from Unimation, becoming the first and leading Japanese producer. Japanese vendors proliferated, as companies that had earlier built robots for their own use (e.g., Pentel, Seiko) entered the external domestic market. Across a relatively broad range of industries and firm sizes, Japanese firms adopted robots and other forms of automation relatively quickly because of a shortage of skilled, entry-level labor in Japanese manufacturing industries, particularly those industries in which production work was considered onerous.

During and since the 1970's, other major producers of robots have appeared in various European countries. Trallfa of Norway is a major producer of spraying robots; its technology is licensed to DeVilbiss. ASEA of Sweden is a major producer of arc-welding robots; it has a U.S. subsidiary and operates in several other countries. Vendors based in France, Italy, West Germany, the United Kingdom, and other European countries, where indigenous industries tended to develop around the local auto industries, also began to sell robots in the United States.

Recent/Contemporary

The robot market has reportedly grown to exceed $200 million in sales in the United States, and perhaps $1 billion worldwide.* The robot business, however, remains unprofitable—the growth of sales has been described by Laura Conigliaro, a financial analyst of the robot industry, as "profitless prosperity. " One industry participant recently compared the estimated $200 million in 1982 sales with about $500 million in costs.[53] The ITC con-

"Ibid.

*,Japanese robot production (not necessarily restricted to U.S. robot definition) grew from 200 units ($1.6 million) in 1968 to 8,600 units ($8.7 million) in 1977 and 19,387 units ($314 million) in 1980. "Japanese Production Runs Limit Robotic Investments, '*Aviation Week and Space Technology,* Aug. 2, 1982.

*Industry analysts estimate that 1982 sales were $200 Million, while 1983 sales are believed to approach $240 Million. The International Trade Commission estimated that 1982 U.S. sales by domestic firms alone were under $140 million. Note that it is hard to measure sales and profits because most vendors are privately held or are small parts of large companies that do not break out sales data. Therefore, industry analysts generally seek to count units sold and estimate sales based on average price. Average price, however, will vary depending on customer preferences for accessories and other items accompanying the sale of the basic manipulator.

[53]Laura Conigliaro and Christine Chien, "Computer Integrated Manufacturing, " report of the April 1983 Prudential-Bache Securities Symposium on Computer-Integrated Manufacturing, Prudential-Bache Securities, Aug. 2, 1983.

eluded from its industry survey that robot vendors lost money through the 1979-83 period.[54] **There are** several reasons for this situation, which stems from the immaturity of the market. Vendors are trying to position themselves in a nascent market, they often deliver products they have yet to perfect, and users often require extremely high levels of service and support to make an application successful. Consequently, high costs for marketing, applications development, support, and production of special tooling erode profits from robot sales. Table 58 lists shipment estimates from ITC (note that since 1980, shipments have included a significant fraction of robots for instructional purposes)."

Among users, the auto industry continues to dominate; other major users include aerospace, electronics, machinery, foundries, and miscellaneous light manufacturing (see table 59). Among applications, spot welding, machine loading, spray painting, and materials handling are most prevalent, although arc welding, inspection, and assembly applications are becoming more common, in part because of a growth in sensor technology, especially vision systems, for robots. From 70 to 80 percent of robots in the auto industry are used for welding.

Because the robot market holds the prospect of eventual profits, U.S. robot vendors have proliferated since 1980. While Unimation and Cincinnati Milacron still lead the market, they face competition from a diverse set of market entrants, including small, innovative startup firms and large, diversified multinationals. There are about 100 U.S. vendors, compared with about 250 in Japan and several dozen in Europe. * The market includes both full-fine firms and niche firms. The strongest competitors offer a range of products. In addition to robot assemblers, there are other firms concen-

"'Competitive Position of U.S. Producers of Robotics in Domestic and World Markets, " U.S. International Trade Commission, Publication 1475, December 1983.

"Ibid.

[56]See, for example: Laura Conigliaro, "Trends in the Robot Industry (Revisited): Where are We Now?" *13th International Symposium on Industrial Robots* **and** *Robots 7,* conference proceedings, Robotics International of SME, Apr. 17-21, 1983.

*Also, there are at least 30 Japanese firms that produce robots only for themselves and their shareholders. Paul Aron, "The Robot Scene in Japan: An Update, " Paul Aron Report No. 26, Daiwa Securities America, Inc., Sept. 7, 1983. It is not clear how many U.S. firms produce for their own use, although IBM and Texas Instruments are examples of firms believed to do so. Square D, for example, is an electrical equipment maker that bought a young robotics firm, U.S. Robots, Inc., (which produces "Maker" robots) to obtain robots for its own small-part production. The ITC concluded from its industry survey that only 6% of shipments were intracompany (captive). The prevalence of user-producers in Japan accounts for the greater number of special-purpose robots in Japan.

Table 58.— Robots: U.S. Producer's Domestic Shipments, by Types, 1979-83

Type	1979	1980	1981	1982	1983"
			Quantity (units)		
Spot welders	155	344	644	434	372
Arc welders .,	28	52	57	91	196
Coaters	0	0	26	156	153
Assemblers and material handlers[k] ., . .	114	153	259	550	1,025
Metalworking apparatus .,	4	7	10	16	15
Loaders/unloaders .,	79	111	167	163	188
Others[L] . ,	63	141	344	697	717
Total .,	443	808	1,507	2,107	2,666
			Value (1 ,000 dollars)		
Total	19.168	43.293	90,076	122,523	134,916
			Unit value		
Average	$ 43,267	$ 53,580	$ 59,772	$ 58.150	$ 50,606

`'Ddtd for ```````1983 are bdsed on projections provided by U S producers
[t]Data are combi ned 10 prevent 151 sc losu re
Includes small instruct ion al and ed ucatio nal de, c es
[d]Data by types are not available

SOURCE Compiled from data submitted in response 10 quest ionnai res of the U S I nternation al Trade Commission

Table 59.—U.S. Robot Population by Application and Industry, End of 1982

	Auto	Foundry	Nonmetals light Manufacturer	Electrical, elec-tronics	Heavy equp-ment	Aero-space	Total
	1“				1		2200 (35%)
Material handllng		1	1	1			1550 (250/o)
Machine loadlng	2	2			2		1250 (20%)
Spray palntlng, fln!shlng	3		2	3	3	1	600 (1 00/o)
Assembly				2		2	200 (3%)
Machlnlng							100 (2%)
Other							300 (5%)
Total	2500	1250	1050	700	600	100	6200 (1 000/o)
	(400 ’0)	(2000)	(170’0)	- (110’0)	(10%)	*(2%)*	

‘About 70 80 petcent robots auto industry areused for welding

SOUCE Tech Tran Corp.

trating on ancillary products such as end-of-arm tooling, motors, and other components for robots. Finally, not all vendors produce their wares: probably only about 50 U.S. firms actually produce robots.” Competition is intense, and some firms have already exited the market (e.g., Black & Decker, Kulicke & Soffa).[58] Copperweld Corp. left the robot market after recent losses on robotics systems and vision products, although it was considered the largest U.S. maker of small robots when it entered the market in 1979 (via acquisition). Similarly, Nordson Corp. is planning to divest the robotics division it formed in 1980.

Entry into the market has occurred through licensing of foreign technology, mergers, and acquisitions, as well as through new-product development. GE, for example, entered in 1981 by licensing Italian and Japanese-designed robots. GCA and Automatix are among the many companies that distribute Japanese robots under their own names, and at least one American firm has licensed a Scottish-designed robot.[59] * Cross-fertilization, through licensing, outsourcing, joint ventures, or other means, is a key feature of this market (see discussion below). Several vendors even offer robots using the same basic manipulators.[60] The prevalence of cooperative efforts is not surprising given the fact that developing a prototype robot alone costs upwards of $1 million, while the full costs of market entry are closer to $15 million to $20 million. The costs of entering and operating the business are even higher.

Several firms have been financed by venture capital, although external financing is believed to be less available now than it was just a few years ago. Intelledex, for example, was founded in 1981 by former Hewlett-Packard employees using venture capital; it is developing sophisticated robots with vision for electronics assembly. Control Automation, founded at about the same time by former Western Electric personnel and funded by venture capital, also aims to serve the electronics assembly market. As these examples suggest, several new firms draw on computer backgrounds or emphasize electronics applications; this contrasts with the more mechanical orientation of most of the early vendors.

Robot producers supply robots as stand-alone devices with basic systems engineering, as custom-turnkey systems, or as modular-turnkey systems. As in other PA markets, turnkey firms combine robotics components made by others with controls, software, and tooling tailored to meet the requirements of specific applications. Robot systems are avail-

[57]See “Competitive Position of U.S. Producers of Robotics in Domestic and World Markets, ” U.S. International Trade Commission, Publication 1475, December 1983.

[58]Kulicke & Soffa had formed a new division and invested over $1 million in robotics research over a 2-year period. See “Recession Even Hits Robots, ” *The New York Times*, Jan. 12, 1983.

“’’Cameron Gets Robot License, ” *American Metal Market/Metalworking News*, June 6, 1983.

*Bendix, for example, distributed three Yaskawa robot systems in the Western Hemisphere under the Bendix name and provided support and services. Wall *Street Journal*, Dec. 7, 1982.

‘“’’ Robotics. Too Many Firms for the Market?” *The Journal of Commerce*, Apr. 25, 1983.

able based either narrowly on a robot or more broadly on a manufacturing cell served by a robot (e.g., as a machine tender/loader). Automatix, for example, was founded as a vision company that imported Japanese manipulators and sold them with vision systems of its own design. It recently introduced a line of robotic assembly cells with vision systems that can be combined into a larger assembly system. Robot systems with vision capabilities have grown more common; 25 to 30 percent of machine vision systems sold are sold with robots.[61]

Both large, diversified vendors such as IBM, GE, and Westinghouse, and smaller ones such as GCA and Cybotech, offer to integrate robots or robotic systems with a variety of other types of production automation. Several vendors, such as GCA and IBM, offer to link CAD units to robots, allowing robots to be programed and applications to be simulated through CAD systems. The strategy of some of these vendors is to treat robots as additional terminals in larger, computer-based systems. Such systems can eliminate the need for separate robot programing and related support activities.

While the manipulator (the basic robot hardware) accounts for over half the total cost of installing a robot (see fig. 32) the increased attention to controls, software, and service accompanying the trend toward treating robots as part of systems is reducing the role of hardware in the robot business. As one industry participant observed:

> To me, the robot system is probably fifty percent controls and software and another twenty-five percent peripheral application and tooling and staging. And only twenty-five percent of it is the basic robotic mechanism that you see.[62]

Thus, at the Robot 7 exposition, for example, Cincinnati Milacron demcmstrated only three robot models and one control unit, available with different options. The hardware was standardized, but different customer needs could be met by varying the software.

For both simple and complex applications, pre- and post-sale support and service are increasingly considered essential by both vendors and users. One indicator that service and support have been inadequate is the fact that buyers have occasionally abandoned robots, something that has not been a problem for CAD systems and other types of programmable automation. A lot of pre-sale support–planning, training, facilities preparation, etc.—is often needed, for a couple of reasons in particular: Robots have yet to be viewed as the only alternative for certain tasks (unlike, say, lathes); and there are no single, correct approaches to applying robots in given situations. Because robot technology is still developing, and because users often adopt their first robots as a preliminary to broader process change, post-sale support—e.g., software updates, service contracts–is also important. While early robot vendors (e.g., Unimation, Prab, and Cincinnati Milacron) initially focused on manipulator production, growing competition has made service increasingly important to the business.

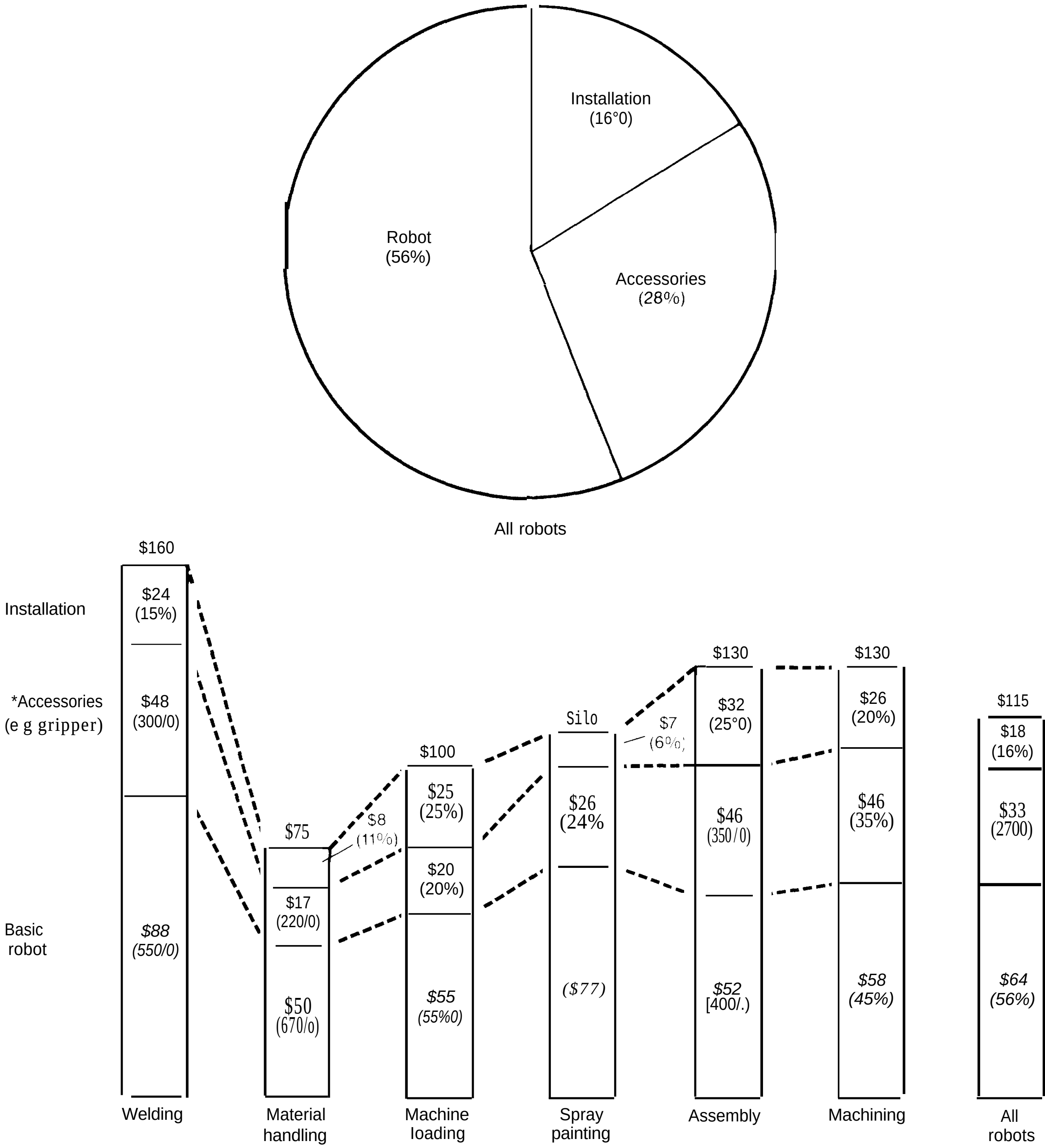
Some vendors have altered their pricing patterns in recognition of this situation, although pricing strategies appear to vary too much to permit meaningful inferences. For example, rather than offer a $100,000 robot, a vendor may now offer the "robot" for $30,000 and support/service for $70,000. Indeed, some industry analysts have somewhat cynically observed that selling robots is analogous to giving away (virtually) razors and profiting from

[61] See Robert N. Stauffer, "Sensors: 50,000 Machine Vision Systems Seen by 1992," Robotics *Today,* April 1983. Tech Tran estimates that, as of early 1983, only 400 to 500 machine vision systems were in use, but up to 50,000 systems may be used by 1993. Machine vision systems currently cost $25,000 to $30,000 but may cost less than S1O,OOO by 1993.

*The vision system market is believed to contain over 100 suppliers, Vision system sales have been estimated at $18 million to $25 million in 1982, and forecast to grow rapidly during the mid to late 1980's.

[62] Laura Conigliaro and Christine Chien, "Computer Integrated Manufacturing," report of the April 1983 Prudential-Bache Securities Symposium on Computer-Integrated Manufacturing, Prudential-Bache Securities, Aug. 2, 1983.

Figure 32.—Typical Robot System Cost Breakdown



the sale of razor blades: the money is in the follow-on sales of complementary products. Another interpretation is that vendors have yet to offer products that users really want. In particular, there is some evidence that users want simpler systems.[63]

Large and small system-oriented vendors have responded to perceived needs for service by enlarging their service capacity, and by adding systems-planning consulting units. For example, IBM has a Robotics Assembly Institute; GCA has two demonstration centers; Prab has a systems engineering unit; and GE has a few robot applications centers. In addition, third-party robotics consulting/service firms have emerged. These include Productivity Systems, Inc. (Mich.); Ceeris International, Inc. (Corm.); Franklin Institute Research Laboratories, Inc. (Pa.); Scientific Applications, Inc. (Va.); and Automation Systems/American Technologies (N.J.). Third-party or nonmanufacturing firms have a place in the robotics business, as in the CAD business, because the hardware is less important than the applications engineering, software development, and other aspects that combine in an application (see CIM section below). These firms may also become more prominent because the amount of capital available for new-start manufacturers is shrinking, and consulting is less expensive to launch than manufacturing.

The robot market continues to be strongly international, although it is believed that robot imports comprise less than 10 percent of the market.[64] This compares with a 25 to 30 percent import penetration for automobiles. According to ITC, U.S. imports of complete robots grew in value from $3.8 million in 1979 to $15.1 million in 1982 and may have grown to $28.9 million in 1983. Imports of robot parts and subassemblies grew from $126,000 in 1979 to $6.7 million in 1982 and may have grown to $15.2 million in 1983. According to Paul Aron of Daiwa Securities America, Inc., 425 units valued at about $11.4 million were imported in 1982, of which 59 percent came from Japan, compared with a total of $195 million in domestic production.[65]

Japan has been the principal source of robot imports; Sweden and Norway follow, together accounting for less than half of the value of Japanese imports. Sweden follows Japan and the United States as the third largest robot producer. Its principal robot manufacturer, ASEA, is a leading, maker of industrial machinery. ASEA produces about half of Sweden's robot output. The remaining portion of imports (about 20 percent by value, 9 percent by volume) comes from West Germany, Italy, and the United Kingdom. These countries primarily supply robots to the United States through resale agreements. Five firms produce most of West Germany's robot output. The two leading German firms are Volkswagen Werk and Kuka." Several foreign firms serve the U.S. market by specializing in niches (e.g., ASEA, Yaskawa, and Hitachi in arc weMing), and most others serve the low end of the market.

U.S. robot makers also export, principally to European countries. ITC estimates that U.S. robot exports grew from $8.9 million in 1979 to $20.3 million in 1982 and may have grown to $33.7 million in 1983, accounting for 20 percent of the shipments.[G7]

A principal difference between foreign and domestic firms, until recently, has been the prevalence of user-producers among foreign firms. The greater experience of foreign firms (particularly Japanese firms) with robotic applications has been an important selling point. Also, the larger market in Japan helps to lower the cost of Japanese robots exported to the United States. And "the Japanese also are

[63]See, for example: Frank Cogan, "Some Robots Being Simplified to Attract Users, " *Amen-can Metal Market/Metalworking News,* Sept. 13, 1982.

[64]Laura Conigliaro and Christine Chien, "Computer Integrated Manufacturing, " report of the April 1983 Prudential-Bache Securities Symposium on Computer-Integrated Manufacturing, Prudential-Bache Securities, Aug. 2, 1983.

[65]Paul Aron, "The Robot Scene in Japan: An Update, " Paul Aron Report No. 26, Daiwa Securities America, Inc., Sept. 7, 1983.

"'Competitive Position of U.S. Producers of Robotics in Domestic and World Markets, " U.S. International Trade Commission, Publication 1475, December 1983.

"'Competitive Position of U.S. Producers of Robotics in Domestic and World Markets, " U.S. International Trade Commission, Publication 1475, December 1983.

willing to make use of less sophisticated robots rather than wait for the most perfect design. . . . In Japan, the stress is constantly on the application. "[68]

The international dimensions of the robot industry are complicated by the prevalence of captive imports, licensing (often involving the manufacture abroad of key hardware), and joint ventures. Licensing is a particularly attractive vehicle for foreign firms wishing to enter a remote market because it eliminates the need for setting up a new distribution system; it appeals to the licensee, on the other hand, as a quick and easy means of entering a new market. R&D needs are lower, as are production costs. Many U.S. vendors, from large, diversified firms (e.g., IBM, GE) to smaller, innovative firms (e.g., GCA, Automatic), license manipulators, especially from Japan* (see table 60). As Phillipe Villers, President of Automatix, recently noted:

> If you are going to produce something in much lower volumes than a competitor, then you had better be able to command a premium for some innovative aspects . . . Now, in robotic arms as distinguished from the robot as a whole, that is a relatively mature art, and the opportunity for commanding a tremendous premium for a bettter arm is somewhat limited. At the present time, the leading Japanese manufacturers are producing arms in the thousands per year in a number of cases. For manufacturers here to compete in arms while producing ten times less of that device, the laws of economics says that you can't produce it as cheaply . . . In the controls area it's not the same.[69]

Finally, there are a growing number of international joint ventures, although these remain less common than licensing agreements. For example, Renault of France and Ransburg of the United States formed Cybotech in the late 1970's. A new joint venture, GMF Robotics, paired a major Japanese producer, Fanuc Ltd., with a major U.S. user, GM. Although its

[68] Paul Aron, "How to Play Catchup in Robotics, " *Electronics*, June 16, 1983.

*Other countries also supply robot hardware. For example, Steelweld Robotic Systems (United Technologies) sells robot systems using Niko robots made in West Germany and accessories and peripheral equipment made in the United States. *Automotive News,* Sept. 26, 1983.

[69] Laura Conigliaro and Christine Chien, "Computer Integrated Manufacturing, " report of the April 1983 Prudential-Bache Securities Symposium on Computer-Integrated Manufacturing, Prudential-Bache Securities, Aug. 2, 1983.

Table 60.—Some Agreements Existing Between U.S. and Foreign Robotics Producers

From	Type of agreement	To
DEA (Italy)	License and marketing	General Electric Co.
Volkswagen (West Germany)	License and marketing	General Electric Co.
Hitachi Ltd. (Japan)	License and marketing	General Electric Co.
Fujitsu Fanuc (Japan)[a]	Joint venture	General Motors Corp.
Unimation	License	Kawasaki Heavy Industries (Japan)
Unimation	License	Nokia (Finalnd)
Prab Robots, Inc.	Manufacturing	Fabrique Nationale (Belgium)
Prab Robots, Inc.	Manufacturing	Murata Machinery (Japan)
Prab Robots, Inc.	Manufacturing	Canadian English Co. (Canada)
Trallfa (Norway)	License	DeVilbiss Co.
Renault (France)[a]	Joint venture	Ransburg
Yaskawa Electric (Japan)	Marketing	Hobart Brothers
Yaskawa Electric (Japan)[a]	Technology exchange	Machine Intelligence Corp.
Sankyo Seiki (Japan)	Purchase	IBM
Komatsu (Japan)	License and marketing	Westinghouse Electric
Mitsubishi Electric (Japan)	License and marketing	Westinghouse Electric
Olivetti (Italy)	License and marketing	Westinghouse Electric
Basfer (Italy)	License and marketing	Nordson
Dalnlchi Kiko (Japan)	Marketing	GCA
Hitachi Ltd. (Japan)	Marketing	Automatix
Nachi Fujikoshi (Japan)	License	Advanced Robotics Corp.
Nimak (West Germany)	License	United Technologies
ASEA (Sweden)	Subsidiary	ASEA, Inc.
Cincinnati Milacron	Manufacturing	Dainichi Kiko (Japan)

[a] Information and technology flow in both directions

SOURCE Compiled from various sources by the staff of the U S International Trade Commisson management claims to aim for no more than 50 percent of sales for automotive application, GMF appears to be gaining a major share of GM's robot business. GM's new Buick complex in Flint, Mich., for example, will include 103 robots—all from GMF.[70]

International joint ventures are also a factor in foreign markets. For example, Cincinnati Milacron and Utsumi Machinery Co. (Japan) will produce robots in Japan this year for sale in Asia and Australia. Cincinnati Milacron's Japanese subsidiary will assemble the robots from manipulators made by Utsumi and Cincinnati Milacron controllers made in the United States. Cincinnati Milacron claims that building the manipulators in Japan will cost about 20 percent less than building them in the United States.[71] Lower production costs reflect, in part, the exchange rate, as well as higher production volumes in Japan.

Likely Change

Estimates of the 1990 U.S. robot population generally range from 50,000 to 150,000, or a 6- to 18-fold increase relative to today. Sales forecasts for 1990 typically range from $1 billion to $2 billion. Clearly, changes of these magnitudes are uncertain; they depend, in particular, on a strong economy. A "shakeout" in the robot industry, with the number of vendors falling at the same time sales are growing, is widely anticipated within the industry and among analysts. Because the nature of production costs, the rate of technology change, and the growth of the market are all uncertain, there is controversy as to the prospects of new v. old firms, or large v. small firms (see table 61). During a recent forum for industry participants, the problem was underscored when representatives of several small robot manufacturers expressed their desire to be the "IBM of robotics. " Because both large and small firms have strengths, and because the market is expected to broaden, it is likely that the industry will support both large, "supermarket" suppliers of automation and smaller firms oriented toward robot niches. Moreover, large diversified firms—especially those supplying a variety of types of programmable automation—may persist in the robot market even without earning profits there because (as with FMS) identification with the robot industry has strategic value.

Growth in applications will be a key to broadening the market. The rate at which robot use spreads to nonmetalworking industries will depend on many factors, including broad-based changes in manufacturing processes and standardization of equipment, languages, and interfaces (which may occur informally through the emergence of dominant products and vendors). Both growth in applications and reductions in cost should expand the market among small firms, in particular; at present, single-robot purchases are usually hard to justify on financial grounds.[72] Materials handling, assembly, and inspection applications, which can be found in virtually all manufacturing industries, will grow during this decade, in part because of advances in sensing and adaptive control (see ch. 3).

Robots are already considered feasible for materials handling in applications ranging from textile processing and apparel manufacture to personal-care product packaging, pharmaceuticals, and cigarette packaging. GCA, for example, is providing robots for materials handling in the printing and paper packaging industry. Assembly applications are becoming more common and diverse, especially in the electronics industry, with applications ranging from wire-harness assembly to insertion of components into circuit boards. Substantial markets for robots may also grow during the 1990's in nonmanufacturing applications, from battlefield missions to disposal of hazardous wastes to health-care services and food processing. Forestry, fishery, mining, agricultural, and oceanographic applications are also under development.

[70] Stuart Brown, "Accurate Fixturing Not Required for Vision-equipped Robot System, " American *Metal Market/Metalworking News, Nov. 7, 1983.*

[71] "Cincinnati Milacron Plans to Have Robots Made in Japan in 1984, " *The Wall* Street *Journal,* Sept. 12, 1983.

[72] Steven M. Miller, "Potential Impacts of Robotics on Manufacturing Cost within Metalworking Industries, Doctoral Dissertation, Carnegie-Mellon University, 1983.

Table 61 .—Prospects of Different Classes of Robot Vendors

Startups

Strengths:

- Few if any perceived or real dissatisfactions among end-users.
- Ability to attract and hire some of the most aggressive and smart individuals in robotics and related industries.
- Small size allows rapid shifts in strategies if necessary. (This was particularly important during the recession when certain kinds of orders became scarce.)
- Technological advances WiIl probably come from smaller companies.
- Small starting base means that each order, regardless of size, is important. Thus, the best of these companies would tend to offer more support for a given size order.
- The best of these companies have attracted Important venture capitalists, gaining impressive support and financial backing,

Weaknesses:

- Little name recognition for some of them.
- Far more competitive environment in robotics than is generally ideal for startups -i.e., little room for error or for learning from mistakes.
- Cannot afford to be consistently agresslve in pricing.
- Need some early successes in order to retain venture capitalists. Otherwise cash flow insufficiency can become a fatal disease.

Large company entrants:

Strengths:

- Name recognition.
- Major financial strength,
- In many instances, applications of robots and other flexi bile automation technologies i n their own factories is a marketing plus.
- Already offer a large variety of products other than robots for different aspects of factory automation.

Weaknesses:

- Powerful financial strength for the corporation as a whole should not be interpreted as being equivalent to unlimited financial resources for the robot unit. The commitment of the company to robotics and how robotics fits into the company's overall strategy for factory automation will vary. (These commitments can diminish if the robot entity continues to underperform expectation s.)
- The robot entity IS one tiny group within the corporate organization. Robotics alone will make no difference to the profitability or growth of most of these companies.
- Large companies are often hampered by their own inertia.
- Inability to attract or keep aggressive entrepreneurial types for robot units, These individuals often prefer the looser organizational structure of smaller companies, where they can also get an equity position.

SOURCE Laura Conigliaro Trends in the Robot Industry (Revisited Where Are We Now? *Proceed/rigs of the* 13th *Inlernational* Symposium *on* Industrial *Robots* April 1983

Growth in systems applications and sales and advances in the automation of other production equipment will result in a rather small market for stand-alone robots, at least within metalworking industries. Moreover, these trends may also make it easier for firms to supply robots without manufacturing them themselves. Whether they do or do not produce manipulators, robot manufacturers are increasingly likely to produce their own computer controls. Also, the software side of the market should grow with software enhancements—for sensing, diagnostics, and other functions. The growth in systems applications and sales, the relative importance of controls, software, and customization, and the option of relying at least in part on foreign sources of low-cost hardware suggest that product differentiation and service may be more important than pricing for competition within the robot market,

Future trade patterns in robots would appear to depend on development of technology for new applications, prospects for continued cooperative efforts among producers, and the degree of emphasis placed on systems and services. Table 62 contrasts the distribution of robot applications in Japan and the United States.

The greater use of robots for assembly, "intelligent robots, " and unsophisticated units aimed at small firms in Japan may benefit Japanese imports later in the decade. * However, simple comparisons of numbers made and used may be misleading. Most assembly and intelligent robots are relatively unsophisticated at this time. Moreover, the Japanese apparently consider U.S. assembly technology to be superior to their own. The Japan Economic Journal notes that the IBM 7565 system robots introduced in early 1983 "seem to be better than any factory assembly robots so far commercially developed in Japan" because of superior software, programing, sensors, and computerization. 73 Meanwhile, U.S. companies

*Japanese firms have recently expanded their efforts to reach small manufacturers (and restaurants and schools) by offering robots through department stores. *Philadelphia Inquirer,* July 9, 1983.

"'Robot Makers are Sensing Strong U.S. Competition, "*Japan* Economic *Journal,* Feb. 8,1983.

Table 62.–installed Operating Industrial Robots by Application, Dec. 31, 1982 (U.S. Definition)

	Japan		United States	
	Units	Breakdown in percent	Units	Breakdown in percent
Welding[a]	8,052	25.2	2,453	38.9
Painting	1,071	3.4	490	7.8
Assembly	6,099	19.1	73	1.2
Casting	557	1,7	875	13.9
Materials handling	6,797	8.1	1,300	20,6
Machine loading/unloading	2,578	8.1	1,060	16.8
Others	6,746	21.2	50	0.8
Total	31,900	100	6,301	100

a JaPan Industrial Robot Association reported separately arc welding (3,874) and spot welding (4,278) Robot Institute of America (U S) did not distinguish between these two categories

NOTE These estimates are generally consistent with those of Table 59: the contrast illustrates the unreliable data problem

SOURCE: Paul Aron, ' The Robot Scene in Japan: An Update," Daiwa Securities America Inc , Sept 7, 1983

have begun to sell more robots in Japan. For example, a young firm called American Robot Corp. has sold electronic assembly robots in Japan, and it will produce robots there through a Japanese subsidiary to increase Japanese sales (it hopes to lower costs and prices).

Access to foreign markets may become more difficult and import competition may grow as a result of foreign policies supporting robots (and other forms of programmable automation) as a favored domestic product (see ch. 9). Spurring the production and use of robots, robot associations of various sorts exist in many countries, including Australia, Belgium, the United Kingdom, Denmark, France, West Germany, Italy, Japan, the United States, Singapore, Spain, Sweden, and China. These groups often work with policymakers on issues relevant to robot technology development, sales, and trade. A Swedish committee, for example, has proposed a campaign to increase robot production and use in Sweden, and Swedish-owned ASEA anticipates that robots will supersede autos as the main national product.[74]

France has even imported Japanese assistance to develop its robot business. In response to French Government requests for "Japanese cooperation in developing and introducing robets and other high-technology products as a step to revitalize the French economy, " Yaskawa Electric Manufacturing Co. (Japan) and Cie Electro-mecanique (France) have teamed up. Yaskawa w-ill supply large robots for CEM to market in France; it will sell small CEM robots in Japan; and it will help CEM produce large robots in France.[75] Also, ASEA will prcduce robots in France.

If robot systems grow in popularity, licensing may be the most effective way for Japanese manufacturers to reach the U.S. market, because most of them are primarily manipulator builders; U.S. strengths, by contrast, are in software and systems development. However, Japanese producers are working on robot systems of their own. For example, Sumitomo Shoji (a trading company), NEC (an electronics firm), and Dainichi Kiko (a robot maker) are developing robot systems with vision and voice sensors for sale in 1984.[76]

In the long term, U.S. manufacturers may bcxome less interested in licensing as they gain experience in robotics, while the Japanese and others may establish U.S. subsidiaries to better provide service and hardware packages and to adapt to potential or actual restrictions on imports. Hitachi, for example, has a U.S. subsidiary which recently formed several inde-

"Laura Conigliaro and Christine Chien, "Computer Integrated Manufacturing" report of the April 1983, Prudential-Bache Securities Symposium on Computer-Integrated Manufacturing, Prudential-Bache Securities, Aug. 2, 1983.

[75]"Japan Agrees With France on Interchange of Robots, " *Japan Economic Journal,* Jan. 11, 1983.

[76]Roy Garner, "Japanese Robot Industry Slows Down, " *Financial Times,* Mar. 2, 1983.

pendent sales and service centers to allow Hitachi to sell complete robot systems in the United States and to facilitate future robot production in the United States in the event robot imports are restricted. Hitachi now imports the basic robot and sells it with other equipment (e.g., welding and painting devices) and services provided by U.S. firms.[77]

An emphasis on service or on integrating robots into complex systems would argue against a strong import presence (in the traditional sense), because close relations with customers and retaining a local presence are important aspects of service provision and applications planning. Emhart Corp., for example, chose to work with ASEA of America in developing its first robot application because of the geographic proximity of the vendor's facilities to its own. Also, U.S. experts believe that U.S. firms lead in systems technology. However, a movement toward turnkey supply of systems is consistent with importation of hardware and components, packaged by domestic firms. Japanese hardware, in particular, is likely to grow more attractive as compe tition in Japan lowers prices.[78] Alternatively, foreign (and U. S.) firms may locate production or assembly facilities in different markets. ASEA, for example, has robot plants in Japan, West Germany, Spain, Sweden, and the United States.

Other PA Markets

Automated Materials Handling/ Storage/Retrieval Systems

Automated materials handling (AMH), storage and retrieval systems (AS/RS) and their components are supplied primarily by a few firms, which are typically suppliers of more conventional materials handling equipment and systems, such as conveyors and conveying equipment (SIC 3535), hoists, overhead cranes, and monorails (SIC 3536), and industrial trucks (SIC 3537). Principal vendors include Eaton-Kenway, Esco/Hyster, Litton, Clark Equipment, Jervis B. Webb, and S1 Handling Systems. AMH firms have historically served customers in the mining and wholesale/retail trade industries as well as manufacturers, although products such as automatic guided vehicles ("robot carts") have recently been developed with particular attention to manufacturing-industry applications. AGV systems are already produced and used in Sweden, France, Italy, and West Germany, and British companies are also planning to enter the AGV market. The AS/RS market is more or less distinct from other AMH markets because the systems are more complex. They are generally sold in packages of hardware, software, engineering, and controls by firms operating in turnkey fashion.

The overall materials handling industry has contracted recently, in large part because of declining capital investment. Although imports in the conveyor, hoist, and industrial truck industries grew (in current dollars) by 14 to 20 percent in 1982, the ratio of imports to new supply (imports plus domestic production) for each of these industries overall was less than 10 percent.[79] However, there is a growing tendency for foreign sourcing of hardware in these markets, as in others. And, for some AMH products, import competition is strong. Makers of other PA equipment are entering the market, and some materials handling companies are expanding their involvement in order to have a stake in the manufacturing automation market as a whole. Harnischfeger Corp., for example, seeks to increase its materials handling business and shift away from its predominant business in heavy equipment. It is hiring more engineers, increasing AMH R&D and applications engineering, and developing new controls for AMH systems .80

While spending for materials handling equipment is strongly tied to business invest-

[77] Lauri Giesen, "Hitachi Offering Complete Robots in U. S," *American Metal Market/Metalworking News,* Apr. 25, 1983.
[78] " Matsushita Electric is Japan's Top Robot Maker, " *Japan Economic Journal,* May 24, 1983.

[79] U.S. Department of Commerce, 1983 *Industrial Outlook.* Note that these figures may not capture larger penetrations for specific products.
[80] Lauri Giesen, "Harnischfeger Veers to Material Handling, " *American Metal Market/Metalworking News,* Jan. 16, 1984.

ment patterns in general, new interest among manufacturing firms in automating and linking materials handling and production equipment will create new demand. Indeed, a major trade association, the Material Handling Institute, replaced their 1984 "Automated Material Handling and Storage System Conference" with an "Integrated Systems Conference" and formed an advisory "Advance Technology Council."[8] However, since FMS and other aspects of production integration are still being developed and are of limited use, highly integrated systems are not likely to have a major influence on the materials handling market during this decade. Also, AS/RS have tended to be practical only for very large-volume storage needs and relatively frequent turnover of inventories, although smaller systems are being developed.

Manufacturing Resources Planning (MRP) and Other Management Systems

The market for MRP and other management systems is a part of the overall market for management software. These systems have been sold to a wide range of firms, including metalworking, electronics, and miscellaneous manufacturing companies, firms which in many cases are unlikely to buy other, production types of programmable automation. They are sold by computer vendors, software houses, engineering and other consulting firms, and service bureaus. Professional societies (e.g., the American Production and Inventory Control Society) are important in promoting the diffusion of such systems.

MRP systems are available primarily as software packages for mainframes and minicomputers. Sperry Corp., for example, offers a manufacturing control system with "modules" for bill of materials generation and inventory control, manufacturing and purchase order control, materials requirements planning for scheduling, and production-costing and "shop-floor control" functions.[82] Several other companies also offer such multifaceted systems. Availability of minicomputer versions, and more recently microcomputer-based systems, has opened the market to more buyers and sellers. Also, in many cases users develop their own systems. Management software ranges in price from under $1,000 for single-function, microcomputer packages to over $250,000 for complex multifunction "MRP II" packages.[83]

Many vendors and consultants are hoping to increase their sales to smaller firms. The availability of micro-based systems in particular is expected to enlarge the small-firm market. Digital Microsystems, Inc., for example, offers an MRP system aimed at companies with up to $25 million in sales. The system, offered with training, includes a local-area network, MRP software, and software for office automation and business graphics. As this example illustrates, vendors may try to meet customer needs with packages that simultaneously computerize a number of functions. While the erratic production flow of small, batch-production firms makes planning for MRP challenging, the potential for increased inventory control afforded by such systems may reduce the financial volatility typical of such firms.

"'"Newsletter," *Modern Materials Handling,* April 9, 1984.

[82] "Sperry Unveils Manufacturing Control System," *Computerworld,* Dec. 12, 1983.

"''Micro Software Brings Material Control to the Desk Top," *Modern Materials Handling,* Jan. 23, 1984.

Computer-Integrated Manufacturing: Potential Market Developments

A separate "CIM market" does not exist. Although users of programmable automation are achieving greater integration of their equipment, systems, and activities; and some vendors, in turn, are touting their ability to implement CIM and meet diverse needs for manufacturing integration, no one yet sells "CIM" as a total product nor has any vendor fully implemented CIM. Indeed, some in industry contend that users are still pioneering the application of CIM. If needs remain highly idiosyncratic (which is quite likely) and attempts at CIM few in number (which is possible), most CIM maybe developed by users; in that case, a true market will not exist. Development by users is especially likely for large firms; smaller firms may lack the resources to develop their own systems (or to integrate pro duction completely).

The fragmentation of PA supply among myriad firms of different types and sizes may impede development of a CIM market, especially in the absence of standard equipment and interfaces. A spokesman for Caterpillar Tractor, for example, has argued that a major barrier to buying or using CIM is the absence of standard programing languages, data formats, communications protocols, teaching methods, controls, and well-developed offline programing capabilities.[84] This view is echoed by others in industry.

Insofar as commercial supply does develop, CIM maybe provided through modular or all-at-once packages. Modular systems, which can be expanded over time, could be provided by various types of firms, from those specializing in one type of automation to those offering a full range of systems. The success of the commercial CIM packages expected to be offered in the mid-1980's by Hitachi and by a Norwegian-West German joint venture may provide a measure of the potential for a true CIM market.

A key uncertainty for a possible CIM market is the role of large, "supermarket" suppliers of programmable automation. The advantage that may accrue to suppliers of multiple forms of PA is hard to measure. In principle, such an advantage may exist because of what economists call "economies of scope "—savings in costs in the production of related products through joint R&D, marketing, component manufacturing, and accumulation of know-how. The potential automation "supermarkets' –GE, IBM, Westinghouse, et al.–have each expanded their automation production capabilities within the past few years. GE, for example-already an established manufacturer of industrial electronics (including programmable controllers and local communications networks) —acquired Calma for computer graphics and Intersil for integrated circuits; formed a joint venture with Structural Dynamics Research Corp. to design and sell CAE progr aming; developed and licensed robots for assembly, painting, welding, and other applications; and developed optoelectronics for machine vision. GE has also established a manufacturing automation systems engineering unit, and expanded its research capability in electronics, including VLSI technology. By contrast, Westinghouse acquired Unimation but divested other production operations (for CNC, parts programing, and time-sharing) in a shift toward service business and away from manufacturing. 85

Size may not be essential for broad PA capability. GCA, for example, is a relatively small producer of robots (and other equipment) that has established links with Japanese and U.S. firms to supply robotics hardware, vision systems, and CAD units; its own efforts are concentrated on controls technology and software development.

Regardless of size, know-how will be particularly important for a CIM market: In the words of a GE representative, "The factory of the future is a knowledge game, not a hardware game. '[86] Consequently, it is likely that systems houses and engineering consulting firms will play a major role in providing CIM. Such firms have already played an important role in developing markets for individual types of programmable automation. They are a conduit for applications engineering and other services for tailoring available equipment to

[84]Laura Conigliaro and Christine Chien, "Computer Integrated Manufacturing, " report of the April 1983 Prudential-Bache Securities Symposium on Computer-Integrated Manufacturing, Prudential-Bache Securities, Aug. 2, 1983.

[85]Bruce Vernyi, "Westinghouse Poised to Sell CNC, Parts Programming, Time-Share Lines, " *American Metal Market Metalworking News*, Aug. 8, 1983.

[86]Jack Norman, "Impact of Automation Downplayed, " *Milwaukee Journal*, June 14, 1983.

specific needs. Also, they are sometimes better able to obtain customer confidence than are vendors who have a stake in a given product line. Because hardware production is not essential for CIM "supply," some analysts believe that nonmanufacturing organizations such as Battelle Memorial Institute, Booz-Allen & Hamilton, and A. T. Kearney may become important in the CIM market.[87]

Since PA is commonly construed by vendors and users alike to be an answer to manufacturing problems, companies who sell many types of automation and can integrate them may be assumed to have a better notion of what constitutes the right solution to a given production problem, especially if they use PA themselves. Because the firms that seek to be PA supermarkets have each accumulated substantial experience with programmable automation in their own production operations, the know-how (and reputation) with which they enter the market might be a critical advantage. On the other hand, a combination of consultants or service bureaus and smaller, specialized producers of PA might achieve the same end. The viability of the latter approach depends in part on whether and when standard components and/or interfaces become available.

Computer vendors will likely play a major role in CIM supply, given the common element of computerization in PA products, and because of these vendors' own experiences in adopting advanced automated systems. Computer vendors (and even semiconductor manufacturers) have demonstrated a growing interest in participating in PA supply generally. IBM, for example, recently reorganized its Industrial Automation, Graphics Systems Programs, and Industry Applications system units into a single unit to focus the management of its industrial automation business.[88] Moreover, the growth of computerization without integration-through so-called islands of automation and through growth in computerized management systems (particularly those aimed at nonproduction activities)-may benefit computer vendors by providing both a basis for future integration and a market for interfaces and networking systems. Finally, the overall spread of computerization in office as well as production activities may convey an advantage to computer vendors, who are becoming increasingly familiar to managers of potential customer firms. *

[87] "G.E. is Seeking to Dominate Robot Field, " Minneapolis, *Finance & Commerce Daily*, Oct. 13, 1983.

[88] Mitchell York, "IBM Forms Units for Distribution, Industrial Systems, " *Computer Systems News*, Nov. 21, 1983.

*Also, AT&T may become involved in this market. It has planned to join with Bailey Controls (division of Babcock & Wilcox) "in linking communications technology with process control systems, numerically controlled machines, mainframe computers, engineering automation systems and personal computers. " "AT&T Unit, Bailey Set Linkup in Technology, " *American Metal Market/Metalworking News*, Nov. 21, 1983.

Themes and Conclusions

OTA'S evaluation of programmable automation industries reveals several broad themes. These are: 1) there has been a discrepancy between vendor and buyer views of needs and capabilities; 2) systems planning and other services are key features of PA supply, while manufacturing itself plays a smaller role; 3) vendors are likely to package and/or distribute hardware and software elements made by several firms; 4) both large and small firms have played distinctive roles in the development of PA markets; and 5) governments have had a major influence on PA market development.

Vendors v. Users.–Despite past and predicted rapid growth rates, key barriers to further market growth have been: 1) the need for users to learn how to adopt programmable automation successfully; 2) vendor inability to fully meet user needs and wants; and 3) the immaturity of automation technology, principally for system integration. Programmable automation seems to require greater customer sophistication than conventional automation if applications are to succeed. Vendors continue to speak of the need for 'missionary work, " for educating the prospective and actual buyer. The discrepancy between vendor offerings and user needs lies behind the slow start of automation industries; it is typical of new technology markets. What is unusual about these markets, however, is the growing role of user-producers: companies are developing proprietary equipment and systems and increasingly seeking to market them (or associated know-how) externally.

Systems and Service.–Automated equipment can be sold on a stand-alone basis, but is increasingly sold in systems that are tailored to individual needs through control technology and software modifications. Demands that users plan and adjust their organizations to accord with new processes grow with the size and complexity of the installation. Consequently, vendors undertake sophisticated marketing efforts and provide a variety of services to train users to plan for, operate, and maintain their systems. Thus, PA vendors offer both services-the development of applications, systems, and support functions—and goods; vendors are not all manufacturing firms, per se. This trend resembles conditions in the computer industry generally. Indeed, there are some firms and divisions of firms that are strictly service-oriented; they provide PA consulting and engineering services, Overall, the proportion of manufacturing activity in this industry is declining as the role of services grows; the absolute level of manufacturing activity may also decline due to outsourcing practices.

Cross-fertilization. –Licensing, outsourcing, mergers and acquisitions, limited-equity investments, and joint ventures have been frequent means of entry into PA markets. These arrangements enable firms with different strengths to enter markets for complex products quickly. They also provide a means for distant firms to enter remote markets. The cross-fertilization trend for programmable automation is symptomatic of trends affecting the overall information-processing and electronics industries. These broad industrial categories have seen a decline in levels of vertical integration because new products are becoming more complex, product change is accelerating, international competition is strengthening, and product development costs are rising.

Many cooperative ventures link firms from different countries. In particular, substantial numbers of U.S. firms license or buy Japanese hardware and European software; Japanese firms have licensed U.S. software recently, as they earlier did hardware. Collaboration facilitates entry into foreign markets, especially in the case of Japan; local firms provide remote ones with distribution and support networks. Cooperative ventures have thus hastened the international diffusion of PA technology and the growth of global markets.

The long-term implications of cross-fertilization are unclear. They depend on whether firms can and do acquire the strengths of their partners and therefore become new, independent competitors. Because of this possibility, some pessimists characterize cooperative ventures as "Trojan Horses" that may harm domestic firms in the long run.

Firm Size.–Because large and small firms offer both advantages and disadvantages in the PA market, it is hard to predict future tendencies for industrial structure. Typically, industries grow as small, innovative firms expand or are acquired; remaining small firms serve specialized niches. This pattern can be seen with programmable automation, but a larger role for small firms is also possible. This is in part because vertical integration is relatively uncommon. Small firms may continue to find opportunities as service bureaus or consultants. Also, the proliferation of software packages and limited-function, low-cost equipment and systems may continue to provide a role for small firms in PA supply.

The emergence of standards for components andlor interfaces may also help smaller vendors, even if standards develop de facto as the product designs of larger, dominant manufacturers. This has been the pattern in the computer industry. By contrast, large firms may offer more experience with applications and may be relatively well-suited to assembling large, complex systems.

Government Role.–Governments have played key roles in the development of U.S. and foreign markets for PA. As described in chapter 9, differences in government roles reflect differences in national context (labor market conditions, industrial composition, technology strengths, etc.). The U.S. Government role has been largely limited to support for military programs aimed at meeting defense procurement needs. Other governments appear to have provided more support for commercial PA development and use, although the effectiveness of such support is hard to appraise.