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ROBOTICS AND ITS RELATIONSHIP TO THE AUTOMATED FACTORY

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This report was prepared for the Robotics Workshop of the Congressional Office of Technology Assessment held in Washington, D.C. on July 31, 1981.

Basic Analysis

ROBOTICS AND ITS RELATIONSHIP TO THE AUTOMATED FACTORY

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INTRODUCTION

More attractive technology, the end of the baby boom, the need to modernize an aging U.S. manufacturing base and to reduce the use of labor more expensive than most of our international competition, and a more favorable tax structure will lead to increasingly automated factories. One product, the robot, is likely to become a key building block in the penetration of factory' automation into the manufacturing world. The purpose of this report is to provide a framework for analyzing the robot industry and its interrelationship with U.S. manufacturing techniques.

This report is divided into several sections:

- An overivew of the general status of U.S. manufacturing and the potential need for robots.
- An analysis of current and potential uses of robots.
- An analysis, from the robot producers' point of view, of the likely evolution of the robot market and key competitive factors.
- A discussion of the impact of robots on manufacturing operations.
- A discussion from both the producers and users' point of view of capital availability and potential financial incentive programs which could foster the development of the robot industry.

OVERVIEW: REDISCOVERING THE FACTORY

The automated factory has been a dream of the manufacturing world. The production manager, always pressured to improve output, has been influenced by classical economists who ranked technological advancement as the most important determinant of productivity (38%), capital investment second (25%), with labor accounting for only 14% of the changes. However, U.S. business has had to operate in an exceptionally difficult economic environment during most of the 1970s, a period of rapidly increasing inflation, exploding energy prices and gyrating money markets. These factors contributed to a decade of sluggish economic growth, weak research and development spending and economic policies that favored consumption over investment, resulting in real capital spending that significantly trailed the strong outlays of the 1960s. The 1.5% productivity growth during 1973-79 was half our historic average, with some economists suggesting that labor may have been the only factor in the classical equation that contributed more to productivity growth since 1973 than it did from 1948.

July 31, 1981

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	Real GNP Growth	Real Gross Private Fixed Investment	Real Producers Durable Equipment	Real P&E	Productivity y Growth
1959-72	3.8$	4 . 9 %	5 .7%		3.1%
1973-79	2 .5%	2. 1%	2.8$	2.1$	1 .5%

The economic environment of the 1970s also favored capital outlays that resulted in a quick payback. As economists Burton G. Malkiel has pointed out:

> "From 1948 to 1973 the (net book value of capital equipment) per unit of labor grew at an annual rate of almost 3 percent. Since 1973, however, lower rates of private investment have led to a decline in that growth rate to 1.75 percent. Moreover, the recent composition of investment (in 1978) has been skewed toward equipment and relatively short-term projects and away from structures and relatively long-lived investments. Thus our industrial plant has tended to age..."

The deline of the U.S. manufacturing base can clearly be seen by looking at the age of U.S. machine tools in place (Table 1) :

> Two-thirds of all U.S. machine tools are over ten years old and one-third are more than twenty years old.
>
> The technological penalty is even more severe as sophisticated numerical control equipment has made only slight inroads into the manufacturing process.

By contrast, capital investment as a percentage of GNP in France and West Germany was more than 20% greater than that in the U.S. , while in Japan the percentage was almost double ours.

Corporate managers, shocked by faltering productivity and loss of markets to international competition, have begun to perceive a connection between their deteriorating competitive positions and the neglect of the part of their businesses that actually produces goods. However, until recently, productivity was an economist's term rarely used by businessmen. It is now dawning on some managements that responsibility for their competitive listlessness cannot be blamed simply on the decline of work effort, unreasonable government regulation or a shortfall in capital investment. Rather, they are beginning to see it as symptomatic of something wrong with the way manufacturing operations are set up and organized.

As previously indicated, technological advancement, including improved management techniques and integration of the manufacturing process, is the most important factor in the classical equation for productivity. Hence, two related technologies, computers and robots, offer prime opportunities for improvement. U.S. industry today is just beginning to reap the harvest of computerized innovations that could revolutionize production processes during the 1980s.

Until recently, the rationale for robots was that they were useful in heavy, hot, hazardous and even boring environments. In addition to this ability to remove people from an unhealthy and/or even dangerous environment, robots are a key engine of change in the manufacturing process. Robots, particularly with the addition of computer type circuitry, are the initial entry into flexible automation.

American corporations have been behind the Japanese in recognizing the potential of computers and robots for reducing production costs and increasing the flexibility and versatility of factory operations. While the pentration of robots and computers into

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Table 1: Machine Tools in Use*

		% of Total Machines in Use	Under 10 Years	10-20 Years	Over 20 Years	% Numerical Controlled
I.	United States		31.0%	35.0%	34.0%	2.0%
	Transportation Equip.	13.7%	23.8	33.0	43.2	2.1
	1. Motor Vehicles	6.7	23.8	31.4	44.8	0.6
	2. Aircraft & Parts	5.3				
	Non-Electrical Machinery	36.5	32.8	35.1	32.1	3.1
	Electrical Machinery	12.9	33.0	41.7	25.3	1.4
	Fabricated Metal	24.0	27.4	35.2	37.4	0.9
	Precision Instrument	5.0	38.0	36.8	25.1	1.9
II.	West Germany		37.0	37.0	26.0	NA
III.	United Kingdom		39.0	37.0	24.0	NA
IV.	Japan		61.0	21.0	18.0	NA
V.	France		37.0	33.0	30.0	NA
VI.	Italy		42.0	30.0	28.0	NA
VII.	Canada		47.0	35.0	18.0	NA

Source: American Machinist: 12th American Machinery Inventory of Metal Working Equipment 1976-78; Verein Deutscher Werkzeugmaschinenfabrik e.V.; NMTBA Statistical Handtools.

*Data based on 1976-78, except for Japan, France and Italy where the data is based on a 1973-75 survey.

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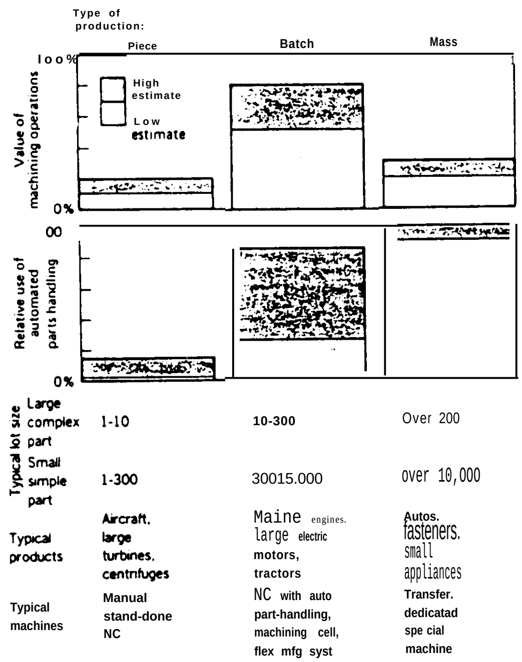
the manufacturing world will be concentrated initially into those areas which will result in reduced manufacturing costs primarily through direct labor savings and enhanced quality, the ultimate evolution will probably be toward encompassing that technology as part of a flexible manufacturing systems approach to production. A recent Machine Tool Task Force study highlighted the characteristics of manufacturing (Figure 1) and advocated the development of flexible manufacturing systems to handle production at more economical costs and at an increased rate of productivity.

Figure 1

Characteristics of manufacturing



Source: Machine Tool Task Force on Machine Tool Technology

Table 2: Time Losses in Manufacturing

	Low Volume	Mid-Volume	High Volume
Productive Cutting	6%	8%	22%
Cutting Conditions	2	4	--
Set-up/Loading/Gauging	12	7	14
Tool Change	.-	7	7
Idle Time	2	--	--
Incomplete Second and Third Shifts	44	40	
Holidays and Vacations or Plant Shutdown	34	28	27
Equipment Failure	--	6	7
Inadequate Storage	--	--	7
Work Standard Allowance and Miscellaneous			16

Source: Machine Tool Task Force on Machine Tool Technology

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The decade of the 1980s will see the need to modernize the U.S. manufacturing base at a time when the change in demographics will result in a sharp decline in the number of workers available for blue collar jobs as well as an overall drop in the number of people entering the work force as a whole. U.S. industry will have to quicken its pace of automation if it is to remain competitive, and only through the widespread use of computers and robots in the manufacturing sector will the automated factory eventually become a reality.

AN ANALYSIS OF ROBOT USE

What Exactly Is a Robot?

Disagreement exists among both foreign and American manufacturers over the appropriate definition of an industrial robot:

> The most widely quoted definition has been published by the Robot Institute of America (RIA) , a trade association of trade manufacturers and users. The RIA defines a robot as "...a reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable motions for the performance of a variety of tasks."
>
> The Japanese Industrial Robot Associates (JIRA) specified four levels of robots:
>
> 1. Manual manipulators that perform fixed or preset sequences.
> 2. Teaching playback robots that repeat fixed instructions after being taught a work procedure.
> 3. N.C. robots executing operations on the basis of numerically coded information.
> 4. Intelligence robots that perform various functions through its sensing and recognizing capabilities.

While many other definitions abound, the key difference is that by commonly accepted American standards, a robot should be both programmable and versatile. Hence, the RIA would not include manual manipulators, so that Japanese and U.S. robot population statistics are not precisely comparable. Definitional differences aside, Japan leads all other countries in its acceptance, use and government support of robots. Their industry lead is substantial, particularly when viewed in relationship to the relative size of their GNP.

Table 3: Geographic Distribution of Robots

	As Reported	Using RIA Definition	% of Total
Japan	47,000	10,000	57%
Us.		3,255	19
Europe			
West Germany	5,850	850	5
Sweden		600	3
Italy		500	3
Poland	720	360	2
Norway		200	1
England		185	1
Finland		130	1
Belgium		20	—
Other		1,400	8
Total		17,500	100

Source: R-IA, JIRA, Business Week.

Breakdown of U.S. Market

		Units
Programmable Non-Servo Controlled —General Purpose		1,100
Servo Controlled --Point to Point	1,800	
-Continuous Path	355	2,155
		3,255

source: JIRA, RIA.

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There are basically two classes of robots:

Non-servo controlled robots in which the tool center point can stop only at the end points of each axis. Many different motions can be programmed in sequence, but only to these end points. There is no provision for acceleration or deceleration.

Servo controlled robots are far more sophisticated and can generally be programmed to stop at any point within its range of movement. Motion is controlled by oil flowing through servovalves or by D.C. motors, allowing acceleration or deceleration to be achieved.

Robot control usually takes two forms --point to point and continuous path. A point to point robot can be programmed to stop at predetermined points, but movement is not controlled between these points. A continuous path robot can follow an irregular path exactly.

Low technology robots can often complete a task as well as the more sophisticated models. The Japanese appear more acutely aware of this and tend to concentrate on implementing existing technology. Above all, the industrial robot must be a practical device to successfully penetrate the manufacturing world. Our discussions with many industrial manufacturers indicates three key characteristics required by users:

1. Flexibility of applications, either in the area of (material) handling or as a processor (painting, welding, etc.).

2. High level of reliability with a minimum of downtime.

3. Ease of teaching, either with on or off line programmability, usually with teach boxes.

Who Would Use
Robots: How and Why

In 1979 the RIA estimated that six industry segments accounted for the bulk of unit robot shipments in the U.S.

Table 4: 1979 Estimated Unit Shipments

	Units	% of Total
Automotive	249	18
Casting/Foundry	298	21
Heavy Manufacturing	138	10
Light Manufacturing	513	37
Electrical/Electronic	156	11
Aerospace	13	1
Other	33	2
Total	1,400	100

Source: RIA.

As the majority of robots installed in the U.S. today are low or medium technology devices, the analysis of user purchases of robots by value would probably yield a different hierarchy of industry segments, with the automotive industry clearly in front. Our end use market by industry sector appears to be developing along the lines of the Japanese industry (Table 6).

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Table 5: Japanese Market
Production Share of Industrial Robots, by Type

	% Units	% Value
Manipulators and Sequential Robots	89%	70%
Teaching Playback Robots	5	17
N.C. Robots	1	4
Intelligent Robots	5	9

Source: J.I.R.A.

Table 6: Value of 1979 Robot Shipments to Users in Japan

Automobile Industry	38.4%
Electrical Machinery	17.5
Plastic Molding	10.8
Metal Products	8.1
Precision Machining & Metal Working	6.0
Iron & Steel	4.2
Other	15.0
Total	100.0

Source: J.I.R.A.

Whether or not the auto industry was the dominant purchaser of robots in the U.S. in the 1970s is a moot point; it clearly will be the driving force for the industry in the 1980s. It's no longer a secret that General Motors has projected an installed base of robots in its facilities as high as 14,000 by 1990.

Table 7: Possible GM Robot Base (Cumulative)

	1978	1979	1980	1984	1986	1988	1990
Cumulative	160	230	302	3,500	6,500	10,000	14,000

Source: GM.

As the robotics market is expected to be dominated by the automotive and other heavy manufacturing segments, at least during the first half of the 1980s, the principal applications are unlikely to vary significantly from the current uses over the near-term:

- Spot welding, which we estimate to account for 35-40% of total robot industry sales.
- Material handling, including machine loading and unloading.
- Die casting, investment casting, stamping, forging and press loading.
- Paint spraying and finishing.
- Palletizing.
- Assembly.

Toward the middle of the 1980s, arc welding systems should begin to grow rapidly and become the most important welding sector as demand for spot welders plateaus. During the latter part of the decade, it is likely for arc welders, machine loading and unloading and assembly robots to be the primary areas of growth, with assembly alone perhaps representing 35-40% of the total and perhaps nearly half of the annual growth.

The traditional rationale as to why industry purchased robots was that they offer a means to increase productivity and free workers from boring and unsafe tasks. A recent Delphi Survey by the Society of Manufacturing Engineers (SME) indicates that there are two key factors as

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the important crieteria for robot purchases :

1. Reduce manufacturing costs

2. Provide direct labor savings.

Other factors also cited include enhanced product quality, an improved working environment and tying into other forms of computerized automation though the relative importance of these are clearly below the first two mentioned. The median average expected payback period runs between 2-3 years and is not expected to change materially during the first half of the 1980s.

Table 8: Median Average Expected Payback Period

	Now	1985
Automotive	2.7 Years	2.0 Years
Casting/Foundry	3.0	2.5
Heavy Manufacturing	3.0	3.0
Light Manufacturing	2.0	2.0
Electrical/Electronic	2.0	2.0
Aerospace	2.0	2.5

Source: RIA.

While foreign built robots are not a significant factor currently, it is expected that increased exports from Japan by 1983 as well as foreign owned U.S. manufacturing facilities will lead to foreign manufacturers maintaining a significant presence in the market. The SME survey suggested that 20% of the dollar value of robots is likely to be supplied by foreign manufacturers, with cost advantage and overall quality (manufacturing and design) being the key factors that led to a foreign built purchase.

Robot Demand Expected To Be Sensitive To Economic Cycles"

It appears quite likely that demand for robots as well as other factory automation equipment will be a cyclical as well as a growth market. Using expected cost reduction and direct labor savings as well as productivity improvement as part of a return on investment analysis suggests that manufacturers will be sensitive to a reduction in business expectations and cash flow which can result from an economic downturn. This has been the case in Japan where industrial robot sales in terms of both unit production and value showed moderate sensitivity to economic conditions in 1971 and 1975 despite the small size of the industry.

It is conceivable for the U.S. robot sector to evolve into a strong cyclical growth market somewhat akin to the minicomputer or semiconductor sector, i.e. strong unit and sales growth with each trough in demand significantly higher (perhaps 30-40%) than the previous trough.

Table 9: Production of Japanese Industrial Robots

	Units (000 Units)	Value (Bill)
1968	0.2	0.4
1969	0.4	1.5
1970	1.7	4.9
1971	1.3	4.3
1972	1.7	6.1
1973	2.5	9.3
1974	4.2	11.4
1975	4.4	11.1
1976	7.2	14.1
1977	8.6	21.6
1978	10.1	27.3
1979	14.5	42.4

Source: JIRA.

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AN ANALYSIS OF
ROBOT MANUFACTURING

Multisector Industry To Evolve in the 1980s

In 1980, sales of robots by U.S. based companies approached $100 million, up sharply from the estimated $60-65 million in sales in 1979. While a growth of 50% is impressive during a recessionary environment, the robot industry size was still less than 2% of the $4.69 billion machine tool industry with which it often was mistakenly included and an insignificant part (4/1000 of 1%) of U.S. GNP. While robots are commonly assumed to be an extension of the machine tool industry because of its strong ties with manufacturing, we believe that the industry will evolve into its own subset of the flexible automation equipment sector with a multitude of segments much akin to the early development of the minicomputer industry in the 1960s and early 1970s. However, in contrast to the minicomputer industry, it is conceivable for the major participants in robotics to significantly change character by the next decade. We believe it is likely for a significant portion of robot manufacturers to become part of major companies organized to , supply systems and subsystems for the factory of the future. A pure robot company might only service a small, specialized segment of the factory automation market.

It is our opinion that the structure of the robotic sector will evolve in a manner similar to the early stage development of the minicomputer industry. Through the mid-1960s, the minicomputer industry was dominated by two major computer manufacturers. Beginning in the second half of the 1960s and into the 1970s, this sector developed a more elaborate structure.

Table 10: Structure of the Minicomputer Industry in 1970

	Buys	Makes	Sells to
Minicomputer Manufacturers	Peripherals Software	Mainframes Peripherals Software systems	OEM's Independent systems houses End-user
Peripheral Equipment Manufacturers	Minicomputers Software	Peripherals (includes terminals and secondary memories) *Minicomputers*	Minicomputer manufacturer OEM Independent Systems Manufacturer End-user
Original Equipment Manufacturers	Minicomputers Peripherals Software Engineering	Peripherals Software Systems Minicomputers	End-user
Programming		Software	OEM End-user
Independent Systems	Minicomputers Peripherals	Systems Software	OEM End-user

The interfaces depicted by this structure can essentially be split into four subsegments:

1. The end users who could. .
2. purchase a system from the original equipment supplier directly, or. . ,
3. sometimes go to a group Of independent consultants who help the purchaser put together systems and subsystems, or. . .
4. sometimes turn to a company that has developed a turnkey product using OEM supplier equipment as the heart of the system.

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As users became more sophisticated, they assumed greater responsibility for the integration of the system. A service segment began to evolve about a decade later as the indicated base of the product grew.

The robot industry appears to be developing along the same lines. Currently, two manufacturers, Unimation (subsidiary of Condec) and Cincinnati Milacron, dominate the industry with an estimated 70% of the market. These companies are four to five times larger than the nearest competitor (Table 11).

Table 11: Estimated 1980 U.S. Robot Sales by Manufacturer

	Sales Millions
Unimation (Condec)	$ 40.0
Cincinnati Milacron	30.0
DeVilbiss (Champion Spark Plug)	9.0
ASEA (U.S. Operation)	7.5
PRAB	6.0
AutoPlace (Copperweld)	4.5
Nordson	0.7
Mobot	0.7
Automatix	0.4
Other	1.2
Total	100.0

Source: PWMH.

Purchasers during the early marketing stages worked with the robot supplier in order to integrate robots into the manufacturing process and occasionally outside consultants were used because of the lack of support available for the process.

Over the past several years, U.S. manufacturers have shown increasing interest in the concept of families of parts for greater manufacturing efficiency. This has heightened the interest of Us. companies in flexible manufacturing systems and manufacturing cells with the primary goal of generating a high level of production of a wide range of family components with the flexibility to change, a capability previously available only with a sharp reduction of output. This change in the manufacturing concept has refocused the efforts of robot manufacturers toward the growing areas of applications and systems. Moreover, new "companies such as Automatix, Inc. and Robogate Systems Inc. , were founded on the concept of turnkey installations integrating robots into flexible manufacturing systems.

The likely evolution of these developments can probably be illustrated by the responses of U.S. manufacturers to the 1981 SME Delphi Forecast for Robotics (Table 12). In essence, the purchasers of robots will continue to make use of independent consultants, but also will turn more and more to turnkey system suppliers during the 1980s.

Table 12: Users Will Seek More Help for Robot Integration (Median Estimate)

	1980	1985	1990
% of Robots Purchased by Users with Assistance of Outside Independent Consultants Doing Systems Engineering	10%	15%	15%
% of Robots Procured as a Turnkey Package with One-Source Layout, Robot Supply and Installation	20	25	30
Purchaser Procures on Individual Basis; Purchaser Assumes Responsibility for Layout and Integration with Installation Done by Equipment Manufacturer	80	70	70

Source: 1981 SME Delphi Forecast --Median Results.

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Longer-Term Trends:
Automation Companies
Will Likely be Large

While robots are often used in an initial isolated application (primarily to gain experience) the evidence is clear that the robot is viewed as a piece of equipment to be integrated into the production process. Moreover, the U.S. production base is in dire need of modernization and, most important, the mid-1980s demographic shift will lead to a drop in the entry level work force at a time when the average skilled machinist in this country is currently estimated to be about 56 years old. These fundamentals suggest that U.S. manufacturers will have to adjust their methods and philosophy of production, emphasizing the substitution of capital for labor or, in one word --automation.

The evolution of factory automation outside the U.S. has an interesting characteristic. Most of the companies in the forefront of the technology are part of the organization that makes much of the equipment used. What emerges is that the knowledge of the factory environment is the key factor to the successful implementation of automation. In Japan, for example, Toyota was originally a subsidiary of a machine tool company (Toyoda) and its machine tool technology cannot be sold externally without the car company's approval. Nissan has a machine tool company as does Hitachi and Komatsu, the sixth largest producer of transfer lines in Japan.

A similar phenomenon is developing around the world with respect to the implementation of Robots, i.e. many of the companies introducing robots into the manufacturing process produce a version for internal consumption. Besides many Japanese concerns, #e list would also include companies such as Volkswagen, Renault and Fiat.

Alternatively, U.S. manufacturing companies rarely produce equipment for their own use. However, as automation techniques begin to take hold, the phenomenon has begun to change. In robots, for example, companies like General Electric, Texas Instruments and IBM all produce robots for internal use and General Motors recently announced its own paint spraying robot. Further, strategic planning within many corporations has led to the identification of the field of automation as bath a strategic internal operation requirement and a future business opportunity. This has led to significant acquisitions and internal studies as to how to best service this cyclical growth phenomena (Table 13).

Table 13: Strategic Purchases by Larqe Companies in the Field of Automation

	Bought
Energy Related Companies	
Exxon	Reliance Electric
Schlumberger	Fairchild Manufacturing Data Systems Inc
General Electric	Calma Intersil License DEA Allegro Robot
Transportation Related Companies	
Eaton	Cutler Hammer Kenway
Bendix	Warner & Swasey
Other Companies with Automation Related Divisions	
TRW	
Gould	
Square D	
Litton	
Automation Approach Under Study	
IBM	
Texas Instruments	
Digital Equipment	
Westinghouse	
Emerson Electric	

Source: PWMH.

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The logical evolution of the factory of the future company is one which can put together the sophisticated systems largely involving computer technologies, electronics and software, controllers and, of course, robots. The requirement for the various technical disciplines, the high development costs and financial and marketing skills suggest that these companies will tend to be quite large in nature, with suppliers of industrial pieces of equipment occupying a small niche in the broad spectrum market for the automated factory.

Robot Production: Generalists With A Niche for Specialists

The potential widespread use of robots suggests that the industry will continue to segment in various ways:

- Work envelope and load capacity applications have often been the determinant of market segmentation by lift capacity:

  1. Extremely heavyweight applications (lift capability in excess of 350 lbs.)
  2. Heavy applications, including spot welding resulting in lift capacity between 50 and 350 lbs.
  3. Medium to low weight applications requiring lift capacity of less than 50 lbs.

- Small parts, pick and place and assembly-requirements led to the development of the market for robots with lift capacity of less than five pounds. The driving force for market development was the realization that upwards of 90% of the parts of the average automobile weighed less than three pounds.

- Segmentation by process applications, including painting, spraying and coating and arc welding.

An analysis of these market segments suggested that a family of general purpose robots with a choice of drive mechanism, lift capacity and wrist configuration could be produced, with the intelligence of the robot (electronics and software) used to tailor the general purpose robot for a specific application. While the major robot producers have adopted this approach, a small market nich has also developed for a dedicated system, particularly in paint spraying, primarily because of the intricacies of coating technology. We believe it is likely for this generalist approach to pervade in the industry, with some specialized niches developing because of unique process technologies.

R&D: A Crucial Investment

For robots to be useful across a wider breadth of markets in the future, they must be able to adjust automatically to alternative production set-ups and have the capability of recognizing reorienting and manipulating disordered parts. For many assembly and installation procedures, this adaptive ability would be essential.

The key to the wide market expansion, we believe, lies in the breakthrough in at least two areas of technology:

- Sensory capabilities, including:

  1. Force with application in fitting operations.
  2. Tactile with application in both positioning and orienting.
  3. Vision with application in positioning, inspection and monitoring.

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The ability of the robot to interface with large, computer controlled manufacturing systems. This includes the ability to create a task description without the necessity of using a robot's actual motion. The development of off-line programing would also ease the actual programing task.

Further, the key to better robots lies in vastly improved electronics and software, enhancement of existing software and incorporation of advances in other areas, such as:

- Material: Robots in the future are likely to be built out of various composites and/or plastics rather than metal.
- Spread processes such as coating techniques.
- Mechanisms and material handling.

This suggests that robots have all the characteristics of a high technology industry:

1. High levels of R&D spending are a must, with 7-10% of sales, or more, likely. (Note: Similar to the semiconductor industry.)
2. The vast number of technologies involved suggest that joint ventures are likely to occur for advancing the state of the art in robots:
   - Unimation's PUMA robot was developed in a joint venture between GM and Unimation. Development of the product ended the relationship.
   - Cybotech has been formed as a joint venture corporation by Renault and Ransburg, hopefully to develop a robot by bringing the expertise of two companies together.
3. Significant R&D will be done by academia with support help from companies. This is particularly true in sensors and some vision work is currently being done by RPI, Purdue, UCLA, Florida State (Gainesville), Stanford, University of Rhode Island, etc.

R&D ability is fast becoming a barrier to entry in the robot field. Further, it is likely for proprietary technology to be much more important than patent protection, Similar to the major technological fields dominated by software and electronics.

Learning Curve
Pricing Key to
Industry Growth

The heavy emphasis on computers, electronics and software as the key method of adapting general purpose robots for specific application suggests that the pricing of robots will follow the characteristics of high technology industries. Currently, we estimate that around 30% of the cost of a robot is the electronics and software, with even a higher percentage for the more sophisticated models. Hence, we believe that the learning (experience) curve is very important to robotics, and prices should fall as volume increases. For example, one of the major manufacturers introduced its robot line four years ago. Despite the widely inflationary times of the past few years, selling prices have remained essentially unchanged, implying an estimated 30% price reduction in real terms --directly related to the sharp volume increases.

While the base price of robots is likely to decline, the average price per unit is likely to increase over the next five years. This reflects that robots will probably be equipped with more extensive accessories such as sensors and vision. Assuming technological advancement and learning curve pricing, we believe that the robot industry during the 1980s could achieve a revenue growth upwards of 35% (cyclically), with industry revenues estimated at $500-600 mil– Lion by 1985 and approaching-$2 billion by 1990.

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Table 14: Rapid Robot Industry Growth Projected

	Sales Millions	Units
1981	$ 150	2,100
1985	500-600	7,000- 8,000
1990	2,000	30,000-40,000

Source: PWMH.

As in most high technology industries, the cost of being wrong in product and/or market decisions is high and could easily be catastrophic for smaller entrepreneurial concerns.

One potential future market development is the growth of the robot leasing business. As in the computer business, small companies may never have adequate capability to implement robots efficiently. Leasing robots, along with full support from suppliers, could make sense for smaller companies with limited capital and no robot-wise employees, making the latest technology readily available.

ROBOT INTRODUCTION A SIGNIFICANT IMPACT ON MANUFACTURING OPERATIONS

There is no doubt that robots will revolutionize the workplace. Even if no further technological advancements were made in fields such as sensory perception, robots would still have a place in the manufacturing process. However, it is impossible to ignore the awkward period of realignment that must precede the robotics revolution. It is clear that technology is far more sophisticated compared to the understanding of the social system of the factory.

Robots are threatening to the existing work force. Recent estimates have suggested that upwards of twenty million industrial jobs around the world could be replaced by robots. This includes four million assembly workers, two million machinists, one million painters, two million welders and flame cutters and six million machine operators. Retraining is believed to be the major social problem created by rapid robotization, not unemployment.

In both the U.S. and Sweden, for example, many unions have come to accept robots as a method of easing the most burdensome manufacturing tasks and increasing productivity, both viewed as a route to a higher standard of living. Swedish unions have actually classified certain dangerous or monotonous jobs as unfit for humans and demanded that they be carried out by robots. The UAW has. been quoted in publications as stating that higher wages and productivity go hand in hand and technology, automation and new methodology are a major way to increase productivity.

The method of robot introduction into a manufacturing organization tends to follow the pattern of selling an initial unit to a company. The sale by the manufacturer has to include:

Extensive customer support, including back-up support and technical services, simple repairs and parts replacement.

Comprehensive training programs and customer education, as potential users often do not have the technical background *or* expertise to make a robot work on the plant floor.

The first installations tend to be most important, for they are the ones watched most carefully by both management and labor. As companies become more comfortable in using robots, multiple orders follow, but the need for continuing manufacturers' support remains. In the future, robot producers will have to face the problem of support networks that extend throughout the world and offer a variety of services, including education.

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Within the manufacturing corporation, the jobs created by widespread use of robots and unmanned manufacturing --programmers, technicians, engineers --for the most part require a high degree of technical training. The jobs which robots eliminate, e.g. assembly workers, painters and machine operators, are frequently of a lower skill or, if even skilled, require little technical knowledge. **Massive** training programs will be needed to prevent the creation of an oversupply of workers whose skills have become obsolete and a simultaneous shortage of engineers and technicians. It appears that the manufacturing industry has recognized the problems by the responses to the SME Robotics Delphi Poll (Table 15) .

Table 15: Sources of Future Robotic Technical Personnel

Updated In-House Manufacturing Engineering Personnel	50%
Hiring of Experienced Personnel from Manufacturer	20
Hiring of Experienced Personnel from Robot Vendor	10
Graduating College Student	15

Source: 1981 SME Delphi Poll.

To date, however, only the barest beginnings of such programs are in place. We also have recently seen the development of an academic robotics curriculum to help meet the demand for robot technicians. Macomb County Community College in Warren, Michigan has just introduced such a program and the State of South Carolina is subsidizing academic training programs at locations near the new Cincinnati Milacron robot plant.

While we believe the **critical** issues of manufacturing techniques and labor displacement can be handled in the short-term, we are becoming more concerned that the magnitude of the problem could be serious during the second half of the 1980s. Technological advances enhance the capability, economic viability and availability of assembly and inspection robot systems:

> The design of products that are compatible with robot handling will increase in importance. One implication is that the robot specialist will have to be involved in the product design phase.
>
> It is estimated that assembly workers constitute upwards of 15% of the U.S. manufacturing work force, and inspection workers probably 5-10%. These are two areas where advanced robotics could be applied with astonishing impact.

CAPITAL: KEY TO SUCCESS OF BOTH PRODUCERS AND USERS

The need to finance a business in an industry capable of growing 35% annually and requiring significant levels of R&D and an extensive support network suggests that profitability and availability of capital is vital. Fortunately, ‘it appears that the members of the robot industry have been able to tap the capital market as needed. There is no doubt that all the favorable publicity the robot sector has received, including being on the covers of both Time and Business Week in 1980, has helped contribute to the exceptionally favorable opinion held by the investment community as to the prospects for robotics.

It is our view that the government would probably not have to get intimately involved in the financial requirements of the robotics industry. A free market approach should allow this sector to attract the necessary capital required because of the well-above average growth prospects. This does not preclude the necessity of general policy incentives required by American businesses. We believe that tax relief, especially higher depreciation write-offs, are the kinds of programs which would benefit robot producers as well as manufacturers.

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Government programs which could be useful in the future would be in the area such as aiding R&D expenditures through either tax credits or government funds being made available for basic research.

We believe government aid to the users would be more beneficial to robot manufacturers. This could take the form of:

Helping companies afford the introduction of robotics into their production process. We believe this aid could become crucial for smaller companies.

Establishing some sort of showcase, perhaps a national demonstration program, to provide inspirational leadership and develop a cogent policy for manufacturing techniques.

We believe that manufacturers' ability to afford robots and other aspects of factory automation is ultimately related to their cash flow. A stable period of economic growth, reasonable levels of interest rates and controlled inflation as well as government tax policies providing investment incentives would typify the ideal environment for companies in general to increase their investment in automated equipment.

However, it's important to note that the introduction of robots into the manufacturing process essentially breaks the shackles as to how things are done. This implies an important degree of risk for companies to implement robotic programs, a risk taken currently by the larger companies in this country.

It appears that government incentives could be exceptionally useful in helping smaller companies absorb the technological risk of introducing automated equipment. The Japanese government, through the Ministry of Trade and Industry (MITI), has adopted programs addressing this issue in line with the decision that robot production is a major strategic industry for Japan's future:

MITI has permitted manufacturers who install robots to depreciate an additional 12 1/2% of the purchase price in the first year.

MITI has arranged for direct government, low interest loans to small and medium scale manufacturers to encourage various type of robot installations.

MITI has helped encourage the founding of a robot leasing company --Japan Robot Lease. The objective is to support robot installations by small and medium scale manufacturers.

We believe it would be advantageous for U.S. policy to consider following the lead of the Japanese. We also believe that the U.S. government could consider programs to help foster the spread of automated techniques throughout industry. Heretofore, the Japanese have led the way with the Japanese Automated Factory Project sponsored by the Agency of Industrial Science and Technology of MITI. The project, initiated in 1977, aims to help take existing technological advances into the marketplace, with the acknowledged long-term goal of unmanned manufacturing.

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LONG TERM: A REPLAY OF
THE AGRICULTURAL SECTOR

Today, 3. 8% of the U. S. work force is in agriculture, a major change from yesteryear, when it was the dominant employment sector. This 3.8% produces enough food to feed this country and makes the U.S. the leading exporter of food. The decline of population in the agricultural sector occurred with the substitution of capital for labor. There are many people who believe that, through automation, the percentage of the work force in manufacturing will decline significantly from the current 28.6%. While we do not necessarily believe the extreme number of 1-3% in the next century, there is no doubt that the U.S. work force employed in manufacturing as we know it today will markedly decline over the next 25 years. Through technology such as electronics, software, and systems architecture including robots, eventually the automated factory will begin to be a reality.

July 31, 1981

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BIBLIOGRAPHY

1. Lustgarten, Eli S.: Factory Automation, Paine Webber Mitchell Hutchins Basic Analysis, May 27, 1981.
2. Luber, Robert: Rediscovering the Factory, Fortune, July 13, 1981, pp. 52-64.
3. Malkiel, Burton G.: Productivity - The Problem Behind the Headlines, Havard Business Review, May/June 1979, p. 81.
4. Hayes, Robert H. and Abernathy, William J. : Managing Our Way to Economic Decline, Harvard Business Review, July/August 1980.
5. Robotics Today, Robotics Institute of America (RIA) News, Spring 1980, p. 7.
6. Fisk, John D. : Industrial Robots in the U.S. , 'Issues and Perspectives, Office of Technology Assessment, Report No. 81-78E, 3/30/81.
7. Conigliaro, Laura: Robotics, Bache Halsey Stuart Shields Inc. 4/27/80.
8. Fruehlich, Leopold, Robots to the Rescue, Datamation, January 1981, pp. 85-96.
9. Robots Join the Labor Force, Business Week, June 9, 1980, pp. 62-73.
10. ____________________ American Machinist, October 1980, Special Report 726, pp. 105-128.
11. 1981 Delphi Forecast -Robotics, Society of Manufacturing Engineers (SME).
12. Kitao, Y.: Mechatronics, Nomura Securities Co., Ltd., 10/20/80.

U.S. GOVERNMENT PRINTING OFFICE : 1982 O - 90-240