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Paul Aron Report (#25) : ROBOTS REVISITED : ONE YEAR LATER

Introduction: Statistics and Definitions

Just about one year ago I issued the Paul Aron Report #22 "Robotics in Japan" which aroused considerable interest as the first serious and comprehensive study by an American analyst. In a note to that Report, I wrote: "Of course, one could continue to search for additional data which would probably improve the presentation. In view of the extensive American discussion of productivity and the spate of articles on robots, excellent though insufficiently attentive to Japan experience, timeliness demanded the publication of what we know now. Thus, as with all learning, the report must be considered tentative and preliminary not exhaustive". This note could well be descriptive of this current report. This report is an update but to facilitate reading. I have included the relevant material from the previous report. (Report # 22 is still available on request) .

In reexamining the conclusions of my earlier effort, viewed at the time by some as overly optimistic, I find that the report, while basically correct, understated the tempo of 'growth. The Japanese industrial robot industry is growing at a faster pace than anyone had previously estimated. The original forecast by the Japan Industrial Robot Industry Association (JIRA) for 1979 shipments was Y 36 billion (about $180 million); actual shipments amounted to Y 42.4 billion, exceeding the original estimate by 17. 8%. JIRA had initially estimated shipments for 1980 at Y 43 billion; later it revised the forecast upwards by 39. 5% to Y 65 billion. In actuality, shipments were Y 78.4 billion (about $ 392 million) fully 82.3% above the original estimate. JIRA is now estimating shipments for 1981 in excess of = 100 billion (about $ 500 million) and for 1985 approximately Y 500 billion (about $2.5 billion). For 1990 the current "unofficial" estimate is = 1 trillion (about $5 billion). These estimates should be compared with the initial JIRA estimate in early 1980 of = 195 billion for 1985 which many critics argued could not be achieved until 1990. Even JIRA has difficulty keeping up with the forecasts as late in 1980 it was estimating shipments of Y 240- 300 billion for 1985 and Y= 450- 600 billion for 1990.

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TABLE I

Industrial Robot Production Value

Year	Y Billion	$ Million
1968	.4	
1969	1.5	
1970	4.9	
1971	4.3	
1972	6.1	
1973	9.3	
1974	11.4	
1975	11.1	
1976	14.1	
1977	21.6	
1978	24.7	
1979	42.4	
1980	78.4	392
1981E	100. 0+	500
1985E	500.0	2,500
1990E	1,000.0	5,000

**Exchange Rate: Y 200 = $ 1.00

(For convenience only, I have used a single exchange rate of Y 200 = $ 1.00 throughout the report for the past, present and future.)

It may be argued that Japanese data on robots is confusing to Americans because of a difference in definitions. The Electric Machinery Law of 1971 in Japan defined an industrial robot as an all purpose machine, equipped with a memory device, and a terminal device (for holding things) and capable of rotation and of replacing human labor by automatic performance of movements. JIRA classifies industrial robots by the method of input information and teaching as follows:

1) manual manipulator--a manipulator that is worked by an operator.

2) fixed sequence robot--a manipulator which repetitively performs

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successive steps of a given operation according to a predetermined sequence, condition, and position, and whose set information cannot be easily changed.

3) variable sequence robot--a manipulator which repetitively performs successive steps of a given operation according to a predetermined sequence, condition, and position, and whose set information can be easily changed.

4) playback robot--a manipulator which can produce, from memory, operations originally executed under human control. A human operator initially operates the robot in order to input instructions. All the information relevant to the operations (sequence, conditions, and positions) is put in memory. When needed, this information is recalled (or played back, hence, its name) and the operations are repetitively executed automatically from memory.

5) NC (numerical control) robot--a manipulator that can perform a given task according to the sequence, conditions and position, as commanded via numerical data. The software used for these robots include punched tapes, cards, and digital switches. This robot has the same control mode as an N. C. machine.

6) intelligent robot--this robot with sensory perception (visual and /or tactile) can detect changes by itself in the work environment or work condition and, by its own decision-making faculty, proceed with its operation accordingly.

I have used three different robot definitions:

(1) "Robots by Japanese Definition "--all 6 classes

(2) "Robots by U.S. Definition "--classes 3,4, 5,6

(3) "Sophisticated Robots "--classes 4,5,6

The American Robot Industry Association (RIA) defines a robot as "a manipulator designed to move material, parts, tools, or specialized devices, through variable programmed motions for the performance of a variety of tasks. " Thus, the U.S. definition of robots eliminates the manual manipulators and fixed sequence machines.

The following is a breakdown by the nature of input information and teaching (in yen value) .

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TABLE 2

Share in Total Shipment

By Nature of Teaching and Input Information

	1974	1975	1976	1977	1978	1979	First Half F. Y. 1980
1) Manual Manipulator	6.5%	7.8%	11. 4%	8.7%	5.6%	5. 0%	7. 8%
2) Fixed Sequence Robot	68.0 }	73.0 }	47.6	39.0	37,1	47.0	35.8
3) Variable Sequence Robot			8.9	10.9	14.6	18.0	13.3
4) Playback Robot	10.5	10.2	12.7	18.0	17.4	17.0	25.0
5) NC Robot	0.2		0.4	0.4	0.5	4.0	2.6
6) Intelligent Robot	0.1	1.7	6.2	10.3	12.2	9.0	9.9
7) Attachments	14.7	7.2	12.8	12.7	12.6		5.6
	100.0	100.0	100.0	100.0	100.0	100.0	100.0

The sophisticated robots clearly represents an increasing share of p reduction--37. 5% by the first half of 1980 compared to only 10.8% in 1974.

Data is available for the number of units per type produced in 1979 and the number of robots installed and working at the end of 1979.

TABLE 3

Shipments of Industrial Robots - 1979

Type	Units	Value =Y Million)
Manual Manipulator	1,051	2,100
Fixed Sequence Robot	10,721	19,990
Variable Sequence Robot	1,224	7,700
Playback Robot	662	7,200
NC Robot	89	1,700
Intelligent Robot	788	3,800
	14,535 units	42,400

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TABLE 4

Industrial Robots - Installed and Operating

12/31/79

Manual Manipulator	7,290
Fixed & Variable Sequence Robot	45,760
Playback & NC Robot	2, 410
Intelligent Robot	788
	56, 800 units

As JIRA previously had not differentiated fixed and variable sequence robots, the number of operating variable sequence robots installed in 1979 must be estimated. I prefer the more conservative estimate of 4300 rather than the higher IO, 250.

Final data is not yet available for 1980 but, based on the latest preliminary data shipments and installed working robots at the end of 1980 can be estimated as follows:

TABLE 5

Industrial Robots - Installed and Operating (Estimated)

12/31 /80

	Units
1) Manual Manipulator	8,790
2) Fixed Sequence Robot	56,460
3) Variable Sequence Robot	6, 100
4&5) Playback & NC Robot	3,460
6) Intelligent Robot	1,690
Total	76,500

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TABLE 6

Shipments of Industrial Robots Estimated

1980

		Units
1)	Manual Manipulator	1,500
2)	Fixed Sequence Robot	15,000
3)	Variable Sequence Robot	1,800
4)	Playback Robot	900
5)	NC Robot	150
6)	Intelligent Robot	'350
	Total	19,700

Using the more restrictive U.S. definition of industrial robots, the following chart compares the relative positions.

TABLE 6A

Us. - Japan Comparison

Industrial Robots

1980

	Japan	Us.
Production in Units 1980	3,2000	1, 269
Production in Value ($ Mil.) 1980	180	100
Installed Operating Units 12/31 /80	11,250	4,370

The most optimistic estimates for U.S. production in 1980 is 1,500 and for U. S. installed robots 5, 000 but even if this estimate were correct the U.S. position is hardly altered.

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In 1980 the United States probably placed third in the unit production of industrial robots--the Soviet Union produced an estimated 2,000- 3,000 industrial robots. Soviet production, however, tends to concentrate on the less sophisticated robots. Somehow, Americans seem to have taken comfort with an estimate published in Time in December 1980, of 25 robots in the Soviet Union (at the very moment that the Soviet Union was producing about 70 different robot models) . Incidentally, Soviet robotics began even later than Japan--in 1971-72 the first three Soviet robots were produced. The United States produced its first robot in 1961--a Unimate based on a patent originally issued in 1954. It was only in 1967 that Tokyo Machinery Trading Co. started to import and sell a Versatran robot, then produced by AMF, Inc. In November, 1968, Heavy Industries concluded a technology license agreement with Unimation and in 1969 began to produce robots in Japan. Thus, the U.S. enjoyed at least an eight year lead over Japan and a ten year lead over the Soviet Union.

What does the future hold?--My estimates or better "guesstimates" for Japan is necessarily very tentative.

TABLE 7

Japanese Industrial Robot Demand Forecast--Paul Aron

In Units

	1980 (E)	1985 (E)	1990 (E)
Manual Manipulator	1,500	6,000	12,000
Fixed Sequence	15,000	30,000	45,000
Variable Sequence	1,800	14,000	18,650
Playback	900	6,500	13,000
NC Robot	150	1,400	2,800
Intelligent	350	10,000	23,000
Total	19,700	67,900	114,450

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TABLE 8 (Japanese Industrial Robot Demand Forecast--Paul Aron[cont.])

In Value - Billion Y

	1980(E)		1985(E)		1990 (E)	
	(Y)	(%)	(Y)	(%)	(Y)	(%)
Manual Manipulator	3.0	3.8	10	2	20	2
Fixed Sequence	38.4	49.0	60	12	90	9
Variable Sequence	12.0	15.3	75	15	100	10
Playback	12.1	15.4	70	14	140	14
NC Robot	3.7	4.7	15	3	30	3
Intelligent	4.9	6.3	120	24	280	28
Auxiliary Equipment	3.0	3.8	70	14	140	14
Export	1.2	1.5	80	16	200	20
Total	78.4	100%	500	100%	1,000	100%

Using the more restrictive American definition of robots, Japanese industrial robot production is estimated to achieve a unit output of 31,900 with a value of $ 2.15 billion in 1985 and 57, 450 units and $ 4.45 billion in 1990. If this were to occur, Japanese output in 1985 would be four times greater in units and value than the most optimistic forecast for the U.S.

Why have industrial robots enjoyed such success in Japan and why do the Japanese place such high confidence in their future?

LABOR :

Japan's success in robot production and installation can be traced, in large measure, to its labor practices. The Japanese employees in major corporations are guaranteed lifetime employment (until the age of 55-60) . In addition, all employees receive two bonuses, each ranging from 2-5 months pay, in June and December, which, while negotiated between the union and management, are ultimately based upon the company profitability. The Japanese union is not based on crafts, skills or occupations: the union is on a company wide basis and covers all member of the bargaining unit. Employees identify with the company, not with a skill and they are often shifted from one job to another within the company. The worker, not fearing loss of employment, does not oppose automation; in addition, as automated production generally enhances quality and profit and consequently the bonus, the Japanese employees welcome the robots. In Japan the company assumes the responsibility for retraining the employees who have been displaced by the robots. The large companies, at least in the last 20-25 years have assumed the responsibility of training and retraining their employees; lifetime employment deprives most companies of the opportunity to recruit skilled workers from other companies and therefore, necessitates training. Not fearing the loss of trained workers, companies are encouraged to devote considerable effort to training programs. Finally, as robots are used in dangerous, unhealthy and repetitive jobs, the employees consider production by robots as a means of relieving monotonous and environmentally harmful tasks in manufacturing. Employees, displaced by robots, have moved to jobs, more challenging intellectually and less demanding physically.

The practice of QC circles has played an important role in developing employee participation in problem-solving. They are voluntary teams of 8-10 employees who began in the mid-sixties to study quality problems and to suggest improvements. These teams expanded their range of activity from quality to many other areas including productivity, especially during the seventies. Studies indicate that both the unions and particularly the QC circles have often been involved in introducing robots into plants. It should be no surprise that those companies which have the most active QC circles are also the leaders in robotization. Of course, the relatively high tempo of real economic growth in Japan, with its consequent demand for increased labor, has more than compensated for the losses of jobs resulting from increasing productivity, automation, and robot introduction. Some Japanese economists, however, are already warning that the saturation by industrial robots might create an unemployment problem in the 1990's.

The Japanese seem to believe that they displaced the U.S. as the "Number One" in robot production largely because of the labor problem. In America and Western Europe, the introduction of robots is frequently debated and the crucial point in such debates is the unemployment problem. This is rarely discussed in Japan and instead the positive effects of robots are discussed: improvement of quality and productivity and greater safety for the employees. Stress is placed on the new opportunities for greater and higher level employment, as robot operators, robot maintenance workers, and "software engineers", and for opportunities in new industries such as ocean resource gathering made possible by robots. Unlike Japan, few U.S. companies have assumed the responsibility for retraining workers that could be displaced by robots. Furthermore, the American worker does not directly benefit from the increased savings and profit created by robotics. It is interesting that the TV program on productivity ("If Japan can do it, etc.") omitted any discussion of the bonus in Japan.

COSTS OF LABOR AND ROBOTS

The advantages of industrial robots can be better understood in the context of the relationship of labor costs and robot costs. The accomplishments of the robot introduction in Japan from 1968 to 1973 were not promising because of the wide divergence of labor and robot costs. Before the 1973 "Oil Shock", Japanese labor costs were still relatively inexpensive while industrial robots were still high-priced because of the low level of electronic development. During the decade of the seventies labor costs rose sharply in Japan. The manufacturing cost of industrial robots of all types at first declined from 1970-1975. After 1975, the price of the simpler and less electronic "robots" rose, but the "semiconductor revolution" in Japan continued to reduce the cost of the more sophisticated robots. The following table based on a JIRA survey is revealing.

TABLE 9

Ratio of Robot Costs to Labor Costs

(Unit ¯Y 1000)

Total		1970	1975	1978
A.	Labor Cost Per Man	990	2,300	3,000
B.	Average Price -- Robot (Japanese definition)	4,600	4,100	5,000
C.	cost -- Playback Robot	12,000	11,000	11,000
	Ratio B/A	4.6	1.8	1.7
	Ratio C/A	12.1	4.8	3.7

The decline of robot costs relative to labor costs is especially sharp in the field of sophisticated robots. Superficially, a playback robot can be amortized within four years on a single shift and within two years on a double shift. The actual expenses of robot installation and maintenance resulted in a slower rate of amortization. In the future, labor costs are expected to increase 6 - 7% annually while robot costs, thanks to declining microprocessor prices, should remain level or decline.

In a questionnaire distributed by JIRA on the motives for installing industrial robots in the future, the responses in order of importance were as follows: (1) economic advantage, (2) increased worker safety, (3) universalization of production systems, (4) stable product quality, and (5) labor shortage.

Hence, the economic advantage of the industrial robot over human labor which seems certain to grow in the future is considered the most important factor in the increased application of industrial robots.

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MANAGEMENT

Japanese management on all levels has been more responsive to the introduction of robots than their American counterparts. Life-time employment has created greater security and a more long-range attitude among Japanese managers. The absence of stock options reinforces this attitude. Japanese managers are able to tolerate the high initial costs of incorporating robots into p reduction and are willing to accept a much longer payoff than their American counterparts. In the first year of robot introduction, costs can be very high-- not only increases in depreciation, interest costs, and miscellaneous costs related to the robot (changes in the plant and its equipment to accommodate the robots) , but also interference and slowdowns in production while the robot is being fully integrated into p reduction. In one case study in Japan, for example, the company had anticipated that robots would increase production, and thus would permit write-off of all costs within the first year. Instead, production declined and total costs grew by 30%. Similar experiences have caused many American managers to abandon their robot program. But the Japanese persisted and at the end of the second year total costs were 25% less than if the product had continued to be produced manually.

Japanese managers are generalists, often shifted from one area to another that bears little relationship to their previous experience. On the other hand, American managers tend to be specialists and stay within one area of work during their entire career. This, at times, creates opposition, if not hostility, to a novelty such as a robot that might undermine their position. American reports are replete with tales of opposition to robots by middle and lower managers and conflicts between manufacturing engineers seeking to introduce new technology and production departments seeking to maximize current production and intolerant of any interference in output. Even the front line of management-the foreman-often see the robot as a threat to their status especially when the robot requires "care and feeding" by an inexperienced youth with a training in electronics who substitutes knowledge for strength.

In an atmosphere of relatively high interest rates the financial side of U.S. management constantly seeks shorter and shorter payouts and American roboticists often see these "bean counters" as their enemy. The non-adversary relationship and the long-term outlook which pervades the Japanese company has successfully coped with the issues of robot introduction.

American and European companies were also, to some extent, sidetracked in robotics as they had been in the production of numerical control machinery. The Americans developed very expensive and very complicated NC machines so that when the computer broke down, the entire maachine, virtually a machine shop in itself, halted. The Japanese developed smaller, simpler, less expensive machines that catered to small-scale production and could produce in small batches. In robotics the European and American producers often concentrated on the most expensive robots and permitted the Japanese to develop robotics gradually from the unsophisticated manual manipulators to more complex systems that incorporate "intelligence".

INDUSTRY STRUCTURE FOR INDUSTRIAL ROBOTS

At present about 130-140 firms in Japan are manufacturing robots of whom 37 are members of the JIRA. Most large manufacturers, actual or potential, are JIRA members but some important exceptions should be noted--Matsushita Electric Industries, Osaka Transformer Corporation, Seiko, and the pen manufacturers.

The existing robot makers are widely distributed over the whole range of business scales. In size of capitalization, robot makers are broadly distributed from small firms to giant corporations. In examining the table below, the 55 small companies with less than Y 100 million capitalization (equal to about $ 500, 000) represents 41. 4% of the enterprises; the medium firms with (Y 100- 300 million) represent 23. 3%, while the firms with over Y 3 billion capitalization (equal to about $ 15,000, 000) represent 35. 3% of the corporations. The same trend is evident when we examine the robot makers by number of employees. The small firms with less than 500 employees represent 46. 6% of the total, the medium firms with 500 to 5000, 30. 1%, and the giant firms with over 5000 employees, 23. 3%. This data, based on a JIRA survey in 1979, of 133 robot makers, is shown below:

TABLE 10

Industrial Robot Maker Distribution

By Size of Capital

Less than Y 10 million	19 companies	14.3 %
Y 10 million - Y 100 million	36 companies	27.1 %
Y 100 million - Y 1 billion	23 companies	17.3 %
Y 1 billion - Y 3 billion	8 companies	6.0 %
More than Y 3 billion	47 companies	35.3 %
Total	133 companies	100.0 %

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TABLE 11

Industrial Robot Maker Distribution

By Number of Employees

Less than 50	33 companies	24.8 %
50 - 500	29 companies	21.8 %
500 - 1000	15 companies	11.3 %
1000- 5000	25 companies	18.8 %
More than 5000	31 companies	23.3 %
Total	133 companies	100.0 %

The wide distribution of industrial robot makers is the result of several factors. The giant electrical equipment and heavy machinery makers were attracted by the high growth potential of industrial robots and entered the field to diversify their business. Many have been motivated originally by the need for robots within their own business to increase productivity and safety, overcome shortage of some skilled workers, and to enhance their ability to undertake small and medium batch multi-product manufacturing. This applies to the large electrical manufacturers such as Hitachi, Matsushita, Toshiba, Mitsubishi Electric and Fuji Electric. It also applies to the heavy equipment manufacturers such as Kawasaki Heavy Industries, Mitsubishi Heavy Industries, Tokico, Shinmeiwa, and Ishikawajima-Harima. Some of the steel makers such as Kobe Steel and Daido, in diversifying their operations into heavy machinery, also were attracted to robots.

Since robot application often must be custom-made for each and every user according to his specific production process, the robot maker, even if small, can specialize in a specific area of application and successfully compete with the big corporations. Some of these smaller companies undertook to produce robots in order to enhance their major products such as Aida in the hydraulic press manufacturing. The production of robots often enabled the manufacturer to offer a total system rather than an individual piece of equipment. This phenomenon is seen mainly among the machine makers such as Fujitsu Fanuc, Toshiba Seiki, Nachi-Fujikoshi and Komatsu. Other small enterprises began to manufacture robots for their own use and then ultimately marketed them. This applies to firms such as Seiko and Sailor Pen. Many firms branched into robots from manufacturing materials handling equipment and conveyors. This included firms such as Tsubakimoto and Motoda.

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The Japanese are currently debating the future of this structure of robot makers. Some expect no radical change in the industry structure within the foreseeable future. They believe that the small to medium enterprises will continue to carve out markets for themselves in the many specialized areas. Others visualizing the increasing role of minicomputers and intelligent robots expect that the large electric manufacturing companies because of their superiority in IC and LSI technology, will dominate the robot industry. At present, each individual robot maker has its own area of special expertise such as Yaskawa in arc welding, Kobe Steel in large paint sprayers, Aida in press application, Fujitsu Fanuc in machine tool processing. However, all makers are using the technology developed in their specialty area for applications of other areas. Kawasaki is the most active in this approach with its Unimates entering almost all areas of application. But many other manufacturers are aspiring to be "universal robot makers". The emergence of an electronically-oriented universal robot maker depends on the rate of development of intelligent assembly robots.

Unlike the United States, where two robot makers hold over one half of the market share, the Japanese market is widely dispersed and changing each year. In the U.S. , despite the many new companies entering the field, companies actually manufacturing robots probably number less than 20 compared to about 140 in Japan. Kawasaki Heavy Industries has only 3-4% of unit volume of all Japanese robots (by Japanese definition) . By the more strict U.S. robot definition, Kawasaki produced 450 of the 3300 robots made in Japan in 1980 for a market share of 18% in units. Because of its relatively higher price, the market share of Kawasaki in value is probably somewhat higher. In many respects the production of robots in Japan resemble the fierce competition that grew up among manufacturers of television sets, digital watches, desk and hand calculators and video-tape recorders. After a period of intense competition among many firms, production ultimately was concentrated in a few large firms. It should be noted that this period of competition also resulted in Japanese domination in the world market for these products. As the spokesman for the Long Term Credit Bank of Japan confidently puts it: "It is only a matter of time before the industrial robot becomes one more piece of merchandise which symbolizes Japan".

This industrial structure has given the Japanese several advantages. The American robot manufacturers must sell their robots to users; few can test their equipment in actual production conditions at their own plants. With the entry of IBM, Texas Instruments, and Westinghouse into the robot market, this should be altered. But in Japan all through the decade of the seventies the major manufacturers now emerging-Hitachi. Matsushita, Toshiba-had been using robots within these companies. Furthermore, many other companies entered the robot field because they had developed

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robots initially for their own needs-Sailor Pen, Pentel, Pilot in the pen and pencil industry, Okamura in the furniture industry, Tokico in the compressor industry. Many companies developed robots to sell their own products -Aida, Japan leading press manufacturer , developed a series of loading and unloading robots for its presses. Fujitsu Fanuc developed a series of robots to service their N. C. machines. In turn, Fanuc's competitors developed robots to stay in competition with Fanuc while Fanuc in turn developed an assembly robot to help reduce the costs of producing its robots. In some cases companies developed robots for affiliates. That Mitsubishi Electric should develop a "Window Cleaning Robot" , a fixed sequence machine for high buildings, can be better understood when we know that its sister, Mitsubishi Estate, owns many of the tall buildings in Tokyo's Wall Street. This automatic cleaning operation, reduced maintenance cost, eliminated dangerous work, provided better cleaning, and protected "privacy in offices, hotels, and other places". Tovoda Machine Works provided welding and handling robots for Toyota. Mitsubishi Heavy Industries provided robots originally just for Mitsubishi Motors, its automobile making subsidiary.

Because the robots were used within their own factories, the robot makers in Japan offered for sale not just robots but total systems which already had been tested for several years in their own factories. This compelled companies that had originally just produced robots to begin to develop total systems. One example of this is a completely unmanned computer-run dry noodle factory-which includes an automatic warehouse, battery-operated cars, loading and unloading robots, automatic manufacturing and inspection, and packing.

GOVERNMENT POLICY

It is quite evident that MITI has been interested in robots since the beginning of the seventies. It would seem unlikely that JIRA would have been formed without some government encouragement. However, it was not until 1978 that the industrial robot was officially designated as an "experimental research promotion product" and as a "rationalization promotion product" with promulgation of the special Machine Information Industry Promotion Extraordinary Measures Act. While the Electric Machinery Law in 1971 had defined an industrial robot, industrial robot terminology was first standardized in 1979 under the Japanese Industrial Standards.

Following the typical policy of cooperative rather than adversary relations with business, the Ministry of Trade and Industry (MITI) , having identified robot production as a major strategic industry for Japan's future, undertook several measures to popularize their utilization.

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(1) With MITI encouragement, if not direction, a robot leasing company, Japan Robot Lease, (JAROL) , was founded in April, 1980 with the initial paid-in capital of Y 100 million. This company is jointly owned--70% by 24 JIRAmembers and 30% by ten non-life insurance companies. The aim of JAROL is to support robot installation by small and medium-scale manufacturers and increase their productivity. As 60% of operating funds are financed by low cost loans from the government's Japan Development Bank, and the rest from the Long-Term Credit Bank, Industrial Bank of Japan and the city banks, JAROL is in a position to lease industrial robots under conditions more advantageous than the ordinary leasing companies. For its first year of operation (fiscal year 1980) , JAROL planned Y 700 million robot leases; actually its leasing contracts numbering 52 amounted to Y 1, 150 million (about $ 57 1/2 million) . The average term of the lease was 6.5 years and provided a full payout. In April, 1981 JAROL offered a more flexible 2- 3 year rental agreement (not a full payout) and after the expiration of the agreement planned to rent the robot to the same or a different user. At the same time JAROL began discussions with MITI to enter overseas leasing of robots. This resulted from a request of an Australian firm to lease Japanese-made robots. Some question arose as to the propriety of using government loans for overseas leasing but JAROL suggested loans from the Japan Export and Import Bank. Positive action on this matter will greatly strengthen Japan's competitiveness in overseas industrial robot markets.

(2) MITI has arranged for direct government low-interest loans to small and medium-scale manufacturers to encourage robot installation for automating processes dangerous to human labor and for increasing productivity. The government budgeted for fiscal year 1980 Y 5.8 billion for these loans which are extended through the Small Business Finance Corporation, a government finance agency.

(3) MITI has permitted the manufacturer who installs a robot to depreciate 12. 5% of its initial purchase price in the first year in addition to taking ordinary depreciation. This extra depreciation is a common practice in Japan when MITIseeks to promote a particular industry or product. Extra depreciation has been as high as 50%. Generally it can be taken over a three year period and is usually repaid in five annual installments beginning in the sixth year. B y installing an industrial robot, a firm can depreciate 52. 5% in the first year, 12. 5% plus 40% (5 year depreciation double declining) .

(4) MITI created an atmosphere favorable to the introduction of the industrial robot, but it had depended largely on the private companies to determine the direction and scale of production and to undertake R & D. However, MITI has now just announced plans for a huge R & D program to be discussed in the following section.

ORGANIZATION OF ROBOTIC RESEARCH AND DEVELOPMENT

Research on robotics in Japan is conducted by three major types of institutions --colleges and universities, national and public research institutes, and research laboratories of private firms. The number of robot research laboratories in universities and public research institutions grew from 43 in 1974 to 85 in 1980. In fiscal 1979, the universities spent 100 million yen (or about $.5 million) on robot research and the public research institutes about 220 million yen (about $ 1 million) . This total of about $ 14 million is hardly a very large amount. But this statistic omits "personnel expenditures" and is therefore a substantial understatement. Some 270 researchers at colleges and universities and 80 researchers at institutes worked on robots in 1979. Public research has concentrated on theoretical problems, many of which have direct and immediate application such as-- speed control (acceleration of robot when its grip per holds nothing) , improved positioning accuracy, simplification and modularization of robots, sensory perception, pattern recognition ability.

The expenditure of private enterprises on robots has not been made public but up to now has been the overwhelming source of robotic R & D. Of the 107 robot manufacturers surveyed by JIRA in 1979, twenty had a specialized robot research division in their in-house research laboratories, while another fifty-two without a special robot research division had one or more researchers specializing in robot research.

The private research laboratories have concentrated on R & D most closely linked to application–-increased speed, miniaturization, computer control, weight reduction and modularization (development of interchangeable robots) .

A major change has just occurred--MITI announced a seven year Y 30 billion national robot research program to begin April 1, 1982. MITI will create a new R & D group to carry out the program whose purpose is to make robots suitable for a wider application and to develop Japanese robot technology instead of relying on imported American and West European know-how. Stress is to be placed on intelligent robots especially for assembly work, and on robots for nuclear, space, oceanic, and earth-moving industries. The development of sensory perception, language systems, and motional capacity are to receive top priority. This program is called a nationally important major technology development scheme.

SOCIO-ECONOMIC IMPACT OF INDUSTRIAL ROBOTS

This section expresses the Japanese views on this topic and is greatly indebted to Mr. Yonemoto of JIRA, Japan's most prominent authority on this subject. Industrial robots have three major characteristics which, in large measure, determine their socio-economic impact.

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1) Industrial robots ,unlike special purpose automated machines, are programmable, and, as a consequence, are both flexible and versatile. A robot's movements may be altered merely by changing its program.

2) Industrial robots can perform beyond the physical and mechanical abilities of humans. They do not tire from long and continuous hours of work in an environment which may be uncomfortable, if not hazardous to humans. (They require no breaks to overcome fatigue or to meet personal needs) .

3) Industrial robots perform with a high fidelity and accuracy in compliance with the instructions which they receive from man.

As a result of their versatility, super-human capability, and high fidelity to programming, industrial robots have changed in many ways the production scene in which they are employed.

1. Automation of Multi-Product Small Batch and Mixed-Flow Production Line.

The flexibility and versatility of industrial robots makes possible the automation of multi-product small batch and mixed-flow-line production. The special purpose automated machine is restricted to limited model mass production. Recently, consumer demand has become increasingly diversified to the point where according to Japanese estimates, fully 80% of mechanized industry's products are manufactured in a moderate-to-low volume of output. Thus, the nature of contemporary consumer demand and particularly Japan's desire to accommodate a wide diversity of export requirements necessitated and encouraged the use of industrial robots.

2. Ease of Phasing in Product Design Modification and Model Changeover.

A complete changeover or even a modification in a product model often require changing or at least radically rebuilding a special purpose automated machine. Where an industrial robot is used instead, a mere change in program is required. As the product life cycle shortens, the flexibility and versatility of industrial robots becomes increasingly advantageous .

3. Improved Operating Ratio and Increased Operating Time.

Unlike men, industrial robots can operate on a 24 hour basis and therefore, the machines, they service can **also** operate on a 24 hour basis. Furthermore, industrial robots are capable of performing functions at a high speed which exceed human limitations.

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4. Ability to Withstand Severe Working Conditions.

The industrial robot can work in an environment which is adverse to humans. Human beings require a host of conditions to make the working atmosphere both pleasant and safe-ventilation, proper lighting, air conditioning, or at least temperature control, and a variety of safety devices and conditions.

5. Ability to Execute Proper and Accurate Motions and the Ability to Cope Elastically with Changing Production Volume.

The sustained stability of industrial robot operation--their ability to work continuously and accurately faithful to their man-given instructions--eliminates slumps and spurts and provides a smoother production flow. This ability also enables increased production demands to be met effectively.

6. Change in Nature of Production System.

To the Japanese the introduction of industrial robots means a change in the p reduction system. In the typical traditional mass production line the machine determines the activity of the operators--something pointedly satirized in Chaplin's famous film, "Modern Times". The operator programs the industrial robot and therefore, the human dominates the system. According to the Japanese, the industrial robot reduced psychological resistance to the conveyor system and thus permitted its more effective use. They believe that human satisfaction derived from the human control over the robot and this attitude led to qualitative improvement in labor.

7. Creation of New Technologies.

The characteristics of the industrial robots--combined with the change in the production system to a man-dominated robot-machine system led to the creation of completely new technologies and to their application in exploiting oceanic resources and in increasing utilization of nuclear energy. Robot applications to health, household, and cleaning duties have also been forecast.

The wide socio-economic Impacts of the application of industrial robots expected by the Japanese roboticists has begun to be evident.

1. Improvement of Productivity.

The automation of small-batch and multi-product mixed-flow line production saved man-hours and reduced in-process and accumulated inventory. The improved operating ratio and increased operating time also reduced man-hours. The relative ease with which an industrial robot could be fit for a product design changed saved the time usually required for retooling. The more effective use of the conveyor system made possible by the industrial robot,also contributed to enhanced productivity.

2. Stability and Improvement in Product Quality.

The super-human capacities of the industrial robots and their fidelity to human instruction led to a uniformity of products and hence made possible the stability and improvement of product quality. By working 24 hours the industrial robot eliminated the incidence of inferior or defective products which often occur during factory start-up operations. The quality variations which result from long hours or the differing abilities of operators were eliminated.

3. Improvement in Production Management.

Production management has improved for several reasons:

a) Reduction of inventory and in-process products as a result of automation of small-batch and multi-product mixed-flow -line-production.

b) Reduction in set-up time and elimination of retooling the production line.

c) The durability and accuracy of industrial robots facilitated production planning.

d) Industrial robots reacting more elastically to production volume change reduced problems of manpower reallocation.

e) Industrial robots have helped to improve the quality of work life and led to greater employment stability. In addition, they have contributed to overcoming the skilled manpower shortage in such areas as welding and painting.

4. "Humanization" of Working Life.

a) Industrial robots released humans from hazardous and unhealthy working conditions preventing accidents and occupational diseases.

b) Industrial robots released humans from monotonous work and thus reduced psychological stress.

c) The man-robot-machine production system eliminated the psychological resistance to the conveyor system, and improved labor quality and human satisfactions from the human control of robots. Such a system corresponded better to a more highly educated and aging society. In recent years, Japan's society has witnessed a growing shift from blue-collar to white-collar occupations and the industrial robot enables corporations to accommodate to this trend. Human resources liberated from adverse work environments and from monotonous repetitive manual jobs are rechanneled into more intellectually demanding robot operations and maintenance positions. For example, manual wire bonding of IC's require the fatiguing performance of monotonous, repetitive tasks under a microscope, and a training period of 4 - 5 months. The industrial robot reduces the training period to 15 minutes and eliminates the fatiguing manual operation.

Robot utilization makes possible greater employment opportunity for the infirm, elderly and female work force in industries where heavy and continuous loading /unloading or carrying a heavy welding gun were required. The "humanization" or work life contributed to employment stability, reducing absences from work.

5. Resource Conservation.

Industrial robots contributed to conservation of resources, a high priority factor especially since the oil crisis of 1973. These savings were achieved in a variety of ways:

a) The robot saved material-the paint spraying robot, for example, used 20- 30% less than the manual painters in many operations.

b) The ease of accommodating the robot to product design changes reduced investment in purchasing and /or rebuilding equipment.

c) The reduced defective ratio saved resources.,

d) The industrial robot, by working in unpleasant environment, reduced the energy consumption of air conditioning, ventilation, lighting, etc.

d) By its ability to operate on one, two or three shifts, the industrial robot resulted in reducing investment.

ROBOT APPLICATION

Robot shipments are also classified by user which shows the automobile as the primary buyer except in 1980, when the electric appliance industry, which usually occupied second place, took the lead for the first time.

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TABLE 12

Breakdown of Industrial Robots by User (In Value)

Japanese Definition

	1974	1975	1976	1977	1978	1979	1980P
Auto	35. 5%	19. 9%	30.5%	33. 6%	34. 5%	38. 4%	30. 0%
Electric Appliance	9.6	12.8	20.9	23.1	24.6	17.5	36.0
Machinery	4.5	5.6	7.6	8.8	7.0	5.3	
Metal Products	5.8	3.8	5.8	3.4	7.1	9.0	
Exports	2.9	4.2	2.3	4.5	2.5	1.9	

(P - Preliminary announcement of JIRA)

However, the automobile industry still dominated the sphere of sophisticated robots.

TABLE 13

Shipments of Playback Robots by User

(4/1/80 - 10/1/80)

	Unit	Value
Automobile	61. 5%	52. 4%
Electric Appliance	10.3	11.6
Machinery	3.9	8.3
Metal Products	4.4	5.7
Exports	5.9	6.0
Others	14.0	16.0

The large percentage of exports of playback robots compared to the less than 2% export share of total industrial robot production indicates the direction of Japan's export policy.

Since the playback robot seems to be concentrated heavily in the automotive industry, an analysis of the type of work performed by playback could indicate relative use:

TABLE 14

Breakdown of Playback Robot by Work Process

(4/1/80 - 10/1/80)

	Unit	Value
Arc Welding	18. 8%	26. 0%
Spot Welding	57.1	45. 1
Spray Painting	11.3	17.8
Others	12.8	11.1

It is clear that spot welding represents the major application of the playback robots. A preliminary report on 1980 calendar year robot production revealed that compared to 1979, arc welding robots increased 2 11% in value and 100% in units, and spot welding robots grew 85% and 100% respectively. In addition, assembly robots grew 340% and 33% respectively (certainly from a low base) , and press and conveying robots 60% and 6% respectively. The large growth in assembly robots was mainly for insertion of electronic parts into printed circuit boards (an increase of 440% in 1980 compared to 1979) .

SPOT WELDING

The automobile industry has until 1980 been the largest single consumer of robot production, in large measure because of its purchases of spot welding robots. The majority of Japanese car bodies consist of 300-400 press-formed parts manufactured from sheet steel which are bonded together by 3,000-4,000 spot welds. In the latter half of the 1960's special purpose automatic multi-spot welding machines were introduced. However, with the tendency to product diversification and the shorter life cycle of car models, the return on investment of the multi-spot welders declined. Large monetary expenditures to modify the multi-spot welders were necessitated by model change-over or design modification. During the modification, a considerable period of time was lost and management expenses were consumed for production line reorganization.

Thus, the robots replaced the multi-spot welders because they only require being taught where to weld in the new model in the event of a model change-over. Often merely one hour is required for the new learning process. As production volume is no longer clearly predictable, it became quite risky to invest in special purpose automatic machines.

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Investment in the more flexible robot seemed preferable. The robot also eliminates the need of the manual operator to follow the conveyor line with a heavy welding gun.

The automobile companies then introduced batteries of robot welders. In some assembly plants, a single operator for robots can handle a work load once shared by ten workers. To improve productivity by simultaneous multi-spot welding, efforts have been made to develop multi-arm welding robots and to apply a number of modular robots to welding. Robot introduction into the spot welding line has made possible the automation of multi-product mixed-flow-assembly line on which various model flow one after another.

Nissan has been the largest user of spot welders and by the end of 1980, it had about 300 spot welders. At the same time, Toyota reportedly had 200 spot welding robots, but it ordered 720 robots from Kawasaki Heavy Industries--220 by 3/81, 200 by 3/82, and 300 by 3/83. It has been assumed that most of these would be used for spot welding. Kawasaki is reportedly delivering about 25 units monthly. Mitsubishi Motors has been receiving spot welding robots from Mitsubishi Heavy Industries. Toyo Kogyo and Honda have introduced welding robots.

Kawasaki H .1. is clearly the leader in production of robot spot welders. By spring of 1981, it had delivered 1,500 Unimates primarily for s-pot welding, and its monthly production rate is 60. Mitsubishi H. 1. occupies second place, having delivered 250 robots by the spring of 1981 and with a monthly production rate is slightly over 10. Toshiba Seiki has begun production of a modular spot welding high speed robot which can reach a monthly rate of 35-50. Toyoda Machine Works is also making an inexpensive building block system spot welding playback robot, but they will not be offered for public sale until the fall of 1982. Toyoda expects to sell 1,000 units annually. We do not know how many of these have already been shipped to Toyota. By 1983, Toyoda Machine Works and Toshiba Seiki, if they should be successful in their modular and simpler spot welding robots, could accupy a significant market share.

ARC WELDING

Arc welding operations are conducted in an extremely unfavorable environment where carbonic acid gas, fumes and heat are generated. As a result, arc welders must wear masks and consequently, must take time out frequently. Some loss of operating time is, therefore, inevitable. In addition, the new generation of young workers, being better educated, tend to shun arc welding. As a consequence, arc welding was particularly susceptible to robotics.

However, the large-sized robot such as the Kawasaki Unimate, which could handle heavy loads could hardly be justified economically by an application which largely used light weight welding guns. Yaskawa Electric Mfg., at present, dominates the arc welding robot applications with its relatively low-priced playback robot. Shinmeiwa developed arc welding robots for work on heavy plates while Osaka Transformer developed arc welding robots for work on sheets. Kobe Steel has produced a more expensive, continuous path control, arc welding robot. Hitachi had produced two robots suitable for arc welding: a sophisticated intelligent robot, and a low priced articulated playback robot. Matsushita has introduced a very competitive arc welding robot.

With Matsushita entering the arc welding area and with Hitachi capable of substantially increasing its output, it is entirely possible that these two firms will ultimately dominate the arc welding market.

SPRAY PAINTING AND COATING

Painting robots are the third largest type of playback robots and are *now* growing at the same rate as spot welding robots but not as fast as the arc welding robots. Spray painting and coating offer a rich area of application. To become skilled, a coating worker required 2-3 years of experience. However, the poor working environment and the tendency to a more educated society contributed to a developing skilled worker shortage. The necessity for a large percentage or rework made production planning difficult.

The industrial robot provided certain advantages in painting:

1) They insured stability of product quality and therefore made possible improved production planning and control. Despite the selection of the most skilled workman for finish coating, the quality of the finish varied according to the workers and the conditions of the day. In automobiles, the paint finish of a car, and especially its uniformity, is a determining element in the Japanese domestic consumer preference.

2) They made possible a multi-product mixed batch coating line.

3) They provided continuous production operation and reduced the need for intermediate stocks.

4) The manual workers and special purpose automatic coating machines tended to increase the use of paint to preclude uneven coating, especially in complicated shapes. In addition, special purpose automatic coating machines tend to overspray paint on smaller products in a multi-product coating line. In the case of spray painting an auto body, a savings of 10-20% in the use of paint has been effectuated. Reducing the amount of paint reduced the need for ventilation and therefore, saved on energy consumption.

5) Spray painting is a very unhealthy job because of the chemicals and dust. The spray painting robot could free the operator from staying in the spray booth. It provided a relatively simple way to meet safety regulations.

Kobe Steel introduced the Norwegian Trallfa spray painters--a rather expensive robot. Both Hitachi and Mitsubishi Heavy Industries worked wit h other firms -- Nihon Parkerizing Co. and Iwata Air Compressor Mfg. Co. respectively to develop playback spray robots. Tokico offered a large variety of low priced painting robots while Nachi Fujikoshi offered a spray robot with both remote and direct teaching.

Considering the demand for spray robots (Nissan alone is reportedly seeking 300 units) it seems evident that production objectives will be increased. It is still too early to predict the future market share as changes are expected shortly, at least in Hitachi.

MACHINE LOADING AND UNLOADING

Industrial robots have been applied to a wide variety of production processes in which the basic breakdown of the process indicated that the robot is being used primarily, if not exclusively, for (1) loading and unloading, (2) trans-shipping and (3) palletizing and depalletizing. This refers to applications in the following areas:

1) die casting
2) forging
3) press work
4) plastic molding
5) machine tool loading
6) heat treatment

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In each production process, fierce competition exists between those who designed industrial robots, often relatively unsophisticated, for particular production processes and the universal robot makers who offer playback and intelligent robots. In most cases, however, the specialists seem to have won out as of now. In press working operations Aida Engineering seems to have won dominance though strongly challenged by Toshiba Seiki. Similarly, Fujitsu Fanuc seems to enjoy supremacy now in the loading of machine tools, although Kawasaki H. 1. has mounted a strong challenge.

In plastic molding (the automatic unloading of injection molded products) the small manufacturers dominate. Ichikoh Engineering Co. and Kyoshin Electric offer a complete line of fixed sequence machines. Star Seiki offers both fixed and variable sequence robots. Sailor Pen, likewise, offers relatively unsophisticated machines. For unloading workplaces from a die casting machine, Ichikoh offers its fixed sequence machine while Shoku and Daido offer variable sequence robots.

For putting workplaces into a furnace Shinko Electric has a relatively sophisticated variable sequence robot. Nachi Fujikoshi offers a specially designed robot to tolerate hot temperature which has bee n used to transfer workplaces from a furnace to a press.

In the forging area, a great number of robot makers offer a variety of specialized products: Aida, Kobe Steel, Komatsu and Nachi Fujikoshi.

MACHINING

In Japan one operator of NC machine tools serves on average less than two NC machine tools. This low ratio is the result of manual loading and unloading of the work pieces, manual disposal of chips and maintenance. Many Japanese firms sought robotic solutions to this problem. One of the consequences of the application of robots to machining besides improved productivity was improved production management. Robots could respond more elastically to changes in production volume and in the event of temporary requirements for increased production they could easily be worked overtime. Where the process was computerized, it was possible to know beforehand when a machinery operation would be completed.

While several other companies manufacture robots for machining Fujitsu Fanuc dominates this application area with an output of 100 units monthly. The Fanuc Model O uses the NC of the single machine tool which it services; the Model 1 and 2 (known in U.S. as 3) have their own NC and service up to two and five machines respectively. These machines make possible an unattended machining system that operates automatically at night.

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The entry of Fujitsu Fanuc into robots has caused some of its competitors and some of the machine tool manufacturers to develop and produce robots of their own. This is especially true of Okuma which supplies its own NC for its machine tools. In addition, Yamatke-Honevwell and Ikegami Iron Works have started Production of NC robots. Fanuc plans to introduce-additional models in the summer of 1981,

Fanuc's competitors now are other manufacturers of robots who have modified their products to service machine tools.

TRANSFERRING

Closely allied to the machine loader/unloaders are the robots which are engaged primarily in the transfer of materials. Many robots equipped for specialized processes such as welding and painting can also be modified for transferring of materials. In addition, many conveyor equipment manufacturers were compelled to produce robots to compete with robot manufacturers entering their market. Some robot makers entered the materials handling market trying to carve a special niche for themselves.

Shinko Electric, Taiyo, and Kayaba Industry are manufacturers of machine loading robots that entered into the transfer field. The conveyor manufacturers that entered the field include Tsubakimoto and Sanki Engineering. The "universal robot makers" offering machines for transferring include Kawasaki, which offered modifications of its Unimate for that purpose, Daido Steel, Yaskawa, Nachi Fujikoshi and Toyoda Machine.

Some firms specifically developed a line of materials handling robots. Dainichi Kiko has developed a line of heavy duty transfer robots. Motoda (now Oriental Terminal Products) makes a complete line of what is described as multi-purpose versatile robots in both variable sequence and playback versions. Their major, if not exclusive, market, seems to be the materials handling area but Motoda claims that these robots can be used for welding and spray painting. Toyo Keiki has developed a series of variable sequence robots specifically dedicated to palletizing and depalletizing. The entire area of transfer robots like the area of machine loading robots is still too greatly splintered to provide a meaningful market share analysis.

ASSEMBLY ROBOTS

Assembly robots capable of inserting, screwdriving, bonding, and similar p recesses exist largely either in the R & D or the early application stage in Japan. Most major electrical manufacturers, such as Hitachi, Matsushita, Mitsubishi, NEC, Oki, and Fujitsu, have developed fully automatic systems for bonding All these use cameras for visual perception to position by shape or pattern and in the case of Hitachi and Mitsubishi Electric, to detect defects. Fuji Electric's "Checker robot", which examines and rejects pharmaceutical pills is not a robot but does advance both visual (by use of a camera) and tactile perception for quality inspection.

In addition, special purpose automatic assemblers provided considerable data for constructing assembler robots. Hitachi built for Nissan an automatic tire fitting system which uses a machine hand to detect the hub bolts, position them, and tighten them. Hitachi also developed a fully automatic system for fitting rubber belts to tape recorders from which they learned assembly principles suitable for automobile and electric appliance belt fitting.

Hitachi manufacturers an intelligent robot with a 25 step memory capacity and a 200g. load capacity that can fit different components one by one in a specified order. The robot moves fast requiring only 1-2 seconds to fit workplaces. Its finger support is flexible to prevent excessive force. Its positioning precision does not have too close a tolerance but a special searching function automatically detects the holes of workplaces and fits them properly even when positioning is not accurate. An automatic rejecting function within the robot prevents assembly of defective workplaces.

Both Hitachi and Matsushita have built experimental robots to assemble electric vacuums.

The larger electronic/electrical manufacturing companies are planning to robotize 50-75% of their assembly operations by 1985. This would indicate that far more activity and experimentation has taken place than has so far been publicly revealed. (Still this forecast seems too optimistic to me.)

In March, 1981, Hitachi publicly announced a task force of 500 key technology experts to fashion and install a standardized assembly robot with both visual and tactile sensors, microcomputer control, and mobility and projected a 60% robotization of its assembly processes by 1985. In April, 1981, Matsushita announced a plan to marshall the entire staff of its technological division to develop intelligent industrial robots controlled by microprocessors and modularized (BBS) . Matsushita revealed that some BBS robots were already functioning at its plants. The new robots were to be of three types (1) robots that position workplaces accurately, (2) robots that assemble workplaces, (3) robots that adjust the finished product to function as originally designed.

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NEC then reported that it had developed a factory robot that assembles electronic machinery and appliance parts and components with a speed of 45 centimeters per second and a positioning accuracy of only 8 microns. The high precision and speed has been realized by computerization and by the application of the principle of electronic magnetic repellence, utilizing the linear-motor levitation technology that has been used by the Japanese National Railways in developing the "floating" train. The NEC linear-motor driven robot arm and hand picks up a machine part or component with a maximum load of 2 kilograms and carries it around by making it float over the work table. The high precision of movement is achieved by the robots's set of 16 sensors (visual) supported by a built-in microprocessor. NEC has been producing these assembly robots so far for its own factories and those of affiliated companies and in 1981 NEC plans to manufacture 50 units of these assembly robots.

In June, 1981, Ishikawajima Harima Heavy Industries, a close ally of Toshiba, announced plans to produce its Group Manipulator Module System (GMMS) with an articulated arm with the most advanced parallel circuit-type 16K RAMS in its microprocessor. In October, 1981, the GMMS will be tested (possibly at Toshiba?) and hopefully would be marketed by September, 1982 the latest.

Fujitsu Fanuc has also developed an assembly robot but no details are known except that it is being used at their new Fuji plant. Fujitsu is working closely on robot development with its affiliate.

The heavy emphasis on assembly and sense perception by both the private firms, universities, and public research institutes would seem to indicate the possibility of achieving the goal of popularization of assembly robots by 1985. As will be discussed later, the Japanese consider that the intelligent robot is an important element of export policy for the future.

BUILDING BLOCK SYSTEM (BBS)

The trend to incorporate various models into a single production line and to run these lines at higher speeds created some problems for the conventional universal type spot welding robot. In a mixed-flow production, line robot capacity was not fully and efficiently utilized. Furthermore, it required a large floor space for installation.

After a year of development and design and a half year of testing a new robot, the BBS became operational in May, 1978. The BBS is more compact in size and therefore, lower in cost than the conventional robot. It is a fully articulated multi-welding system wherein one control panel can control simultaneously up to 8 units (48 axes) and a hydraulic unit, separate from the robot main body, controls three robots.

A study of two years of operation of the BBS welding in an auto plant indicated that its investment efficiency was 30% greater than a conventional robot system. The floor space required was reduced almost in half. The downtime of a BBS robot was one third of the downtime of a conventional robot.

BBS is the aim of most of the makers of sophisticated robots. How many of these building block systems are now operative in Japan is not known, but the several years of experience and the concentration of private research laboratories on the BBS would tend to substantiate the Japanese expectation of a substantial increase of the BBS far beyond application only to spot welding. Toyoda Machine Works and Toshiba Seiki have developed successful BBS robots but detailed production information for these companies and other BBS makers is currently unavailable.

FROM ASSEMBLY ROBOT TO FLEXIBLE MACHINE SYSTEM

The ultimate aim of the assembly robot is the creation of a comprehensive flexible manufacturing system (FMS) sometimes called the " unmanned factory". Such a system as exemplified by Fuji Electric's turnkey noodle factory would combine industrial robots with an automated warehouse, unmanned transport vehicles, belt conveyors, and computers which would simultaneously operate and record production.

Fujitsu Fanuc has invested Y 8 billion to create such as factory at Fuji to serve both as an automated manufacturer and a showroom. Its production capacity can be expressed in terms of monthly sales of Y 1.5 billion or in terms of production output-- 100 industrial robots, 150 electric discharge wire cutting machines, 100 numerical controls. The total number of employees is 100--19 machine processors, 63 assemblers, 4 inspectors, and 14 management and clerical personnel. A factory of this scale normally requires five times as many people.

The Japanese argue that the FMS actually results not only in reduced labor costs but reduced capital investment. Fuji operates 24 hours a day (unmanned at night) and equipment utilization ratios are close to the maximum. Furthermore, model changes can be made easily. With robots, machines need not be replaced or rebuilt; only the program must be changed. Prior to the introduction of industrial robots, factories often shut down for months to make the required alterations for a model change. In addition, a substantial amount of peripheral factory equipment such as lighting (the robots run at night in an unlighted plant) , air conditioning and atmosphere control became unnecessary, at least in those areas where robots work without humans in proximity. Finally, the miniaturization of industrial robots, which

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is beginning to take place, will enable robots to be positioned very close to each other permitting a higher degree of efficiency in space utilization, a major element in Japan where industrial land is relatively scarce and high-priced. This plant contrasts sharply with the custom-made, almost handicraft assembly of many American robot manufacturers. The ability of Fanuc to increase its output swiftly is understandable; when they speak of an ultimate capacity of 360 units per month of industrial robots (which I presume includes both machine loading/unloading robots now being sold and their new assembly robots) it seems quite feasible.

FUTURE OF JAPAN'S INDUSTRIAL ROBOTS

The demand projections for rapid growth are based on the following analysis:

(1) The intelligent robot with an internal microcomputer and sensory perceptions has emerged and its field of application, especially in assembly and inspection, will widen and expand very rapidly. The announced plans of the major electrical manufacturers should provide substantial markets within each company and its affiliates.

(2) The shortage of skilled labor and the aging of the workforce will hasten the acceptance of industrial robots.

(3) The ability of industrial robots to work in adverse work environments resulting in savings on anti-pollution devices and energy will also accelerate acceptance of industrial robots.

(4) The government policies of financial aid and accelerated depreciation will encourage the use of industrial robots among the small and medium corporations. To the extent that such firms are suppliers of the larger process industries, they will be compelled to introduce industrial robots to provide swift on-time delivery of components, (the Komban System of Toyota) .

(5) To increase Japan's competitiveness in international markets not only against the advanced Western nations, but also against its low labor cost competitors in East Asia (South Korea, Taiwan, Singapore, Hong Kong) , Japanese firms are being compelled to automate.

(6) As demand for goods becomes less uniform and more diversified, small and medium batch multi-product production and constant modification will become predominant. The industrial robot, especially the BBS, has greater flexibility than the dedicated, single purpose automatic equipment.

(7) Japan has made robots a top priority both for research and production and an unrestrained effort is being made in that direction.

(8) The Japanese expect **a** substantial expansion of robots to areas

other than the process industries such as electrical and automobile manufacturing. In agriculture, robots will be used for crop dusting and spraying chemicals, harvesting fruit trees, tilling ground and even milking and feeding of cows. The Japanese expect robots to be used in many aspects of forestry.

A top priority has been given to underwater geological surveying and welding and machining (under 300 meters) . Komatsu already has an underwater robot being used in bridge building. In mining, robots are being developed to work coal and ore faces. Robots are also being planned for building construction (especially multi-storied) and road construction. In the service industries robots are being developed to clean walls and floors of buildings, cleaning of boat hulls, cleaning electrical insulators in nuclear energy. The Japanese also expect to expand robot use in the hospital and the home. However, it should be emphasized that the top priority for the first half of the decade remains the intelligent robot for assembly.

(9) Japan expects to be a major exporter of industrial robots. This requires some additional comment.

The Japanese expect that Western Europe and the U.S. , as well as Eastern Europe, will make strong efforts to increase worker productivity. These "reindustrialization" programs will necessarily involve increased use of industrial robots and Japan plans to export them. While exports of robots were less than 2% in 1980, the Japanese expect that in 1985 and 1990, exports will constitute about 20% of p reduction.

The Japanese attitude is expressed *in the* following view of Machida of the Long Term Credit Bank: "The industrial robots presently in use are, technologically speaking, still in their infancy. During the 1980's they will mature from boyhood to the young adult stage. At present, Japan is the number one country qualified to be the parent of this child".

Accepting the challenge of Japan's lack of innovativeness and creativity, Machida wrote "It has been said that Japan cannot be victorious in the pioneer technology which is producing sophisticated, knowledge-intensive products because we do not possess high creativity. However, the expanding exports of Japanese intelligent robots will soon bear testimony to the fact of our international competitive strength, not only in improvement technology and application technology, but in pioneer technology as well".

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Machida concludes his overview asserting that the "intelligent robot is representative of the leading edge of technology products" and that "the growth of the industrial robot industry will bear eloquent testimony to our strong international competitiveness even in the area of state-of-the-art technology". These views reflect the Japanese attitude of placing major stress on the export of intelligent robots as proof of Japan's creativity.

Returning to the estimated demand forecast, the most substantial growth through the eighties will be the intelligent robot. Playback and NC robots will grow at an accelerating rate in the first half of the decade, but should slow down in the second half. Variable sequence robots will also grow significantly in the first five years but level off in the second five years. The manual manipulators and fixed sequence machines show growth but their total share of output will decline significantly in value terms. Thus, in 1974, the sophisticated robots constituted 10. 8% of total value; in 1980 26. 4%, in 1985, 41%, and in 1990, 45%.

In terms of production, the two processes certain to grow throughout the decade will be assembly and inspection and measurement, probably at a rate of almost 40% annually. Spot welding, arc welding, and machine loading will continue to grow but at a decelerating rate. Spray painting should maintain continuous growth. In 1985 the production process for which robots are produced have been estimated as follows (in % of value).

1)	Assembly	21. 7%
2)	Machine Tool Process	13.1
3)	Arc Welding	10.5
4)	Inspection	10.0
5)	Spot Welding	7.5
6)	Spray Painting	5.0
7)	Molding	3.3
8)	Others	28.9

How will the **U.S.** and Japan compare in the future? Using the U.S. definition of robots the following table includes the latest estimates.

TABLE 15

U.S. -Japan Comparison

Industrial Robots (U. S. Definition)

	Units		Value (million $)	
	U.S.	Japan	U.S.	Japan
1980	1,269	3,200	100.5	180
1985	5,195	31,900	441.2	2,150
1990	21,575	57,450	1,884.0	4,450

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This is probably the best estimate of the future, assuming a continuation of those elements presently at work in each country. If we learn anything from history, it is that the future is never a simple continuation of the present. Therefore, hopefully the estimates remain "tentative and preliminary".

FOOTNOTE : While I alone am responsible for this report and its conclusions, many others provided assistance. In particular, Mr. Karl Kamita of Daiwa Securities ably researched and translated numerous articles on robotics in Japan. The works of Mr. Yonemoto of the JIRA, Mr. Machida of the Long Term Credit Bank of Japan, Prof. Ueda of Nagoya University, and Mr. Engelberger and Mr. Tanner, two "veterans" of U.S. robotics, not only added to my fund of knowledge but greatly influenced my thinking.

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