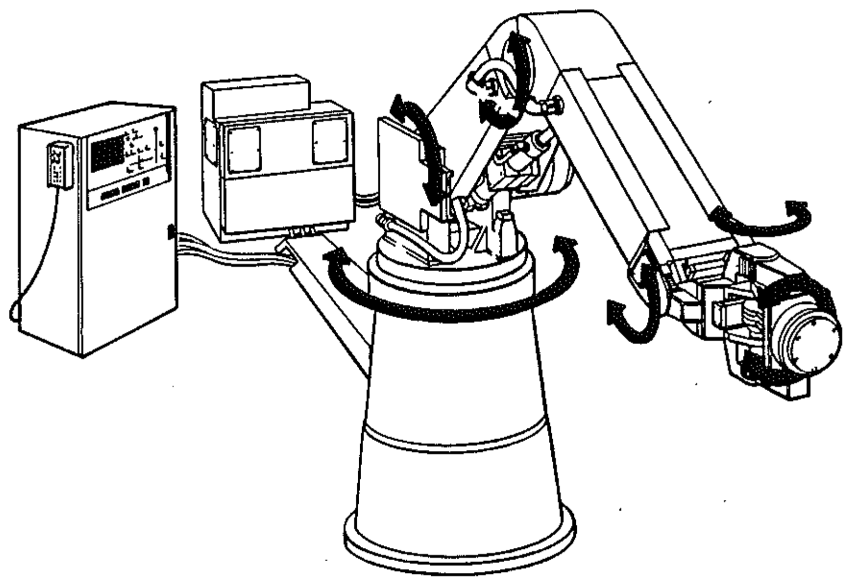
# NATIONAL SECURITY ASSESSMENT OF THE U.S. ROBOTICS INDUSTRY



U.S. DEPARTMENT OF COMMERCE
BUREAU OF EXPORT ADMINISTRATION
OFFICE OF INDUSTRIAL RESOURCE ADMINISTRATION
STRATEGIC ANALYSIS DIVISION

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## EXECUTIVE SUMMARY

### National Security Assessment of the U.S. Robotics Industry

This assessment was conducted by BXA's Office of Industrial Resource Administration when industry sources advised the Commerce Department that the U.S. robotics industry was rapidly losing market share to foreign competitors and in danger of falling behind in many areas of the technology. The assessment analyzes the industry's historical performance and examines both the national security and commercial importance of the U.S. robotics industry within the context of international competitiveness.

Robotics is critical to U.S. national security. Robotics was identified by the 1990 Department of Defense Critical Technologies Plan as vital to long-term U.S. defense capabilities. Robotics are incorporated in current weapons systems and will play a larger role in future systems. While defense and commercial development follow largely separate paths, a strong domestic industry is essential to maintaining U.S. involvement in the continuing overall development of robotics technology.

Robots have wide-ranging commercial implications. Robots are used extensively in the automotive industry, primarily for welding, painting and material handling applications. The electronics, aerospace, metalworking and consumer goods industries are also major robot users. Integrated factory automation systems, to which robot technology is key, affect nearly all types of manufacturing. In the near future, productivity and competitiveness in these industries will depend in large part on flexible automation through robotics.

U.S. robot manufacturers have lost market share throughout the 1980s. U.S. manufactured robot shipments fell 33 percent from $225.5 million in 1984 to less than $150.6 million in 1989. Despite the weakening of the dollar against other major currencies after 1985, imports during this period rose from $88.4 million to $181.4 million, a gain of more than 105 percent. Import penetration grew to at least 62.7 percent by 1989, and to an estimated 75 percent if account is taken of "reshipments" of imported robots. Although third calendar quarter new orders rose from 672 units in

1989 to 1,236 in 1990, actual U.S. production failed to rise correspondingly as over 80 percent of these orders were filled by imports.

Low profitability has forced many U.S. producers from the industry. The robotics industry as a whole reported losses four out of five years from 1985 to 1989. A return of 2.3 percent was reported for 1986. U.S. manufacturers have been unable to produce the high volumes necessary to realize economies of scale and generate revenues to cover their high costs. Many large firms, such as Westinghouse and Cincinnati Milacron, faced with low profitability, have exited the industry.

Investment has been inadequate to maintain robot production capacity in the United States. Total investment by U.S. robot producers peaked in 1986 at $22 million and fell to $6.5 million in 1989. Investment by individual firms varies a great deal. One large firm's investment in buildings alone greatly inflated the first three years' figures. Those firms most dependent on the auto industry saw their investment decline with the drop in motor vehicle orders after 1986.

Total employment for the surviving robotics companies fell 6.8 percent. The number of employees in the U.S. robot industry dropped from 1,440 in 1985 to 1,345 in 1989. Within occupational groupings, the number of production workers dropped 11.8 percent during the same period. In 1989, the proportion of production workers to total employment was only 18.8 percent, down from 19.9 percent in 1985, which is far below the norm for the manufacturing sector. This is indicative of the declining amount of manufacturing that actually occurs in the United States.

Productivity in the domestic robotics industry has declined. Sales per employee were down from $138 thousand in 1986 to $103 thousand in 1989. In recent years, capacity utilization has been low, which tends to drive productivity down. For instance, in 1989, capacity utilization was an average of only 54 percent of production capability.

The U.S. robotics industry is at a disadvantage in funding for Research and Development(R&D). U.S. industry investment in Research and Development, an average of over nine percent of sales, is comparable with percentage investment by foreign industry. However, in aggregate dollars, it is dwarfed by foreign investment and inadequate to undertake all the projects needed to maintain competitiveness. It is at a further disadvantage compared to Japanese and Western European robotics industries which have received substantial government assistance. In the United States, the largest amount of Government assistance in robots supports R&D for often unique space and military projects which, while important in their own right, have little direct commercial application. We estimate less than five percent of the world's total commercially related R&D in robots is funded in the United States.

Strategic miscalculations have hurt the development of the U.S. robot industry. Early U.S.-produced robots were often too complicated, with unrealistically high productivity gains expected from them, causing major U.S. end-users to shift to foreign suppliers. One major user-turned-producer pursued hydraulic robots when the market moved decisively to electric robots.

The United States is nearly out of the industrial robot business. A major reason has been the slow development of the factory automation market in the United States. Currently, only a few small firms exist on the edges of robotics technology surviving in application-specific niches. Most produce accessories, peripherals or sensors for end-effectors that are added to imported robot arms and bodies. Many industry observers believe it is too late to restore a viable domestic industry.

The absence of a domestic robotics industry will slow future applications development. The absence of U.S. robotics producers will force U.S. factory systems integrators, both commercial and defense, to focus automation alternatives on the available foreign made robots, rather than develop new robots to provide optimal solutions for U.S. manufacturers. In many cases, this will bring less than desired results, especially for small- and medium-sized firms that lack the leverage of larger firms. Also, foreign sales and support offices are no substitute for the complete technical support a domestic robotics manufacturer could provide.

Historically, U.S. manufacturing firms have been slower to install robots in their plants than some of our major trading partners. A major reason was related to the lower capability level of earlier robots, which were developed and used in labor shortage countries (Japan, Sweden, and West Germany) as labor substitutes. The United States had an abundance of unskilled and semi-skilled labor that was less costly to manufacturers than robots. Further, labor unions have historically had an anti-automation bias. In addition, older vintage machinery in many American factories is less robot compatible, inhibiting manufacturers from purchasing and integrating robots.

In trying to develop recommendations which would be useful for policy officials at the Department of Defense, the Office of Science and Technology Policy, NASA and other concerned agencies, we were confronted with some major unanswered questions regarding the extent to which the domestic robotics industry's viability affects defense concerns. These questions were beyond the scope of our study. Nevertheless, we were able to develop some specific recommendations that may assist the industry in limited areas:

- The robotics and factory automation R&D programs at the National Institute of Standards and Technology could be broadened and expanded, and Commerce could take the lead in coordinating efforts between the U.S. robotics industry and robot end-users.

- The Robotic Industries Association and its membership should be encouraged to explore shared flexible centers for integrated manufacturing and R&D consortia, which are promoted by the Department of Commerce's Technology Administration.

- The Bureau of Export Administration's Office of Industrial Resource Administration (OIRA) should continue to monitor the status of the domestic robotics industry. This will allow policy makers access to current information on the health and viability of this critical sector.

## INTRODUCTION

### Background

The U.S. Department of Commerce, Bureau of Export Administration (BXA) is delegated authority under the Defense Production Act of 1950, as amended (DPA), and related Executive Order 12656 to identify critical industries; assess their capabilities to meet national security needs; evaluate current and potential production bottlenecks; and propose remedial action when necessary. The Office of Industrial Resource Administration (OIRA), Strategic Analysis Division (SAD) is responsible for conducting these national security industrial assessments.

In the course of an industry assessment, particular consideration is given to such factors as: industry structure, investment, research and development (R&D), employment, production capacity, foreign sourcing and dependency, technological factors, trade patterns and market trends, and international competitiveness. Necessary data are collected by SAD from the private sector under authority of Title VII of the DPA. Independently, as well as in cooperation with the Armed Services, OIRA has completed a number of national security assessments including studies of the anti-friction bearings, machine tools, investment castings, gears, precision optics and other industries supplying products critical to defense.

OIRA initiated an industrial capabilities assessment of the U.S. robotics industry in February 1989. The reasons were twofold. First, industry sources advised the Commerce Department that the U.S. robotics industry was rapidly losing market share to foreign competitors, and in danger of falling behind in many areas of the technology. Moreover, robotics is a technology that is vital to maintaining the manufacturing and industrial base of the United States. These reports were substantiated in a preliminary OIRA assessment, that included consultations with both public and private industry experts and a review of recent literature on the industry.

Second, in response to the National Defense Authorization Act, the Department of Defense (DOD) forwarded the second Annual Defense Critical Technologies Plan that identified 20 technologies determined by the Secretaries of Defense and Energy to be the technologies most critical to ensuring "the long-term qualitative superiority of United States weapon systems." Machine Intelligence and Robotics was named as one of these critical technologies in the Defense Critical Technologies Plan for two consecutive years.

## Survey Methodology and Scope

An industry survey questionnaire was distributed to nine firms in the robotics industry under mandatory collection authority provided under section 705(e) of the DPA in March 1990. It was determined that a mass survey of the entire robotics industry was unnecessary to obtain the information needed for this assessment. Further, a nine company survey would lessen the paperwork burden on the industry, and reduce the administrative costs to the U.S. Government. The nine firms surveyed included producers of a full range of material handling, arc and spot welding, assembly, painting, machine loading and sealing robots. Several companies surveyed also produced automated systems for flexible manufacturing. The survey encompassed U.S. firms as well as two joint ventures and several domestic sales establishments set up for the marketing of foreign produced robots. Some of the robot manufacturers also produce related devices for automation, inspection and assembly tasks. The survey was supplemented by a review of the available literature, and related visits were made.

This assessment begins with an examination of the national security and commercial importance of robots and a discussion of the reasons why American industry has not installed robots to the degree its major international competitors have. A detailed product description is presented, followed by some of the more prominent applications and markets. Next, a historical background is provided, detailing the development of the current American robot industry, industry statistics, major company profiles, production capabilities and information on foreign sourcing.

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Most of the industry survey results are presented in the section on industry performance. This section assesses the U.S. robot industry's health and viability by discussing recent trends in shipments, import-export trade, profitability, investment, employment, and R&D information. A world overview follows to give the reader an idea of where the United States stands relative to its major trading partners in terms of robot use and capabilities. This is followed by an analysis of the international competitiveness of the U.S. robot industry and its prospects for long-term survival. The assessment ends by summarizing the major findings and recommendations.

## MAJOR ISSUES

National Security Perspective

In a section of the October 1990, *Department of Defense Report to Congress on the Defense Industrial Base: Critical Industries Planning* devoted to machine intelligence and robotics, it was stated:

> "Aggressive development and application of machine intelligence and robotics technologies are needed for the U.S. to remain competitive on the battlefield as well as in manufacturing. The potential uses of Machine Intelligence/Robotics are extremely broad. In fact, the Navy terms it a 'generic' technology because of its vast number of potential applications. It is very much a multi-use technology area, with equally strong benefits accruing from military, commercial, and space applications."

Direct robot utilization by the military is still relatively small, but includes activities as varied and critical as explosive ordnance disposal, underwater research and recovery, biological and chemical defense and nuclear weapons applications. Robotics technology also has rapidly growing applications in more complex weapon systems. Robotic mechanisms have a wide range of military applications in helicopters, ground vehicles, weapon systems and robotic work tables and devices. In addition, articulated mechanical devices are major components in military vehicles with rotating turrets, recoiling barrels and automatic ammunition handling equipment. Robotic systems are of special interest in the welding of tank suspension systems, minefield breaching, refueling and reloading devices and armament systems. With the introduction of composite materials into the design of robotic arms, robots will be able to accomplish such tasks more rapidly and with less power consumption.

Robots need to be trained only once and can thereafter efficiently repeat the same action. Advancements in artificial intelligence, which are progressing at a rapid rate, will allow robots to operate sophisticated military machinery and equipment and decrease the need for manpower in such applications. The Electronic Industries Association, in its forecast of the defense electronics market, names the use of autonomous systems (such as robotic vehicles/aircraft) as one of the major trends in electronic content of military systems.

In general, robotics military applications will reduce the need for manpower, while improving human response times. Other benefits will result from the use of autonomous vehicles and unmanned aerial vehicles. Robotics can also be applied to remove crews from hazardous environments and exposed platforms, resulting in improved survivability.

DOD is currently working in the area of robotic material handling systems for logistic applications. The inroads made in the area of fiber-optic-guided missiles (FOG-M) offer encouragement regarding the use of tele-operated systems. DOD is also succeeding in its efforts to develop a tele-operated mobile platform that can serve as an unmanned reconnaissance platform. In conjunction with this program, efforts are underway to control multiple platforms via a single mobile Robotic Command Center (RCC). Another application of the tele-operated robot will be the development of Caleb, a small vehicle capable of reconnaissance, surveillance and target acquisition operations for the infantry.

Robots also play a vital role in flexible manufacturing which can be used to produce many products, including defense critical parts and weapon systems. Robot use in manufacturing results in more flexible manufacturing capabilities with shortened production lead times and enhanced quality. Further, inventories and associated carrying costs can be lessened, and in many cases, eliminated, and capital costs (except for software) can be reduced to zero for many new products. The increasing use of robots in production of defense related products and the industrial base makes the availability of robots during a national security emergency critical to meet surge production requirements.

## Commercial Perspective

From a commercial perspective, the single most important consideration about robots and robot technology is the potential for increasing manufacturing productivity. In a broader perspective, robots are playing an ever expanding, and arguably more important, role in the evolution of factory automation. As a result, many robot producers are taking on the expanded role of systems integrators. Systems integration, making extensive use of computers, electronically links the machinery and equipment on the factory floor, coordinates the flow of materials, and strives to utilize each available machine and piece of equipment to the maximum extent, thereby attaining the highest possible productivity.

In this respect, robots can be viewed as another form of automated equipment. The technology still has a way to go before the "promise" of robots is fulfilled. While we are moving in that direction, practice to date has demonstrated that robots have not been "revolutionary" in their impact on the production floor, at least not in the United States.[1] Robots have made their greatest inroads into jobs undesirable or hazardous for humans. These include spray painting, heavy lifting, operating furnaces, or digging for coal. Also, robots can be constructed with special skills different from humans, such as infrared or microscopic vision, ultra high or low frequency hearing, temperature sensitivity, or exceptional strength that make them particularly useful in certain specialized applications.

Through the installation of robots in manufacturing facilities, productivity gains of 20-30 percent have been realized. In light of much higher expectations, these results were not particularly impressive to many end-users. However, with further advances in artificial intelligence (such as learning and decision making abilities) and sensors (vision, tactile, etc.), robots will gradually climb the "skill" ladder, and may soon even approach

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the level of skilled machinist. In the meantime, incremental productivity advances have made robots (and factory automation) more and more a competitive imperative.

Currently, as a process technology, robots are between two extremes: custom production and dedicated automation.[2] At one extreme, custom production, general purpose machines are usually hand operated by skilled workers to produce a single item or small lots of that item. Capital equipment costs may be low but total unit costs are high because set-up time can be considerable, individual machining can be a demanding and time consuming task, and all of the costs must be spread over a very small number of units produced.

At the other extreme stands dedicated (or hard) automation, where the initial fixed capital investment can be quite high but total unit costs are typically very low, because the automation of production increases speed and ensures constant quality. The highly specialized equipment (dedicated automation) is set up once and thereafter production of a single product can flow continuously.

Robots are not yet clearly identified with either of these extremes, although they are rapidly pushing toward both ends. For now, set-up time for a robot still exceeds that of a human operator in custom production, and the speed of a robot is usually no match for dedicated automated equipment.

Robots are today also between these two extremes in terms of total cost to the manufacturer and capability. The fixed capital costs of a robot installation exceed that for custom production but are less than dedicated automation. In terms of capability, robots are still no match for the subtle skills of a precision machinist, nor can a robot repeat a single task as perfectly as highly specialized automated equipment.

In terms of flexibility, robots have improved in recent years to the extent of matching, and in some instances, surpassing a skilled human operator. Robots can adjust a workpiece, correct a minor flaw, and carefully check each piece as it is produced. On

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[2]Adapted from Human Resource Implications of Robotics, by H.A. and T.L. Hunt, 1983.

the other hand, dedicated automation is capable of producing a single product only. Specialized hard automation sometimes must be scrapped when the product is changed, whereas the robot can be reprogrammed to perform a new task.

Despite the fact that robots represent a compromise between the extremes of custom production and dedicated automation in terms of cost, capability, and in certain respects, flexibility, more than half the robot usage in the United States today has been in mass production facilities where human workers or the type of work itself already limits the speed of the overall facility. Thus, robots are serving primarily as a cheaper alternative to dedicated automation rather than being applied to automate batch production facilities.

The goal, and possibly the most important impact of robots, is to make custom production as efficient and productive as dedicated production, and to make dedicated production more flexible and adaptable to product changes. In the first instance, batch production can be made much more productive; in the second, overall capital costs that otherwise might result from even minor product design changes can be greatly reduced. Where 100 percent utilization of each machine has been built into the system in the case of dedicated production, at the batch level, 100 percent utilization is now becoming possible by programming it into the system. This is being accomplished in conjunction with so-called "universal" machines such as machining centers or CNC lathes that combine multiple metal removal functions (drill, mill, plane, turn, or bore) into a single machine. Robots are fundamental to the smooth and efficient operation of such a system.

## Constraints to Using Robots

U.S. manufacturing firms have been slower to install robots in their production plants compared to some of our major trading partners. In 1988, in terms of robots installed per 10,000 manufacturing employees, the United States stood fifth among major nations. The following table compares robot use in the seven nations with the largest robot populations (excluding the Soviet Union and former Eastern Bloc countries).

NUMBER OF ROBOTS PER 10,000 MANUFACTURING EMPLOYEES

| | Robots/10K employees | | Robot Population | |
|---|---|---|---|---|
| | 1983 | 1988 | 1983 | 1988 |
| Japan | 33 | 117 | 47,000 | 176,000 |
| Sweden | 16 | 83 | 1,452 | 8,000 |
| Germany | 6 | 21 | 4,800 | 17,700 |
| France | 4 | 18 | 1,920 | 8,026 |
| United States | 4 | 17 | 8,000 | 32,600 |
| Italy | 3 | 16 | 1,510 | 8,300 |
| United Kingdom | 3 | 9 | 1,753 | 5,034 |

Source: UN, Economic and Social Council, and OECD Statistics

There are several reasons why the United States has been slower to install robots than others. Perhaps the number one reason has to do with the availability and cost of unskilled and semi-skilled labor. Shortages of unskilled and semi-skilled labor have existed in Japan since the 1960s, and to a growing extent have also occurred in Europe. This has forced wages up in these countries and actually made robots more attractive as labor substitutes, especially for low skill tasks. In economic terms, these other countries essentially substituted "capital" for labor. It can be assumed the marginal product of capital in these countries was greater than the marginal product of labor. Thus, capital, in this case robots, was added.

Had robots been valuable to U.S. manufacturers as simple "substitutes" for scarce labor, undoubtedly the robot population today would be much greater. However, in the United States, robot sales hinged on substantially raising productivity. Robots were expected to surpass labor in capability, quality and performance. Thus, a very important constraining factor for the United States in the past was the relatively low level of robot technology development.

Further, U.S. manufacturing plants generally have older vintage machinery and equipment than plants in many other advanced nations. It is very difficult to integrate robots with older equipment without extensive modifications. While robots can function effectively as stand alones, especially in hazardous applications, their utilization is dependent on the pace set by the factory. Also, the technology has so far required a highly structured environment, where the functioning of the robot was totally dependent on "work" taking place exactly where planned. This generally added cost to the purchase of a robot faster than it added benefits. The trend is now moving toward fully automating factories, and disposing of the older equipment.

Additionally, many manufacturers have adopted a "wait and see" attitude. Over time, the cost of controllers and vision systems and other parts of the robot has declined, driving the overall cost of robots down. And while the cost has come down, the capabilities and performance of robots have improved, making them more attractive as an investment with each passing year.

Also, labor unions have exhibited a bias against automation of all types, including robots, that threatened jobs of their membership. This attitude retarded the use of robots to an unquantified extent and persists today. The unions' concerns are not totally unfounded, as automation has reduced the overall labor content in manufacturing.

A last consideration concerns the retarded development of the robot industry itself in the United States. According to industry sources, the robotics industry, as well as end-users, has done relatively little in the way of applications research, while focusing heavily on technology development. The results have been underdeveloped markets and a fragmented industry. Meanwhile, the robotics industries in other countries, particularly Japan, West Germany and Sweden, have focused on applications and developed several formidable robot producers much larger than American firms. One result is that today foreign firms dominate the production of robots worldwide.

Until recent years, the United States still had both an adequate skilled labor force and a large pool of unskilled and semi-skilled workers such that adoption of automation was not seen as a necessity. However, this may be changing. Many manufacturers now complain that there are insufficient numbers of high school graduates with adequate mathematical and verbal skills. It is difficult to attract young people to the manufacturing sector when starting wages are often lower than service sector wages, working hours are longer, and long-term employment security questionable.

Further, the National Tooling and Machining Association (NTMA) has predicted that, by 1995, the United States will have at least a 20 percent shortfall of skilled machinists needed for our manufacturing facilities. In addition, the average age of the workforce will rise during the 1990s. The percentage of the population aged 35 to 54 will grow by more than 44 percent between 1987 and 1993, while the 15 to 34 age group from which new employees are drawn will decline by almost 13 percent.

Thus, ironically, as robot technology climbs the skill ladder, an emerging problem to installing robots in the United States may actually be finding and training enough robot technicians and various other skilled workers (at a competitive price) to efficiently operate and manage automated factories.

## PRODUCT DESCRIPTION

The Product and Technology

Since the inception of robot technology, producer countries have had difficulty in defining a robot. The word itself is derived from the Slavic root for "work" or "worker" and was introduced into the English language in 1922 with the production of Karl Capek's play *Rossum's Universal Robots*. The Robotic Industries Association, however, defines a robot as "a reprogrammable multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks." This definition is similar to that used by the Organization for Economic Cooperation and Development (OECD). The Japanese Industrial Robot Association (JIRA), however, commonly uses a definition which includes lower level manipulators (e.g., pick and place assemblers). The dissimilarity of definitions across the globe makes comparison of international robotics data somewhat misleading.

Robot Types - There are various types of robots, performing a variety of tasks. The major group of robots is classified as industrial robots because of their use in the manufacturing process. When equipped with various end effectors (end-of-arm tooling), industrial robots can accomplish material handling, machine loading and unloading, palletizing and assembly. Equipped with other tools, these robots can drill, grind, cut, deburr, weld, paint, and glue. The industrial sectors that use these robots most extensively are the automotive, electronics, aerospace, metalworking and consumer goods industries.

Robot technology is also expanding into human service areas such as health care, education, security, military, space, underseas exploration, and hazardous environments such as nuclear disposal or fire fighting. In addition, robots are being developed for fields as diverse as mining, agriculture and parasurgery as well as aiding the elderly and handicapped.

Robot Components - Industrial robots have three major components in common: the manipulator, the power supply, and the control system. In addition, various accessories, peripherals and sensors, such as vision, sonic or tactile sensors, can also be considered parts of the robot.

The manipulator is basically the robot's arm; it is the component which allows the robot to lift, grip, place or perform various other operations. There are basically four types of manipulators which are classified according to the coordinate system used and the axes of motion:

(1) cylindrical coordinate - the work envelope is the shape of a portion of a cylinder;

(2) spherical (polar) coordinate - the work envelope is the shape of a portion of a sphere;

(3) jointed arm (revolute) - the arm, which is mounted on a rotary base, operates similarly to a human shoulder and elbow; and

(4) rectangular coordinate (cartesian) - rectilinear motions in stacked axes (as opposed to pivoting or angular).

The power supply drives the robot and is usually one of three types: electric, hydraulic or pneumatic. Production demands for acceleration, lifting capacity, manufacturing environment and cost will determine the best choice for a power supply. In the United States, most industrial robots are now fitted with an electric power supply, with hydraulic and pneumatic systems on the decline.

Electrically driven robots are more expensive than the other two types, but provide operational benefits. Electric drives have been shown to offer greater reliability in the control and positioning of the manipulator. They are the preferred drives for precision assembly operations where accuracy and speed are essential. Developments in the technology have also allowed electric robots to operate in more hazardous environments than was possible in the recent past. The drawbacks that are associated with this type of power supply are the limits on lift capacity (when compared to hydraulic) and the cost. At an added cost, a gear system can enhance the lifting capacity of electric drives.

Hydraulically driven robots, using pressurized fluids for motion control, are often preferred in unsafe working and manufacturing environments. A major advantage of this type of power drive is its ability to lift very heavy payloads. Hydraulic robots are slower and less efficient than their electric counterparts. They are unable to stop quickly and change position. Once a motion has begun, the robot will continue through the sequence until it is completed. An ancillary problem that must be contended with is the propensity to develop leaks, which is not acceptable in many applications such as painting or clean rooms. In addition, the fluids must be at a certain temperature before the robot can be functional. Therefore, hydraulic power has a limited environmental range in which it is effective.

Pneumatic, or compressed air, robots are mainly employed because of their low cost. They do, however, suffer from the drawbacks of less accuracy and the ability to lift only light payloads. This type of robot is much less common today than in the past and is used primarily in assembly operations.

The control system is the brain of the robot. It communicates instructions to the manipulator and in more advanced systems receives feedback from the outside environment. The control system may be structured as either a "closed loop" or "open loop" system; that is, the system may use feedback (closed loop), or it may simply perform its programmed function without verification of results (open loop). In its simplest form, the control system can consist of a series of adjustable mechanical stops or limit switches.

Most robots being sold today use some type of servo-mechanism. This type of control works with a sophisticated three dimensional computer control which allows the robot to be more flexible than with just simple limit switches. Most servos allow the robotic motion to be automatically decelerated so as not to overshoot the final location. This technology has both safety and accuracy considerations. Servo-controlled robots can be divided into three different types:

1. <u>Fixed sequence robots</u> operate sequentially in conjunction with information that cannot be easily modified, and variable sequence robots which can be easily reprogrammed, increasing flexibility.

2. <u>Point-to-point robots</u> move from one specific point to another without any particular path definition. The points between which the robot travels can be inputed to memory through a variety of means including mathematical formulae, by simulation, by computer, or manually through a keyboard.

3. <u>Continuous path robots</u> use a series of computer generated points which record all the motion needed to develop patterns and tracks for each pass that is repeated.

In addition, playback robots repeat an operation based on information provided by manually moving the robot, taking note of sequence and position. Numerically controlled robots use computer controls which execute an operation based on a loaded program. These controls are similar to those used on numerically controlled machine tools. More sophisticated control systems utilize artificial senses such as tactile and vision as inputs from which decisions or paths are chosen. Thus, these robots are capable of recognizing changes in the environment and utilize the information to modify their own operation to accommodate for variations.

<u>Technology</u> - Robot technology is still developing, with advances proceeding along a number of paths. The most effective robots to date have actually been the simplest. Until further advances are made, robots will continue to require highly structured environments, where each move is preplanned and predictable.

Future developments in robot technology will focus mainly on new applications and improved accuracy, leading to enhanced capabilities. Work will also continue in combining robot technology with other technologies such as artificial intelligence, computer architecture, software and composite materials (for lightweight robots). Application and integration of robotics and other intelligent machines in the manufacturing process will result in higher productivity with shorter lead times as well as improved quality and accuracy. These developments will help improve the health of the U.S. industrial base through more efficient production.

Developments in artificial intelligence and system controls are still in the early stages and the abilities of these technologies to be incorporated with robotic systems are still changing rapidly. System controls and computers are able to coordinate the production process of the machinery with the robot's articulated skill to move its effectors or components with a high degree of precision. In instances where decision making is necessary, artificial intelligence and system controller logic commands are introduced so that the system computer can modify the manufacturing operations to accommodate for changes in the environment.

Advances in controls, vision systems and sensor systems will allow for continuous assessment and correction during an operation and will result in a more autonomous robot. Artificial intelligence will make the robot more capable of independent decision making, providing for a truly automated operation. These advances have direct defense applications in the development of robotic vehicles and aircraft. The United States leads in the area of software development and more complex robot applications. Several European nations and Japan, however, hold a lead in applying robot technology to the production floor.

In summary, technological advances have allowed robots to perform more quickly and accurately and to lift heavier payloads. As machine vision and other sophisticated sensors are further developed, a new generation of robots will evolve with greater capabilities which will expand robotic applications dramatically, and it is this new generation that is the primary concern.

## Applications

Robots can either stand alone or be integrated into complete workcells in conjunction with machine tools, assembly equipment, hand tools and other manufacturing equipment to create a fully automated operation. An example of this integration is as follows: after downloading a robot program, a robot can transport and insert raw materials into a machine tool for processing, extract the piece after machining, deburr the holes, grind or polish the surface, clean and inspect the piece, assemble the workpiece with other components and then finally palletize the subassembly for transport and downstream processing. User demand for such processes must first catch up with evolving technology before the advantages of flexible manufacturing cells and incorporation of robots with other machines can be realized.

Most of the robots in use today are industrial robots and, as capital equipment, are highly dependent on the investment climate in the markets into which they are sold. The diversity and strength of these end markets can impact greatly on the performance of the robotics industry.

Industrial robots have become essential and integral to automated manufacturing. Robots are used for many applications, from welding to material handling to painting. Welding applications include arc and spot welding, mainly in the automotive industry for welding various auto parts and the car body to its frame. In addition, robots are used in laser cutting applications especially for high speed cutting and for cutting through thick materials. Laser cutting robots are used for cutting plastic, wood, fabric and metal.

Robots fitted with grippers perform a range of material handling tasks including fixing parts to pallets, loading machines with parts to be machined, or placing parts on a conveyor to be moved for further processing. These types of robots are used similarly in the food, chemical and paper industries. Material handling robots are constructed to handle parts as small as semiconductor chips or as large as the front end of a car.

Robots can also be fitted with tooling for industrial painting or sealing functions. Robots are now used to paint furniture, household appliances and farm equipment. The most widely used application, however, is for painting cars. Robots are also made to reach in and around various parts of a car and can even open and close the doors, trunk and hood and paint the inside. Robots are also used to dispense various types of sealant, including window adhesives, sound proofing and weather stripping.

The major markets for robots in the United States are the automotive sector, which has purchased about 50 percent of the total, and the electronics industry with approximately 25 percent. These two sectors are followed by aerospace (7 percent), other industries such as food processing, metalworking and pharmaceuticals (7 percent), industrial equipment (4 percent), and fabricated products (3 percent).

The dependence of the U.S. robotics industry on the cyclical (and now foreign dominated) automotive industry has been as a serious limitation to developing the technology. Industry sources indicate the need to further penetrate non-automotive sectors such as the aerospace, electrical and pharmaceutical industries in order to smooth out cash flows and further stimulate technical innovations. In addition, the service sector could be a major growth area for robots in coming years. The potential applications for service robots are countless, including cleaning rooms, assisting the elderly or working as gas station attendants.

In contrast, Japan is the major industrial robot user and has a very different market profile from the United States. The electronics industry uses the largest share of robots in Japan (33 percent). Many of these are "intelligent robots" used in manufacturing cells. The automotive sector ranks second with 26 percent of the market, consisting mainly of playback robots.[3] Other sectors utilizing robots include plastic molding and processing (14 percent), general machinery manufacturing (12 percent), and metalworking and precision machinery manufacturing.

## Standards

Standards are critical to the interface of robots and robot parts with each other, as well as with the numerous machines with which robots will electronically link to form an automated system. The large number of different computer languages and hardware packages available to U.S. manufacturers has created confusion and added costs to moving toward integrated manufacturing. The Japanese have actually benefitted from Fanuc's near monopoly

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[3]While the automotive sector ranks second in Japan, it is still a larger relative user than the U.S. auto industry, which ranks first in robot use in the United States.

position in Japan in controllers for machine tools and robots in that they are all compatible. The standards issue is being addressed at the international level. Underlying the problem, however, is the fragmentation of the American robotics industry, and in a much broader sense, of the entire factory automation sector.

The main body for standards setting in the United States is the American National Standards Institute (ANSI). ANSI provides the mechanism for creating voluntary standards and serves to eliminate duplication of efforts in standards activity. The organization works toward eliminating conflicting standards and creating single, nationally accepted standards.

In addition to ANSI, there are various organizations and committees working on robotics standards in the United States. One such committee is part of the Robotic Industries Association (RIA); another committee works under the American Society for Testing and Materials (ASTM). From an international perspective, the committee working on robotics standards is Subcommittee 2 of the International Standards Organization (ISO) Technical Committee 184 (TC 184).

The RIA committee has been named Committee R15 and is concerned with the development of American standards for the construction, installation, operation and maintenance of robots and robotic systems as well as safety guidelines for personnel who use or install such systems. The Committee currently has six working subcommittees in the areas of: Electrical Interface, Human Interface, Mechanical Interface, Communications/Information, Performance and Safety. RIA also acts as a liaison between U.S. committees and the ISO in regard to industrial robot standards.

The committee under the ASTM is called ASTM F-28 on Robotics Systems and its goal is to develop standard terminology, test methods, practices, classifications and guides for robotic systems. This is further broken down into subcommittees covering terminology, performance criteria and system categorization.

The third committee, ISO/TC 184, focuses on terminology, symbology and classification, performance and testing, safety, programming methods, requirements for information exchange and mechanical interfaces.

These various domestic organizations work independently and then coordinate with the international organizations to ensure that U.S. products can interface with foreign produced robots and related equipment. Through these committees, ANSI can make the U.S. position on standards felt on an international level.

The formation of a single internal market by the European Community in 1992 will result in the European adoption of Community-wide standards for many products, including robots. This only emphasizes the need for standards to be in place as soon as possible. The United States will have to work diligently to promote EC consideration of U.S. ideas on standards for robots.

## U.S. INDUSTRY DESCRIPTION

### Historical Background

The robot was developed in the United States in the early 1950s. The technology evolved from developments in servo mechanisms for remote control of naval weapons and aircraft control systems, tele-operator manipulators used in the nuclear industry, and machine tools. George C. Devol is credited with the first robot related patent in 1954. In 1961, the first industrial robot was built by an American industrialist -- Joseph Engelberger -- who went on to found Unimation, the world's first commercial robot producer. These robots, equipped with hydraulic drives, were the prototype for years to come, as Unimation remained America's number one robot producer until the early 1980s.

Significant commercial production of robots began in the second half of the 1960s. In 1968, Mr. Engelberger licensed Unimation's technology to Japan's Kawasaki Heavy Industries. Kawasaki was potentially a major user as well as producer of robots. Kawasaki began experimenting with the now dominant electric drives for the robots almost immediately, and successfully applied the technology by the early 1970s. The firm is currently the third major producer of robots in Japan. The firm manufactures a broad range of industrial products including machinery, motorcycles, aircraft and ships, all of which now comprise numerous robot applications.

The United States remained the leading robot manufacturer until the mid-1970s, when surpassed by Japan. A number of circumstances not present in the United States propelled robot development in Japan. These included:

- very rapid economic growth, particularly in the robot intensive automotive, appliance and electronics industries;

- a growth-constraining labor shortage and rapidly rising wages that encouraged robot use as a substitute for unskilled labor, coupled with supportive labor unions, often underwritten by lifetime employment policies;

- a low cost of capital and favorable tax incentives for production plant modernization;

- government funding and support for commercial R&D; and

- "cut-throat" competition among Japanese firms, especially during their mid-1970s' recession and inflation period, that greatly stimulated productivity enhancing investments.

However, while robotics grew rapidly in Japan, the late 1970s and early 1980s was a period of slow demand growth in the United States. Following the deep recession of the early 1980s, new robot orders increased, stimulated especially by plant modernizations by the major auto manufacturers. In fact, it was estimated General Motors (GM) alone accounted for 40-45 percent of total robot demand. This, combined with overly optimistic forecasts, brought a short-lived resurgence to the American robot industry. The period was characterized by massive investments in robot development and promotion by well known firms such as General Electric (GE), United Technologies, Bendix and Westinghouse. One industry source noted that GE spent over $100 million in its failed robot efforts.

Today, the U.S. robot industry has an in-place production capacity for complete robots of less than $200 million, compared to Japan's more than $2.0 billion. In hindsight, the development of the robot industry in the United States is replete with strategic miscalculations and excessively optimistic forecasts. Sales of robots never approached the very high projections made in the 1970s and early 1980s. At that time, it was predicted that by 1990 over 100,000 robots would be installed in U.S. plants. Today, the actual number is about 39,000. In fact, GM announced in 1980 that the company planned to purchase 20,000 robots by 1990, to restore quality and raise productivity. This never materialized as GM purchased fewer than half that number. By 1986, GM was releasing statements to the effect that robots were only part of the answer to its problems, and that productivity increases through robotics were not as great as expected.

Optimistic projections for the domestic usage of robots led to foreign investment in the U.S. market by both Japanese and

European firms, and an over-expansion of capacity on the part of several U.S. producers. The U.S. market was also characterized by robot end-users aggressively entering the market as producers, to supply their own needs, and in most cases, to sell on the open market. The major user-turned-producer firms such as GM, IBM, GE and Westinghouse significantly impacted the structure of the U.S. robotics industry as well as the strategies employed by existing independent robot firms.

With the decline in robot demand after the mid-1980s, several firms, such as DeVilbiss (U.S.) and ABB Robotics (Swedish-Swiss), closed U.S. manufacturing facilities. Most of the large end-user firms also exited the business. Import penetration expanded rapidly during this period. Foreign concerns interested in participating in the U.S. robot market targeted a particular niche, underpriced the domestic producers and drove them out of the market. Many U.S. robot producers, facing this intense import competition, looked offshore for lower-cost components or complete robot suppliers. Numerous joint ventures and sales agreements[4] were established during this period as well.

In the early 1980s, GM, by far the largest robot user in America, became impatient with the slow pace of robot development in the United States. In 1982, after exploring a possible partnership with several U.S. robot manufacturers, including Unimation[5], GM finally entered into a joint venture with Fanuc -- a major Japanese robot producer. This particular joint venture, GMFanuc, largely removed GM from the open market, materially impacting many independent U.S. producers that lost the GM business, such as Unimation and Cincinnati Milacron. GMFanuc now leads in sales of robots in the United States, and is the second largest producer in the world at about $170 million. Almost all of GMFanuc's robot production is in Japan. A small amount also occurs in the United States.

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[4]See Appendix D for examples of cooperative agreements.

[5]Unimation declined, believing that GM would do better concentrating on applications development, while buying the robots it needed from a specialist.

In 1983, after an intense bidding war with GE, Westinghouse purchased Unimation for three times its book value.[6] Believing the optimistic market projections for robots, Westinghouse hoped to turn its $107 million investment in Unimation into a billion dollar company by 1990. It failed, however, to invest the funds needed in R&D in the correct areas, and over time its sales dropped along with its market share. Also, within a year, much of the Unimation's exceptional engineering staff defected, and created their own robot company, Adept Technology, Inc.[7]

Although Westinghouse inherited Unimation's reputation for the best controller software in the world, Unimation's hydraulic drives turned out to be the incorrect technology for the changing market. A Westinghouse spokesman noted that the company continued to promote hydraulics despite the fact that end-users were rapidly turning to robots with electric drives. In a study (by Westinghouse), it was shown that hydraulics sold on average for $48,000, compared to electrics for $70,000. Thus, there was some justification for Westinghouse's effort. However, a later study showed hydraulics cost $12,000 per year to operate, versus only $6,000 for electrically driven robots. In addition, hydraulics often leaked, broke down more frequently, and were less precise than electrics.[8]

In 1986, Westinghouse came out with a new PUMA model, which was electrically driven. However, it was too late to recapture its former customers and lost market share. After suffering a few years of heavy losses and realizing that it was too far behind in technology development, Westinghouse sold its Unimation division in 1988 to Staeubli International AG, a company based in Switzerland, and the remainder of its factory automation division to Daimler-Benz of Germany. Staeubli continues to produce the Unimation line and markets it in the United States through Westinghouse.

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[6] Wall Street Journal, November 6, 1990, page 1.

[7] Some of the engineering staff that defected from Westinghouse/Unimation were previously with Stanford's artificial intelligence program. Adept Technology is today the fastest growing and most successful U.S. robot producer.

[8] Wall Street Journal, November 6, 1990, page 1

What proved to be another miscalculation in the development of the robot business in the United States was the attempt to make the robot too complex and capable of too many varied tasks before the technology was ready, thus increasing the likelihood of a failure. This is exemplified by GE's failed attempt to build a four-armed assembly robot in the 1970s that was too expensive, and repeatedly broke down.[9] The very idea of "complexity" may be related to the early misconception that robots were a "revolutionary," rather than an "evolutionary" process technology. Further, without a pressing labor shortage in the United States, robot producers may have believed that a quantum leap in productivity was necessary for robots to break onto the factory floor.

This failure to have robots effectively perform complex tasks only resulted in discouraged customers. In fact, because of frequent breakdowns, many robot users found in practice that robots were often more expensive than a worker's salary. In contrast, the Japanese started with a simple robot, capable of a simple operation, with an incremental increase in productivity. The Japanese robot has, on average, 30 percent fewer parts than a comparable U.S. model.

In a related issue, U.S. robots were often produced for sale as stand alone or single units, not as part of an integrated system where the productivity gains have been demonstrated to be greatest. To integrate these robots, the robot users and the robot industry came to realize that the robot's control system needed to be compatible with existing processes on the production floor. Again, the Japanese robot manufacturers came to this realization very early in the game and were working closely with their Japanese customers to make the robots operate effectively.

These events -- the miscalculations, the high expectations, the demographics, and the unique conditions of our national economy -- have resulted in a domestic market that is today characterized by a growing reliance on imported technology and foreign-produced robots. One of the few remaining domestic robot producers, Cincinnati Milacron, signed a letter of intent in September 1990, to sell its robot business to ABB Robotics (Swedish-Swiss). ABB,

[9] Wall Street Journal, November 6, 1990, page 1.

the world's largest robot producer with nearly $300 million in sales worldwide, plans to move the robot production and technology to Sweden, where it can presumably be done more efficiently in higher volumes.

Industry Statistics

In 1987, the Bureau of the Census reported 38 "establishments" in the United States produced robots and/or robot parts as their primary production.[10] These establishments were classified under the newly created SIC 3569-7. Total shipments from these establishments were valued at $209.2 million.[11]

The industry employed 2,100 people in 1987. About 1,100 of these were production workers, representing 52.4 percent of the work force. This is significantly below the percentage for all manufactures, which in 1987 was 64.7 percent. However, the robotics industry employs relatively larger numbers of engineers, service and sales people. It is an advancing technology that requires educating as well as servicing many customers. In the broader four digit SIC 3569 (General Machinery), production workers are more prevalent at 58.2 percent of the work force, and in the much broader two digit SIC 35 (Capital Goods), even more so at 61.8 percent.

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[10]In 1987, as an extension to the Standard Industrial Classification (SIC) system of the United States, the Bureau of the Census established a five digit product class for robots and robot parts, SIC 3569-7. Classification under this system is establishment based. Establishments (production plants) are treated as the basic economic unit, and the primary product produced at the establishment governs its classification. About 460 four digit industry codes are used to define all manufacturing plants in the United States, with over 1,300 product class codes, including robots, being more narrowly defined parts of four digit industries. At the four digit level industry data on employment, wages, cost of materials, value added, industry shipments, and new investment is published each year. At the five digit level of detail, which applies to robots, information will be published once each five years in the Census of Manufactures.

[11]Many of the establishments within SIC 3569-7 sell to each other, resulting in total shipment values that include a degree of double counting.

Value added for the industry came to $115.7 million in 1987. With large numbers of engineers, service and sales people, payroll represents more than half the value added at almost 54 percent. This is significantly higher than most other industries. The average wage for production workers was $12.43 per hour in 1987. This was more than 25 percent higher than all manufactures nationwide ($9.91). However, since wage rates tend to reflect local economies, it is difficult to conclude any substantial differences in skill levels. Average value added per employee was $55 thousand, and average shipments were $100 thousand the same year.

Production of robots and robot parts can also take place in establishments where the primary production is something other than robots or robot parts. Census reported that a total of 65 firms shipped robots or robot parts, many as secondary production. A tally of all "product" shipments in 1987 totalled $294.7 million.[12]

ROBOTICS INDUSTRY STATISTICS, 1987

| | | |
|---|---|---|
| Number of Establishments | 38 | |
| All Employees | 2.1 | thousand |
| Production Workers | 1.1 | " |
| Production Worker Hours | 2.1 | million |
| Production Worker Wages | $ 26.1 | " |
| Average Hourly Wage | $ 12.43 | |
| Payroll | $ 62.0 | million |
| Value Added | $115.7 | " |
| Cost of Materials | $ 94.5 | " |
| Value of Shipments | $209.2 | " |
| New Investment | $ 4.9 | " |

[12]Under the SIC system, an important distinction exists between "industry" shipments and "product" shipments. Industry shipments include the total shipments from establishments classified under a particular SIC code. This includes both primary products produced at the establishment and secondary products. Product shipments are total shipments of just the primary products regardless of who produces them. Thus, some establishments (not classified as robot producers) may produce robots or robot components as secondary products, which will be captured as "product shipments" by Census. Product shipments (even at the five digit level) are published annually.

ROBOTICS INDUSTRY STATISTICS (continued)

| | | |
|---|---|---|
| Product Shipments | $294.7 | million |
| Number of Firms Reporting Product Shipments | 65 | |

COMPARATIVE RATIOS, 1987

| Key Ratios | Robotics (SIC 3569-7) | General Machinery (SIC 3569) | Capital Goods (SIC35) |
|---|---|---|---|
| Employees per Estab. | 55 | 125 | 133 |
| Prod.Wkers./All Empl. | .524 | .582 | .618 |
| Cost Mat'ls/Shipments | .452 | .403 | .457 |
| Payroll/Value Added | .536 | .450 | .426 |
| Value Added/Shipments | .553 | .599 | .542 |
| Value Added/Prod.Wker. | $105 | $98 | $104 |
| Value Added/Empl. | $55 | $57 | $64 |
| Shipments/Prod.Wker. | $190 | $163 | $192 |
| Shipments/Empl. | $100 | $95 | $119 |

Note: Excludes establishments with fewer than 20 employees.

Source: DOC, Bureau of the Census

Domestic producers of robots today are a mix of U.S. and joint venture groups. Although there are over 100 members in the Robotic Industries Association, only a handful are actual robot manufacturers in the United States, with the remainder composed of distributors, accessory equipment suppliers, system integrators and machine vision manufacturers and suppliers. The robotics industry in the United States also has a large representation of foreign firms who have set up U.S. operations to import complete robots or, in some cases, robotic arms from overseas and then add the end of arm tooling and a control to the robot. As shown on the following table, a few robotics companies hold a large part of the U.S. market.

The four companies with a majority of their robot shipments manufactured in the United States accounted for $101 million (33 percent) of 1988 robot industry sales of $305 million. By 1989, the share held by these four companies had slipped to 26 percent ($98 million of $370 million total shipments). With the impending sale and closure of Cincinnati Milacron -- the largest company with majority U.S. manufacturing -- such companies will account for less than one-fifth of U.S. robot sales.

ROBOT SALES IN THE UNITED STATES, BY COMPANY: 1988-1989
(in millions of dollars)

| | 1988 | 1989 |
|---|---|---|
| GMFanuc Robotics ........................ | 114 | 148 |
| ABB Robotics ............................ | 42 | 50 |
| *Cincinnati Milacron ..................... | 40 | 35 |
| Kawasaki ................................ | 19 | 28 |
| *Adept Technology ........................ | 24 | 26 |
| *Graco Robotics .......................... | 20 | 23 |
| Cimcorp ................................. | 14 | 16 |
| Westinghouse ............................ | 15 | 16 |
| *Prab Robotics ........................... | 17 | 14 |
| Motoman ................................. | NA | 14 |

*Majority of robot shipments manufactured in the United States

Source: Metalworking News, June 4, 1990

The Robotic Industries Association publishes quarterly information on robot order backlogs and shipments by the Association's membership. This data includes both domestic and foreign produced robots (and robot parts), and is more an indication of U.S. consumption trends than domestic shipments. The data presented below compares various statistics at the beginning and end of the third calendar quarter for 1989 and 1990.

ROBOTICS ORDER BACKLOG
END OF THIRD QUARTER, 1989 AND 1990

| | 1989 | | 1990 | |
|---|---|---|---|---|
| | Units | $Millions | Units | $Millions |
| Unfilled Orders End 2nd Qtr. | 2,459 | $266.3 | 2,472 | $291.1 |
| 2nd Qtr. Activity | | | | |
| Gross New Orders | 672 | 81.2 | 1,236 | 147.1 |
| Cancellations | 22 | 1.2 | 4 | 1.4 |
| Net New Orders | 650 | 80.0 | 1,232 | 145.7 |
| Shipments | 1,110 | 110.4 | 1,108 | 122.7 |
| Unfilled Orders End 3rd Qtr. | 1,999 | $235.9 | 2,596 | $314.1 |

Source: Robotic Industries Association

New orders during the third quarter of 1990 rose very dramatically to 1,232 units, valued at $145.7 million, from 650 units, valued at $80 million in 1989. The order backlog increased by one-third from $235.9 million at the end of the third quarter 1989, to $314.1 million in 1990. The year's performance was dampened by the economic slowdown and a downward adjustment to the capital spending plans of the auto industry.

Company Profiles

**ABB Robotics Inc.** (ABB) is one of 50 business areas of the Swedish-Swiss ASEA Brown Boveri Company (1989 sales totalled over $20 billion). In 1989, ABB achieved a robotic sales turnover of about $300 million, and it is by a wide margin the largest robotics firm in the business. The next largest are GMFanuc with $170 million and Matsushita with $150 million. ABB has manufacturing facilities in Sweden, Switzerland and Norway, and until 1986, in the United States. In addition, it has systems companies in the UK, Germany, Sweden and the United States. The U.S. facility markets and sells the finished products from overseas. ABB is the second largest supplier of robots to the United States, behind GMFanuc. With the recent acquisition of Cincinnati Milacron's robot operation, ABB will increase its share of the U.S. market to about 20 percent. The company also has over 30 percent of the European robot market and is making progress in penetrating the Japanese market. The firm regularly invests 10 percent of its turnover in R&D. In absolute dollars, this amount is almost two-and-a-half times as much as the total reported by U.S. industry. ABB manufactures seven different painting and coating robots in addition to a line of material handling and sealing robots and, with the purchase of Cincinnati Milacron, welding robots. ABB also produces software for use in programming its robot-based systems.

**Adept Technology Inc.**, of San Jose, California, was founded in 1983 as a spinoff of Unimation by two pioneers in the robotic industry, Brian Carlisle and Bruce Shimano, who helped develop the first assembly robot. Adept's growth has been explosive and internally generated, rising from almost nothing in 1983, to over $30 million in 1989. Adept is a leading producer of assembly robots and has been one of the few successful U.S. robot manufacturers.

The company designs, manufactures, and markets integrated flexible automation products for the device-level factory automation market. Its main products include industrial robots, machine vision systems, automation software and controls. The equipment is used in a variety of applications, including electronic and mechanical assembly, machine loading and unloading, material handling, inspection and testing, and packaging. Advanced controls and software are the core of Adept's success and its large R&D effort will be key to its continued success. Adept recently introduced what they call the world's most accurate robot. The UltraOne assembly robot has an accuracy within 0.0002 inch.

Exports currently account for 25 percent of the company's business and Adept is increasing its sales to Southeast Asia through partnerships with integrators and manufacturers. Adept robots are currently sold under license by Kawasaki Heavy Industries in Japan.

**Cincinnati Milacron, Inc., Industrial Robot Division** (CM), signed a letter of intent in September 1990, to sell its robot business in Greenwood, South Carolina, to ABB Robotics, Inc. CM entered robotics in 1977, with a wide range of robots, when the industry looked poised to expand into many areas of manufacturing. In recent years, however, CM decreased the size of its robotics operations as the firm lost sales to the automotive industry and eventually decided that it was not a profitable part of its overall operation. CM's strategy was to provide a full line of robots and compete in the high volume end of the market; however, it was unable to compete in the automotive sector with lower-priced robots produced by GMFanuc or imported from Japan. The sale of Cincinnati Milacron's robot division marks the exit of what was in 1989 the leading U.S. producer of robots. CM will continue to focus on systems integration and maintain its machine tool division.

**DeVilbiss** began producing paint spray guns in 1910 and by the mid-1920s, had introduced spray painting to the automotive industry. Its specialty lies in automated spray finishing robots. In 1975, the paint spraying robot was introduced to the U.S. market through an agreement with Trallfa Nils Underhaug A/S of Norway. DeVilbiss produced robots in the United States until 1986. In April 1990, DeVilbiss was acquired by Illinois Tool Works.

**GMFanuc Robotics** is a joint venture between GM and Fanuc Ltd. of Japan established in June, 1982. With nearly all its robot production in Japan, GMFanuc has become the leading robot supplier to the United States, and a major supplier to Europe and Japan. In 1987, GMF established a joint marketing agreement involving electric painting robots with the DeVilbiss Company of Ohio. In 1989, the company had a 43 percent growth in sales, extending their leadership position in the U.S. robotics industry. In 1985, GMFanuc entered into machine vision with three different systems and also developed KAREL[R], a programming language that integrated various aspects of automation systems including robots, vision systems and automated guided vehicles. During that same year, a technology development center was established in Rochester Hills, Michigan. Also that year, West German and Canadian subsidiaries were formed. The firm is a world-class systems integrator, heavily involved in factory automation.

**Graco Robotics Inc.** (GRI) began producing robots in Livonia, Michigan, in January 1983. GRI offers five models of paint finishing robots, and after a merger with Graco Automatic Finishing systems, provides complete finishing systems including paint circulating systems and spray attachments for robots. In addition, GRI produces a paint recovery chamber. Approximately 60 percent of Graco's business is derived from the automotive industry, with GRI being the largest U.S. supplier to the Chrysler Corporation and Ford Motor Company.

**Intelledex Inc.** is a privately held company, founded in 1981 by a group of engineers and managers from Hewlett-Packard. The company is located in Corvallis, Oregon, with offices across the United States and in Belgium. Intelledex designs and manufactures six different light assembly robots and three machine vision systems for a range of precision assembly, material handling applications and part inspection tasks. A separate division, Automation Technology, develops custom automation systems for clean rooms in the electronics and semiconductor industries.

**Kawasaki Heavy Industries (USA) Inc.** is a wholly-owned subsidiary of Kawasaki Heavy Industries (KHI) in Japan. In 1968, KHI entered into robotics through a licensing agreement with Unimation which allowed KHI to manufacture and distribute Unimation Robots to East Asian markets. By 1981, KHI had developed its first robot and by 1983 had developed its own line of electric robots for heavy material handling and painting applications. These were marketed in the United States through an Original Equipment Manufacturing agreement with Westinghouse-Unimation. Since 1985, KHI has manufactured and sold the Adept Technology robot in Japan under license.

In 1986, the KHI-Westinghouse agreement was mutually terminated and KHI established its own sales and support organization in Detroit. This organization offers training, documentation, application, controls, project engineering, and after sales service and support to its North American customers. Kawasaki Robotics is planting itself in the U.S. market and introduced five new models of robots at the recent trade show in Detroit.

**Motoman Inc.** is a joint venture company formed by Hobart Brothers of Troy, Ohio, and Yaskawa Electric America of Northbrook, Illinois, in June 1989. The company draws upon various sources for application expertise including Hobart Brothers for robotic arc welding; Yaskawa Electric for industrial robots and application technology; Torsteknik as a European automotive systems integrator; and Multicon as a diverse application systems integrator. Motoman imports robots and adds welding equipment in the United States, providing various arc and spot welding, robotic painting, material handling, assembly, gluing/sealing, deburring and machine vision products.

Prior to the joint venture, Yaskawa's only penetration into the U.S market was in arc welding arms sold as part of Motoman machines.

**Nachi Robotic Systems Inc.** (NRS) located in Farmington Hills, Michigan, is the U.S. headquarters for the Robotic Systems division of Nachi-Fujikoshi. NRS was established in February, 1989, to provide a central organization for the sales, service and systems applications of Nachi robots in North America. Nachi offers a complete line of industrial robots for a variety of applications including: spot and arc welding, painting, deburring, sealing, material handling and assembly. The robots are imported directly from the Japanese production facility in Toyoma, Japan.

**Prab Robotics Inc.**, of Kalamazoo, Michigan, was founded in 1950 as Prab Conveyors, and first developed an industrial robot operation in 1968. In 1979, the company expanded with the purchase of the Versatran robot line from AMF. The firm was reorganized in 1981 as Prab Robots, Inc. and went public later that year. That same year, Prab expanded into an international operation with licensing agreements with Can-Eng Manufacturing Ltd. of Canada and Murata Machinery of Japan.

In 1982, the company expanded its efforts into robot systems and today more than 80 percent of Prab's revenue is from automation systems. In the late 1980s, Prab acquired a license from Westinghouse to manufacture and remanufacture the Unimate hydraulic robot line. In addition, Prab has opened a European division to market the Unimate and Prab series of robots.

**Westinghouse Electric Corp.** has the sole U.S. distribution rights for Unimation products. This arrangement is the only link remaining between the two firms since the sale of Unimation by Westinghouse. This arrangement runs for four years from January 1, 1989.

## Production Capabilities

Robotic production capacity is difficult to quantify with any accuracy. It can be likened to assembly of customized machine tools, with final assembly firms involved in component or parts manufacture to varying degrees. There is little actual factory integration. The process is highly dependent on outside vendors for components. Production is generally confined to small numbers of robots with a relatively high engineering content. Much of the work in the United States consists of adding parts to imported robotic arms, as these are made cheaply in high volume abroad, notably in Japan. For 1989, surveyed companies reported their capacity to produce complete robots at $189.3 million, and capacity utilization at 54 percent. Capacity will decline significantly from this total with the exit of Cincinnati Milacron from the business.

Production in the United States during 1989 was mostly assembly, painting and spot welding robots. The least activity was found in the area of machining type robots. Capacity utilization ranged from as little as 20 percent for one firm, to 100 percent for another.

The data provided by the companies indicates that during times of surge or mobilization under a national security emergency, expansion of production would be possible assuming the availability of a substantial number of imported parts and components. Companies reported that the average times necessary to double monthly unit production rates ranged from one to five months, with the major constraint being reliance on foreign suppliers for major components, and parts such as bearings. Other constraints cited include domestic vendor supplies and skilled labor.

The market share reportedly held by the surveyed companies for various types of robots ranged from 1 percent up to 44 percent. Most U.S. companies hold only a minor portion of their respective markets for a particular type of robot. The share of the U.S. market held by imported robots (as estimated by the companies) ranged from only 2 percent for one particular product line, to 95 percent. The highest import levels were attributed to arc welding and gluing and sealing robots.

<u>Foreign Sourcing</u>

As repeatedly noted, foreign sourcing has become very prevalent in the robotics industry. Six out of seven U.S. manufacturers surveyed import some percentage of the parts and components necessary for robot assembly or production. Foreign sources accounted for an estimated $15.2 million worth of parts and components in 1989.

Many reasons were cited for foreign sourcing. Some necessary parts are reportedly not available domestically. In other instances, lower cost, design or performance considerations caused manufacturers to look overseas. Service does not seem to be a problem for domestic suppliers as neither delivery time nor maintenance appeared as a reason for foreign sourcing.

Bearings were the parts most often imported, frequently due to a lack of an acceptable U.S. supply. Motors, ball screws and other components were also obtained from abroad. Japan was by far the leading foreign supplier. Germany, France, Norway and Sweden also supplied significant amounts of various items. Imported whole component systems, such as manipulators, power supplies or control systems, may be assembled domestically, along with accessories and peripherals.

Manufacturers may import whole robots in addition to parts and components. Usually, this is done to round out product offerings and build market share. A total of $42.3 million complete robots were imported by the surveyed companies. In these cases, it is not clear what, if any, value is added in the United States. However, each company reporting counted these as U.S.-manufactured shipments.

## RECENT INDUSTRY PERFORMANCE

Overview

Since 1984, imports of robots (and robot parts) have made significant inroads into the U.S domestic market, while at the same time, overall domestic consumption and the domestic robot industry have actually declined. Apparent consumption of robots fell from $308.3 million[13] in 1984, to less than $289.4 million in 1989, a 6 percent decline. In what has been a very volatile market, consumption peaked at over $400 million in 1985 and 1986, and reached its lowest level at $278.8 million in 1988.

U.S. manufactured robot shipments during this period fell almost 33 percent from $222.2 million in 1984, to less than $150.6 million in 1989. Imports expanded dramatically over the same time frame from $88.4 to $181.4 million, for a gain of more than 105 percent. Import penetration (imports as a percent of apparent consumption) also grew steadily during this period from 28.7 percent in 1984, to 62.7 percent in 1989. It will be shown below that actual import penetration is higher.

ROBOT SHIPMENTS, IMPORTS AND EXPORTS, 1984-1989
(in millions of dollars)

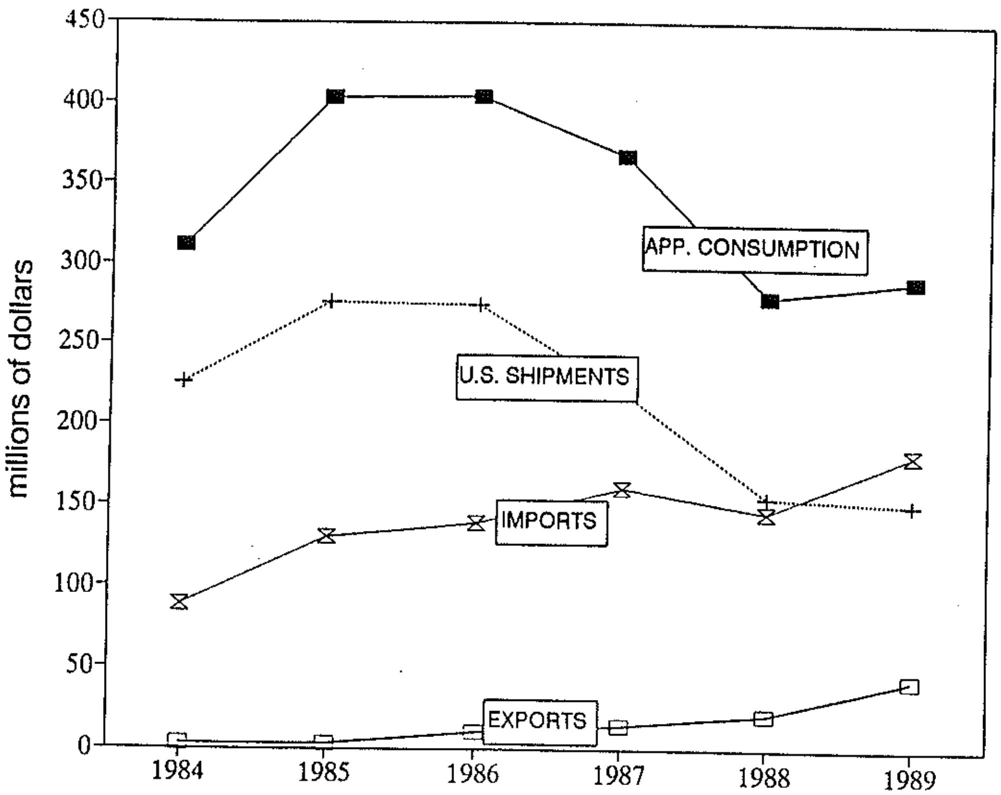
| | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|---|
| U.S. Shipments | 222.2 | 272.9 | 271.6 | 211.2 | 154.8 | 150.6 |
| Imports | 88.4 | 129.8 | 139.0 | 160.9 | 145.3 | 181.4 |
| Exports[14] | 2.6 | 2.6 | 9.9 | 13.8 | 21.3 | 42.6 |
| App. Consumption | 308.0 | 400.1 | 400.7 | 357.6 | 278.8 | 289.4 |
| % Imports | 28.7 | 32.4 | 34.7 | 45.0 | 52.1 | 62.7 |

Source: DOC, Bureau of the Census

[13] Current dollars are used throughout this section.

[14] Exports for the years 1985-1988 were taken directly from the totals of the OIRA industry survey. Although the surveyed companies did not represent total shipments, especially in the earlier years, industry sources indicated they account for the majority of exports during that period. The 1984 export amount, a year not included in the survey, was assumed to be the same as 1985's amount. The 1989 figure is taken from the Bureau of the Census, and is the first year such figures were available.

FIGURE 1- ROBOTIC TRADE PATTERNS
1984-1989




Source: DOC, Bureau Of The Census

As noted above, the 62.7 percent import penetration level shown for 1989 is actually understated. About 30.5 percent of U.S. shipments were reported by surveyed companies as reshipments of "imported complete robots", resulting in double counting. It is unclear what value is added in the United States, or what the mark-up is on these robots. However, taking them at face value, a 30.5 percent reduction in 1989 U.S. shipments (equal to $45.9 million) would leave $104.7 million in U.S. manufactured shipments, and reduce apparent consumption by an equal dollar amount to $243.5 million. This means that the actual import penetration level for complete robots is 74.5 percent (181.4/243.5).

Additionally, the surveyed companies reported that imported components and parts made up 15.8 percent of the value of their U.S. complete robot shipments. Again, the mark-up on these components is not known. If $16.5 million (15.8 percent of 104.7) is added to imports and taken away from shipments, the foreign content of U.S. apparent consumption rises to 81.3 percent [(181.4+16.5)/243.5].

The same trends demonstrated for robots in dollar terms apply to robots in unit terms. Import penetration levels are higher, however, reflecting the lower average prices of imported robots. Import penetration levels rose from 51.2 percent in 1981 to 81 percent (preliminary estimate) in 1989.[15]

ROBOT SHIPMENTS, IMPORTS AND EXPORTS, 1984-1989
(in number of robots)

| Year | U.S. Shipments | Exports | Imports | Apparent Consumption | Import Penetration |
|---|---|---|---|---|---|
| 1984 | 3,246 | na | 3,411 | 6,657 | 51.2% |
| 1985 | 3,474 | na | 4,461 | 7,935 | 56.2 |
| 1986 | 3,616 | na | 3,907 | 7,523 | 51.9 |
| 1987 | 2,782 | na | 5,473 | 8,255 | 66.3 |
| 1988 | 2,408 | na | 3,989 | 6,397 | 62.4 |
| 1989 | 2,217 | 747 | 6,278 | 7,748 | 81.0 |

Source: DOC, Bureau of the Census

## Information Sources

Much of the statistical information in this section on shipments, imports and exports was drawn from publicly available documents published by the Department of Commerce's Bureau of the Census. Census began collecting robot and robot component statistics in 1984, and publishes the information annually in a Current

[15]The imported units for 1989 were estimated using the average prices (per country of origin) calculated for 1988 imports. In the transition to the Harmonized Tariff Schedule, unit imports were very much overstated at over 25,000 units. The detailed documentation is being reexamined by Census officials to determine the cause of the problem.

Industrial Report (MA35X), Industrial Robots. The most recent publication covers 1989 shipments.[16]

Also in 1984, imports of robots were first classified as a distinct product under the Tariff Schedule of the United States (TSUS). Between 1984 and 1988, three TSUS commodity code numbers were used to record robot import statistics. Their numbers and tariff rates were as follows:

| Commodity Code | Description | Tariff Rate (%) |
|---|---|---|
| 664.1005 | Industrial Robots, Lifting | 2.4 |
| 678.5086 | Industrial Robots, NSPF[17] | 3.9 |
| 683.9005 | Industrial Robots, Welding | 2.3 |

Since January 1, 1989, trade data has been collected under the Harmonized Tariff Schedule (HS), a system which the United States implemented to provide better statistical comparability with our major trading partners. Further, with the adoption of HS, imports and exports now use the same classification system. Thus, beginning in 1989, robot export statistics have also become available. The three HS commodity code numbers and their tariff rates are as follows:

| Commodity Code | Description | Tariff Rate (%) |
|---|---|---|
| 8428.90.0010 | Industrial Robots, Lifting, Hand, Load, or Unload | 2.0 |
| 8479.89.9040 | Industrial Robots, Multiple Uses | 3.7 |
| 8479.90.8040 | Parts For Industrial Robots | 3.7 |

The product descriptions of the HS system differ from those of the previous schedule, making direct comparability with pre-1989 data difficult. Also, the transition to the HS system has

[16]This report is being discontinued as not enough information to justify collection is available. The 1989 report will be the last one unless the product category is expanded or broadened, perhaps to include automated systems.

[17]NSPF stands for "not specifically provided for."

presented a number of problems that may lead to data revisions, as misclassifications or data entry errors are discovered under closer scrutiny. Thus, the 1989 and 1990 import (and export) statistics should be viewed as preliminary.

In addition to publicly available information, extensive use was made of company responses to the robot industry survey distributed by OIRA to collect information from U.S. robot producers. The survey included questions covering the period 1985 to 1989 on shipments, exports, profitability, investment, employment, and R&D expenditures, all of which comprise subsections to this section. A copy of the survey instrument is attached as Appendix A.

Although nine major robot producers were surveyed, the robot industry has very few actual producers of complete robots. In fact, only seven firms provided the bulk of the information that makes up this section. A comparison of these seven surveyed firms' shipments with Bureau of the Census robot shipment data indicates the seven surveyed firms constituted slightly over 92 percent of total U.S. shipments of complete robots in 1989. A survey response was not received from Westinghouse (Unimation), which stopped manufacturing robots in the United States in 1988, or from several other producers that left the business prior to 1989. Thus, available data is not as complete for 1985-1988 as it is for 1989.

## SHIPMENTS, IMPORTS, AND EXPORTS

**U.S. ROBOT SHIPMENTS** - U.S. shipments of industrial robots ranged from a high of $273 million in 1985 to a low of $151 million in 1989, almost a 45 percent decline over the period. Servo controlled robots, which accounted for over 90 percent of these shipments, fell from $255 million to $136 million, down 47 percent. Point-to-point controlled welding robots peaked at $86 million in 1986, before sliding sharply to only $29 million in 1989. Continuous-path controlled welding robots fell almost 90 percent, from $22 million to only $2 million over the same period. This drop was connected to major declines in automotive related business, much of which shifted to foreign suppliers. Shipments of spray painting robots, although hidden in the statistics, also fell sharply for the same reasons. Nonservo controlled robots fell just over 17 percent, from $18 million to $15 million.

Robot components and parts shipments rose from $70 million in 1985 to $105 million in 1989, a 52 percent increase. Sensors rose from $18 million to $20 million over the same period, a 15 percent expansion. End of arm tooling rose from $3.7 million in 1985 to over $8 million in 1986, and then fell to $3.4 million in 1989. Other parts and accessories, not specified by kind, rose from $43 million to $73 million between 1985 and 1989, an increase of almost 70 percent.

ROBOT INDUSTRY SHIPMENTS, 1985-1989
(in thousands of dollars)

| | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|
| Servo Controlled | | | | | |
| Point-to-Point | | | | | |
| Welding | 74,646 | 86,047 | 64,598 | 32,301 | 29,314 |
| Assembly | 17,761 | 19,091 | 19,573 | 7,984 | 8,091 |
| All Other | 49,393 | 52,002 | 51,726 | 30,202 | 35,353 |
| Continuous-Path | | | | | |
| Welding | 22,352 | 13,768 | 9,020 | 3,694 | 2,249 |
| Coating/Sealing | 41,416 | 36,864 | 41,348 | 30,128 | 35,111 |
| All Other | 49,358 | 48,104 | 16,755 | 33,384 | 25,567 |
| Nonservo Robots | 18,015 | 15,691 | 8,153 | 17,077 | 14,872 |
| Complete Robots | $272,941 | $271,567 | $211,173 | $154,770 | $150,557 |
| Robots Parts | 69,518 | 71,383 | 64,592 | 73,876 | 105,413 |

Source: DOC, Bureau of the Census

Shipments of robots in unit terms generally followed the same trends as shipments shown in dollar value. The declines in units were steeper in many cases as U.S. firms retreated from the higher volume robot business, which is mostly automotive.

ROBOT INDUSTRY SHIPMENTS, 1985-1989
(in number of robots by type)

| | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|
| Servo Controlled | | | | | |
| Point-to-Point | | | | | |
| Welding | 839 | 969 | 675 | 304 | 273 |
| Assembly | 547 | 443 | 535 | 296 | 238 |
| All Other | 528 | 804 | 644 | 278 | 196 |
| Continuous-Path | | | | | |
| Welding | 287 | 198 | 110 | 79 | 31 |
| Coating/Sealing | 339 | 296 | 297 | 292 | 254 |
| All Other | 438 | 455 | 306 | 823 | 848 |
| Nonservo Robots | 496 | 451 | 215 | 336 | 377 |
| Complete Robots | 3,474 | 3,616 | 2,782 | 2,408 | 2,217 |

Source: DOC, Bureau of the Census

The average price level for U.S. shipments of robots fell almost 14 percent, from $78 thousand in 1985 to $68 thousand in 1989. Servo controlled robot prices fell about the same percentage from $86 thousand to $74 thousand over the period. The decline in robot prices is partly explained by a larger number of smaller assembly type robots in the total. Displacement of U.S. robot producers from the automotive sector and an increased focus on lower volume custom markets -- robots with a greater engineering content -- caused an increase in average welding robot prices. Point-to-point welding robot prices rose nearly 21 percent.

AVERAGE U.S. SHIPMENT PRICES BY ROBOT TYPE, 1985-1989
(in thousands of dollars)

| | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|
| Servo Controlled | | | | | |
| Point-to-Point | | | | | |
| Welding | 89 | 89 | 96 | 106 | 107 |
| Assembly | 32 | 43 | 37 | 27 | 34 |
| All Other | 94 | 65 | 80 | 109 | 180 |
| Continuous-Path | | | | | |
| Welding | 78 | 70 | 82 | 47 | 73 |
| Coating/Sealing | 122 | 125 | 139 | 103 | 138 |
| All Other | 113 | 106 | 55 | 41 | 30 |
| Nonservo Robots | 36 | 35 | 38 | 51 | 39 |

Source: DOC, Bureau of the Census

**IMPORTS** - Between 1984 and 1989, imports of robots increased from $88.4 million to $181.4 million. Most of the growth in imports came from Japan, as imports from that country increased from $68.0 million in 1984, to $138.8 million in 1989. Japan had more than a 76 percent share of the import market in both these years. The expansion in imports is now feeding, if not enabling, the accelerating growth of the American market for robots, and can be expected to continue. Most of the Japanese imports come from GMFanuc, Kawasaki, Nachi, Matsushita (Panasonic) and Yaskawa.

GMFanuc sells mainly to GM as part of their joint venture agreement. However, the firm also has marketing agreements with DeVilbiss to sell paint spray robots; with Niko and Bleichert to sell GMF gantry robots (robots that move on tracks, usually overhead); and with about 13 full service distributors to sell GMF robots. Further, Kawasaki opened an office in Detroit, and Nachi established itself in Farmington Hills, Michigan, in both instances to market Japanese built robots. Prior to its sale to ABB Robotics, Cincinnati Milacron entered into a sales agreement with Panasonic to market a line of small welding robots beginning in 1990. And in 1989, the Hobart Brothers Company set up a joint venture in Troy, Ohio, with Yaskawa Electric to market Japanese made welding robots. Japanese suppliers now supply almost all of the American auto market, and are making strides into many other markets.

IMPORTS OF ROBOTS BY COUNTRY, 1984-1989
(in thousands of dollars, Customs Value)

| | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|---|
| JAPAN | 67,952 | 89,039 | 85,759 | 114,396 | 94,857 | 138,814 |
| WEST GERMANY | 12,975 | 19,271 | 21,569 | 19,554 | 18,758 | 9,338 |
| SWEDEN | 1,640 | 4,823 | 741 | 7,800 | 14,129 | 9,127 |
| CANADA | 1,341 | 2,513 | 5,018 | 3,852 | 6,507 | 8,908 |
| SWITZERLAND | 1,078 | 1,227 | 1,811 | 862 | 1,253 | 4,462 |
| UNITED KINGDOM | 391 | 2,933 | 4,841 | 4,699 | 1,794 | 3,308 |
| FRANCE | 1,197 | 1,190 | 1,589 | 844 | 2,887 | 1,530 |
| ITALY | 385 | 6,211 | 14,105 | 6,578 | 1,014 | 1,462 |
| ISRAEL | 0 | 154 | 257 | 268 | 1,132 | 782 |
| ALL OTHERS | 1,428 | 2,441 | 3,344 | 2,083 | 2,928 | 3,663 |
| WORLD TOTAL | 88,387 | 129,802 | 139,034 | 160,936 | 145,259 | 181,392 |

Source: USDOC, Bureau of the Census

IMPORTS OF ROBOTS BY COUNTRY, 1984-1989
(in Units imported)

| | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|---|
| JAPAN | 2,800 | 3,427 | 2,901 | 4,520 | 2,947 | 4,313 |
| SWEDEN | 63 | 215 | 43 | 158 | 277 | 944 |
| WEST GERMANY | 260 | 346 | 355 | 291 | 262 | 130 |
| CANADA | 27 | 43 | 63 | 101 | 115 | 157 |
| SWITZERLAND | 16 | 34 | 31 | 21 | 30 | 107 |
| UNITED KINGDOM | 46 | 118 | 183 | 174 | 157 | 289 |
| FRANCE | 21 | 64 | 63 | 38 | 33 | 17 |
| ITALY | 10 | 103 | 145 | 34 | 18 | 26 |
| ISRAEL | 0 | 6 | 7 | 4 | 6 | 3 |
| ALL OTHERS | 168 | 105 | 116 | 132 | 144 | 291 |
| WORLD TOTAL | 3,411 | 4,461 | 3,907 | 5,473 | 3,989 | 6,278 |

Source: USDOC, Bureau of the Census

In addition to Japan, significant imports are also purchased from Sweden and Germany. In 1989, these three countries accounted for almost 87 percent of all robot imports. This was down somewhat from the 93.5 percent share (of a much smaller dollar amount) these countries represented in 1984. Over this time period, Sweden gained U.S. import share, increasing from 1.9 percent in 1984, to almost 10 percent in 1988, and 5 percent in 1989. Because of declines in the market, ABB Robotics of Sweden stopped producing robots in the United States at its New Berlin, Wisconsin, facility in 1986. A direct result was a precipitous increase in ABB's imports from Sweden. With the purchase and closing of Cincinnati Milacron's robot facilities in South Carolina, imports from Sweden should increase further in the future. Recently, ABB was awarded a large order by GM for welding robots. Germany lost some market share with its imports making up only 5.1 percent of total imports in 1989, down from 14.7 percent in 1984.

PERCENT OF IMPORTS, BY COUNTRY (CUSTOMS VALUE)

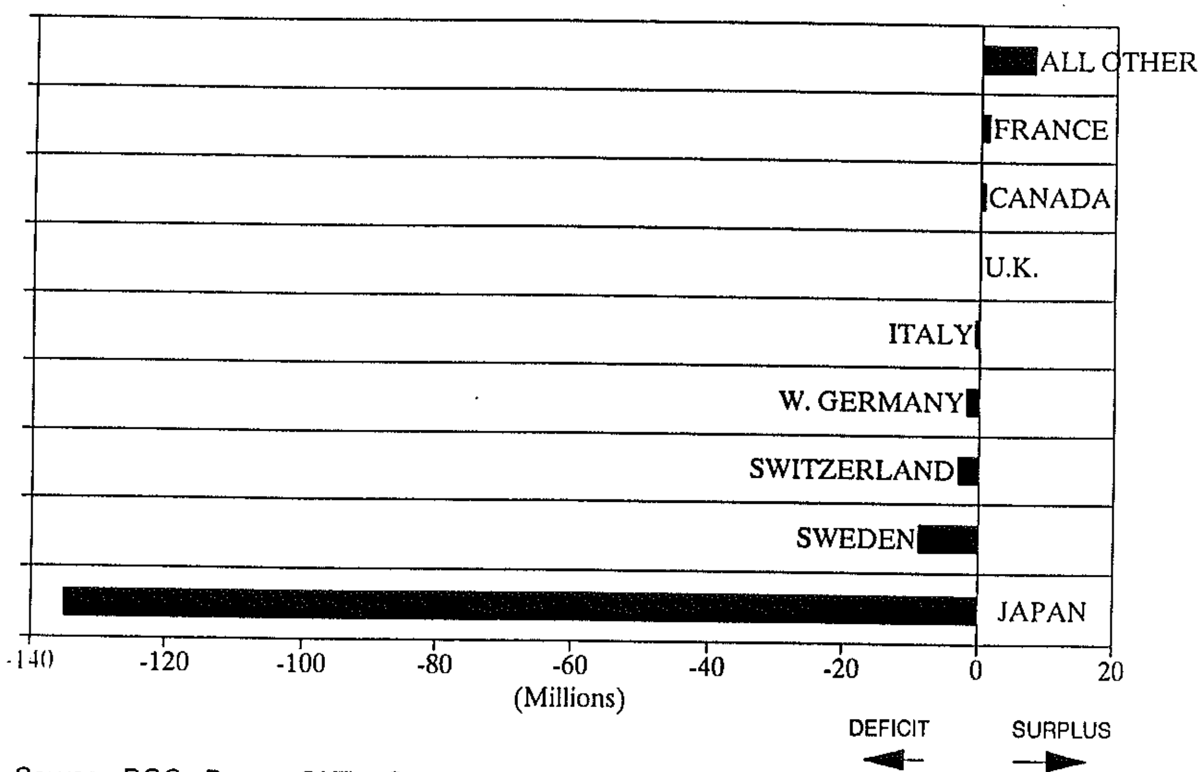
| Year | Japan | Germany | Sweden | All Others |
|---|---|---|---|---|
| 1984 | 76.9 | 14.7 | 1.9 | 6.5 |
| 1985 | 68.6 | 14.8 | 3.7 | 12.9 |
| 1986 | 61.7 | 15.5 | 0.5 | 22.3 |
| 1987 | 71.1 | 12.2 | 4.8 | 11.9 |
| 1988 | 65.3 | 12.9 | 9.7 | 12.1 |
| 1989 | 76.5 | 5.1 | 5.0 | 13.4 |

Source: USDOC, Bureau of the Census

**EXPORT SHIPMENTS** - Based on surveyed company responses, exports as a percentage of total U.S. shipments rose steadily from 1.4 percent in 1985, to 28.3 percent in 1989. In dollar value, exports peaked in 1989 at $41.0 million, up from only $2.6 million in 1985. According to Census data, Canada and Germany were the two major destinations of export shipments in 1989. Exports to Canada totalled $9.7 million, and to Germany, $7.5 million. The third major destination was Japan at $3.8 million, followed closely by Mexico ($3.6 million), and the United Kingdom ($3.5 million).

A breakdown of exports by major robot type, as reported by the surveyed companies, indicated several trends. The welding sector suffered a marked decline over the five year period, with the dollar value of export shipments falling in 1989 to less than half the figure in 1985. Assembly robots fared much better, with the dollar value of exports actually increasing by a substantial margin over the five year period. Exports of painting robots also increased dramatically between 1985 and 1989.

FIGURE 2- BILATERAL ROBOTICS TRADE
U.S. SURPLUS (DEFICIT), 1989




Source: DOC, Bureau Of The Census

**BILATERAL TRADE** - In 1989, the United States experienced a trade deficit in robotics of $138.8 million. While imports reached record levels in 1989 at $181.4 million, exports also attained a record level at $42.6 million. The overall ratio of imported to exported robotics was about 4.3, or for every dollar exported, $4.26 was imported.

In 1989, the robotics trade deficit with Japan was $135 million. This far exceeded all others, and accounted for over 97 percent of the total U.S. deficit in robotics. The United States imported $138.8 million from Japan, but only exported $3.8 million in return. Stated in another way, for every dollar of robotics exported to Japan, about $36.40 was imported.

Assuming the Japanese market for robotics was about $2.0 billion (estimate) in 1989, U.S. producers supplied less than two-tenths of one percent of the Japanese market. In contrast, the Japanese supplied almost half the American market (about $300 million).[18] A possible explanation for this imbalance may have to do with the structure of the robot industry in Japan. Unlike the U.S. robot industry, the Japanese robot industry is characterized by vertical integration, where large end-user firms (Matsushita, Kawasaki, Toyota, Yaskawa, etc.) supply much of their own robot requirements. The Japanese industry is also much larger, with more production experience, better overall quality and lower prices than U.S. producers. The little that is exported to Japan is due primarily to superior technology.

The deficit with Sweden is the next largest at a comparatively small $8.8 million, followed by Switzerland at only $3.0 million. Being a subsidiary of ASEA Brown Boveri (Swedish-Swiss), ABB Robotics, Inc. has major production facilities in both Sweden and Switzerland, from which it exports robots to customers in Europe and the United States. Also, Westinghouse sold Unimation's production rights to Staeubli-Unimation in Switzerland in 1988, but has retained exclusive U.S. distribution rights until the end of 1992. This has boosted imports from Switzerland. West Germany's deficit of $1.8 million is minor. For each dollar of robotics exported to Germany, about $1.24 was imported. The scale of robotics trade with our European trading partners is actually very small. In the future, with EC92 approaching, trading opportunities should expand. The table that follows shows the bilateral robotics trade with our major trading partners.

[18]The Japanese may have supplied over half the American market if imported parts and component systems as well as complete robots are taken into account.

BILATERAL ROBOTICS TRADE
(in thousands of dollars)

| COUNTRY | IMPORTS | EXPORTS | SURPLUS (DEFICIT) | IMPORT/ EXPORT RATIO |
|---|---|---|---|---|
| Japan | $138,814 | $3,817 | ($134,997) | 36.4 |
| Sweden | 9,127 | 287 | (8,840) | 31.8 |
| Switzerland | 4,463 | 1,454 | (3,009) | 3.1 |
| West Germany | 9,338 | 7,519 | (1,819) | 1.2 |
| Italy | 1,462 | 982 | (480) | 1.5 |
| United Kingdom | 3,308 | 3,486 | 178 | .9 |
| Canada | 8,908 | 9,685 | 777 | .9 |
| France | 1,530 | 2,830 | 1,300 | .5 |
| All Other | 4,442 | 12,531 | 8,089 | .3 |
| World | $181,392 | $42,591 | ($138,801) | 4.3 |

Source: USDOC, Bureau of the Census

**FOREIGN EXCHANGE RATE EFFECTS** - The U.S. dollar steadily weakened against major foreign currencies after 1985, and lost over 40 percent of its value by 1988. However, during this period, robotic imports increased by almost 12 percent, from $130 to $145 million. This happened while U.S. robot consumption declined over 30 percent, from over $400 to $279 million. Thus, while foreign currencies grew stronger, imported robots expanded their share of the American market from 32 to 52 percent.[19]

Between 1985 and 1988, robot imports from Japan rose from $89 to $95 million (up 6.5 percent), as Japan expanded its share of the U.S. market from 22 to 34 percent. This happened while the Japanese yen appreciated 86 percent against the dollar. Robot prices from Japan rose 24 percent in the aggregate. Robot imports from West Germany, the second largest source, declined slightly from $19.3 to $18.8 million (down 2.7 percent). However, the German share of America's market climbed from 4.8 to 6.7 percent, while the German deutsch mark rose by 68 percent. Average robot prices from Germany rose 29 percent.

Import information was available for three categories of robots: lifting, welding, and all other (mostly spray painting). Imports of these robots from Japan and West Germany, with average prices, exchange rates and percentage changes shown for 1984 to 1988, are presented on the table below.

[19]The 1989 import data would have been used, except the unit information is incorrect, and distorts robot prices. For this analysis, little if anything is lost using the 1988 data.

EXCHANGE RATE IMPACT ON ROBOTICS FOR JAPAN AND WEST GERMANY

| JAPAN | 1985 | 1986 | 1987 | 1988 | Percent Change (85-88) |
|---|---|---|---|---|---|
| Quantities Imported | | | | | |
| lifting robots | 616 | 526 | 666 | 631 | 2 |
| welding robots | 1129 | 1179 | 1164 | 940 | (17) |
| all other robots | 1682 | 1196 | 2690 | 1376 | (18) |
| Total | 3427 | 2901 | 4520 | 2947 | (14) |
| Prices ($000) | | | | | |
| lifting robots | $14 | 13 | 27 | 16 | 14 |
| welding robots | $43 | 44 | 43 | 45 | 5 |
| all other robots | $19 | 22 | 17 | 31 | 63 |
| Total Average | $26 | 30 | 25 | 32 | 24 |
| EXCHANGE RATE | | | | | |
| U.S. cents/100 Yen | 42 | 59 | 69 | 78 | 86 |

| WEST GERMANY | 1985 | 1986 | 1987 | 1988 | Percent Change (85-88) |
|---|---|---|---|---|---|
| Quantities Imported | | | | | |
| lifting robots | 17 | 118 | 63 | 85 | 400 |
| welding robots | 242 | 62 | 35 | 20 | (92) |
| all other robots | 87 | 175 | 193 | 157 | 80 |
| Total | 346 | 355 | 291 | 262 | (24) |
| Prices ($000) | | | | | |
| lifting robots | $47 | 44 | 75 | 55 | 17 |
| welding robots | $59 | 83 | 98 | 95 | 61 |
| all other robots | $48 | 64 | 59 | 78 | 63 |
| Total Average | $56 | 61 | 67 | 72 | 29 |
| EXCHANGE RATE | | | | | |
| U.S. cents/DM | 34 | 46 | 56 | 57 | 68 |

Source: DOC, Bureau of the Census, International Monetary Fund

The weakened dollar did not affect robotics imports as much as other competitive factors. Overall average import prices rose moderately, but failed to rise in conjunction with exchange rates. The majority of imports are relatively high volume spot welding and spray painting robots for the auto industry. The auto companies have influence over prices from all their suppliers, and may have been a factor in the import prices' moderate increase. This was also a time of declining demand in the United States. Further, it is evident that most imports no longer compete head-to-head with American made robots, and are now challenged primarily by other foreign made robots.

The weakened dollar may have helped boost exports. U.S robotics exports expanded from a tiny base of under $3.0 million in 1985, to about $21 million in 1988. Most of the exports were to Canada and Europe, with very little to Japan. Another effect of the weakened dollar is the enhanced ability of firms located in strong currency nations, such as Japan and West Germany, to purchase prime American robotics companies.

## Profitability

Robot production in the United States has not been profitable in recent years. The industry as a whole reported losses four of the five years from 1985 to 1989. The industry's only positive income was in 1986, when it made only $4.3 million (before taxes) on sales of $185.8 million, a 2.3 percent return. At least half the firms reported losses each year, except in 1988. One firm showed losses every year, and another four of the five years.

The profit statements are from the industry survivors. This picture would be bleaker if Unimation were included, as the company by some accounts lost over $10 million per year while under Westinghouse ownership (1983-1988). In light of the mass exodus from the industry in recent years, others from whom we have no reports probably also lost money in the business.

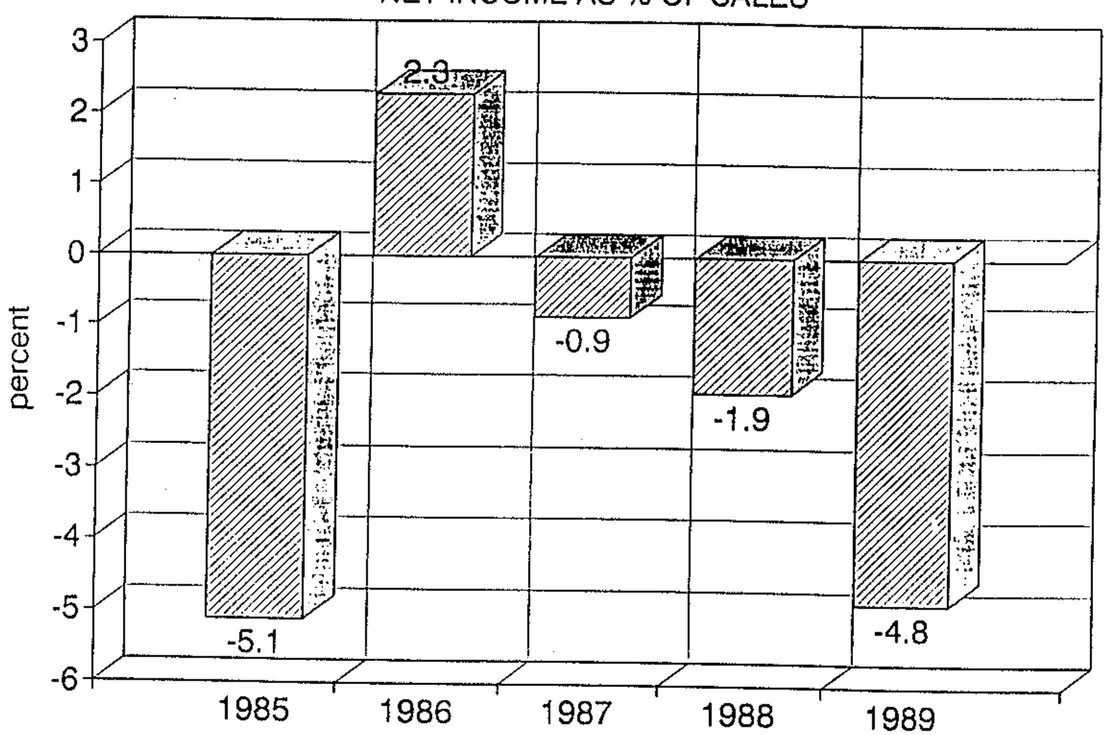
The companies report unusually high general, administrative and selling costs. These costs (plus current depreciation and amortization of R&D expenditures) are the difference between operating income and net income (before taxes). These costs have ranged over 30 percent of sales each year from 1985 to 1989. They are much higher than the 20 percent rate experienced by the General Machinery Industry (SIC 3569) in 1989.

ROBOT INDUSTRY PROFITABILITY, 1985-1989
(in thousands of dollars)

| | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|
| Net Sales | $193,673 | $185,814 | $125,960 | $123,320 | $138,694 |
| Cost of Goods Sold | 144,414 | 123,738 | 84,783 | 83,597 | 98,925 |
| Operating Income | 49,259 | 62,076 | 41,177 | 39,723 | 39,769 |
| Net Income | (9,918) | 4,282 | (98) | (2,356) | (3,903) |
| Aftermarket Revenues | 8,044 | 9,083 | 8,735 | 11,209 | 14,564 |

Source: OIRA Robot Industry Survey

FIGURE 3- PROFITABILITY, 1985-1989
NET INCOME AS % OF SALES




Source: OIRA Robot Industry Survey

A large portion of these costs is for administrative and other employees, which make up about 50 percent of the work force. In conversations with industry officials, it was discovered that many of the individuals in this category are actually sales people attempting to expand business, including some located in overseas offices. Such a high ratio of "administrative and other" may be expected for an infant industry, where markets need development, and in this case, massive doses of customer education are required. However, only one of the surveyed firms actually expanded sales during this period, while each of the others contracted by varying degrees.

Further, it is evident the companies are not engaged in high volume production, and capacity utilization has been low. Most of the firms are now producing customized robots with a very high engineering content. As survivors of the recent shake-out, these companies are shipping fewer U.S. produced robots to the U.S. auto industry and are operating without an important source of cash flow.

Production workers were reported as less than 20 percent of the work force by the surveyed companies. It is readily apparent such a low percentage of the work force would be hard pressed to produce a sufficient value of robots to cover overhead and staffing expenses, and may be a reason for the losses. It is also possible for companies to move losses from one division to another, or for transnational firms to move profits to countries where the tax incidence is least. However, this is difficult to show, given the available information.

Despite these heavy losses, the surviving firms in the industry remain solvent. In 1989, total debt in the industry was recorded at $66.3 million. However, over 80 percent of this debt is short-term (payable in less than a year), which presumably is used to finance rather high inventories. It can be discerned from the surveys that the high inventories are comprised mostly of imported robots or robot parts. However, the overall debt/equity ratio of .78 exhibited by the companies is considered sound. Two firms reported no debt at all.

The current ratio (current assets/current liabilities) for the group is 1.39 (all manufacturing was about 1.5 in 1989), and indicates in general the firms can meet short-term expenses. One firm reported a current ratio of only .86, which may be a problem. Liquidation value, measured by total assets over total liabilities, stood at 1.70, which is also good. One firm, the same firm that reported the low current ratio, also registered below 1.0 for this measure.

The inventory turnover rate for the industry was 2.8 times. This could be improved, although it is another indication of a reliance on imported robots and robot components, which tend to inflate inventories (the denominator in this equation). Also, in 1989 the industry operated at a low rate of capacity utilization, reflecting low sales. The highest recorded inventory turnover rate was 3.7, followed by 3.0 times -- recorded by the two most profitable firms.[20]

ROBOTICS INDUSTRY FINANCIAL STATUS, 1989

| BALANCE SHEET ITEM | SUMMARY ($000s) | FINANCIAL RATIOS | |
|---|---|---|---|
| Assets | | | |
| Current | | Current Ratio: | 1.39 |
| Cash and Equivalents | 4,040 | | |
| Accounts Receivable | 77,207 | | |
| Inventories | 65,980 | Debt to Equity: | .779 |
| Other | 4,702 | | |
| Total Current | 151,929 | | |
| Property, Plant & Eqmt. (book value) | | Inventory Turnover: | 2.8 |
| Land and Buildings | 47,414 | Assets to Liab.'s: | 1.7 |
| Machinery and Eqmt. | 24,613 | | |
| Allowences for Depreciation | (25,705) | | |
| Other | 8,053 | | |
| Total Assets | 206,304 | | |
| Liabilities | | | |
| Current | | | |
| Accounts Payable | 28,874 | | |

[20]The 1989 final inventory turnover figure for all manufacturing was 6.9; for durables manufactures, 5.6; for the Capital Goods industry (SIC 35), 5.5; and for machine tools, 3.4.

ROBOTICS INDUSTRY FINANCIAL STATUS (continued)

| | |
|---|---|
| Short-Term Debt | 54,875 |
| Current Portion of Long-Term Debt | 200 |
| Other | 25,648 |
| Total Current | 109,597 |
| Long-Term Debt | 11,250 |
| Other | 301 |
| Total Liabilities | 121,148 |
| Equity | 85,156 |

Source: OIRA Robot Industry Survey

The poor income performance the companies reported for their manufacturing operations was offset somewhat by aftermarket revenues, which increased over the period, although this was primarily for two companies. As the installed robot population continues to increase, aftermarket revenues should increase further as the demand for repairs, rebuilds and servicing increases, and a small secondhand robot market develops.

## Employment

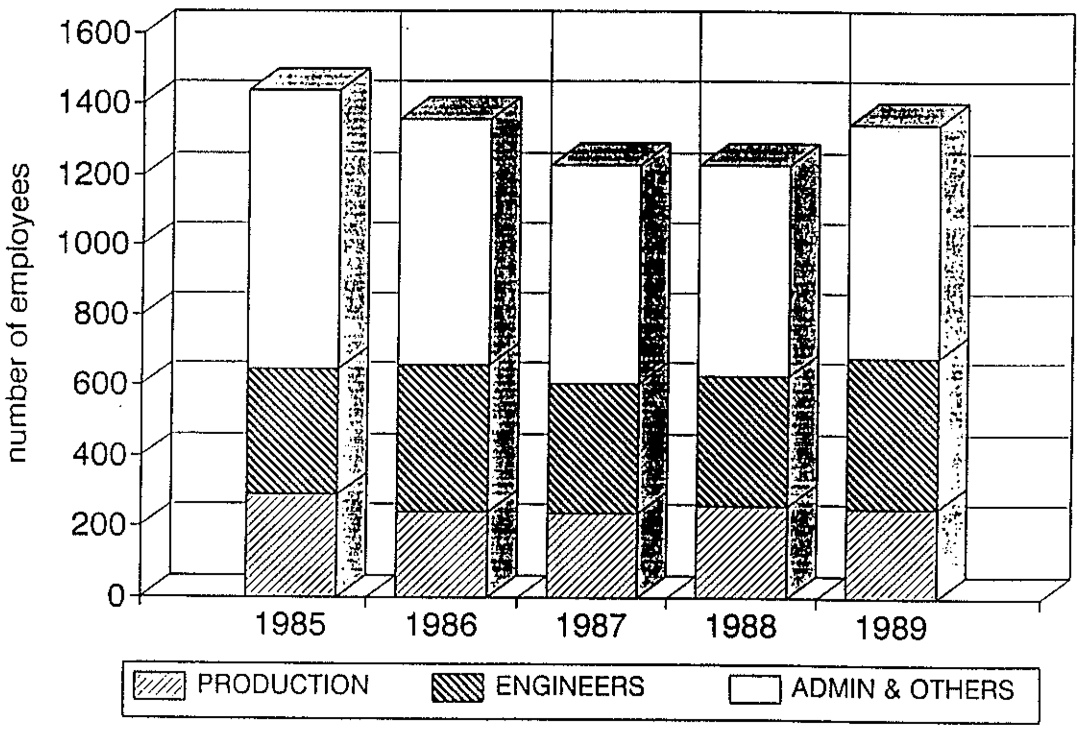
Based on the OIRA industry survey, total employment in the robot industry fell 6.8 percent - from 1,440 people in 1985, to 1,345 in 1989. Employment reached its lowest level of 1,228 in 1987, which coincided with the industry's lowest level in shipments. Within occupation groupings, the largest employment drop over the period occurred among administrative and other types, which declined 16.4 percent. Production workers fell 11.8 percent, while engineers actually increased 19.3 percent. The following table shows the yearly changes in employment by occupation category.

ROBOT INDUSTRY EMPLOYMENT BY OCCUPATION, 1985-1989
(in number of employees)

| Occupation | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|
| Engineers | 358 | 416 | 368 | 369 | 427 |
| Production Workers | 287 | 241 | 236 | 257 | 253 |
| Admin. and Others | 795 | 703 | 624 | 605 | 665 |
| Total | 1,440 | 1,360 | 1,228 | 1,231 | 1,345 |
| Sales per Employee ($000s) | 134 | 137 | 103 | 100 | 103 |

Source: OIRA Robot Industry Survey

FIGURE 4- EMPLOYMENT BY OCCUPATION
1985-1989




Source: OIRA Robot Industry Survey

The decline in the number of robot production workers is not a good sign for the manufacture of robots in the United States. Only two companies increased the number of production workers, and one of these by a marginal amount over the 1985 to 1989 period. Among the surveyed companies, production workers represent a relatively minor share of total employment. This is indicative of the little manufacturing that actually takes place in the United States. In 1989, the proportion of production workers to total employment was only 18.8 percent, down from 19.9 percent in 1985.[21] For individual companies, this measure ranged from a low of only 5.7 percent to a high of 44.2 percent. Companies that manufactured predominantly in the United States had a higher percentage of production workers.

Engineers increased both as a percentage and in absolute numbers in the work force between 1985 and 1989. In 1984, engineers made up about 25 percent of the work force; in 1989, almost 32 percent. However, only two companies are responsible for the entire increase in engineers, as each of the others showed declines. Some of the engineers may actually be performing production jobs as well. There has also been a migration toward systems integration, which requires more engineering input.

The companies showed a decline in worker productivity. Sales per employee declined from a high of $138 thousand in 1986, to $98 thousand in 1987 and 1988, and then up slightly to $103 thousand in 1989. Only one firm actually showed improvement in this measure. Sales per employee is very sensitive to changes in capacity utilization, which was low at 54 percent in 1989. It was probably even lower in the two prior years. The lower productivity may also be an indication of hoarding labor. Persons previously trained in certain skills by the company may be expensive to replace. The companies may be waiting for the market to pick up, at which time the costs and time of training will not have to be incurred again. It may also be that qualified candidates are becoming difficult to find.

---

[21]Employment data is drawn from U.S. manufacturers of complete robots rather than robot "establishments" as defined by the Bureau of Census; the latter also includes producers of robot parts and components.

Investment

Investment by the surveyed companies has been inadequate to maintain robot production capacity in the United States. Total investment peaked in 1986, at $22 million, falling to only $4.1 million in 1988, and then $6.5 million in 1989. During the first three years of the period, one company was responsible for over 80 percent of total investment. However, more than three quarters of this firm's investment was in buildings. As a percent of net sales, investment was highest in 1987, at 12 percent, and lowest at 3.3 percent in 1988. The earlier year's percentages were, of course, inflated by the outlays of one firm.

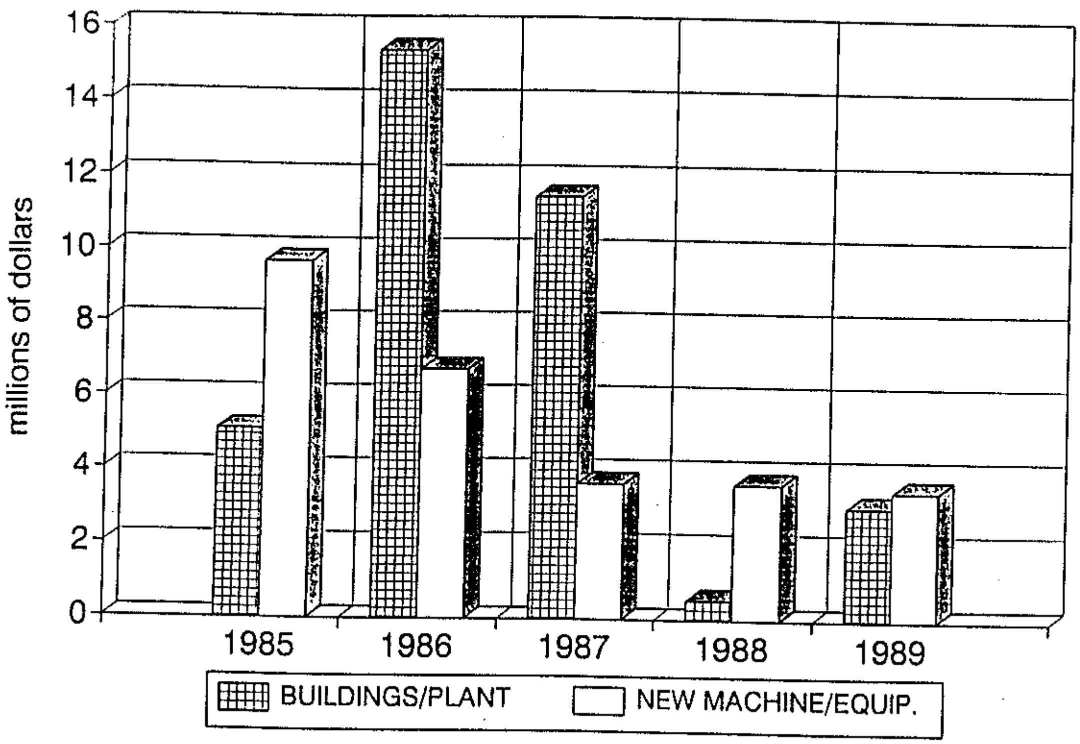
ROBOT INDUSTRY INVESTMENT, 1985-1989
(in thousands of dollars)

| Category | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|
| Plant | $5,072 | 15,344 | 11,473 | 502 | 3,044 |
| New Mach./Eqmt. | 9,666 | 6,703 | 3,647 | 3,622 | 3,461 |
| Total | 14,738 | 22,047 | 15,120 | 4,124 | 6,505 |
| % of Net Sales | 7.61 | 11.87 | 12.00 | 3.34 | 4.69 |
| % New Mach./Eqmt. of Net Sales | 4.99 | 3.61 | 2.90 | 2.94 | 2.50 |

Source: OIRA Robot Industry Survey

Investment by individual firms varies a great deal. One firm never invested more than 3.0 percent of sales, and for the period, averaged only 1.0 percent. Another firm, more successful in both sales and profits, never invested less than 5.5 percent of sales, and averaged almost 7.7 percent. However, the remaining firms exhibited more volatility in their investment expenditures, although one of them reported four years below 3.0 percent, and another, three years less than 1.0 percent.

FIGURE 5-INVESTMENT IN PLANT & EQUIP.
1985-1989




Source: OIRA Robot Industry Survey

The one consistently high percentage investor among the surveyed robot companies is aggressively developing applications and markets for its robot products all over the world, although mostly in the United States. Also, the firm is not dependent on the automotive industry for sales, as some of the others were, so its investment did not decrease in proportion to the steep declines in motor vehicle orders after 1986. So much of the auto robot business has now gone offshore, it is doubtful remaining American firms in this sector of the business can long survive. At this stage, according to industry sources, capital investment (and R&D) should be heavily focused on developing applications in a wider cross section of industries.

## Research and Development (R&D)

Research and development (R&D) expenditures by the robot manufacturing industry are almost totally dedicated to improving the capability and productivity of the robot on the production floor. While Government funded robot research projects are important in their own right, and invariably advance areas of the technology that may ultimately be useful in manufacturing, they are seldom directly related to enhancing the productivity and competitiveness of U.S. manufacturing. In the absence of a thriving U.S. robotics industry, the United States is at a distinct disadvantage compared to some foreign nations. Not only do these nations have thriving robotics industries, their industries enjoy government support. We estimate the U.S. share of commercially related robotics R&D funding is less than 5 percent of the world total.

U.S. industry significantly lags behind the Japanese industry in the industrial application of flexible factory automation, robotics and control devices. The United States is still in the forefront of basic technology such as software development, tactile sensors and vision systems, but is lagging in the simple hardware components of robots.

The United States may still be slightly ahead of many of its European competitors in industrial robot technology, but this lead is diminishing as the Europeans continually outspend the United States in R&D projects devoted to key areas such as industrial controls and flexible automation -- technologies that have become essential to international competitiveness.

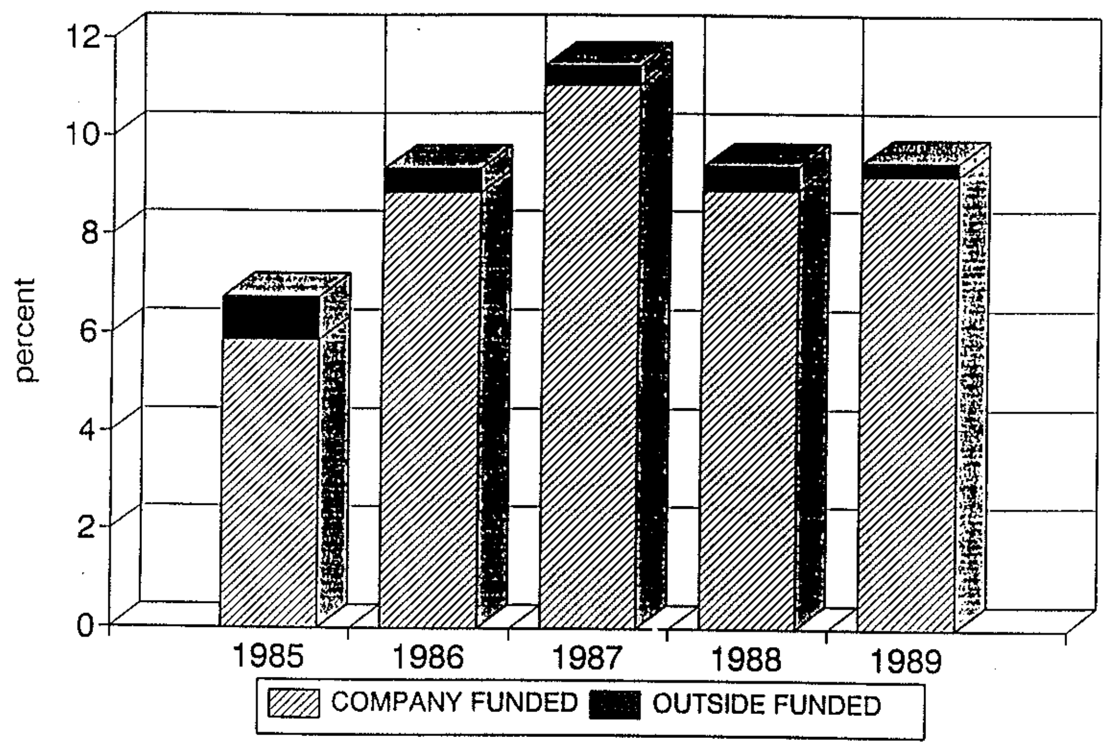
From 1985 to 1989, R&D expenditures by U.S. robot producers averaged just over 9 percent of sales, about 2.7 times greater than the average for all manufacturing. R&D expenditures by the companies have been maintained at a high level despite a decline in sales, negative cash flow, and rising levels of imports. All companies responding to the survey reported high rates of R&D spending, although some were consistently higher than others. In 1989, the three largest companies accounted for almost 82 percent of the R&D expenditures. R&D attained its highest level in 1986, when $17.4 million was spent.

INDUSTRY REPORTED R&D EXPENDITURES, 1985-1989
(in thousands of dollars)

| Source of Funding | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|
| In-House[22] | $11,358 | $16,399 | $13,921 | $10,965 | $12,705 |
| Government | 0 | 0 | 0 | 0 | 0 |
| Customer | 60 | 50 | 0 | 68 | 70 |
| Joint Venture | 1,637 | 910 | 523 | 550 | 347 |
| Total | $13,055 | $17,359 | $14,444 | $11,583 | $13,122 |
| % R&D to Sales | 6.74 | 9.34 | 11.47 | 9.39 | 9.46 |

Source: OIRA Robot Industry Survey

FIGURE 6- RESEARCH & DEVELOPMENT FUNDS
AS % OF SALES, 1985-1989



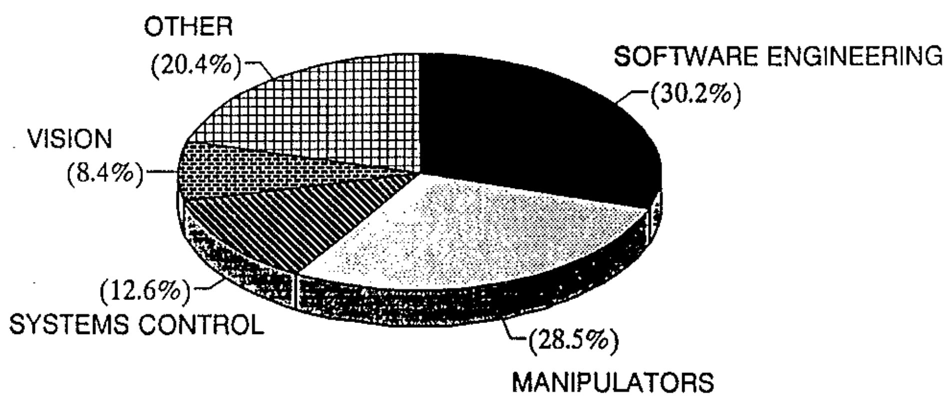

Source: OIRA Robot Industry Survey

[22]Funded by the robotics company from internal sources.

By far, the major source of funding for R&D has been in-house. In 1989, this amounted to approximately 97 percent of the $13.1 million in total R&D funds for the surveyed companies. Another source for funding came from various joint venture arrangements which ranged from a high of $1.6 million in 1985, to a low of only $347 thousand in 1989. Only one instance was cited in which R&D was funded by the end-user. This may indicate the domestic robotics industry is unable to meet the requirements of major end-users. Many of America's largest original equipment manufacturers, such as Caterpiller, IBM, GE and GM have turned to foreign firms in order to develop robot solutions.

All of the reported R&D funding came from private sources. This is quite a contrast to Japan and Europe where the governments have provided financial incentives to both the manufacturers of robots and their users for installing robots in their facilities.

FIGURE 7- MAJOR AREAS OF R&D, 1989
(TOTAL EXPENDITURES, 13.1 MIL.)




Source: OIRA Robot Industry Survey

Most U.S. manufacturers concentrate their R&D spending on software engineering and manipulators. The companies surveyed spent nearly $7.7 million on R&D in these two areas in 1989, over 50 percent of the total spent. This reflects the U.S. focus on software development. The next most popular area was in systems control, at $1.65 million, or almost 13 percent of the total. None of the companies reported spending funds in the area of sensors or artificial intelligence. This may be because these areas are actually separate industries with numerous applications other than robots from which to draw sales or R&D funding.

AREAS OF R&D EXPENDITURES, 1989
(in thousands of dollars)

| | |
|---|---|
| Software Engineering | $3,957 |
| Manipulators/Mechanics | 3,740 |
| Systems Control | 1,650 |
| Vision | 1,100 |
| Applications | 552 |
| Power Supply | 462 |
| End of Arm Tooling | 130 |
| Guidance Systems for Welding/Coating | 74 |
| Sensors | 0 |
| Artificial Intelligence | 0 |
| Other | 1,457 |
| Total: | $13,122 |

Source: OIRA Robot Industry Survey

Artificial intelligence and sensor technologies are on a converging course with robotics and factory automation. Artificial intelligence will endow future robots with decision making capability and allow operation in less structured, or even unstructured environments. This will result in greater efficiency and precision, and less overall cost to the buyer. Further, sensors will allow the robot to evaluate its working conditions, and make adjustments for any changes in the environment. Developments in these two areas will allow the robot to be more precise and accurate, to react to changes in its environmental inputs and, in general, to react to information provided by the sensors.

Federal Government R&D

Of six Federal agencies with significant robotics R&D funding, the National Aeronautics and Space Administration (NASA) alone accounts for more than two-thirds of the total. Most of these NASA funds are slated for the development of space station Freedom's Flight Telerobotic Servicer (FTS). The total funds earmarked for this program are estimated at $140-150 million, although an unknown portion of this, probably only a small percentage, is actually for robot research and the rest for devlopment. The objective of the telerobotics program is to develop, integrate and demonstrate the science and technology of remote manipulation that will lead to increased operational capability, safety and cost effectiveness and raise the probability of success of future NASA missions. The FTS will be capable of precise manipulations in space. It has been described as a cross between a person-controlled tele-operator and a preprogrammed robot. It will be used to help astronauts assemble and maintain space station Freedom.

In addition to FTS, NASA has spent an additional $10 million in each of the past two years on basic research in four related areas -- robotics, supervisory control, advanced tele-operations, and launch processing. In the area of launch processing, NASA has had great success, at a cost saving, in using robots to perform dangerous operations, including filter and tile inspection, and rewaterproofing of the space shuttle's tiles. Advanced tele-operations has been targeted for research because of its enormous potential in helping perform many of the critical assembly-type operations in space. Advances in this area will provide both visual and kinetic feedback to humans, enabling them to make better control decisions. In spite of a seemingly large payoff to NASA's space program, the applicability of these technologies to private industry has been negligible thus far.

The U.S. Army and Marine Corps have also formed a joint office for developing surveillance and reconnaissance robots. This action was taken after Congress consolidated all combat robotics in 1988 under the tactical warfare programs. This consolidation was done in part to eliminate duplication and develop operational requirements to avoid glitches and cost overruns. A five year memorandum of understanding between the Army and Marine Corps addresses funding issues generally, but does not specify the contribution from each service. The project will develop tele-operated vehicles to be used for reconnaissance, surveillance and target acquisition missions. The $21.6 million budgeted for this project will be spent in five areas: (1) communication, (2) navigation, (3) mission functions, (4) systems architecture, and (5) systems support.[23]

The Department of Defense's Defense Advanced Research Projects Agency (DARPA) is concentrating robotic R&D efforts on its autonomous weapons systems (funding estimated in the $10's of millions). Much of this effort is focused on artificial intelligence and robot manipulators for air and land vehicles.

The Autonomous Air Vehicle (AAV) and Autonomous Land Vehicle (ALV) programs are probably the most visible on-going programs DARPA is undertaking. The AAV is a "smart" aircraft that would combine radar with infrared sensors to identify targets such as tanks and then proceed to make the kill. The ALV is an autonomous robot tank that has a built-in map and is able to successfully maneuver around obstacles on the battlefield. These and similar combat robotic projects are expected to yield results in the near future, with combat robotics playing a significant role on the battlefield sometime early next century. Aside from these programs, DARPA spends considerable R&D funds in non-program areas. These expenditures are presented on the following table.

DARPA SELECTED R&D EXPENDITURES
(in millions of dollars)

| | 1988 | 1989 | 1990 |
|---|---|---|---|
| Actuators and Sensors | 2.1 | 1.9 | 1.4 |
| Legged Locomotion | 1.3 | 1.0 | .6 |
| Servo and Task Controls | 1.2 | 1.7 | 1.3 |
| Major Demonstration Robot | - | .1 | .1 |
| Manipulator Development | 1.3 | - | - |
| Miscellaneous | .9 | .1 | - |
| Total | 6.8 | 4.8 | 3.4 |

Source: DARPA

[23] Defense News, November 19, 1990, page 9.

The commercial applications of the technologies being developed in these programs have yet to be seen.[24] Most U.S. Government expenditures for robotics have been for direct military or space applications. The National Science Foundation (NSF) may be an exception to the above, although it has a very modest budget. In 1989 and 1990, the NSF spent an estimated $15 million annually on robotics R&D and expects to commit a growing proportion of funds to this area over the next few years. The NSF funds commercially applicable projects conducted in-house, at universities, and at private institutions.

The Commerce Department's National Institute of Standards and Technology (NIST) conducts both basic and applied R&D projects in robotics. For fiscal years 1989 and 1990, NIST has been involved in R&D projects totalling over $8 million annually. In fiscal year 1990, NIST performed $0.8 million worth of in-house basic R&D; $2 million more is budgeted for fiscal year 1991. NIST officials expect this figure to increase to $4.2 million for fiscal year 1992. The in-house projects are concerned mostly with basic research, managed under the Center for Manufacturing Engineering.

In addition to basic research, the institute also performs applied research on a contract basis for various other Government agencies and for the private sector. For example, NIST is currently performing work for the Navy, the Air Force, and the Department of Interior's Bureau of Mines. Under a $200 thousand contract with the Bureau of Mines, NIST is working on an automated mining project. Further, under a major project with Martin Marietta that calls for $19 million over a three-four year period, NIST will push to develop next generation controllers of commercial grade for use in applications such as high-tech machine shops.

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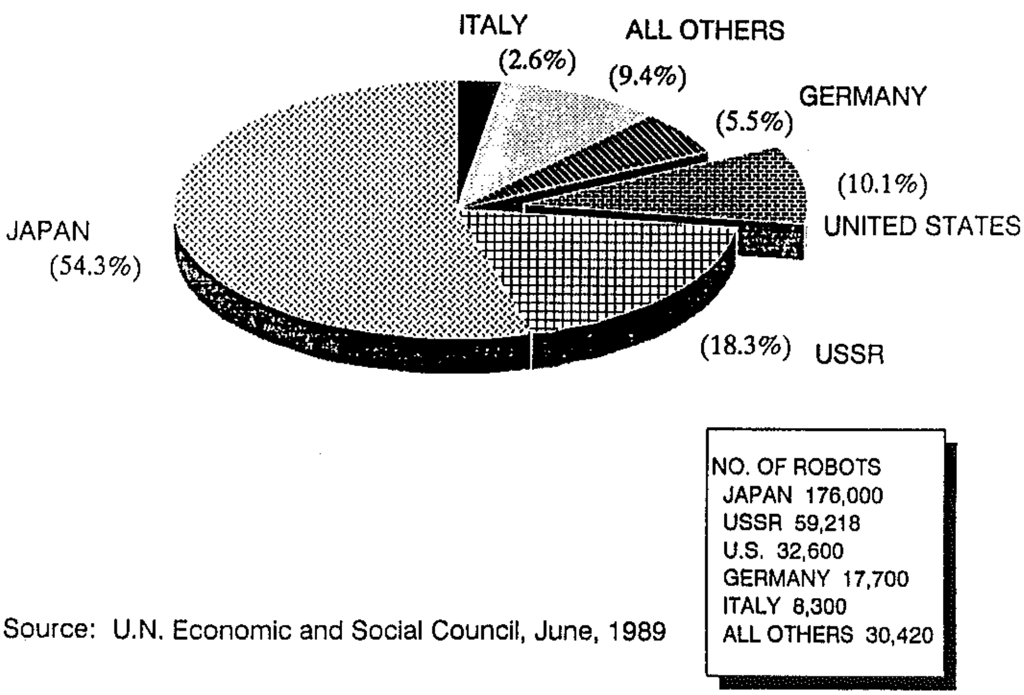
[24] Business Week, October 31, 1988, page 156.

## WORLD OVERVIEW

To better understand the robotics industry in the United States, it is instructive to briefly examine robotics in other industrialized countries. Japan, in particular, has a highly developed robotics industry. In Western Europe, the Federal Republic of Germany figures most prominently. France, Sweden and Switzerland are also major West European robot users and producers. Robot populations and applications in these nations can provide insight into how the international competitiveness picture has taken shape. A statistical summary of the growth of robot populations in selected countries can be found in Appendix C.

FIGURE 8- INSTALLED ROBOT POPULATIONS
SELECTED COUNTRIES, 1988




Source: U.N. Economic and Social Council, June, 1989

## Japan

Japan has emerged as the largest and most competitive robot producer nation in the world. Favorable governmental, economic and social conditions have contributed to this leading position. For these reasons, Japan has been the biggest user of robots in the world, providing lucrative home market sales for an estimated 300 companies, a few of whom are leading robot suppliers worldwide. In contrast to the United States, the working age population under 30 years old in Japan fell sharply after 1955, from about 45 percent of the total work force to a low of only 30 percent by 1985. The decline during the 1970s was particularly steep, down from slightly over 40 percent in 1970 to about 32 percent in 1980. The resulting severe shortage of entry-level people created conditions for exceptionally strong user demand for robots and factory automation.

The early domestic market for Japanese robots was mainly the automotive industry, with Nissan as the first key customer. However, robots have since widely penetrated Japanese manufacturing, from heavy industry to consumer electronics. High wage rates and an enduring labor shortage made robot automation particularly attractive to Japanese industry. Japanese labor unions also accepted the widespread adoption of robots in manufacturing. Unlike unions in the United States and Europe, where labor-management relations tend to be adversarial, Japanese unions are generally affiliated with only one company and view robots as an advantage to the overall operation of the company rather than as an attempt to replace a worker with a machine.

Rapid adoption of robots was also the result of intense competition in Japanese manufacturing industries. When one company installed robots, others followed in order to remain competitive. Robotized production lines gain greater flexibility as strides are made to integrate them with features such as artificial intelligence. Japan uses more robots than all other countries combined. There are close to 250 thousand robots installed in Japan. In fact, one year's robot production in Japan, at about 80 thousand in 1990, is more than twice the total installed robot population in the United States.

For the past two decades, the Government of Japan has recognized the importance of robotics to advanced manufacturing and has afforded financial incentives to manufacturers for installation of robots in their plants. In 1980, the Japanese Government enacted several policies to stimulate robot demand.[25]

- Establishment of a leasing system and the Japan Robot Leasing Company, designed to popularize industrial robots among small- and medium-sized firms;

- Special financing from the Small Business Finance Corporation and the People's Finance Corporation to small- and medium-sized firms in introducing industrial robots designed to ensure worker safety;

- Establishment of a special depreciation system for high performance industrial robots that included computers; and

- Loans and leasing programs covering industrial robots at the local government level to help smaller companies in modernizing their equipment.

Two additional policies were implemented in 1984:

- Establishment of a leasing system for flexible manufacturing systems at special interest rates (special loans from the Japanese Development Bank to the Japan Robot Leasing Company); and

- Establishment of tax incentives for promoting investment in advanced equipment provided with electronics for smaller businesses, involving special depreciation allowances or special deduction of corporate taxes.

The Ministry of International Trade and Industry (MITI) is Japan's primary source of government support for robotics R&D, through the Agency of Industrial Science and Technology (AIST). Several hundred million dollars in direct R&D for commercially related robotics projects have been funded. Additional sums in indirect assistance are also provided. The government's current

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[25] The Competitive Advantage of Nations, M.E.Porter, 1990, page 231.

focus is on projects with a potential for private sector commercialization or for hazardous environment work.

In 1983, an "Advanced Robotics" R&D program was launched jointly by AIST and approximately 20 private corporations. Some of the companies involved are Toshiba, Fujitsu and NEC for vision systems; Fuji Electric for manipulators; Ishikawajima-Harima Heavy Industries for metal skin and Fanuc for actuators. The goal of the research project was to develop robots capable of operation in hazardous environments. The research was focused in three main areas: nuclear energy, ocean oil exploration and disaster recovery. The robots designed for the nuclear power plants are able to perform inspection and maintenance tasks under high radiation levels. The ocean oil exploration robots are capable of working under high water pressure and can work in complete darkness and during unfavorable tides. Advanced robots were also developed that are heat-resistant and able to measure the proportions of a disaster through $CO_2$ gas laser sensors, functions essential to rescue operations.

The NSF outlines the following additional ways in which the Japanese Government supports its robotics industry:

- The Japanese Ministry of Construction implemented tax incentives to promote the use of construction robots. Five types of robots will be eligible for favorable tax treatment. Firms will be permitted to amortize the equivalent of 30 percent of the cost of the equipment in the first year after purchase or will be granted tax relief on 7 percent of the cost of the equipment. Firms leasing robots on agreements of five years or more will also be eligible for tax breaks.

- MITI is also initiating a project to develop space robots in 1991 at a total cost of about $150 million (¥20 billion). The robots are intended for use in fabricating or repairing structures in space and will be put in place around 2000. This will be one of the large industrial technology R&D projects of the AIST.

Federal Republic of Germany

The Federal Republic of Germany has the world's third largest robot population after Japan and the United States. Germany is the dominant user in Western Europe with 37 percent of the total number of robots in that region. By 1989, West Germany had a total of 22,395 installed industrial robots.[26] As in the United States, the German automotive industry is the leading user of robots. The main application areas are spot welding, painting, assembly and arc welding. Volkswagen is one of the larger robot producers in Germany, but it produces primarily for its own plants. Other major firms include Kuka, believed to be the largest with about $110 million (estimate) in sales, Bosch, Reiss and Kloos.

The Germans have experienced an actual decline in population, and to an extent have installed robots in response to a skilled labor shortage, especially since the mid-1980s. They have also, as a nation, concentrated heavily on modernizing facilities to make their labor force as productive as possible. This effort has included robots and other advanced machinery, to maintain exports against the appreciating deutsch mark. The tax policies of the German Government reinforce investment with accelerated depreciation, and other incentives. Also, the German "kultur" continues to produce strength in engineering and education, and an abiding respect for manufacturing quality and efficiency. As a major trading nation (exports equal 40 percent of GNP), about one-third of the work force is in manufacturing related jobs compared to only one in six in the United States, and one in four in Japan.

German producers have turned toward integrating robots with factory automation systems, rather than stand alone units. Typically, a German producer will spend between 8 and 10 percent of turnover on R&D, roughly the same as the average U.S. producer. The highest growth in demand is for robots with assembly applications.

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[26] U.N. Economic and Social Council "Annual Review of Engineering Industries and Automation 1989," 18 June 1990.

Approximately 40 percent of newly installed robots were imports, with most coming from the United States and Japan. The leading foreign producers supplying the German market have included ABB Robotics, Cincinnati Milacron, GMFanuc, Nokia and Staeubli-Unimation.

## France

In the past, the robot population of France has been difficult to determine because there were two sets of figures available: one published by the French Industrial Robot Association (AFRI) and the other by the monthly magazine Axes Robotique. In addition, a common definition of what constitutes a robot had never been clearly established. Recently, however, the two bodies have combined efforts and have settled on a common definition. They now define a robot as a manipulator working on an industrial site, having at least three servo-axes and being both reprogrammable and multipurpose. This is comparable to the U.S. definition.

According to this definition, France had 7,063 robots at the end of 1989, a 24.8 percent increase over 1988. The traditional users of industrial robots are the mechanical engineering and automotive industries. Of the 1,405 robots installed during 1989, 485 were purchased by automotive companies, 224 by the mechanical sector, and 187 by the plastics industry. The greatest growth rate during the year was in the food industry, whose robot population increased 60 percent in 1989. There is a growing interest in France among small- and medium-sized firms to utilize robots in their facilities.

The major area of application for robots in France is spot welding, followed by loading/unloading and arc welding. Other high growth application areas are in education and research. As a producer country, France has a relatively small robotics industry, and only a few French robot producers realize a significant portion of their turnover from exports. French manufacturers have over 50 percent of the French market but are experiencing difficulties in expanding abroad due to tough international competition.

Sweden

Sweden is the second highest per capita robot user with 83 robots per ten thousand employees in 1988. Robots are a key factor in Sweden's push for factory automation and an important area of production for the country. Sweden is a world class robot producer as exports constitute a large part of its annual production. The main Swedish producer is ABB Robotics, which accounts for more than 50 percent of the production and holds a premier presence in the world market. Based on this strong position, ABB has set up production or assembly facilities in the United States, Switzerland, Spain, France and Japan. Major user industries in Sweden are the machine, automotive and transport equipment industries. Sweden's major application areas for robots in Sweden are material handling and welding, with Volvo and Saab-Scania as two key home market customers.

Switzerland

Switzerland has installed automated equipment in nearly all of its manufacturing plants to compensate for the high wage costs in that country. The Swiss have a highly educated population that has been able to quickly take full advantage of new technologies. The investment climate in capital equipment is quite good and financing is easily available.

The Swiss market for industrial robots is dominated by ABB Robotics, holding 50-60 percent of the market. Staeubli-Unimation is also a factor. The remainder of the market is supplied by foreign firms, including GMF, Litton and Cincinnati Milacron. Domestic manufacturers produce 15-20 different types of robot systems, many of them custom made. The U.S. market share of the Swiss robotics market has grown in proportion to the overall market growth and has been particularly strengthened by the very successful Adept assembly robots. Japanese robots, surprisingly, have not made significant inroads in the Swiss market. The main applications of robots in Switzerland, listed in order, are assembly and loading/unloading.

## INTERNATIONAL COMPETITIVENESS

### Competitive Factors

Competition in the robotics business is global and intense. The competition takes place in two major arenas: building market share and pushing the development of robotic technology. The building of market share is critical to providing the revenues to cover expenses and fund R&D. The key end-market for robots has been the auto market, which can be described as high volume-low end robots. In many respects, the auto industry financed the robot industry through its infancy and remains its largest benefactor. Robotic firms with a strong position in the auto market are almost by definition large and aggressive. However, almost all of them are rapidly branching into other markets and putting enormous sums into R&D. R&D is critical because the technology is rapidly emerging and possible robot applications almost unlimited.

U.S. firms have not fared well in this global competition. The competitiveness of robotics firms in the United States has declined dramatically from promising beginnings. America's once largest robotics producer, Cincinnati Milacron, after several years of declining sales, has now sold its patents and marketing rights to ABB Robotics, Inc., and left the business. The U.S. robot industry was abandoned by the auto industry, and it is now rapidly losing the initiative in many other markets as well, including robot sales to major defense contractors. Today, few U.S. robotics producers remain, and most of these are in highly specialized niche markets. Many of these small firms lead the world (and survive) in some aspect of the technology. The best ones are prime candidates for foreign takeover. The largest U.S. producer has less than $40 million in sales. At least a dozen foreign robotics firms have greater sales.

As already noted, U.S. robot producers are at a disadvantage relative to foreign producers at the low end of the robot market, where cost has become an important purchasing consideration. U.S. firms are more competitive with, and sometimes have an advantage over, foreign producers in the production of high-performance, multi-purpose robots, although this advantage is fading.

The price differential between foreign and domestically produced robots is principally caused by U.S. production quantities being much smaller than is the case for Japanese firms.[27] Many U.S. producers have focused their development and marketing efforts on low-volume systems with a high engineering content, or on systems integration -- both high cost areas of the overall robot market.

Virtually all of the high volume, highly repetitive orders for industrial robots worldwide come from the automobile industries in the United States, Europe and Japan. Japanese robotics firms dominate in this world market segment, specifically in the areas of spot welding and finishing/coating robots. Also, prices are generally declining in these market segments, in large part due to the cost advantages that Japanese firms enjoy because of their high production volume relative to U.S. and European robotics firms.

Further, some of the price difference between the average U.S. produced robot and its Japanese competitor can be traced to the difference in complexity of the robot mechanism itself. In the early stages of the development of the world robot market, the tendency of U.S. producers to focus on technically complex, high-performance robots worked to their disadvantage, both in the domestic market and overseas. Early generations of U.S. produced robots were typically complex in design, expensive, and required frequent maintenance.

In contrast, robots being produced in Japan and Europe were mechanically simpler and less expensive, and therefore, easier for users to justify as capital expenditure items. These robots appealed to a much wider range of potential users than the more sophisticated U.S.-developed robots. Overall, the special purpose mechanisms and manipulators favored by Japanese robot producers are less expensive to produce than the general purpose

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[27]Adapted from <u>A Competitive Assessment of the U.S. Robotics Industry</u>, pages 26-29; prepared by Capital Goods and International Construction Sector Group, U.S. Department of Commerce, 1987.

mechanisms on which many U.S. robotics firms have focused their development and marketing efforts.

The Japanese also have the competitive advantage in quality control. Many of the robots marketed by Japanese firms were first developed for in-house use, and robot manufacturers' factories still serve as extensive test-beds for robot development. Emphasis is placed on reliability and predictability in robot motion. Japanese firms have a large base of experience in both robot production and use, experience that assists them in their quality control efforts. This is most evident in arc welding and coating/finishing robots, where Japanese-built robots have a better reputation than their U.S.-built counterparts.

Quality control has been more difficult for U.S. based robot producers. All U.S. auto producers have been plagued by problems with inadequate robot load capacity, failures in robot mechanisms, or at the very least, performance that does not meet expectations. Part of the problem stems from the fact that the U.S. robotics industry has no standard measure of basic robot operational characteristics such as speed or repeatability. This leaves users open to the risk that the robots they purchase will require extensive debugging prior to implementation. This inherent risk explains the preference that many U.S. users have for retaining the services of a systems integrator, whose responsibility it is to provide an operational robot system customized for a particular user's needs.

The international robot market is characterized by an enormous number of cooperative arrangements between robot-producing firms of different nationalities. These arrangements are opportunistic and have facilitated growth in the industry. The arrangements have reduced risk, increased efficiencies, expanded markets and spread robotics technologies. They run the gamut from marketing accords to licensing agreements to full fledged joint ventures. Many of these arrangements involve pairings of U.S. and Japanese or U.S. and European firms. While they have provided Japanese and European firms with unprecedented access to the U.S. market, U.S. firms have not been afforded the same benefits in foreign markets.

Japanese robotics firms are involved in over 100 international agreements. Nearly 70 percent of these agreements are simple marketing/sales agreements, which have given Japanese firms quick access to foreign markets with immediate sales and service support. Japanese firms are involved in comparatively few joint venture or parent/subsidiary relationships with foreign firms. The major joint venture between Japanese and U.S. based firms is GMFanuc. There has been virtually no penetration of the domestic Japanese market by foreign firms, even those operating jointly with Japanese firms.

In contrast to the Japanese approach to international agreements in robotics, nearly 70 percent of the arrangements formed by U.S. firms are either parent/subsidiary arrangments or joint ventures. The balance is mostly licensing agreements.

The growing inclination of new robot users to rely on firms with systems integration capabilities may work to the advantage of U.S. robot producers as robotics spreads outside of its conventional circle of end-users -- automotive, aerospace, and electronics. Some domestic producers have already restructured their operations to include turnkey and systems integration services. Other U.S. robot producers are selling their robots to third party systems integrators. As robot users become more sophisticated, however, and robot applications expand into assembly and materials handling operations, a growing market for high performance robots is developing. This could stimulate a revival in the U.S. robotics industry since, in the past, U.S. firms have exhibited advantages over foreign producers in this area -- especially in the production of high performance robots with substantial value added in peripherals and accessories. Many industry observers, however, think it is too late.

Companies' Assessment

The companies self-assessment of their own competitiveness was not promising. The surveyed companies reported that foreign concerns have major advantages in their cost of capital, production costs and Government support. They also noted their foreign competitors have more engineers, and outspend them by a wide margin on R&D. At the same time, the U.S. companies surveyed reported their major strength as innovation. Also, most of the firms thought they were still ahead in the overall technology, although the lead is diminishing and may disappear in the next five years.

They also noted that the Japanese market is much larger than the U.S. market, which has enabled Japanese firms to drive their costs down with far greater production quantities, and has allowed Japanese producers to enter the American market with lower prices.

A related issue mentioned by the respondents is the pressure in the United States to show quarterly profit and quick turnaround on investment. The companies felt that if there was not such pressure on them, they would be able to take a longer term view of investments and profit. Others suggested Government actions to reform the Tax Code and provision of incentives for domestic manufacturers to buy American products and invest in plant and equipment modernization.

## Industry's Recommendations for Government Action

Most of the robotics firms surveyed believe that U.S. Government support is essential to improve their competitiveness. They noted that strong foreign government support for their domestic robotics industries, combined with a perceived lack of concern by the U.S. Government, has biased the market against U.S. producers.

Respondents also mentioned other problems peculiar to the industry that they feel the Government could take an active role in correcting. One such obstacle is that Japan has a 4-6 percent tariff on robots versus 2-3.7 percent in the United States. This disparity often makes it more expensive to export to Japan while it is easier to export from Japan to the United States. While these percentages are small, margins are also small and can be greatly affected by a few percentage points. Another major problem is limits on robot and robot component exports. These have constrained sales of robots overseas, which for some firms have become very important. A more open export policy would allow these firms to expand exports.

## FINDINGS

The United States is nearly out of the industrial robot business. A major reason has been the slow development of the factory automation market in the United States. Currently, only a few small firms exist on the edges of robotics technology surviving in application-specific niches. Most produce accessories, peripherals or sensors and end-effectors that are added to imported robot arms and bodies. Many industry observers believe it is too late to restore a viable domestic industry. Import dependence has more than doubled in the last five years, to over 80 percent of U.S. robotics consumption. With the recent removal of Cincinnati Milacron's production capacity, dependence will climb to nearly 90 percent.

Robotics technology is vital to ensuring the superiority of future U.S. weapon systems. Robots will have key military applications in aircraft, ground vehicles and other weapon systems. Robots are currently being used in ordnance disposal, underwater recovery, and in chemical and nuclear weapon applications.

The absence of a domestic robotics industry will slow future applications development. The absence of U.S. robotics producers will force U.S. factory systems integrators, both commercial and defense, to focus on the available foreign made robots for automation alternatives, rather than develop specialized robots to provide an optimal solution for U.S. manufacturers. In many cases, this will bring less than desired results, especially for small- and medium-sized firms that lack the purchasing leverage of larger firms. Also, foreign sales and support offices are no substitute for the complete technical support a domestic robotics manufacturer could provide.

Robot technology is still being developed. As the technology matures, robots will play an increasingly important role in factory automation and the competitiveness of numerous end-user industries. Robotics and factory automation are key elements of future competitiveness in manufacturing. The United States is falling behind its major trading partners in this area.

Historically, U.S. manufacturing firms have been slower to install robots in their plants than some of our major trading partners. A major reason was related to the low skill level of earlier robots, which were developed and used in labor shortage countries (Japan, Sweden, and West Germany) as labor substitutes. The United States had an abundance of unskilled and semi-skilled labor that proved less costly to manufacturers than robots. Further, labor unions have historically had an anti-automation bias. Additionally, older vintage machinery in many American factories is less robot compatible, inhibiting manufacturers from purchasing and integrating robots.

U.S. Government funded robotics related R&D ranges in the hundreds of millions of dollars, but very little is related to commercial needs. NASA and the Department of Defense are by far the biggest robotics R&D funders with numerous projects, such as the Flight Telerobotic Servicer for space station Freedom, and the Autonomous Flight/Land Vehicles. These are very exotic projects that are developing certain technologies, some of which may be of commercial benefit to robotics or other industries. However, most of these technologies are beyond the needs of manufacturing, are too expensive and do not address factory robotic applications.

The Japanese Government has provided several hundred million dollars in direct commercially related robotics R&D, and huge additional sums for indirect assistance to support development of both a commercial robot industry and robot market in Japan. Much of this assistance is provided through the Agency for Industrial Science and Technology (AIST). The Japanese have the largest and most competitive robotics industry in the world. This is illustrated by the bilateral robotics trade deficit with Japan, which was $135 million in 1989. Only $3.8 million in U.S. robotics was exported to Japan. While Japanese imports represented about half of U.S. consumption in 1989, exports to Japan are less than two-tenths of 1 percent of the Japanese market. The governments of other major robot producers such as Germany, Sweden, and France have also provided direct and indirect support for the development of a robotics industry and market in their countries.

## RECOMMENDATIONS

As was previously discussed, robotics is an important technology for both commercial and defense manufacturing applications. Robotics is included by the Department of Defense as one of 1990's 20 most critical technologies for "ensuring the long-term qualitative superiority of U.S. weapons systems." Robot technology is also encompassed in the 1990 Department of Commerce Technology Administration list of 12 "emerging technologies" that have the potential to provide large advances in productivity and quality of products. Moreover, because robotics is a key infrastructural industry, robot utilization has unusual multiplier effects throughout the entire manufacturing and industrial base. Industry sources have expressed concern that the U.S. robotics industry is rapidly losing market share to foreign competitors and in danger of falling behind in many areas of technology. Our assessment largely confirms these perceptions of current trends.

In trying to develop recommendations which would be useful for policy officials at the Department of Defense, the Office of Science and Technology Policy, NASA and other concerned agencies, we were confronted with some major unanswered questions which are beyond the scope of our assessment. Can the U.S. successfully participate in developing emerging technologies such as artificial intelligence, sensor technology and flexible computer-integrated manufacturing, each of which is integrally linked with robotics, without a viable domestic robotics industry? Similarly, will the Department of Defense, NASA and U.S. industry maintain the ability to competitively develop next generation weapons and space systems without a viable domestic robot industry? And finally, assuming current industry trends continue, what are the implications of relying on foreign sources of robots for commercial, space and defense uses?

Nevertheless, based on our in-depth analysis of the robot industry in the United States, we were able to develop some specific recommendations that may assist the industry in limited areas:

First, the robotics and factory automation R&D programs at NIST could be broadened and expanded, especially in the areas where U.S. firms have shown strength, and Commerce could take the lead as a catalyst for coordinating efforts between the U.S. robotics industry and robot end-users.

Second, the Robotic Industries Association and its membership should be encouraged to explore shared flexible centers for integrated manufacturing and R&D consortia sponsored by the Department of Commerce's Technology Administration. These programs are designed to help smaller firms form joint venture groups to create and lease production time on state-of-the-art factor flexible manufacturing systems and to promote cooperative participation in shared risk R&D ventures.

Finally, OIRA should continue to monitor the status of the domestic robotics industry. This will allow policymakers access to current information on the health and viability of this critical sector.

PART II. PRODUCTION CAPABILITY AND FOREIGN DEPENDENCE

1. PRODUCTION AND CAPACITY UTILIZATION (Continued)

| | 1989 Unit Production | 1989 Production Value ($000) | 1989 Capacity Utilization | Estimated 1989 Market Share | Estimated 1989 Import Penetration |
|---|---|---|---|---|---|
| **COATING/DISPENSING** | | | | | |
| Painting | ______ | ______ | ______ | ______ | ______ |
| Glue & Sealing | ______ | ______ | ______ | ______ | ______ |
| Other Liquids & Powders | ______ | ______ | ______ | ______ | ______ |
| **MACHINING** | | | | | |
| Grinding/Deburring | ______ | ______ | ______ | ______ | ______ |
| Polishing | ______ | ______ | ______ | ______ | ______ |
| Drilling | ______ | ______ | ______ | ______ | ______ |
| Other ______ | ______ | ______ | ______ | ______ | ______ |
| **OTHER** | | | | | |
| Casting | ______ | ______ | ______ | ______ | ______ |
| Forging | ______ | ______ | ______ | ______ | ______ |
| Inspection | ______ | ______ | ______ | ______ | ______ |
| Hazardous Environments | ______ | ______ | ______ | ______ | ______ |
| Underwater/Space | ______ | ______ | ______ | ______ | ______ |

PART II. PRODUCTION CAPABILITY AND FOREIGN DEPENDENCE (continued)
(Complete Part II for each U.S. establishment)

2. PRODUCTION EXPANSION CAPABILITIES: Under a national security emergency with financing underwritten by the Federal Government, how many months would it take to double the average monthly unit production rate you experienced in 1989 (i.e., 1989 unit production divided by 12); and what constraints (e.g., skilled labor, lead time for additional production equipment, supplies, etc.) would limit your expansion capability?

Expansion Time and Constraints

| | Months | Constraints |
|---|---|---|
| **THE MANIPULATOR** | | |
| (1) Cylindrical Coordinate | ______ | ______________ |
| (2) Spherical Coordinate | ______ | ______________ |
| (3) Jointed Arm | ______ | ______________ |
| (4) Rectangular Coordinate | ______ | ______________ |
| **THE POWER SUPPLY** | | |
| (1) Pneumatic | ______ | ______________ |
| (2) Hydraulic | ______ | ______________ |
| (3) Electric | ______ | ______________ |
| **THE CONTROL SYSTEM** | | |
| (1) Fixed and Variable Sequence | ______ | ______________ |
| (2) Point-to-Point | ______ | ______________ |
| (3) Continuous Path | ______ | ______________ |
| (4) Intelligent Robot | ______ | ______________ |
| **ACCESSORIES & PERIPHERALS** (Please List) | | |
| (1) ______________ | ______ | ______________ |
| (2) ______________ | ______ | ______________ |
| (3) ______________ | ______ | ______________ |
| (4) ______________ | ______ | ______________ |

PART II. PRODUCTION CAPABILITY AND FOREIGN DEPENDENCE (continued)
(Complete Part II for each U.S. establishment)

3. IMPORTED PARTS AND COMPONENTS: Complete the following table addressing which foreign made parts and components (Refer to components in Question 2, Part II) you use in the production or assembly of robots. Use the following coded reasons why a foreign source is used in completing the table.

A. Domestic source not available
B. Lower cost
C. Delivery time
D. Design
E. Performance
F. Maintenance
G. Industry Standard
H. Other (specify)

| Component | 1989 Imported Value | Foreign Supplier Firm | Country of Origin | Reason Foreign Sourced (use codes) |
|---|---|---|---|---|
| ________ | $________ | ________ | ________ | ________ |
| ________ | $________ | ________ | ________ | ________ |
| ________ | $________ | ________ | ________ | ________ |
| ________ | $________ | ________ | ________ | ________ |
| ________ | $________ | ________ | ________ | ________ |
| ________ | $________ | ________ | ________ | ________ |

4. FOREIGN DEPENDENCE: For any foreign sourced items designated by "A" above (i.e., domestic source not available), please describe: a) the adverse impact an interruption in the item's availability would have on your manufacturing operations, b) what measures can be taken to minimize any adverse impacts and, c) the reason(s) the part or component is not produced in the United States (i.e., lack competitiveness, behind in technology, foreign marketing practices, etc.).

______________________________________________

______________________________________________

______________________________________________

______________________________________________

PART II. PRODUCTION CAPABILITY AND FOREIGN DEPENDENCE (continued)
(Complete Part II for each U.S. establishment)

5. IMPORTS OF COMPLETE ROBOTS: Please complete the following table addressing what robots you imported in 1989, and the reasons for importing. Use the following coded reasons why a foreign source is used in completing the table.

A. Rationalization of global operations
B. Round out product offerings
C. Building market share to enter this line
D. Maintain market share against others
E. Import is technically superior to my offerings
F. Marketing agreement
G. Other (describe)

| Equipment Type | 1989 Value Imported | Foreign Producer Firm | Reason Foreign Sourced (use codes) |
|---|---|---|---|
| | $ | | |
| | $ | | |
| | $ | | |
| | $ | | |

6. EMPLOYMENT: Enter the number of employees (end of year) at this establishment from 1985-1989, as requested below. (See definitions of Engineers, and of Production Workers)

| | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|
| Engineers | | | | | |
| Production Workers | | | | | |
| Admin. and Others | | | | | |
| Totals | | | | | |

## PAI XII. SHIPMENTS AND EXPORTS

1. SHIPMENTS (in units shipped). For each establishment, enter total annual shipments of robots for the applications listed below for 1985-1989.

Establishment: ______________________

(in units shipped)

| | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|
| **WELDING** | | | | | |
| Spot/Resistance | ____ | ____ | ____ | ____ | ____ |
| Arc | ____ | ____ | ____ | ____ | ____ |
| Other | ____ | ____ | ____ | ____ | ____ |
| **ASSEMBLY** | ____ | ____ | ____ | ____ | ____ |
| **MATERIAL HANDLING** | | | | | |
| Palletizing | ____ | ____ | ____ | ____ | ____ |
| Machine Loading/Unloading | ____ | ____ | ____ | ____ | ____ |
| Storage and Retrieval | ____ | ____ | ____ | ____ | ____ |
| Other | ____ | ____ | ____ | ____ | ____ |

PART III HIPMENTS AND EXPORTS

1. SHIPMENTS (Continued)

(in units shipped)

| | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|
| **COATING/DISPENSING** | | | | | |
| Painting | ____ | ____ | ____ | ____ | ____ |
| Glue & Sealing | ____ | ____ | ____ | ____ | ____ |
| Other Liquids & Powders | ____ | ____ | ____ | ____ | ____ |
| **MACHINING** | | | | | |
| Grinding/Deburring | ____ | ____ | ____ | ____ | ____ |
| Polishing | ____ | ____ | ____ | ____ | ____ |
| Drilling | ____ | ____ | ____ | ____ | ____ |
| Other ____ | ____ | ____ | ____ | ____ | ____ |
| **OTHER** | | | | | |
| Casting | ____ | ____ | ____ | ____ | ____ |
| Forging | ____ | ____ | ____ | ____ | ____ |
| Inspection | ____ | ____ | ____ | ____ | ____ |
| Hazardous Environments | ____ | ____ | ____ | ____ | ____ |
| Underwater/Space | ____ | ____ | ____ | ____ | ____ |

PART III. SHIPMENTS AND EXPORTS

1. SHIPMENTS (in dollars). For each establishment, enter total annual shipments of robots for the applications listed below for 1985-1989.

Establishment: ______________________

(in dollars)

| | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|
| **WELDING** | | | | | |
| Spot/Resistance | ____ | ____ | ____ | ____ | ____ |
| Arc | ____ | ____ | ____ | ____ | ____ |
| Other | ____ | ____ | ____ | ____ | ____ |
| **ASSEMBLY** | ____ | ____ | ____ | ____ | ____ |
| **MATERIAL HANDLING** | | | | | |
| Palletizing | ____ | ____ | ____ | ____ | ____ |
| Machine Loading/Unloading | ____ | ____ | ____ | ____ | ____ |
| Storage and Retrieval | ____ | ____ | ____ | ____ | ____ |
| Other | ____ | ____ | ____ | ____ | ____ |

PART III ıIPMENTS AND EXPORTS

1. SHIPMENTS (Continued)

(in dollars)

| | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|
| **COATING/DISPENSING** | | | | | |
| Painting | | | | | |
| Glue & Sealing | | | | | |
| Other Liquids & Powders | | | | | |
| **MACHINING** | | | | | |
| Grinding/Deburring | | | | | |
| Polishing | | | | | |
| Drilling | | | | | |
| Other ______ | | | | | |
| **OTHER** | | | | | |
| Casting | | | | | |
| Forging | | | | | |
| Inspection | | | | | |
| Hazardous Environments | | | | | |
| Underwater/Space | | | | | |

## PART III. SHIPMENTS AND EXPORTS

1. EXPORT SHIPMENTS (in dollars). For each establishment, enter total annual shipments of robots for the applications listed below for 1985-1989.

Establishment: ______________________

(in dollars)

| | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|
| **WELDING** | | | | | |
| Spot/Resistance | ____ | ____ | ____ | ____ | ____ |
| Arc | ____ | ____ | ____ | ____ | ____ |
| Other | ____ | ____ | ____ | ____ | ____ |
| **ASSEMBLY** | ____ | ____ | ____ | ____ | ____ |
| **MATERIAL HANDLING** | | | | | |
| Palletizing | ____ | ____ | ____ | ____ | ____ |
| Machine Loading/Unloading | ____ | ____ | ____ | ____ | ____ |
| Storage and Retrieval | ____ | ____ | ____ | ____ | ____ |
| Other | ____ | ____ | ____ | ____ | ____ |

PART III SHIPMENTS AND EXPORTS

1. EXPORT SHIPMENTS (Continued)

(in dollars)

| | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|
| **COATING/DISPENSING** | | | | | |
| Painting | ______ | ______ | ______ | ______ | ______ |
| Glue & Sealing | ______ | ______ | ______ | ______ | ______ |
| Other Liquids & Powders | ______ | ______ | ______ | ______ | ______ |
| **MACHINING** | | | | | |
| Grinding/Deburring | ______ | ______ | ______ | ______ | ______ |
| Polishing | ______ | ______ | ______ | ______ | ______ |
| Drilling | ______ | ______ | ______ | ______ | ______ |
| Other ______ | ______ | ______ | ______ | ______ | ______ |
| **OTHER** | | | | | |
| Casting | ______ | ______ | ______ | ______ | ______ |
| Forging | ______ | ______ | ______ | ______ | ______ |
| Inspection | ______ | ______ | ______ | ______ | ______ |
| Hazardous Environments | ______ | ______ | ______ | ______ | ______ |
| Underwater/Space | ______ | ______ | ______ | ______ | ______ |

PART IV. TECHNOLOGY

1. RESEARCH AND DEVELOPMENT: Please enter research and development expenditures from 1985-1989, associated with your robotics operations as requested below. Enter separately the dollar amounts (in $000s) financed by your firm (in-house), the government, a customer, or as part of a joint venture. (See definition of Research and Development)

(in thousands of dollars)

| Source of Funding | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|
| In-house | ______ | ______ | ______ | ______ | ______ |
| Government | ______ | ______ | ______ | ______ | ______ |
| Customer | ______ | ______ | ______ | ______ | ______ |
| Joint Venture | ______ | ______ | ______ | ______ | ______ |
| Other (specify) | ______ | ______ | ______ | ______ | ______ |
| (________________) | | | | | |
| Totals | ______ | ______ | ______ | ______ | ______ |

2. AREAS OF R & D EFFORT: For 1989, please enter research and development expenditures (in $000s) in the areas specified below.

| Area | Expenditures |
|---|---|
| Manipulators/Mechanics | $__________ |
| Power Supply | $__________ |
| System Control | $__________ |
| Software Engineering | $__________ |
| Vision | $__________ |
| Sensors __________ | $__________ |
| Guidance Systems (welding/coating) | $__________ |
| End of Arm Tooling | $__________ |
| Artificial Intelligence | $__________ |
| Applications | $__________ |
| Other __________ | $__________ |

PART IV. TECHNOLOGY (continued)

3. TECHNOLOGY RANKING: Please specify those manufacturing processes, product offerings, in-house know-how, or other technologies associated with your robotics operations, where your firm is A) the world leader, and B) the U.S. leader. Also, please identify your nearest competitor (either domestic or foreign) in the area you lead, and whether your lead in the area has increased(+)/decreased(-) in the last three years.

A) World Leader in:

i) Product Offering(s): (specify)____________________

________________________________________

Nearest Competitor:____________/____________/______
(name) (country) (lead=+-)

ii) Systems Engineering: (specify)____________________

________________________________________

Nearest Competitor:____________/____________/______
(name) (country) (lead=+-)

iii) Other Technology(ies): (specify)____________________

________________________________________

Nearest Competitor:____________/____________/______
(name) (country) (lead=+-)

PART IV. TECHNOLOGY (continued)

question #3 - TECHNOLOGY RANKING (continued)

B) United States Leader in:

i) Product Offering(s): (specify)____________________

________________________________________

Nearest Competitor:__________ (name) / __________ (country) / ______ (lead=+-)

ii) Systems Engineering: (specify)____________________

________________________________________

Nearest Competitor:__________ (name) / __________ (country) / ______ (lead=+-)

iii) Other Technology(ies): (specify)____________________

________________________________________

Nearest Competitor:__________ (name) / __________ (country) / ______ (lead=+-)

PART IV. TECHNOLOGY (continued)

4. TECHNOLOGY LEAD LOST: Please indicate for the robotics areas listed below where your firm has lost the technology lead to a foreign firm during the past five years; and provide the name of the foreign firm that has the lead in the area today.

i) Product Offering(s): (specify)____________________________

____________________________________________________________

Foreign Technology Leader: ________________/________________
(name) (country)

ii) Systems Engineering: (specify)____________________________

____________________________________________________________

Foreign Technology Leader: ________________/________________
(name) (country)

iii) Other Technology(ies): (specify)____________________________

____________________________________________________________

Foreign Technology Leader: ________________/________________
(name) (country)

PART V. APPLICATIONS AND MARKETS

1. APPLICATIONS: Please complete the following table, identifying your largest sale in 1989 of robotics equipment for use in each of the following markets: A) Military, B) Manufacturing, C) Commercial and D) Space Applications. For each market, provide the name of the customer, the type of robots (you may use the letter codes below), the units and dollar value sold, and the industry in which the equipment will be put to use.

Intended Purpose of Robotics
(select one or more)

Applications:
a) Welding
b) Assembly
c) Materials Handling
d) Surface Coating
e) Machining
f) Other (specify:______________________________)

A) Military:

| Customer Name | Purpose Code | # of Units | Dollar Value | Customer Industry |
|---|---|---|---|---|
| ______________ | ________________ | _____ | $______ | ____________ |

B) Manufacturing:

| Customer Name | Purpose Code | # of Units | Dollar Value | Customer Industry |
|---|---|---|---|---|
| ______________ | ________________ | _____ | $______ | ____________ |

C) Commercial (services, manuf., etc.):

| Customer Name | Purpose Code | # of Units | Dollar Value | Customer Industry |
|---|---|---|---|---|
| ______________ | ________________ | _____ | $______ | ____________ |

D) Space Applications:

| Customer Name | Purpose Code | # of Units | Dollar Value | Customer Industry |
|---|---|---|---|---|
| ______________ | ________________ | _____ | $______ | ____________ |

PART V. APPLICATIONS AND MARKETS (continued)

2. MARKETS: Please characterize your total 1989 sales (in $000s) of robotic equipment by the following end markets, and the percent of foreign origin equipment and parts (on a value basis) contained in your sales to each market segment.

| Market | Total Sales | Foreign Content (percent equipment and parts of foreign origin) |
|---|---|---|
| Military | $________ | ______% |
| Industrial | $________ | ______% |
| Commercial | $________ | ______% |
| Space | $________ | ______% |

PART VI. FINANCIAL INFORMATION

1. PROFITABILITY: For robotics equipment and parts only, please enter the financial information (in $000s) as specified below for the years 1985-1989. Include only dollar amounts that apply to your robotics operations.

| | (in thousands of dollars) | | | | |
|---|---|---|---|---|---|
| | 1985 | 1986 | 1987 | 1988 | 1989 |
| Net Sales (1) | ______ | ______ | ______ | ______ | ______ |
| Cost of Goods Sold(2) | ______ | ______ | ______ | ______ | ______ |
| Operating Income (3) | ______ | ______ | ______ | ______ | ______ |
| Net Income before taxes (4) | ______ | ______ | ______ | ______ | ______ |
| Aftermarket Revenues (5) | ______ | ______ | ______ | ______ | ______ |

(1) Trade (this should equal shipment totals from Part III of questionnaire), but excluding aftermarket revenues
(2) Includes materials and component purchases, direct labor, and other factory costs such as depreciation and inventory carrying costs.
(3) Difference between Net Sales and Cost of Goods Sold
(4) Operating income less general, selling and administrative expenses, interest expenses and other expenses (including uncapitalized R&D expenses), plus other income
(5) Service and repair work related to robots

2. INVESTMENT: Enter expenditures for plant, new machinery and equipment (in $000s) from 1985-1989 as requested below.

| | (in thousands of dollars) | | | | |
|---|---|---|---|---|---|
| | 1985 | 1986 | 1987 | 1988 | 1989 |
| Plant | ______ | ______ | ______ | ______ | ______ |
| New Machinery/Eqmt. | ______ | ______ | ______ | ______ | ______ |
| R & D | ______ | ______ | ______ | ______ | ______ |
| Totals | ______ | ______ | ______ | ______ | ______ |

PART VI. FINANCIAL INFORMATION (continued)

3. BALANCE SHEET: Please provide the balance sheet information (in $000s) as specified below for your latest accounting period. Include only dollar amounts that apply to your robotics operations.

(in thousands of dollars)

| | Assets | | Liabilities |
|---|---|---|---|
| Current Assets | | Current Liabilities | |
| Cash and Equivalents | ______ | Accounts Payable | ______ |
| Accounts Receivable | ______ | Short Term Debt | ______ |
| Inventories | ______ | Current Portion of Long Term Debt | ______ |
| Other | ______ | Other | ______ |
| Property, Plant and Equipment (book value) | | Non-Current Liabilities | |
| Land and Buildings | ______ | Long Term Debt | ______ |
| Machinery and Equipment | ______ | Other | ______ |
| Allowances for Depreciation | ______ | | |
| Other Assets | ______ | Equity | ______ |

PART VII. COMPETITIVENESS

1. COMPETITOR FIRMS: Please identify your two major domestic and foreign competitors.

| | Domestic Competitors | Foreign Competitors | Country |
|---|---|---|---|
| a) | ______ | ______ | ______ |
| b) | ______ | ______ | ______ |

2. COMPETITIVE RANKING: With regard to your major foreign competitors, please comment on your competitive advantages and disadvantages as requested below. In comment area also note (with +, - , =) whether this advantage will change over the next five years

| Competitive Area | My Firm has Advantage yes/no | Comments |
|---|---|---|
| Overall Technology | ______ | ______ |
| Design Capability | ______ | ______ |
| Engineering Capability | ______ | ______ |
| R & D Capability | ______ | ______ |
| Innovation | ______ | ______ |
| Price | ______ | ______ |
| Equipment Quality | ______ | ______ |
| Delivery | ______ | ______ |
| Customer Satisfaction | ______ | ______ |
| Capital Costs | ______ | ______ |
| Applications Engineering | ______ | ______ |
| Government Assistance | ______ | ______ |

PART VII. COMPETITIVENESS (continued)

3. UNFAIR TRADE PRACTICES: Please comment on any unfair trade practices (e.g., tariffs or other trade barriers, market access, foreign government subsidies or incentives, dumping, etc.) that provide your foreign competitors an artificial advantage.

4. OTHER COMPETITIVE CONSIDERATIONS: Please comment on any other competitive considerations that significantly impact your firm, and that should be brought to our attention.

## CERTIFICATION

The undersigned certifies that the information herein supplied in response to this questionnaire is complete and correct. The U.S. Code, Title 18 (Crimes and Criminal Procedure), Section 1001, makes it a criminal offense to willfully make a false statement or representation to any department or agency of the United States as to any matter within its jurisdiction.

__________ (Date)

__________ (Signature of Authorized Official)

__________ (Area Code/Telephone Number)

__________ (Type or Print Name and Title of Authorized Official)

__________ (Area Code/Telephone Number)

__________ (Type or Print Name and Title of Person to Contact re this Report)

COMMENTS: Please use the space below to provide any additional comments or information you may wish regarding your operations, or other related issues that impact your firm.

# APPENDIX

# "B"

# DEPARTMENT OF COMMERCE STATISTICS

# Robots (Shipments)

1984

MA35X(84)-1
Issued August 1985

U.S. Department of Commerce
BUREAU OF THE CENSUS

## SUMMARY OF FINDINGS

The statistics in this publication are based on a new survey of manufacturers and represent total U.S. shipments of robots, robot accessories and components.

Quantity and value of shipments of complete robots were 5,535 units and $306.7 million for 1984, of which 3,690 units and $287.9 million were servo-controlled, 541 units and $15.5 million were nonservo-controlled and 1,304 units and $3.3 million were other types.

A description of the survey methodology and related information appears on page 3.

Table 1. TOTAL SHIPMENTS OF COMPLETE ROBOTS, ROBOT ACCESSORIES, AND COMPONENTS: 1984

(Quantity in units; value in thousands of dollars)

| Product description | Number of companies | Total shipments: Number of units | Total shipments: Value |
|---|---|---|---|
| Robots, robot accessories and components | 75 | (X) | 357,744 |
| Robots (complete) | (X) | 5,535 | 306,746 |
| Servo-controlled robots | 25 | 3,690 | 287,928 |
| Point-to-point type: | | | |
| Welding, soldering, brazing, and/or cutting (welding type) | 8 | 1,139 | 102,391 |
| Foundry, forging, and/or heat treating | 3 | 20 | 1,851 |
| Inspection, measuring, gauging, and/or sorting | 2 | | |
| Metal bending, shearing, and/or forming | - | - | - |
| Plastics molding and/or forming | - | - | - |
| Machine tool loading and/or unloading | 7 | 202 | 10,870 |
| Drilling and/or cutting (machine type) | - | - | - |
| Assembly, for non-electronic products | 5 | 613 | 29,155 |
| Assembly, for electronic products | 6 | | |
| Material handling and/or parts transfer n.e.c. | 11 | 470 | 34,362 |
| Other point-to-point type n.e.c. | 5 | 86 | 4,384 |
| Continuous-path type: | | | |
| Welding, soldering, brazing, and/or cutting (welding type) | 6 | 335 | 21,827 |
| Spraying, painting, gluing, and/or sealing | 12 | 450 | 58,795 |
| Fettling, grinding, polishing, and/or deburring | 3 | 375 | 24,293 |
| Other continuous-path type n.e.c. | 3 | | |
| Nonservo-controlled robots | 10 | 541 | 15,525 |
| Foundry, forging, and/or heat treating | - | - | - |
| Metal bending, shearing, and/or forming | 1 | | |
| Plastics molding and/or forming | 3 | | |
| Machine tool loading and/or unloading | 2 | 221 | 8,089 |
| Inspection, measuring, gauging, and/or sorting | 2 | | |
| Assembly, for non-electronic products | 2 | | |
| Assembly, for electronic products | 1 | | |
| Other nonservo-controlled robots n.e.c. | 1 | | |
| Material handling and/or parts transfer n.e.c. | 6 | 320 | 7,436 |
| Other robots | 8 | 1,304 | 3,293 |
| Educational, hobby, and experimental robots | 7 | 1,304 | 3,293 |
| Other robots n.e.c. | 1 | | |
| Robot accessories, subassemblies, components, and parts (sold separately) | 49 | (X) | 50,898 |
| End-of-arm tooling for robots | 11 | (X) | 1,280 |
| Vision, sonic, force, tactile, and proximity sensors | 18 | (X) | 15,182 |
| Interface modules | 5 | (X) | 2,239 |
| Compliance devices | 3 | | |
| Joint locating and guidance systems for welding | 3 | (X) | 8,326 |
| Guarding and safety devices | 5 | | |
| Robot accessories, subassemblies, components, and parts n.e.c. | 30 | (X) | 23,771 |
| Miscellaneous receipts: | | | |
| Research and development, testing, and evaluation of systems and components (receipts and billings, not reported as shipments of specific products) | 8 | (X) | 14,634 |

Note: Robots presently are classified in the Standard Industrial Classification (SIC) based on their primary industrial function.

- Represents zero. n.e.c. Not elsewhere classified. (X) Not applicable.

Address inquiries concerning these figures to U.S. Department of Commerce, Bureau of the Census, Industry Division, Washington, D.C. 20233 or call Louise Beckett, (301) 763-4085.
For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

# Robots (Shipments)

U.S. Department of Commerce
BUREAU OF THE CENSUS

198[illegible]
MA35X(85)-
Issued August 1[illegible]

## SUMMARY OF FINDINGS

In 1985, manufactures' shipments of complete robots were valued at $317.7 million, an increase of 41 percent from the 1984 total of $225.5 million. Servo-controlled robots were valued at $296.9 million in 1985, an increase of 44 percent from the 1984 value of $206.0 million. Nonservo-controlled robots were valued at $18.0 million in 1985, an increase of 11 percent from the 1984 value of $16.2 million. Other robots were valued at $2.8 million for 1985, a decrease of 15 percent from the 1984 value of $3.3 million.

A description of the survey methodology and related information appears of page 3.

Table 1. TOTAL SHIPMENTS OF COMPLETE ROBOTS, ROBOT ACCESSORIES, AND COMPONENTS: 1985 AND 1984

(Quantity in units; value in thousands of dollars)

| Product description[1] | Number of companies | 1985 Quantity | 1985 Value | 1984[r] Quantity | 1984[r] Value |
|---|---|---|---|---|---|
| Robots, robot accessories and components | 72 | (X) | 387,508 | (X) | 281,189 |
| Robots (complete) | (X) | 5,796 | 317,657 | 6,534 | 225,528 |
| Servo-controlled robots | 26 | 3,272 | 296,862 | 2,676 | 206,018 |
| Point-to-point type: | | | | | |
| Welding, soldering, brazing, and/or cutting (welding type) | 8 | 839 | 74,646 | 627 | 56,932 |
| Foundry, forging, and/or heat treating | 1 | 12 | 745 | 20 | 1,851 |
| Inspection, measuring, gauging, and/or sorting | 3 | | | | |
| Metal bending, shearing, and/or forming | - | - | - | - | - |
| Plastics molding and/or forming | - | - | - | - | - |
| Machine tool loading and/or unloading | 5 | 53 | 3,785 | 67 | 4,131 |
| Drilling and/or cutting (machine type) | - | - | - | - | - |
| Assembly, for non-electronic products | 3 | 547 | 17,761 | 411 | 20,908 |
| Assembly, for electronic products | 6 | | | | |
| Material handling and/or parts transfer n.e.c. | 7 | 463 | 44,863 | 402 | 30,962 |
| Other point-to-point type n.e.c. | 5 | | | 86 | 4,384 |
| Continuous-path type: | | | | | |
| Welding, soldering, brazing, and/or cutting (welding type) | 5 | 287 | 22,352 | 239 | 16,569 |
| Spraying, painting, gluing, and/or sealing | 10 | 626 | 83,352 | 449 | 45,988 |
| Fettling, grinding, polishing, and/or deburring | 3 | 29 | 1,523 | 375 | 24,293 |
| Other continuous-path type n.e.c. | 7 | 416 | 47,835 | | |
| Nonservo-controlled robots | 10 | 496 | 18,015 | 570 | 16,219 |
| Foundry, forging, and/or heat treating | - | - | - | - | - |
| Metal bending, shearing, and/or forming | - | | | | |
| Plastics molding and/or forming | 2 | | | | |
| Machine tool loading and/or unloading | 3 | | | | |
| Inspection, measuring, gauging, and/or sorting | 2 | 259 | 12,450 | 250 | 8,783 |
| Assembly, for non-electronic products | 2 | | | | |
| Assembly, for electronic products | 2 | | | | |
| Other nonservo-controlled robots n.e.c. | 2 | | | | |
| Material handling and/or parts transfer n.e.c. | 7 | 237 | 5,565 | 320 | 7,436 |
| Other robots | 7 | 2,028 | 2,780 | 3,288 | 3,291 |
| Educational, hobby, and experimental robots | 6 | 2,028 | 2,780 | 3,288 | 3,291 |
| Other robots n.e.c. | 1 | | | | |
| Robot accessories, subassemblies, components, and parts (sold separately) | 51 | (X) | 69,851 | (X) | 55,661 |
| End-of-arm tooling for robots | 11 | (X) | *3,929 | (X) | 1,280 |
| Vision, sonic, force, tactile, and proximity sensors | 16 | (X) | 17,965 | (X) | 15,244 |
| Interface modules | 1 | | | | 2,239 |
| Compliance devices | 2 | (X) | 4,708 | (X) | |
| Joint locating and guidance systems for welding | 4 | | | | 8,573 |
| Guarding and safety devices | 5 | | | | |
| Robot accessories, subassemblies, components, and parts n.e.c. | 32 | (X) | 43,249 | (X) | 28,325 |
| Miscellaneous receipts: | | | | | |
| Research and development, testing, and evaluation of systems and components (receipts and billings, not reported as shipments of specific products) | 6 | (X) | 9,161 | (X) | 14,469 |

Note: The percent of estimation of each item is indicated as follows (see "Description of Survey" in the text for a discussion of estimation of missing reports): *10 to 25 percent of this item is estimated.

- Represents zero. N.e.c. Not elsewhere classified. [r]Revised. The large 1984 revisions to U.S. manufacturers' shipments of robots were due to some respondents reporting complete robots which were imported. This survey includes only those robots which were fabricated or assembled in the United States. (X) Not applicable.

[1]Robots presently are classified in the Standard Industrial Classification (SIC) based on their primary industrial function.

CURRENT INDUSTRIAL REPORTS

# Robots (Shipments)

1986

MA35X(86)-1
Issued August 1987

U.S. Department of Commerce
BUREAU OF THE CENSUS

## SUMMARY OF FINDINGS

In 1986, manufactures' shipments of complete robots were valued at $250.9 million, a decrease of 9 percent from the 1985 total of $275.7 million. Servo-controlled robots were valued at $233.5 million in 1986, a decrease of 8 percent from the 1985 value of $254.9 million. Nonservo-controlled robots were valued at $15.7 million in 1986, a decrease of 13 percent from the 1985 value of $18.0 million. Other robots were valued at $1.7 million for 1986, a decrease of 37 percent from the 1985 value of $2.8 million.

A description of the survey methodology and related information appears of page 3.

Table 1. TOTAL SHIPMENTS OF COMPLETE ROBOTS, ROBOT ACCESSORIES, AND COMPONENTS: 1986 AND 1985

(Quantity in units; value in thousands of dollars)

| Product description[1] | Number of companies | 1986 Quantity | 1986 Value | 1985 Quantity | 1985 Value |
|---|---|---|---|---|---|
| Robots, robot accessories and components | 60 | (X) | 310,034 | (X) | [r]345,239 |
| Robots (complete) | (X) | 6,150 | 250,929 | [r]5,466 | [r]275,721 |
| Servo-controlled robots | 22 | 2,718 | 233,499 | [r]2,978 | [r]254,926 |
| Point-to-point type: | | | | | |
| Welding, soldering, brazing, and/or cutting (welding type) | 8 | 969 | 86,047 | 839 | 74,646 |
| Foundry, forging, and/or heat treating | 1 | 17 | 1,669 | 12 | 745 |
| Inspection, measuring, gauging, and/or sorting | 4 | | | | |
| Metal bending, shearing, and/or forming | - | - | - | - | - |
| Plastics molding and/or forming | 1 | | | - | - |
| Machine tool loading and/or unloading | 3 | 40 | 2,636 | 53 | 3,785 |
| Drilling and/or cutting (machine type) | 1 | | | - | - |
| Assembly, for non-electronic products | 6 | 441 | 17,991 | 547 | 17,761 |
| Assembly, for electronic products | 6 | | | | |
| Material handling and/or parts transfer n.e.c. | 5 | 307 | 23,817 | 463 | 44,863 |
| Other point-to-point type n.e.c. | 3 | | | | |
| Continuous-path type: | | | | | |
| Welding, soldering, brazing, and/or cutting (welding type) | 4 | 198 | 13,768 | 287 | 22,352 |
| Spraying, painting, gluing, and/or sealing | 9 | 291 | 39,467 | [r]339 | [r]41,416 |
| Fettling, grinding, polishing, and/or deburring | 2 | 455 | 48,104 | 29 | 1,523 |
| Other continuous-path type n.e.c. | 6 | | | 409 | 47,835 |
| Nonservo-controlled robots | 11 | 451 | 15,691 | [r]460 | 18,015 |
| Foundry, forging, and/or heat treating | 1 | | | - | - |
| Metal bending, shearing, and/or forming | - | | | | |
| Plastics molding and/or forming | 1 | | | | |
| Machine tool loading and/or unloading | 1 | 205 | 9,810 | 229 | 12,450 |
| Inspection, measuring, gauging, and/or sorting | 3 | | | | |
| Assembly, for non-electronic products | 3 | | | | |
| Assembly, for electronic products | 1 | | | | |
| Other nonservo-controlled robots n.e.c. | 1 | | | | |
| Material handling and/or parts transfer n.e.c. | 8 | 246 | 5,881 | 231 | 5,565 |
| Other robots | 3 | 2,981 | 1,739 | 2,028 | 2,780 |
| Educational, hobby, and experimental robots | 3 | 2,981 | 1,739 | 2,028 | 2,780 |
| Other robots n.e.c. | 1 | | | | |
| Robot accessories, subassemblies, components, and parts (sold separately) | 46 | (X) | 59,105 | (X) | 69,518 |
| End-of-arm tooling for robots | 12 | (X) | 8,243 | (X) | [r]3,695 |
| Vision, sonic, force, tactile, and proximity sensors | 13 | (X) | 10,159 | (X) | 17,666 |
| Interface modules | 3 | (X) | 1,644 | | |
| Compliance devices | 3 | | | (X) | 4,908 |
| Joint locating and guidance systems for welding | 5 | (X) | 1,243 | | |
| Guarding and safety devices | 6 | (X) | 1,682 | | |
| Robot accessories, subassemblies, components, and parts n.e.c. | 28 | (X) | 36,134 | (X) | 43,249 |
| Miscellaneous receipts: | | | | | |
| Research and development, testing, and evaluation of systems and components (receipts and billings, not reported as shipments of specific products) | 5 | (X) | 12,445 | (X) | 9,161 |

- Represents zero. N.e.c. Not elsewhere classified. [r]Revised. (X) Not applicable.

[1]Robots presently are classified in the Standard Industrial Classification (SIC) based on their primary industrial function.

# Robots (Shipments)

1987

U.S. Department of Commerce
BUREAU OF THE CENSUS

MA35X(87)-1
Issued August 1988

## SUMMARY OF FINDINGS

In 1987, manufacturers' shipments of complete robots were valued at $187.5 million, a decrease of 32 percent from the 1986 total of $274.6 million. Servo-controlled robots were valued at $176.0 million in 1987, a decrease of 31 percent from the 1986 value of $255.9 million. Nonservo-controlled robots were valued at $8.2 million in 1987, a decrease of 48 percent from the 1986 value of $15.7 million. Other robots were valued at $3.4 million for 1987, an increase of 14 percent from the 1986 value of $3.0 million.

A description of the survey methodology and related information appears on page 3.

Table 1. TOTAL SHIPMENTS OF COMPLETE ROBOTS, ROBOT ACCESSORIES, AND COMPONENTS: 1987 AND 1986

(Quantity in units; value in thousands of dollars)

| Product code | Product description | Number of companies | 1987 | | 1986 | |
|---|---|---|---|---|---|---|
| | | | Quantity | Value | Quantity | Value |
| 35697 | Robots, robot accessories and components | 56 | (X) | 249,912 | (X) | 345,939 |
| | Robots (complete) | (X) | 4,273 | 187,507 | [r]6,673 | [r]274,556 |
| | Servo-controlled robots | 25 | 2,459 | 175,960 | [r]3,165 | [r]255,876 |
| | Point-to-point type: | | | | | |
| 35697 01 | Welding, soldering, brazing, and/or cutting (welding type) | 5 | 476 | 43,944 | 969 | 86,047 |
| 35697 04 | Foundry, forging, and/or heat treating | 1 | | | 18 | [r]3,169 |
| 35697 16 | Inspection, measuring, gauging, and/or sorting | 2 | | | | |
| 35697 07 | Metal bending, shearing, and/or forming | - | 28 | 3,412 | | |
| 35697 10 | Plastics molding and/or forming | 1 | | | | |
| 35697 13 | Machine tool loading and/or unloading | 3 | | | [r]45 | [r]3,716 |
| 35697 19 | Drilling and/or cutting (machine type) | 2 | | | | |
| 35697 22 | Assembly, for non-electronic products | 6 | 535 | 19,573 | 443 | [r]19,091 |
| 35697 25 | Assembly, for electronic products | 6 | | | | |
| 35697 28 | Material handling and/or parts transfer n.e.c. | 8 | 713 | 43,016 | [r]741 | [r]45,117 |
| 35697 31 | Other point-to-point type n.e.c. | 3 | | | | |
| | Continuous-path type: | | | | | |
| 35697 34 | Welding, soldering, brazing, and/or cutting (welding type) | 5 | 110 | 9,020 | 198 | 13,768 |
| 35697 37 | Spraying, painting, gluing, and/or sealing | 9 | 297 | 41,348 | 296 | [r]36,864 |
| 35697 40 | Fettling, grinding, polishing, and/or deburring | 1 | 300 | 15,647 | 455 | 48,104 |
| 35697 43 | Other continuous-path type n.e.c. | 6 | | | | |
| | Nonservo-controlled robots | 11 | 215 | 8,153 | 451 | 15,691 |
| 35697 41 | Foundry, forging, and/or heat treating | 1 | | | | |
| 35697 49 | Metal bending, shearing, and/or forming | - | | | | |
| 35697 52 | Plastics molding and/or forming | 2 | | | | |
| 35697 55 | Machine tool loading and/or unloading | 1 | 125 | 5,948 | 205 | 9,810 |
| 35697 58 | Inspection, measuring, gauging, and/or sorting | 4 | | | | |
| 35697 61 | Assembly, for non-electronic products | 1 | | | | |
| 35697 64 | Assembly, for electronic products | 2 | | | | |
| 35697 70 | Other nonservo-controlled robots n.e.c. | 1 | | | | |
| 35697 67 | Material handling and/or parts transfer n.e.c. | 8 | 90 | 2,205 | 246 | 5,881 |
| | Other robots | 6 | 1,599 | 3,394 | 3,057 | [r]2,989 |
| 35697 73 | Educational, hobby, and experimental robots | 5 | 1,599 | 3,394 | 3,057 | [r]2,989 |
| 35697 76 | Other robots n.e.c. | 2 | | | | |
| | Robot accessories, subassemblies, components, and parts (sold separately). | 44 | (X) | 62,405 | (X) | [r]71,383 |
| 35697 79 | End-of-arm tooling for robots | 12 | (X) | 5,936 | (X) | 8,357 |
| 35697 82 | Vision, sonic, force, tactile, and proximity sensors | 15 | (X) | 15,604 | (X) | [r]14,768 |
| 35697 85 | Interface modules | 2 | (X) | 815 | (X) | 1,684 |
| 35697 88 | Compliance devices | 3 | | | | |
| 35697 91 | Joint locating and guidance systems for welding | 3 | (X) | 3,989 | (X) | 1,243 |
| 35697 94 | Guarding and safety devices | 4 | | | (X) | 1,682 |
| 35697 97 | Robot accessories, subassemblies, components, and parts n.e.c. | 26 | (X) | 36,061 | (X) | [r]43,649 |
| | Miscellaneous receipts: | | | | | |
| 99989 00 | Research and development, testing, and evaluation of systems and components (receipts and billings, not reported as shipments of specific products) | 7 | (X) | 8,437 | (X) | [r]16,833 |

- Represents zero. N.e.c. Not elsewhere classified. [r]Revised. (X) Not applicable.

Address inquiries concerning these figures to U.S. Department of Commerce, Bureau of the Census, Industry Division, Washington, D.C. 20233, or call Louise Beckett, (301) 763-4085.

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

# Robots (Shipments)

1988

U.S. Department of Commerce
BUREAU OF THE CENSUS

MA35X(88)-1
Issued September 1989

## SUMMARY OF FINDINGS

In 1988, manufacturers' shipments of complete robots were valued at $175.4 million, a decrease of 20 percent from the 1987 total of $219.8 million. Servo-controlled robots were valued at $149.0 million in 1988, a decrease of 27 percent from the 1987 value of $203.0 million. Nonservo-controlled robots were valued at $17.1 million which was more than double the value of $8.2 million reported in 1987. Other robots were valued at $9.3 million for 1988, an increase of 8 percent from the 1987 value of $8.6 million.

A description of the survey methodology and related information appears on page 3.

Table 1. TOTAL SHIPMENTS OF COMPLETE ROBOTS, ROBOT ACCESSORIES, AND COMPONENTS: 1988 AND 1987

(Quantity in units; value in thousands of dollars)

| Product code | Product description | Number of companies | 1988 Quantity | 1988 Value | 1987 Quantity | 1987 Value |
|---|---|---|---|---|---|---|
| 35697 | Robots, robot accessories and components | 56 | (X) | 250,136 | (X) | [r]284,382 |
| | Robots (complete) | (X) | 4,557 | 175,373 | [r]5,244 | [r]219,790 |
| | Servo-controlled robots | 26 | 3,026 | 148,960 | 2,567 | [r]203,020 |
| | Point-to-point type: | | | | | |
| 35697 01 | Welding, soldering, brazing, and/or cutting (welding type) | 6 | 303 | 32,273 | [r]675 | [r]64,598 |
| 35697 04 | Foundry, forging, and/or heat treating | 2 | | | | |
| 35697 16 | Inspection, measuring, gauging, and/or sorting | 1 | | | | |
| 35697 07 | Metal bending, shearing, and/or forming | - | 31 | 3,232 | 28 | 3,412 |
| 35697 10 | Plastics molding and/or forming | 1 | | | | |
| 35697 13 | Machine tool loading and/or unloading | 1 | | | | |
| 35697 19 | Drilling and/or cutting (machine type) | 1 | | | | |
| 35697 22 | Assembly, for non-electronic products | 6 | 296 | 22,099 | 535 | 19,573 |
| 35697 25 | Assembly, for electronic products | 5 | | | | |
| 35697 28 | Material handling and/or parts transfer n.e.c. | 9 | 742 | 49,760 | 726 | [r]48,314 |
| 35697 31 | Other point-to-point type n.e.c. | 2 | | | | |
| | Continuous-path type: | | | | | |
| 35697 34 | Welding, soldering, brazing, and/or cutting (welding type) | 3 | 79 | 3,696 | 110 | 9,022 |
| 35697 37 | Spraying, painting, gluing, and/or sealing | 9 | 247 | 27,308 | 297 | 41,348 |
| 35697 40 | Fettling, grinding, polishing, and/or deburring | 1 | 328 | 10,614 | 306 | 16,755 |
| 35697 43 | Other continuous-path type n.e.c. | 5 | | | | |
| | Nonservo-controlled robots | 10 | 336 | 17,077 | 215 | 8,153 |
| 35697 46 | Foundry, forging, and/or heat treating | 1 | | | | |
| 35697 49 | Metal bending, shearing, and/or forming | - | | | | |
| 35697 52 | Plastics molding and/or forming | 2 | 90 | 3,372 | | |
| 35697 55 | Machine tool loading and/or unloading | 1 | | | 125 | 5,968 |
| 35697 58 | Inspection, measuring, gauging, and/or sorting | 4 | | | | |
| 35697 61 | Assembly, for non-electronic products | 1 | | | | |
| 35697 64 | Assembly, for electronic products | 1 | 246 | 13,705 | | |
| 35697 70 | Other nonservo-controlled robots n.e.c. | - | | | | |
| 35697 67 | Material handling and/or parts transfer n.e.c. | 3 | | | 90 | 2,185 |
| | Other robots | 7 | 2,195 | 9,336 | [r]3,145 | [r]8,617 |
| 35697 73 | Educational, hobby, and experimental robots | 3 | 2,195 | 9,336 | [r]3,145 | [r]8,617 |
| 35697 76 | Other robots n.e.c. | 4 | | | | |
| | Robot accessories, subassemblies, components, and parts (sold separately) | 40 | (X) | 74,763 | (X) | 64,392 |
| 35697 79 | End-of-arm tooling for robots | 15 | (X) | 3,302 | (X) | 6,121 |
| 35697 82 | Vision, sonic, force, tactile, and proximity sensors | 13 | (X) | 18,175 | (X) | 15,578 |
| 35697 85 | Interface modules | 2 | (X) | 687 | (X) | 815 |
| 35697 88 | Compliance devices | 3 | | | | |
| 35697 91 | Joint locating and guidance systems for welding | 2 | (X) | 5,735 | (X) | 4,017 |
| 35697 94 | Guarding and safety devices | 7 | | | | |
| 35697 97 | Robot accessories, subassemblies, components, and parts n.e.c. | 26 | (X) | 46,866 | (X) | 38,061 |
| | Miscellaneous receipts: | | | | | |
| 99989 00 | Research and development, testing, and evaluation of systems and components (receipts and billings, not reported as shipments of specific products) | 7 | (X) | 5,194 | (X) | 8,437 |

- Represents zero. N.e.c. Not elsewhere classified. [r]Revised by 5 percent or more from previously published figures. (X) Not applicable.

Table 2. COMPARISON OF VALUES OF SHIPMENTS OF ROBOTS, AS REPORTED IN THE MA35X AND THE 1987 CENSUS OF MANUFACTURES

| Product code | Product description | 1987 MA35X | 1987 Census of Manufactures[p] |
|---|---|---|---|
| 35697 | Robots, robot accessories and components | 284.4 | 306.4 |

[p]Preliminary.

# Industrial Robots

1989

U.S. Department of Commerce
BUREAU OF THE CENSUS

MA35X(89)-1
Issued June 1990

## SUMMARY OF FINDINGS

In 1989, manufacturers' shipments of complete industrial robots were valued at $150.6 million, a decrease of 2.8 percent from the 1988 total of $154.8 million. Servo-controlled robots were valued at $135.7 million in 1989, a decrease of 1.5 percent from the 1988 value of $137.7 million. Nonservo-controlled robots were valued at $14.9 million, a decrease of 14.8 percent from the 1988 total of $17.1 million. Industrial robot accessories subassemblies, components, and parts were valued at $105.4 million in 1989, an increase of 42.7 percent from the 1988 value of $73.9 million.

A description of the survey methodology and related information appears on page 4.

Table 1. TOTAL SHIPMENTS OF COMPLETE INDUSTRIAL ROBOTS, ACCESSORIES, SUBASSEMBLIES, COMPONENTS, AND PARTS. 1989 AND 1988

(Quantity in units; value in thousands of dollars)

| Product code | Product description | Number of companies | 1989 | | 1988 | |
|---|---|---|---|---|---|---|
| | | | Quantity | Value | Quantity | Value |
| 35697 | Industrial robots, accessories, subassemblies, components, and parts | 56 | (X) | 255,970 | (X) | 228,645 |
| | Industrial robots (complete) | (X) | 2,217 | 150,557 | 2,408 | 154,770 |
| | Servo-controlled robots | 22 | 1,840 | 135,685 | 2,072 | 137,693 |
| | Point-to-point type: | | | | | |
| 35697 01 | Welding, soldering, brazing, and/or cutting (welding type) | 4 | 273 | 29,314 | 304 | 32,301 |
| 35697 04 | Foundry, forging, and/or heat treating | 2 | | | | |
| 35697 07 | Metal bending, shearing, and/or forming | - | | | | |
| 35697 10 | Plastics molding and/or forming | 2 | | | | |
| 35697 13 | Machine tool loading and/or unloading | 1 | 34 | 9,309 | 31 | 1,232 |
| 35697 16 | Inspection, measuring, gauging, and/or sorting | 1 | | | | |
| 35697 19 | Drilling and/or cutting (machine type) | 2 | | | | |
| 35697 22 | Assembly, for non-electronic products | 4 | | | | |
| 35697 25 | Assembly, for electronic products | 3 | 238 | 8,091 | 296 | r7,984 |
| 35697 28 | Material handling and/or parts transfer | 7 | | | | |
| 35697 31 | Other point-to-point type | 1 | 162 | 26,044 | r247 | r26,970 |
| | Continuous-path type: | | | | | |
| 35697 34 | Welding, soldering, brazing, and/or cutting (welding type) | 4 | 31 | 2,249 | 79 | 3,694 |
| 35697 37 | Spraying, painting, gluing, and/or sealing | 6 | 254 | 35,111 | r292 | r30,128 |
| 35697 40 | Fettling, grinding, polishing, and/or deburring | 2 | | | | |
| 35697 43 | Other continuous-path type | 4 | 848 | 25,567 | r823 | 33,384 |
| | Nonservo-controlled robots | 9 | 377 | 14,872 | 336 | 17,077 |
| 35697 46 | Foundry, forging, and/or heat treating | 1 | | | | |
| 35697 49 | Metal bending, shearing, and/or forming | - | | | | |
| 35697 52 | Plastics molding and/or forming | 1 | 40 | 2,553 | 90 | 3,372 |
| 35697 55 | Machine tool loading and/or unloading | 1 | | | | |
| 35697 58 | Inspection, measuring, gauging, and/or sorting | 2 | | | | |
| 35697 61 | Assembly, for non-electronic products | 2 | | | | |
| 35697 64 | Assembly, for electronic products | 1 | 337 | 12,319 | 246 | 13,705 |
| 35697 67 | Material handling and/or parts transfer | 6 | | | | |
| 35697 70 | Other nonservo-controlled robots | - | - | - | - | - |
| | Industrial robot accessories, subassemblies, components, and parts (sold separately) | 39 | (X) | 105,413 | (X) | 73,876 |
| 35697 79 | End-of-arm tooling for robots | 9 | (X) | 3,468 | (X) | 3,302 |
| 35697 82 | Vision, sonic, force, tactile, and proximity sensors | 10 | (X) | 20,463 | (X) | 18,175 |
| 35697 85 | Interface modules | 3 | (X) | 1,688 | | |
| 35697 88 | Compliance devices | 3 | (X) | 283 | (X) | r1,300 |
| 35697 91 | Joint locating and guidance systems for welding | 1 | | | | |
| 35697 94 | Guarding and safety devices | 5 | (X) | 6,308 | (X) | 5,733 |
| 35697 97 | Industrial robot accessories, subassemblies, components, and parts n.e.c. | 25 | (X) | 73,203 | (X) | 45,366 |
| | Miscellaneous receipts: | | | | | |
| 99989 00 | Research and development, testing, and evaluation of systems and components (receipts and billings, not reported as shipments of specific products) | 5 | (X) | 2,546 | (X) | 3,196 |

Note: Detail may include shipment value of complete robotic system.

- Represents zero. N.e.c. Not elsewhere classified. [r]Revised by 5 percent or more from previously published figures. (X) Not applicable.

Address inquiries concerning these figures to U.S. Department of Commerce, Bureau of the Census, Industry Division, Washington, D.C. 20233 or call Alexander E. Holgado, (301) 763-4132.

Table 1.--U.S. trade data
Flow: Imports for consumption
Type: Customs value
TSUSA commodity: Total selected commodities
(Thousands of dollars)

| Partner / Time period | 1984 | 1985 | 1986 | 1987 | 1988 |
|---|---|---|---|---|---|
| Australia | 126 | 12 | 0 | 79 | 61 |
| Austria | 166 | 256 | 649 | 128 | 1,351 |
| Belgium and Luxembourg | 0 | 175 | 546 | 211 | 0 |
| Brazil | 96 | 0 | 0 | 0 | 0 |
| Canada | 1,341 | 2,513 | 5,018 | 3,852 | 6,507 |
| Denmark | 0 | 26 | 2 | 199 | 6 |
| Dominican Republic | 0 | 8 | 0 | 0 | 0 |
| Finland | 538 | 258 | 820 | 315 | 764 |
| France | 1,197 | 1,190 | 1,589 | 844 | 2,887 |
| French Guiana | 0 | 0 | 0 | 62 | 0 |
| Germany, West | 12,975 | 19,271 | 21,569 | 19,554 | 18,758 |
| Greece | 0 | 0 | 0 | 99 | 0 |
| Hong Kong | 0 | 0 | 0 | 48 | 0 |
| Ireland | 0 | 48 | 75 | 202 | 90 |
| Israel | 0 | 154 | 257 | 268 | 1,132 |
| Italy | 385 | 6,211 | 14,105 | 6,578 | 1,014 |
| Japan | 67,952 | 89,039 | 85,759 | 114,396 | 94,857 |
| Jordan | 0 | 75 | 0 | 0 | 0 |
| Korea, South | 82 | 571 | 136 | 417 | 0 |
| Mexico | 0 | 0 | 2 | 0 | 0 |
| Nepal | 0 | 0 | 0 | 23 | 0 |
| Netherlands | 260 | 755 | 725 | 228 | 25 |
| Norway | 0 | 0 | 0 | 0 | 381 |
| Singapore | 0 | 0 | 46 | 24 | 22 |
| Spain | 14 | 34 | 153 | 0 | 169 |
| Sweden | 1,640 | 4,823 | 741 | 7,800 | 14,129 |
| Switzerland | 1,078 | 1,227 | 1,811 | 862 | 1,253 |
| Taiwan | 15 | 9 | 71 | 49 | 60 |
| Thailand | 131 | 0 | 0 | 0 | 0 |
| United Kingdom | 391 | 2,933 | 4,841 | 4,699 | 1,794 |
| Venezuela | 0 | 0 | 118 | 0 | 0 |
| Yemen (Sana) | 0 | 213 | 0 | 0 | 0 |
| World | 88,387 | 129,802 | 139,034 | 160,936 | 145,259 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 1.--U.S. trade data
Flow: Imports for consumption
Type: First unit of quantity
TSUSA commodity: Total selected commodities
(NO )

| Partner / Time period | 1984 | 1985 | 1986 | 1987 | 1988 |
|---|---|---|---|---|---|
| Australia | 9 | 1 | 0 | 1 | 3 |
| Austria | 4 | 4 | 9 | 5 | 16 |
| Belgium and Luxembourg | 0 | 5 | 13 | 11 | 0 |
| Brazil | 3 | 0 | 0 | 0 | 0 |
| Canada | 27 | 43 | 63 | 101 | 115 |
| Denmark | 0 | 2 | 1 | 6 | 1 |
| Dominican Republic | 0 | 1 | 0 | 0 | 0 |
| Finland | 122 | 21 | 40 | 6 | 7 |
| France | 21 | 64 | 63 | 38 | 33 |
| French Guiana | 0 | 0 | 0 | 1 | 0 |
| Germany, West | 260 | 346 | 355 | 291 | 262 |
| Greece | 0 | 0 | 0 | 12 | 0 |
| Hong Kong | 0 | 0 | 0 | 5 | 0 |
| Ireland | 0 | 2 | 1 | 4 | 2 |
| Israel | 0 | 6 | 7 | 4 | 6 |
| Italy | 10 | 103 | 145 | 34 | 18 |
| Japan | 2,800 | 3,427 | 2,901 | 4,520 | 2,947 |
| Jordan | 0 | 3 | 0 | 0 | 0 |
| Korea, South | 1 | 28 | 6 | 12 | 0 |
| Mexico | 0 | 0 | 1 | 0 | 0 |
| Nepal | 0 | 0 | 0 | 1 | 0 |
| Netherlands | 23 | 18 | 34 | 13 | 6 |
| Norway | 0 | 0 | 0 | 0 | 4 |
| Singapore | 0 | 0 | 1 | 2 | 2 |
| Spain | 1 | 2 | 2 | 0 | 3 |
| Sweden | 63 | 215 | 43 | 158 | 277 |
| Switzerland | 16 | 34 | 31 | 21 | 30 |
| Taiwan | 3 | 15 | 7 | 53 | 100 |
| Thailand | 2 | 0 | 0 | 0 | 0 |
| United Kingdom | 46 | 118 | 183 | 174 | 157 |
| Venezuela | 0 | 0 | 1 | 0 | 0 |
| Yemen (Sana) | 0 | 3 | 0 | 0 | 0 |
| World | 3,411 | 4,461 | 3,907 | 5,473 | 3,989 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 2.--U.S. trade data
Flow: Imports for consumption
Type: Customs value
TSUSA commodity: 6641005--Industrial robots, lifting
(Thousands of dollars)

| Partner / Time period | 1984 | 1985 | 1986 | 1987 | 1988 |
|---|---|---|---|---|---|
| Australia | 81 | 12 | 0 | 0 | 0 |
| Austria | 0 | 200 | 541 | 9 | 91 |
| Belgium and Luxembourg | 0 | 0 | 206 | 0 | 0 |
| Brazil | 27 | 0 | 0 | 0 | 0 |
| Canada | 613 | 1,438 | 1,819 | 1,008 | 527 |
| Denmark | 0 | 0 | 2 | 25 | 0 |
| Finland | 160 | 258 | 820 | 0 | 676 |
| France | 50 | 87 | 43 | 368 | 1,298 |
| Germany, West | 452 | 791 | 5,239 | 4,720 | 4,636 |
| Hong Kong | 0 | 0 | 0 | 30 | 0 |
| Ireland | 0 | 0 | 0 | 202 | 90 |
| Italy | 4 | 3,754 | 13,276 | 3,269 | 39 |
| Japan | 6,275 | 8,864 | 6,782 | 18,225 | 10,120 |
| Korea, South | 0 | 0 | 0 | 170 | 0 |
| Mexico | 0 | 0 | 2 | 0 | 0 |
| Netherlands | 71 | 20 | 12 | 193 | 25 |
| Norway | 0 | 0 | 0 | 0 | 197 |
| Spain | 14 | 18 | 0 | 0 | 0 |
| Sweden | 27 | 1,563 | 119 | 1,345 | 2,821 |
| Switzerland | 28 | 636 | 581 | 0 | 343 |
| Taiwan | 0 | 9 | 28 | 49 | 60 |
| United Kingdom | 110 | 589 | 307 | 1,213 | 482 |
| Venezuela | 0 | 0 | 118 | 0 | 0 |
| World | 7,913 | 18,240 | 29,895 | 30,825 | 21,406 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 2.--U.S. trade data
Flow: Imports for consumption
Type: First unit of quantity
TSUSA commodity: 6641005--Industrial robots, lifting
(NO )

| Partner / Time period | 1984 | 1985 | 1986 | 1987 | 1988 |
|---|---|---|---|---|---|
| Australia | 6 | 1 | 0 | 0 | 0 |
| Austria | 0 | 3 | 8 | 3 | 5 |
| Belgium and Luxembourg | 0 | 0 | 5 | 0 | 0 |
| Brazil | 1 | 0 | 0 | 0 | 0 |
| Canada | 14 | 20 | 23 | 57 | 55 |
| Denmark | 0 | 0 | 1 | 2 | 0 |
| Finland | 121 | 21 | 40 | 0 | 5 |
| France | 5 | 31 | 4 | 28 | 3 |
| Germany, West | 25 | 17 | 118 | 63 | 85 |
| Hong Kong | 0 | 0 | 0 | 3 | 0 |
| Ireland | 0 | 0 | 0 | 4 | 2 |
| Italy | 2 | 69 | 127 | 12 | 2 |
| Japan | 298 | 616 | 526 | 666 | 631 |
| Korea, South | 0 | 0 | 0 | 1 | 0 |
| Mexico | 0 | 0 | 1 | 0 | 0 |
| Netherlands | 17 | 5 | 3 | 12 | 6 |
| Norway | 0 | 0 | 0 | 0 | 2 |
| Spain | 1 | 1 | 0 | 0 | 0 |
| Sweden | 2 | 101 | 18 | 38 | 57 |
| Switzerland | 2 | 12 | 5 | 0 | 12 |
| Taiwan | 0 | 15 | 5 | 53 | 100 |
| United Kingdom | 11 | 45 | 57 | 98 | 141 |
| Venezuela | 0 | 0 | 1 | 0 | 0 |
| World | 505 | 957 | 942 | 1,040 | 1,106 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 3.--U.S. trade data
Flow: Imports for consumption
Type: Customs value
TSUSA commodity: 6785086--Industrial robots, nspf
(Thousands of dollars)

| Partner / Time period | 1984 | 1985 | 1986 | 1987 | 1988 |
|---|---|---|---|---|---|
| Australia | 45 | 0 | 0 | 79 | 61 |
| Austria | 0 | 0 | 108 | 119 | 136 |
| Belgium and Luxembourg | 0 | 175 | 340 | 130 | 0 |
| Canada | 624 | 849 | 1,449 | 2,052 | 3,003 |
| Denmark | 0 | 26 | 0 | 175 | 6 |
| Dominican Republic | 0 | 8 | 0 | 0 | 0 |
| Finland | 378 | 0 | 0 | 315 | 87 |
| France | 396 | 229 | 1,056 | 433 | 671 |
| French Guiana | 0 | 0 | 0 | 62 | 0 |
| Germany, West | 2,493 | 4,185 | 11,190 | 11,414 | 12,219 |
| Greece | 0 | 0 | 0 | 99 | 0 |
| Hong Kong | 0 | 0 | 0 | 18 | 0 |
| Ireland | 0 | 48 | 75 | 0 | 0 |
| Israel | 0 | 154 | 257 | 268 | 1,132 |
| Italy | 381 | 202 | 352 | 3,310 | 829 |
| Japan | 29,369 | 31,961 | 26,877 | 46,350 | 42,803 |
| Jordan | 0 | 75 | 0 | 0 | 0 |
| Korea, South | 82 | 435 | 48 | 5 | 0 |
| Nepal | 0 | 0 | 0 | 23 | 0 |
| Netherlands | 189 | 703 | 713 | 35 | 0 |
| Norway | 0 | 0 | 0 | 0 | 184 |
| Singapore | 0 | 0 | 46 | 24 | 22 |
| Spain | 0 | 17 | 153 | 0 | 169 |
| Sweden | 1,454 | 3,233 | 574 | 522 | 7,445 |
| Switzerland | 781 | 592 | 992 | 689 | 909 |
| Taiwan | 15 | 0 | 44 | 0 | 0 |
| Thailand | 131 | 0 | 0 | 0 | 0 |
| United Kingdom | 282 | 2,321 | 4,148 | 2,748 | 1,202 |
| World | 36,621 | 45,214 | 48,420 | 68,870 | 70,879 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 3.--U.S. trade data
Flow: Imports for consumption
Type: First unit of quantity
TSUSA commodity: 6785086--Industrial robots, nspf
(NO )

| Partner / Time period | 1984 | 1985 | 1986 | 1987 | 1988 |
|---|---|---|---|---|---|
| Australia | 3 | 0 | 0 | 1 | 3 |
| Austria | 0 | 0 | 1 | 2 | 7 |
| Belgium and Luxembourg | 0 | 5 | 8 | 9 | 0 |
| Canada | 12 | 18 | 25 | 36 | 51 |
| Denmark | 0 | 2 | 0 | 4 | 1 |
| Dominican Republic | 0 | 1 | 0 | 0 | 0 |
| Finland | 1 | 0 | 0 | 6 | 2 |
| France | 7 | 6 | 45 | 8 | 22 |
| French Guiana | 0 | 0 | 0 | 1 | 0 |
| Germany, West | 86 | 87 | 175 | 193 | 157 |
| Greece | 0 | 0 | 0 | 12 | 0 |
| Hong Kong | 0 | 0 | 0 | 2 | 0 |
| Ireland | 0 | 2 | 1 | 0 | 0 |
| Israel | 0 | 6 | 7 | 4 | 6 |
| Italy | 8 | 18 | 9 | 22 | 15 |
| Japan | 1,854 | 1,682 | 1,196 | 2,690 | 1,376 |
| Jordan | 0 | 3 | 0 | 0 | 0 |
| Korea, South | 1 | 21 | 2 | 1 | 0 |
| Nepal | 0 | 0 | 0 | 1 | 0 |
| Netherlands | 6 | 12 | 31 | 1 | 0 |
| Norway | 0 | 0 | 0 | 0 | 2 |
| Singapore | 0 | 0 | 1 | 2 | 2 |
| Spain | 0 | 1 | 2 | 0 | 3 |
| Sweden | 58 | 113 | 21 | 13 | 151 |
| Switzerland | 6 | 22 | 17 | 20 | 18 |
| Taiwan | 3 | 0 | 2 | 0 | 0 |
| Thailand | 2 | 0 | 0 | 0 | 0 |
| United Kingdom | 35 | 72 | 123 | 69 | 13 |
| World | 2,082 | 2,071 | 1,666 | 3,097 | 1,829 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 4.--U.S. trade data
Flow: Imports for consumption
Type: Customs value
TSUSA commodity: 6839005--Industrial robots, welding
(Thousands of dollars)

| Partner / Time period | 1984 | 1985 | 1986 | 1987 | 1988 |
|---|---|---|---|---|---|
| Austria | 166 | 56 | 0 | 0 | 1,124 |
| Belgium and Luxembourg | 0 | 0 | 0 | 81 | 0 |
| Brazil | 69 | 0 | 0 | 0 | 0 |
| Canada | 103 | 226 | 1,750 | 791 | 2,976 |
| France | 751 | 874 | 490 | 43 | 918 |
| Germany, West | 10,029 | 14,295 | 5,141 | 3,420 | 1,903 |
| Italy | 0 | 2,255 | 478 | 0 | 147 |
| Japan | 32,308 | 48,213 | 52,100 | 49,821 | 41,933 |
| Korea, South | 0 | 136 | 88 | 241 | 0 |
| Netherlands | 0 | 31 | 0 | 0 | 0 |
| Sweden | 159 | 27 | 49 | 5,933 | 3,863 |
| Switzerland | 269 | 0 | 237 | 173 | 0 |
| United Kingdom | 0 | 22 | 387 | 738 | 110 |
| Yemen (Sana) | 0 | 213 | 0 | 0 | 0 |
| World | 43,854 | 66,348 | 60,719 | 61,241 | 52,974 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 4.--U.S. trade data
Flow: Imports for consumption
Type: First unit of quantity
TSUSA commodity: 6839005--Industrial robots, welding
(NO )

| Partner / Time period | 1984 | 1985 | 1986 | 1987 | 1988 |
|---|---|---|---|---|---|
| Austria | 4 | 1 | 0 | 0 | 4 |
| Belgium and Luxembourg | 0 | 0 | 0 | 2 | 0 |
| Brazil | 2 | 0 | 0 | 0 | 0 |
| Canada | 1 | 5 | 15 | 8 | 9 |
| France | 9 | 27 | 14 | 2 | 8 |
| Germany, West | 149 | 242 | 62 | 35 | 20 |
| Italy | 0 | 16 | 9 | 0 | 1 |
| Japan | 648 | 1,129 | 1,179 | 1,164 | 940 |
| Korea, South | 0 | 7 | 4 | 10 | 0 |
| Netherlands | 0 | 1 | 0 | 0 | 0 |
| Sweden | 3 | 1 | 4 | 107 | 69 |
| Switzerland | 8 | 0 | 9 | 1 | 0 |
| United Kingdom | 0 | 1 | 3 | 7 | 3 |
| Yemen (Sana) | 0 | 3 | 0 | 0 | 0 |
| World | 824 | 1,433 | 1,299 | 1,336 | 1,054 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 1.--U.S. trade data
Flow: Imports for consumption
Type: Customs value
HS commodity: Total selected commodities
(Thousands of dollars)

| Partner / Time period | 1989 | January-May 1989 | January-May 1990 |
|---|---|---|---|
| Australia | 19 | 9 | 714 |
| Austria | 4,053 | 228 | 2,005 |
| Belgium | 15 | 15 | 370 |
| Brazil | 103 | 0 | 0 |
| Canada | 9,961 | 5,160 | 3,195 |
| Denmark | 120 | 3 | 0 |
| Finland | 235 | 148 | 1,492 |
| France | 3,204 | 1,303 | 122 |
| Germany, West | 19,324 | 7,881 | 8,578 |
| Hong Kong | 121 | 2 | 2 |
| India | 25 | 0 | 0 |
| Israel | 1,019 | 272 | 371 |
| Italy | 2,289 | 1,195 | 1,793 |
| Japan | 161,739 | 63,531 | 37,163 |
| Korea, South | 9 | 2 | 55 |
| Mexico | 9 | 0 | 0 |
| Netherlands | 1,370 | 720 | 84 |
| Norway | 1,448 | 693 | 188 |
| San Marino | 5 | 0 | 0 |
| Singapore | 18 | 12 | 11 |
| Spain | 0 | 0 | 208 |
| Sweden | 10,202 | 4,593 | 5,109 |
| Switzerland | 6,051 | 3,431 | 1,541 |
| Taiwan | 513 | 272 | 136 |
| United Kingdom | 6,754 | 2,518 | 3,302 |
| World | 228,606 | 91,987 | 66,439 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 1.--U.S. trade data
Flow: Imports for consumption
Type: First unit of quantity
HS commodity: Total selected commodities
(NO )

| Partner / Time period | 1989 | January-May 1989 | January-May 1990 |
|---|---|---|---|
| Australia | 1 | 0 | 1 |
| Austria | 15 | 6 | 30 |
| Belgium | 0 | 0 | 11 |
| Brazil | 3 | 0 | 0 |
| Canada | 539 | 191 | 722 |
| Denmark | 8 | 1 | 0 |
| Finland | 3 | 3 | 24 |
| France | 166 | 43 | 1 |
| Germany, West | 2,139 | 1,222 | 582 |
| Hong Kong | 3,412 | 3,400 | 1 |
| Israel | 288 | 51 | 79 |
| Italy | 41 | 33 | 6 |
| Japan | 18,611 | 5,309 | 9,148 |
| Korea, South | 0 | 0 | 61 |
| Netherlands | 107 | 91 | 1 |
| Norway | 13 | 6 | 1 |
| San Marino | 1 | 0 | 0 |
| Singapore | 3 | 1 | 0 |
| Spain | 0 | 0 | 5 |
| Sweden | 211 | 106 | 97 |
| Switzerland | 112 | 69 | 12 |
| Taiwan | 68 | 2 | 0 |
| United Kingdom | 185 | 92 | 75 |
| World | 25,926 | 10,626 | 10,857 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 2.--U.S. trade data
Flow: Imports for consumption
Type: Customs value
HS commodity: 8428900010--Industrial robots for lifting, hand,load or unload
(Thousands of dollars)

| Partner / Time period | 1989 | January-May | |
|---|---|---|---|
| | | 1989 | 1990 |
| Australia | 0 | 0 | 714 |
| Austria | 64 | 51 | 260 |
| Belgium | 0 | 0 | 108 |
| Brazil | 103 | 0 | 0 |
| Canada | 5,739 | 3,202 | 2,145 |
| Denmark | 13 | 0 | 0 |
| Finland | 89 | 89 | 1,492 |
| France | 854 | 4 | 49 |
| Germany, West | 2,290 | 836 | 1,347 |
| Hong Kong | 119 | 0 | 0 |
| Italy | 684 | 684 | 1,361 |
| Japan | 23,518 | 11,281 | 9,074 |
| Netherlands | 1,206 | 653 | 0 |
| Sweden | 4,727 | 2,559 | 2,226 |
| Switzerland | 1,418 | 870 | 448 |
| Taiwan | 44 | 3 | 0 |
| United Kingdom | 2,757 | 351 | 1,580 |
| World | 43,625 | 20,582 | 20,804 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 2.--U.S. trade data
Flow: Imports for consumption
Type: First unit of quantity
HS commodity: 8428900010--Industrial robots for lifting, hand,load or unload
(NO )

| Partner / Time period | 1989 | January-May | |
|---|---|---|---|
| | | 1989 | 1990 |
| Australia | 0 | 0 | 1 |
| Austria | 2 | 1 | 3 |
| Belgium | 0 | 0 | 2 |
| Brazil | 3 | 0 | 0 |
| Canada | 282 | 105 | 183 |
| Denmark | 5 | 0 | 0 |
| Finland | 3 | 3 | 24 |
| France | 32 | 31 | 1 |
| Germany, West | 346 | 5 | 540 |
| Hong Kong | 12 | 0 | 0 |
| Italy | 33 | 33 | 2 |
| Japan | 977 | 474 | 365 |
| Netherlands | 13 | 1 | 0 |
| Sweden | 111 | 65 | 47 |
| Switzerland | 40 | 8 | 8 |
| Taiwan | 61 | 1 | 0 |
| United Kingdom | 61 | 21 | 55 |
| World | 1,981 | 748 | 1,151 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 3.--U.S. trade data
Flow: Imports for consumption
Type: Customs value
HS commodity: 8479899040--Industrial robots for multiple uses
(Thousands of dollars)

| Partner / Time period | 1989 | January-May 1989 | January-May 1990 |
|---|---|---|---|
| Australia | 10 | 0 | 0 |
| Austria | 355 | 171 | 1,521 |
| Belgium | 0 | 0 | 152 |
| Canada | 3,169 | 1,284 | 849 |
| Denmark | 107 | 3 | 0 |
| France | 676 | 42 | 0 |
| Germany, West | 7,048 | 3,484 | 3,068 |
| Hong Kong | 2 | 2 | 2 |
| Israel | 782 | 187 | 289 |
| Italy | 778 | 0 | 192 |
| Japan | 115,295 | 47,127 | 22,095 |
| Korea, South | 0 | 0 | 55 |
| Netherlands | 39 | 3 | 20 |
| Norway | 1,274 | 592 | 121 |
| San Marino | 5 | 0 | 0 |
| Singapore | 16 | 12 | 0 |
| Spain | 0 | 0 | 208 |
| Sweden | 4,400 | 1,711 | 2,499 |
| Switzerland | 3,044 | 1,879 | 527 |
| Taiwan | 216 | 133 | 0 |
| United Kingdom | 550 | 217 | 507 |
| World | 137,767 | 56,846 | 32,104 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 3.--U.S. trade data
Flow: Imports for consumption
Type: First unit of quantity
HS commodity: 8479899040--Industrial robots for multiple uses
(NO )

| Partner / Time period | 1989 | January-May 1989 | January-May 1990 |
|---|---|---|---|
| Australia | 1 | 0 | 0 |
| Austria | 13 | 5 | 27 |
| Belgium | 0 | 0 | 9 |
| Canada | 257 | 86 | 619 |
| Denmark | 3 | 1 | 0 |
| France | 134 | 12 | 0 |
| Germany, West | 1,793 | 1,217 | 42 |
| Hong Kong | 3,400 | 3,400 | 1 |
| Israel | 288 | 51 | 79 |
| Italy | 8 | 0 | 4 |
| Japan | 17,634 | 4,835 | 8,783 |
| Korea, South | 0 | 0 | 61 |
| Netherlands | 94 | 90 | 1 |
| Norway | 13 | 6 | 1 |
| San Marino | 1 | 0 | 0 |
| Singapore | 3 | 1 | 0 |
| Spain | 0 | 0 | 5 |
| Sweden | 100 | 41 | 50 |
| Switzerland | 72 | 61 | 4 |
| Taiwan | 7 | 1 | 0 |
| United Kingdom | 124 | 71 | 20 |
| World | 23,945 | 9,878 | 9,706 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 4.--U.S. trade data
Flow: Imports for consumption
Type: Customs value
HS commodity: 8479908040--Parts of industrial robots
(Thousands of dollars)

| Partner / Time period | 1989 | January-May 1989 | January-May 1990 |
|---|---|---|---|
| Australia | 9 | 9 | 0 |
| Austria | 3,633 | 6 | 224 |
| Belgium | 15 | 15 | 110 |
| Canada | 1,053 | 675 | 200 |
| Finland | 147 | 59 | 0 |
| France | 1,674 | 1,257 | 73 |
| Germany, West | 9,986 | 3,561 | 4,162 |
| India | 25 | 0 | 0 |
| Israel | 238 | 85 | 83 |
| Italy | 827 | 512 | 240 |
| Japan | 22,925 | 5,122 | 5,994 |
| Korea, South | 9 | 2 | 0 |
| Mexico | 9 | 0 | 0 |
| Netherlands | 124 | 64 | 64 |
| Norway | 175 | 101 | 67 |
| Singapore | 3 | 0 | 11 |
| Sweden | 1,075 | 324 | 385 |
| Switzerland | 1,588 | 683 | 566 |
| Taiwan | 253 | 136 | 136 |
| United Kingdom | 3,446 | 1,949 | 1,215 |
| World | 47,214 | 14,559 | 13,531 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 1.--U.S. trade data
Flow: Domestic exports
Type: F.a.s. value
HS commodity: Total selected commodities
(Thousands of dollars)

| Partner / Time period | 1989 | January-May 1989 | January-May 1990 |
|---|---|---|---|
| Angola | 93 | 93 | 0 |
| Argentina | 185 | 185 | 7 |
| Australia | 274 | 120 | 95 |
| Austria | 3 | 3 | 0 |
| Belgium | 92 | 52 | 122 |
| Bermuda | 0 | 0 | 3 |
| Brazil | 15 | 0 | 76 |
| Canada | 9,685 | 4,675 | 20,696 |
| China | 2,512 | 145 | 278 |
| Colombia | 0 | 0 | 60 |
| Costa Rica | 29 | 0 | 8 |
| Denmark | 46 | 0 | 21 |
| Ecuador | 0 | 0 | 6 |
| Egypt | 20 | 0 | 0 |
| Finland | 0 | 0 | 5 |
| France | 2,830 | 1,496 | 1,079 |
| Germany, West | 7,519 | 2,868 | 7,029 |
| Hong Kong | 0 | 0 | 45 |
| India | 486 | 0 | 14 |
| Ireland | 78 | 78 | 0 |
| Israel | 319 | 87 | 124 |
| Italy | 982 | 390 | 929 |
| Japan | 3,817 | 1,170 | 740 |
| Korea, South | 2,393 | 630 | 3,628 |
| Kuwait | 4 | 4 | 0 |
| Luxembourg | 0 | 0 | 3 |
| Malaysia | 118 | 10 | 124 |
| Mexico | 3,641 | 2,329 | 566 |
| Netherlands | 213 | 176 | 100 |
| New Zealand | 55 | 15 | 0 |
| Nigeria | 0 | 0 | 63 |
| Norway | 40 | 0 | 223 |
| Philippines | 4 | 0 | 3 |
| Poland | 253 | 0 | 111 |
| Portugal | 15 | 0 | 38 |
| Republic of South Africa | 0 | 0 | 20 |
| Saudi Arabia | 97 | 0 | 95 |
| Singapore | 449 | 158 | 408 |
| Soviet Union | 50 | 0 | 46 |
| Spain | 402 | 53 | 450 |
| Sri Lanka (Ceylon) | 81 | 81 | 0 |
| Suriname | 0 | 0 | 67 |
| Sweden | 287 | 0 | 370 |
| Switzerland | 1,454 | 292 | 802 |
| Taiwan | 510 | 332 | 177 |
| Turkey | 0 | 0 | 8 |
| United Arab Emirates | 4 | 4 | 0 |
| United Kingdom | 3,486 | 904 | 1,499 |
| Venezuela | 9 | 0 | 50 |
| Yugoslavia | 40 | 0 | 0 |
| World | 42,591 | 16,347 | 40,188 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 1.--U.S. trade data
Flow: Domestic exports
Type: First unit of quantity
HS commodity: Total selected commodities
(NO )

| Partner / Time period | 1989 | January-May 1989 | January-May 1990 |
|---|---|---|---|
| Angola | 5 | 5 | 0 |
| Argentina | 3 | 3 | 0 |
| Australia | 37 | 22 | 11 |
| Austria | 1 | 1 | 0 |
| Belgium | 4 | 3 | 5 |
| Bermuda | 0 | 0 | 1 |
| Brazil | 3 | 0 | 2 |
| Canada | 612 | 395 | 1,593 |
| China | 50 | 18 | 19 |
| Costa Rica | 6 | 0 | 2 |
| Denmark | 9 | 0 | 4 |
| Egypt | 2 | 0 | 0 |
| France | 233 | 111 | 66 |
| Germany, West | 947 | 296 | 296 |
| Hong Kong | 0 | 0 | 15 |
| India | 6 | 0 | 1 |
| Ireland | 13 | 13 | 0 |
| Israel | 29 | 13 | 18 |
| Italy | 59 | 20 | 86 |
| Japan | 163 | 62 | 42 |
| Korea, South | 68 | 6 | 56 |
| Kuwait | 1 | 1 | 0 |
| Malaysia | 6 | 1 | 10 |
| Mexico | 122 | 59 | 43 |
| Netherlands | 36 | 30 | 6 |
| New Zealand | 9 | 2 | 0 |
| Nigeria | 0 | 0 | 1 |
| Norway | 7 | 0 | 11 |
| Philippines | 1 | 0 | 0 |
| Poland | 1 | 0 | 0 |
| Portugal | 3 | 0 | 0 |
| Saudi Arabia | 1 | 0 | 2 |
| Singapore | 78 | 25 | 57 |
| Soviet Union | 1 | 0 | 1 |
| Spain | 15 | 3 | 11 |
| Sri Lanka (Ceylon) | 13 | 13 | 0 |
| Suriname | 0 | 0 | 12 |
| Sweden | 69 | 0 | 35 |
| Switzerland | 107 | 24 | 57 |
| Taiwan | 64 | 57 | 2 |
| United Arab Emirates | 1 | 1 | 0 |
| United Kingdom | 183 | 87 | 64 |
| Venezuela | 2 | 0 | 1 |
| Yugoslavia | 2 | 0 | 0 |
| World | 2,972 | 1,271 | 2,530 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 2.--U.S. trade data
Flow: Domestic exports
Type: F.a.s. value
HS commodity: 8428900010--Industrial robots for lifting, hand,load or unload
(Thousands of dollars)

| Partner / Time period | 1989 | January-May 1989 | January-May 1990 |
|---|---|---|---|
| Angola | 38 | 38 | 0 |
| Australia | 70 | 47 | 11 |
| Canada | 3,792 | 1,583 | 976 |
| China | 363 | 86 | 178 |
| France | 677 | 13 | 342 |
| Germany, West | 344 | 268 | 364 |
| Hong Kong | 0 | 0 | 15 |
| India | 62 | 0 | 0 |
| Israel | 30 | 0 | 14 |
| Italy | 138 | 133 | 165 |
| Japan | 181 | 156 | 84 |
| Korea, South | 690 | 6 | 36 |
| Malaysia | 13 | 0 | 4 |
| Mexico | 3,535 | 2,238 | 43 |
| New Zealand | 10 | 10 | 0 |
| Singapore | 138 | 48 | 77 |
| Spain | 232 | 0 | 0 |
| Sweden | 18 | 0 | 13 |
| Switzerland | 20 | 16 | 0 |
| United Kingdom | 915 | 10 | 28 |
| Yugoslavia | 40 | 0 | 0 |
| World | 11,306 | 4,650 | 2,350 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 2.--U.S. trade data
Flow: Domestic exports
Type: First unit of quantity
HS commodity: 8428900010--Industrial robots for lifting, hand,load or unload
(NO )

| Partner / Time period | 1989 | January-May 1989 | January-May 1990 |
|---|---|---|---|
| Angola | 4 | 4 | 0 |
| Australia | 30 | 16 | 1 |
| Canada | 227 | 172 | 33 |
| China | 36 | 8 | 18 |
| France | 115 | 44 | 16 |
| Germany, West | 72 | 69 | 8 |
| Hong Kong | 0 | 0 | 11 |
| India | 1 | 0 | 0 |
| Israel | 1 | 0 | 1 |
| Italy | 3 | 2 | 14 |
| Japan | 16 | 15 | 5 |
| Korea, South | 8 | 1 | 2 |
| Malaysia | 4 | 0 | 3 |
| Mexico | 115 | 55 | 7 |
| New Zealand | 1 | 1 | 0 |
| Singapore | 28 | 7 | 18 |
| Spain | 3 | 0 | 0 |
| Sweden | 45 | 0 | 1 |
| Switzerland | 14 | 13 | 0 |
| United Kingdom | 22 | 3 | 2 |
| Yugoslavia | 2 | 0 | 0 |
| World | 747 | 410 | 140 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 3.--U.S. trade data
Flow: Domestic exports
Type: F.a.s. value
HS commodity: 8479899040--Industrial robots for multiple uses
(Thousands of dollars)

| Partner / Time period | 1989 | January-May 1989 | January-May 1990 |
|---|---|---|---|
| Angola | 55 | 55 | 0 |
| Argentina | 185 | 185 | 0 |
| Australia | 203 | 74 | 53 |
| Austria | 3 | 3 | 0 |
| Belgium | 92 | 52 | 85 |
| Bermuda | 0 | 0 | 3 |
| Brazil | 15 | 0 | 76 |
| Canada | 5,893 | 3,092 | 12,775 |
| China | 2,150 | 60 | 58 |
| Costa Rica | 29 | 0 | 8 |
| Denmark | 46 | 0 | 21 |
| Egypt | 20 | 0 | 0 |
| France | 2,154 | 1,483 | 402 |
| Germany, West | 7,175 | 2,600 | 5,041 |
| Hong Kong | 0 | 0 | 25 |
| India | 424 | 0 | 9 |
| Ireland | 78 | 78 | 0 |
| Israel | 289 | 87 | 110 |
| Italy | 844 | 257 | 631 |
| Japan | 3,635 | 1,013 | 268 |
| Korea, South | 1,703 | 625 | 392 |
| Kuwait | 4 | 4 | 0 |
| Malaysia | 105 | 10 | 112 |
| Mexico | 107 | 91 | 512 |
| Netherlands | 213 | 176 | 85 |
| New Zealand | 45 | 5 | 6 |
| Nigeria | 0 | 0 | 44 |
| Norway | 40 | 0 | 223 |
| Philippines | 4 | 0 | 0 |
| Poland | 253 | 0 | 0 |
| Portugal | 15 | 0 | 0 |
| Saudi Arabia | 97 | 0 | 77 |
| Singapore | 311 | 110 | 235 |
| Soviet Union | 50 | 0 | 46 |
| Spain | 170 | 53 | 352 |
| Sri Lanka (Ceylon) | 81 | 81 | 0 |
| Suriname | 0 | 0 | 67 |
| Sweden | 269 | 0 | 312 |
| Switzerland | 1,434 | 276 | 635 |
| Taiwan | 510 | 332 | 159 |
| United Arab Emirates | 4 | 4 | 0 |
| United Kingdom | 2,571 | 894 | 512 |
| Venezuela | 9 | 0 | 6 |
| World | 31,285 | 11,697 | 23,334 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 3.--U.S. trade data
Flow: Domestic exports
Type: First unit of quantity
HS commodity: 8479899040--Industrial robots for multiple uses
(NO )

| Partner / Time period | 1989 | January-May 1989 | January-May 1990 |
|---|---|---|---|
| Angola | 1 | 1 | 0 |
| Argentina | 3 | 3 | 0 |
| Australia | 7 | 6 | 10 |
| Austria | 1 | 1 | 0 |
| Belgium | 4 | 3 | 5 |
| Bermuda | 0 | 0 | 1 |
| Brazil | 3 | 0 | 2 |
| Canada | 385 | 223 | 1,560 |
| China | 14 | 10 | 1 |
| Costa Rica | 6 | 0 | 2 |
| Denmark | 9 | 0 | 4 |
| Egypt | 2 | 0 | 0 |
| France | 118 | 67 | 50 |
| Germany, West | 875 | 227 | 288 |
| Hong Kong | 0 | 0 | 4 |
| India | 5 | 0 | 1 |
| Ireland | 13 | 13 | 0 |
| Israel | 28 | 13 | 17 |
| Italy | 56 | 18 | 72 |
| Japan | 147 | 47 | 37 |
| Korea, South | 60 | 5 | 54 |
| Kuwait | 1 | 1 | 0 |
| Malaysia | 2 | 1 | 7 |
| Mexico | 7 | 4 | 36 |
| Netherlands | 36 | 30 | 6 |
| New Zealand | 8 | 1 | 0 |
| Nigeria | 0 | 0 | 1 |
| Norway | 7 | 0 | 11 |
| Philippines | 1 | 0 | 0 |
| Poland | 1 | 0 | 0 |
| Portugal | 3 | 0 | 0 |
| Saudi Arabia | 1 | 0 | 2 |
| Singapore | 50 | 18 | 39 |
| Soviet Union | 1 | 0 | 1 |
| Spain | 12 | 3 | 11 |
| Sri Lanka (Ceylon) | 13 | 13 | 0 |
| Suriname | 0 | 0 | 12 |
| Sweden | 24 | 0 | 34 |
| Switzerland | 93 | 11 | 57 |
| Taiwan | 64 | 57 | 2 |
| United Arab Emirates | 1 | 1 | 0 |
| United Kingdom | 161 | 84 | 62 |
| Venezuela | 2 | 0 | 1 |
| World | 2,225 | 861 | 2,390 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

Table 4.--U.S. trade data
Flow: Domestic exports
Type: F.a.s. value
HS commodity: 8479908040--Parts of industrial robots
(Thousands of dollars)

| Partner / Time period | 1989 | January-May 1989 | January-May 1990 |
|---|---|---|---|
| Argentina | 0 | 0 | 7 |
| Australia | 0 | 0 | 31 |
| Belgium | 0 | 0 | 37 |
| Canada | 0 | 0 | 6,944 |
| China | 0 | 0 | 43 |
| Colombia | 0 | 0 | 60 |
| Ecuador | 0 | 0 | 6 |
| Finland | 0 | 0 | 5 |
| France | 0 | 0 | 335 |
| Germany, West | 0 | 0 | 1,629 |
| Hong Kong | 0 | 0 | 4 |
| India | 0 | 0 | 5 |
| Italy | 0 | 0 | 133 |
| Japan | 0 | 0 | 388 |
| Korea, South | 0 | 0 | 3,200 |
| Luxembourg | 0 | 0 | 3 |
| Malaysia | 0 | 0 | 8 |
| Mexico | 0 | 0 | 10 |
| Netherlands | 0 | 0 | 16 |
| Nigeria | 0 | 0 | 19 |
| Philippines | 0 | 0 | 3 |
| Poland | 0 | 0 | 111 |
| Portugal | 0 | 0 | 38 |
| Republic of South Africa | 0 | 0 | 20 |
| Saudi Arabia | 0 | 0 | 18 |
| Singapore | 0 | 0 | 97 |
| Spain | 0 | 0 | 98 |
| Sweden | 0 | 0 | 45 |
| Switzerland | 0 | 0 | 166 |
| Taiwan | 0 | 0 | 18 |
| Turkey | 0 | 0 | 8 |
| United Kingdom | 0 | 0 | 959 |
| Venezuela | 0 | 0 | 44 |
| World | 0 | 0 | 14,505 |

Source: Compiled from official statistics of the U.S. Department of Commerce.

# APPENDIX

# "C"

# INSTALLED ROBOTS IN SELECTED COUNTRIES

INSTALLED INDUSTRIAL ROBOTS, SELECTED COUNTRIES, 1981-1989

| COUNTRY | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|---|---|---|---|
| AUSTRALIA | 181 | | | 528 | | 800 | 925 | 1200 | 1350 |
| BELGIUM | 242 | 361 | 514 | 775 | 975 | 1035 | 1117 | 1231 | |
| CZECHOSLOVAKIA | | | | | | | | 5691 | |
| FRANCE | 790 | 1385 | 1920 | 2750 | 4150 | 5270 | 6577 | 8026 | |
| GERMANY | 2300 | 3500 | 4800 | 6600 | 8800 | 12400 | 14900 | 17700 | 22395 |
| ITALY | 450 | 1000 | 1510 | 2600 | 4000 | 5000 | 6600 | 8300 | |
| JAPAN | 21000 | 32000 | 47000 | 67000 | 93000 | 116000 | 141000 | 176000 | 219000 |
| SPAIN | | | 433 | 525 | 688 | 859 | 1149 | 1382 | |
| SWEDEN | 1125 | 1273 | 1452 | 1745 | 2046 | 2383 | 2750 | 3042 | 3463 |
| USSR | | | | | 34068 | 44071 | 53115 | 59218 | 62339 |
| UNITED KINGDOM | 713 | 1152 | 1753 | 2623 | 3208 | 3683 | 4303 | 5034 | |
| UNITED STATES | 6000 | 7000 | 8000 | 13000 | 20000 | 25000 | 29000 | 32600 | 37000 |
| ALL OTHER | 130 | 435 | 779 | 1231 | 1810 | 2951 | 3696 | 4814 | |
| TOTAL | 32931 | 48106 | 68161 | 99377 | 172745 | 219452 | 265132 | 324238 | |

YEAR TO YEAR PERCENT CHANGE, INDUSTRIAL ROBOTS

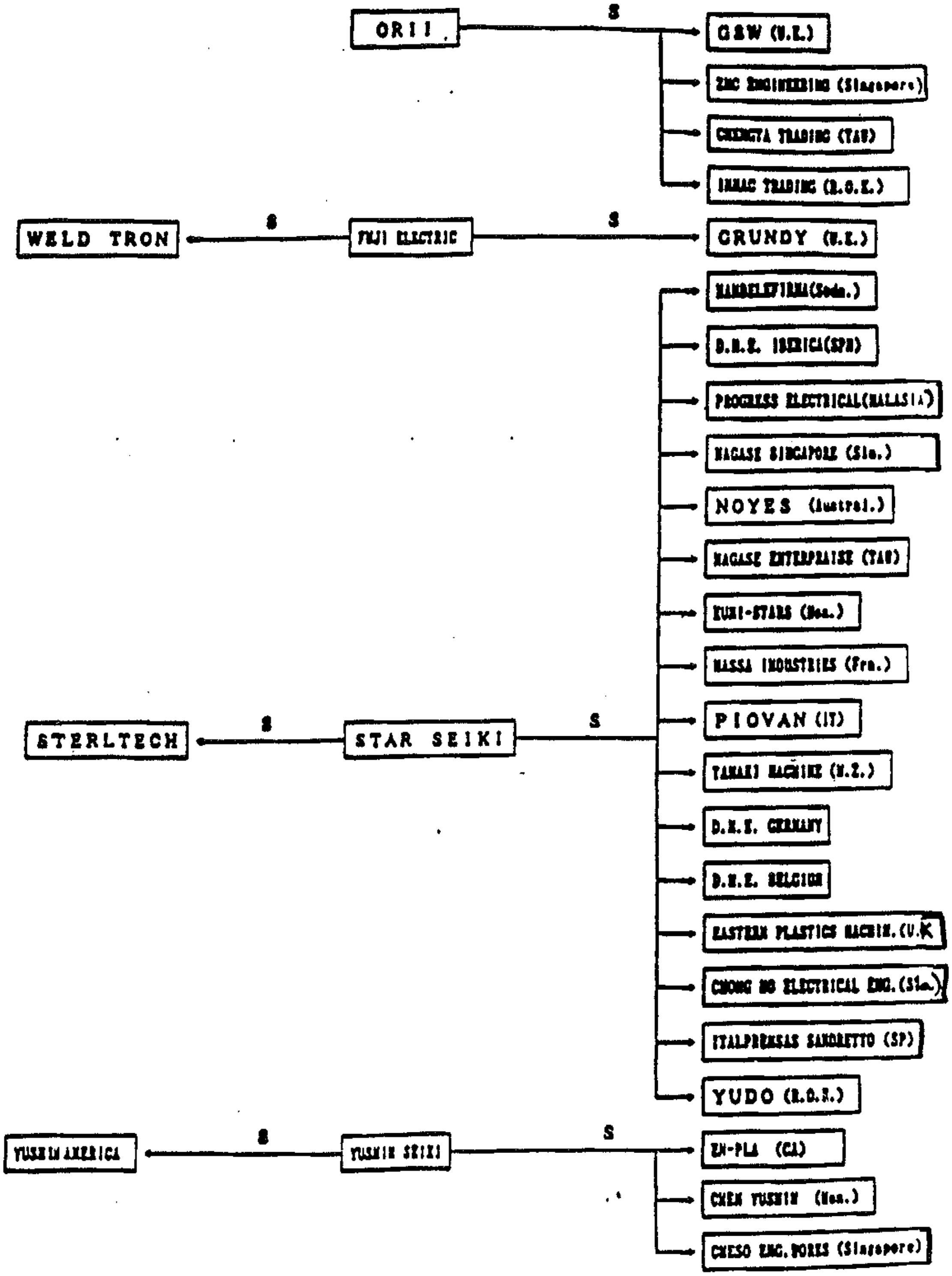
| COUNTRY | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 |
|---|---|---|---|---|---|---|---|---|
| BELGIUM | 49.2% | 42.4% | 50.8% | 25.8% | 6.2% | 7.9% | 10.2% | |
| FRANCE | 75.3% | 38.6% | 43.2% | 50.9% | 27.0% | 24.8% | 22.0% | |
| GERMANY | 52.2% | 37.1% | 37.5% | 33.3% | 40.9% | 20.2% | 18.8% | 26.5% |
| ITALY | 122.2% | 51.0% | 72.2% | 53.8% | 25.0% | 32.0% | 25.8% | |
| JAPAN | 52.4% | 46.9% | 42.6% | 38.8% | 24.7% | 21.6% | 24.8% | 24.4% |
| SWEDEN | 13.2% | 14.1% | 20.2% | 17.2% | 16.5% | 15.4% | 10.6% | 13.8% |
| UNITED KINGDOM | 61.6% | 52.2% | 49.6% | 22.3% | 14.8% | 16.8% | 17.0% | |
| UNITED STATES | 16.7% | 14.3% | 62.5% | 53.8% | 25.0% | 16.0% | 12.4% | 13.5% |
| FOR LISTED COUNTRIES | 46.1% | 40.4% | 45.0% | 40.3% | 25.4% | 20.8% | 22.2% | 22.9% |

Source: U.N. Economic and Social Council, July 1990

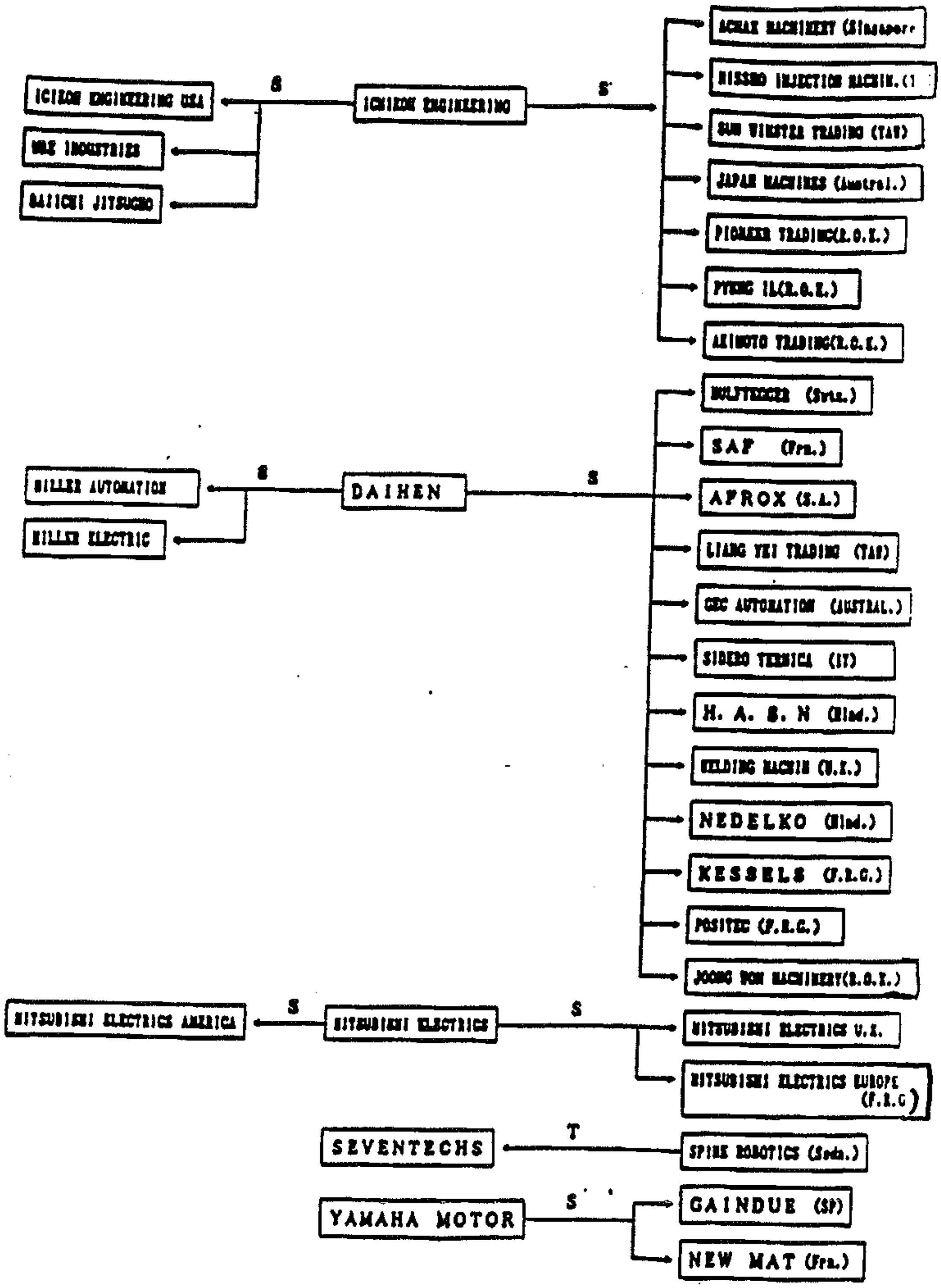
# APPENDIX

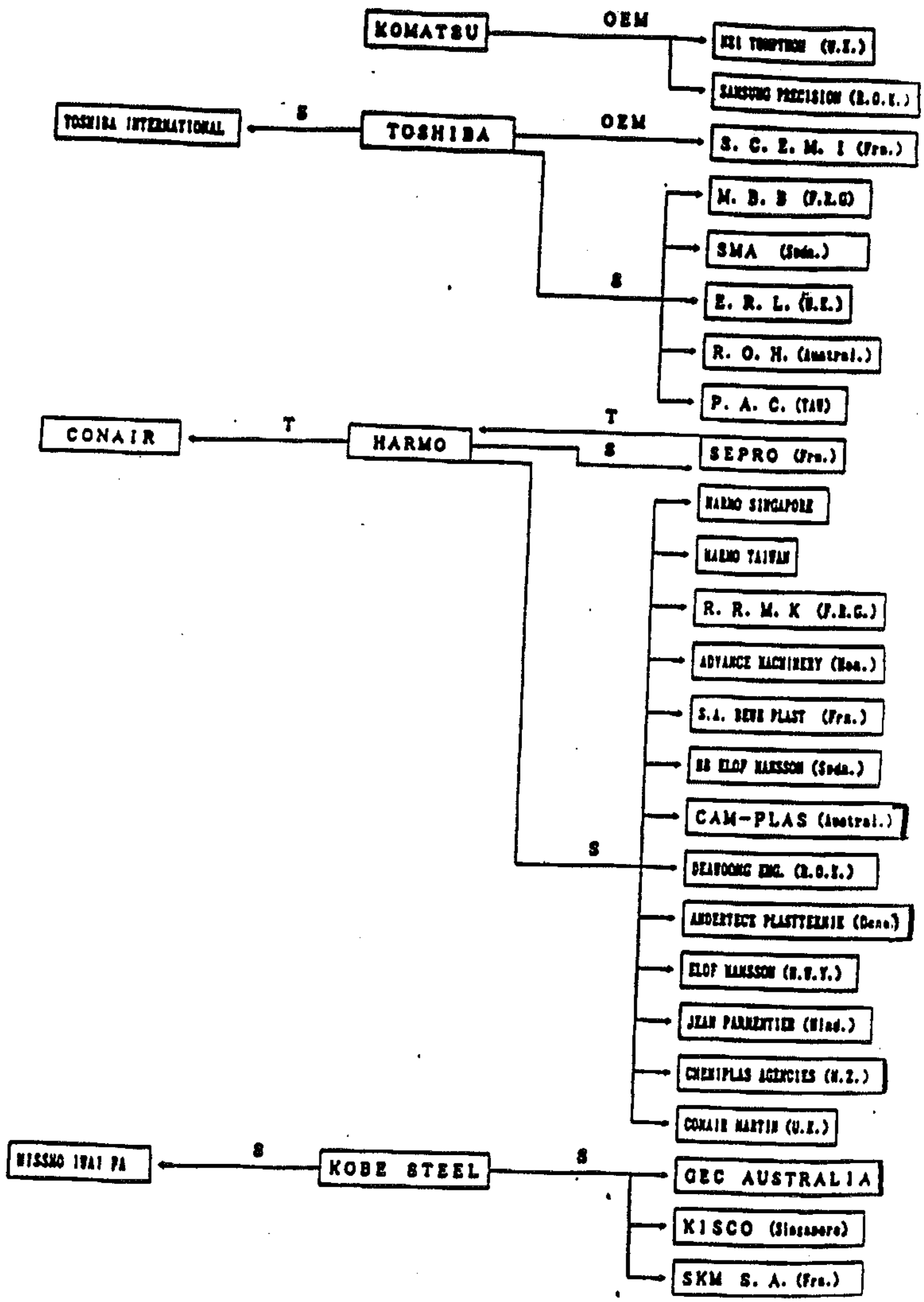
# "D"

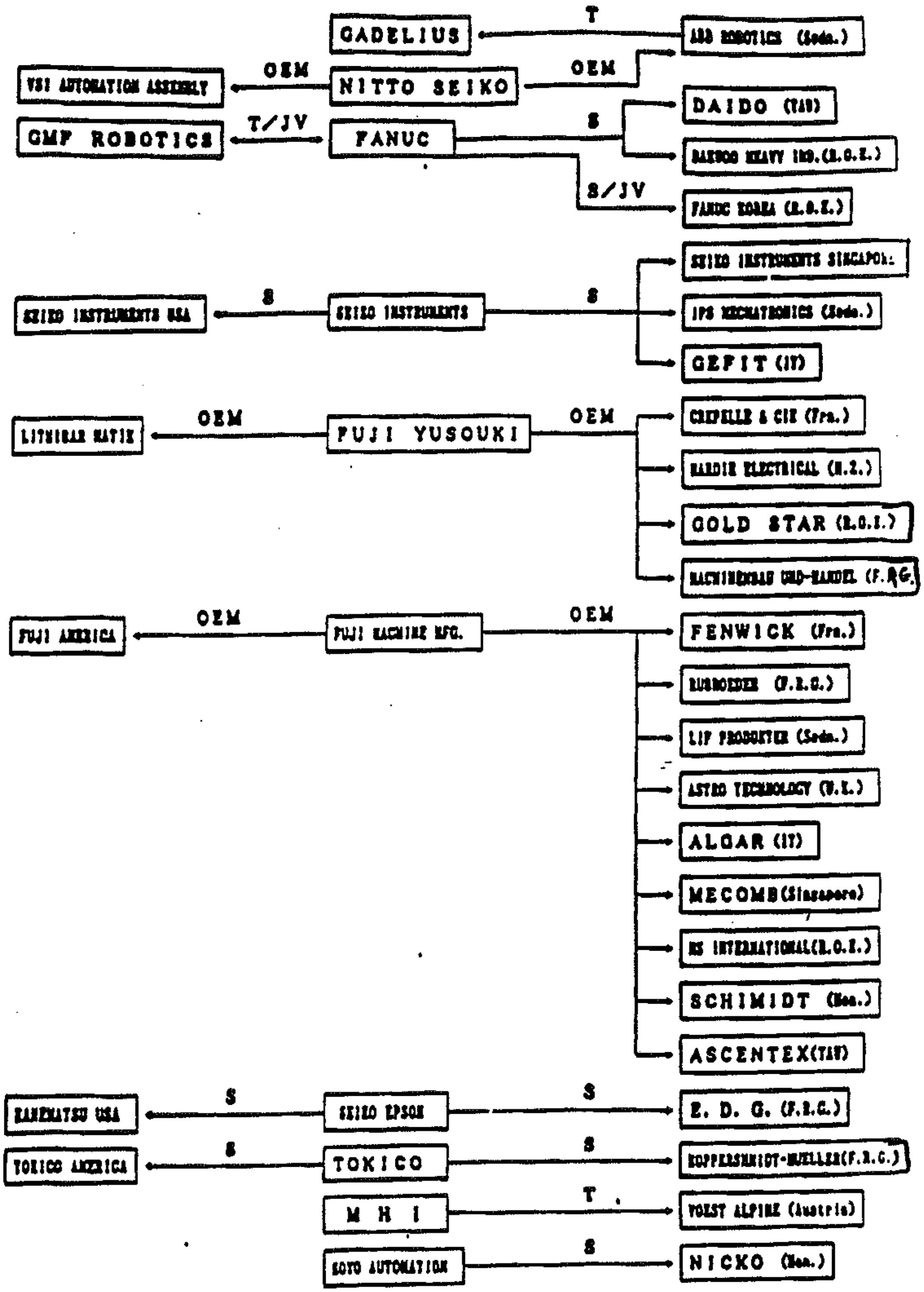
# INTERNATIONAL COOPERATIVE AGREEMENTS



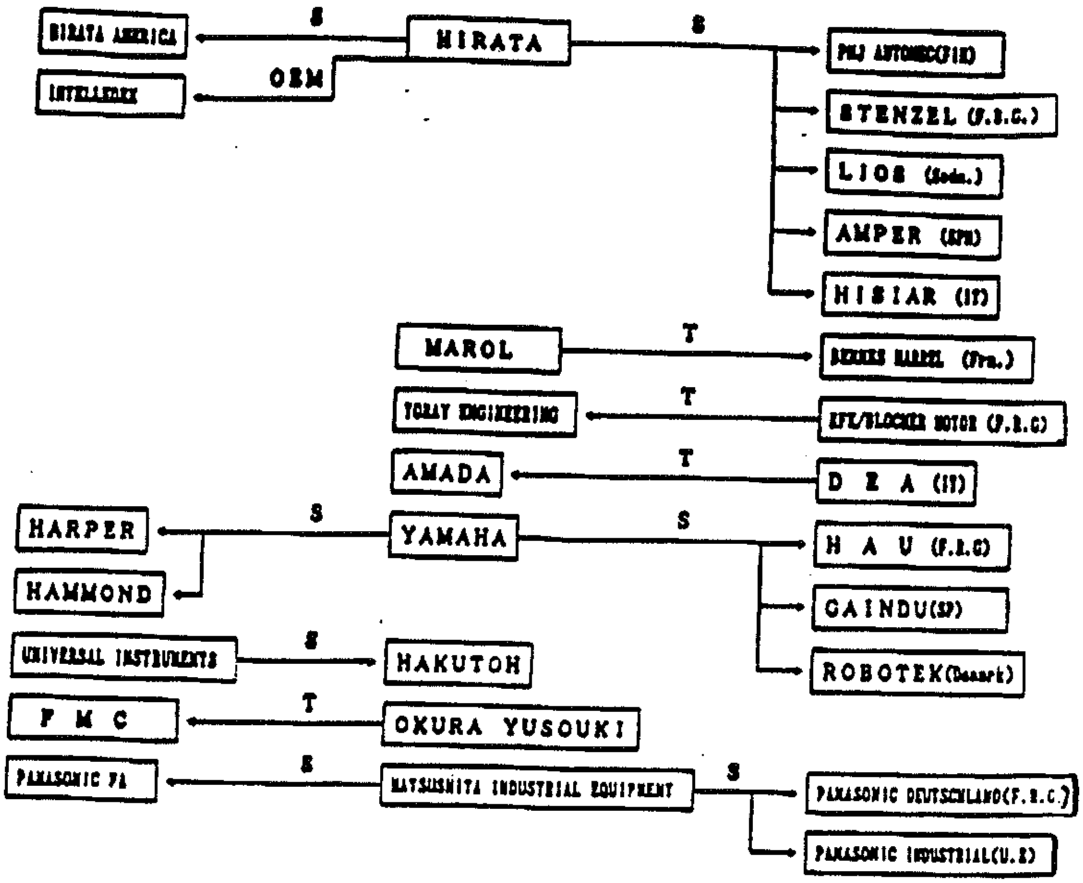
ORII
S
GSW (U.K.)
WELD TRON
S
FUJI ELECTRIC
S
GRUNDY (U.K.)
D.M.E. IBERICA(SPN)
PROGRESS ELECTRICAL(MALASIA)
NAGASE SINGAPORE (Sin.)
NOYES (Austral.)
MASSA INDUSTRIES (Fra.)
PIOVAN (IT)
STERLTECH
S
STAR SEIKI
S
D.M.E. GERMANY
D.M.E. BELGIUM
EASTERN PLASTICS MACHIN. (U.K
ITALPRESSAS SANDRETTO (SP)
YUDO
YUSHIN AMERICA
S
YUSHIN SEIKI
S
EN-PLA (CA)
CHEN YUSHIN


ICHIKOH ENGINEERING USA
DAIICHI JITSUGYO
S
ICHIKOH ENGINEERING
S
PIONEER TRADING(R.O.K.)
AKIMOTO TRADING(R.O.K.)
MILLER AUTOMATION
MILLER ELECTRIC
S
DAIHEN
S
SAF (Fra.)
AFROX (S.A.)
LIANG YEI TRADING (TAI)
GEC AUTOMATION (AUSTRAL.)
SIDERO TEKNICA (IT)
H. A. S. N (Hld.)
WELDING MACHIN (U.K.)
NEDELKO (Hld.)
KESSELS (F.R.G.)
POSITEC (F.R.G.)
JOONG WON MACHINERY(R.O.K.)
MITSUBISHI ELECTRICS AMERICA
S
MITSUBISHI ELECTRICS
S
MITSUBISHI ELECTRICS U.K.
MITSUBISHI ELECTRICS EUROPE (F.R.G)
SEVENTECHS
T
SPINE ROBOTICS (Swdn.)
YAMAHA MOTOR
S
GAINDUE (SP)
NEW MAT (Fra.)


KOMATSU
OEM
SAMSUNG PRECISION
TOSHIBA INTERNATIONAL
S
TOSHIBA
OEM
S. C. E. M. I (Fra.)
M. B. B
SMA
S
E. R. L.
R. O. H. (Austral.)
P. A. C.
CONAIR
T
HARMO
T
S
SEPRO
HARMO SINGAPORE
HARMO TAIWAN
R. R. M. K (F.R.G.)
ADVANCE MACHINERY
S.A.
(Fra.)
CAM-PLAS (Austral.)
S
JEAN PARMENTIER
CONAIR MARTIN (U.K.)
S
KOBE STEEL
S
GEC AUSTRALIA
KISCO
SKM S. A. (Fra.)



GADELIUS
T
ABB ROBOTICS (Swdn.)
VSI AUTOMATION ASSEMBLY
OEM
NITTO SEIKO
OEM
DAIDO (TAW)
GMF ROBOTICS
T/JV
FANUC
S
DAEWOO HEAVY IND. (R.O.K.)
S/JV
FANUC KOREA (R.O.K.)
SEIKO INSTRUMENTS USA
S
SEIKO INSTRUMENTS
S
SEIKO INSTRUMENTS SINGAPORE
IPS MECHATRONICS (Swdn.)
GEFIT (IT)
OEM
FUJI YUSOUKI
OEM
CREPELLE & CIE (Fra.)
HARDIE ELECTRICAL (N.Z.)
GOLD STAR (R.O.K.)
FUJI AMERICA
OEM
FUJI MACHINE MFG.
OEM
FENWICK (Fra.)
LIF PRODUKTER (Swdn.)
ASTRO TECHNOLOGY (U.K.)
ALGAR (IT)
MECOMB (Singapore)
KS INTERNATIONAL (R.O.K.)
SCHIMIDT
ASCENTEX (TAW)
KANEMATSU USA
S
SEIKO EPSON
S
E. D. G. (F.R.G.)
TOKICO AMERICA
S
TOKICO
S
KOPPERSCHMIDT-MUELLER (F.R.G.)
M H I
T
VOEST ALPINE (Austria)
S
NICKO



HIRATA AMERICA
S
HIRATA
OEM
S
STENZEL (F.R.G.)
LIOS (Swdn.)
AMPER (SPN)
HISIAR (IT)
MAROL
T
TORAY ENGINEERING
T
AMADA
T
D E A (IT)
HARPER
HAMMOND
S
YAMAHA
S
H A U (F.R.G)
GAINDU(SP)
ROBOTEK
UNIVERSAL INSTRUMENTS
S
HAKUTOH
F M C
T
OKURA YUSOUKI
PANASONIC FA
S
MATSUSHITA INDUSTRIAL EQUIPMENT
S
PANASONIC DEUTSCHLAND(F.R.G.)
PANASONIC INDUSTRIAL(U.K)

# APPENDIX

# "A"

# SURVEY INSTRUMENT

7. Before returning your completed questionnaire, be sure to sign the certification and identify the person and a phone number should we need to contact your firm. Return completed questionnaire to:

Mr. Brad Botwin, Director
Strategic Analysis Division
Office of Industrial Resource Admin.
Room 3878, BXA
U.S. Department of Commerce
Washington, D.C. 20230

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## DEFINITIONS

**ESTABLISHMENT** - All facilities in which robots are produced. Includes auxiliary facilities operated in conjunction with (whether or not physically separate from) such production facilities. Does not include wholly-owned distribution facilities.

**FIRM** - An individual proprietorship, partnership, joint venture, association, corporation (including any subsidiary corporation in which more than 50 percent of the outstanding voting stock is owned), business trust, cooperative, trustees in bankruptcy, or receivers under decree of any court, owning or controlling one or more establishments as defined above.

**PRACTICAL CAPACITY** - (For purposes of determining capacity utilization in question #1 of Part II, please consider the following.) Sometimes referred to as engineering or design capacity, this is the greatest level of output a robot manufacturing establishment can achieve within the framework of a realistic work pattern. In estimating practical capacity, take into account the following considerations:

1. Under most circumstances assume your 1989 product mix. If no production took place in 1989 of a particular item or items which you have, or will have the capability to produce and can anticipate receiving orders for in the future, include a reasonable quantity as part of your 1989 product mix.

   ...sider only the machinery and equipment in place and ready to operate. Do not consider facilities which have been inoperative for a long period of ... and, therefore, require extensive reconditioning before they can be made operative.

3. Take into account the additional downtime for maintenance, repair, or clean-up which would be required as you move from current operations to full capacity.

4. Do not consider overtime pay, added costs for materials, or other costs to be limiting factors in setting capacity.

5. Although it may be possible to expand plant output by using productive facilities outside of the plant, such as by contracting out subassembly work, do not assume the use of such outside facilities in greater proportion than has been characteristic of your operations.

**PRODUCTION WORKERS** - Persons, up through the line supervisor level, engaged in fabricating, processing, assembling, inspecting, receiving, storing, handling, packing, warehousing, or shipping. In addition, persons engaged in supporting activities such as maintenance, repair, product development, auxiliary production for your firm's own use, record keeping, and other services closely associated with production operations at your firm. Employees above the working supervisor level are excluded from this item.

**RESEARCH AND DEVELOPMENT** - Research and development includes basic and applied research in the sciences and in engineering, and design and development of prototype products and processes. For the purposes of this questionnaire, research and development includes activities carried on by persons trained, either formally or by experience, in the physical sciences including related engineering, if the purpose of such activity is to do one or more of the following things:

1. Pursue a planned search for new knowledge, whether or not the search has reference to a specific application.

2. Apply existing knowledge to problems involved in the creation of a new product or process, including work required to evaluate possible uses.

3. Apply existing knowledge to problems involved in the improvement of a present product or process.

**ENGINEERS** - Persons engaged in research and development work or production operations that have at least a four-year college education in the physical sciences or engineering.

**SHIPMENTS** - Report unit and dollar values of domestically produced robots shipped by your firm from 1985-1989 for each equipment category listed for ...tions in Part III. The value of components sourced from other manufacturers that are included in your end product should also be included in ...nt values. Such shipments should include inter-plant or intra-plant transfers, but should exclude shipments of products produced by other ...facturers for resale under your brand name. Do not adjust for returned shipments.

**UNITED STATES** - The term "United States" includes the fifty States, Puerto Rico, the District of Columbia, and the Virgin Islands.

FORM BXA-0062

U.S. Department of Commerce
Bureau of Export Administration

OMB Approval Not Required: less than 10 respondents

# NATIONAL SECURITY ASSESSMENT OF ROBOTICS MANUFACTURERS

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## THIS REPORT IS REQUIRED BY LAW

Failure to report can result in a maximum fine of $1,000 or imprisonment up to one year, or both. Information furnished herewith is deemed confidential and will not be published or disclosed except in accordance with Section 705 of the Defense Production Act of 1950, as amended (50 U.S.C. App. Sec. 2155).

## GENERAL INSTRUCTIONS

1. Please complete this questionnaire in its entirety as it applies to U.S. robbotic manufacturing and related operations. **Your response is due by March 23, 1990.** The survey has seven parts as follows:

   Part I: FIRM IDENTIFICATION
   Part II: PRODUCTION CAPABILITIES AND FOREIGN DEPENDENCE
   Part III: SHIPMENTS AND EXPORTS
   Part IV: TECHNOLOGY
   Part V: APPLICATIONS AND MARKETS
   Part VI: FINANCIAL INFORMATION
   Part VII: COMPETITIVENESS

2. Complete Part II separately for each of your establishments that produce robotic equipment in the United States. Please make photocopies of this section if additional pages are needed.

3. For Parts I, III, IV, V, VI and VII, firms operating more than one establishment may combine the data for all establishments into a single report. Any necessary comments or explanations should be supplied in the space provided or on separate sheets attached to this questionnaire. Ensure that you reference the proper question if you use extra sheets. If any answer is "none", please indicate.

4. It is not our desire to impose an unreasonable burden on any respondent. IF INFORMATION IS NOT READILY AVAILABLE FROM YOUR RECORDS IN EXACTLY THE FORM REQUESTED, FURNISH ESTIMATES AND DESIGNATE BY THE LETTER "E".

5. Information furnished in response to this questionnaire will be treated as proprietary and will not be published or divulged to reveal the operations of individual firms.

6. Questions related to the questionnaire should be directed to Ms. Rebecca Racosky, Trade and Industry Analyst, at (202) 377-2322, or Mr. Pat McGibbon, Industry Specialist, at (202) 377-0315, Department of Commerce.

PART I. FIRM IDENTIFICATION (continued)

5. U.S. MANUFACTURING ESTABLISHMENT LOCATIONS: For each model (domestic or foreign) provide the following information (make copies of this page for each model):

MODEL ____________________ FUNCTION ____________________

PRODUCTION FACILITY ____________________ ________ ________
City State Zip

| COMPONENT | TYPE | PRODUCED IN-HOUSE | COMPONENT SUPPLIER | DOMESTIC/ FOREIGN |
|---|---|---|---|---|
| Manipulator (cylindrical, spherical, etc.) | ______ | ______ | ______ | ______ |
| Power Supply (electric, pneumatic, etc.) | ______ | ______ | ______ | ______ |
| Control System (fixed, point-to-point, etc.) | ______ | ______ | ______ | ______ |
| Accessories & Peripherals (please list) | | | | |
| ______ | ______ | ______ | ______ | ______ |
| ______ | ______ | ______ | ______ | ______ |
| ______ | ______ | ______ | ______ | ______ |

PART I. FIRM IDENTIFICATION

1. COMPANY ADDRESS: Please provide the name and address of your firm or corporate division.

______________________________

______________________________

______________________________

2. PARENT FIRM: If your firm is wholly or partly owned by another firm, indicate the name and address of the parent firm and extent of ownership.

______________________________

______________________________

______________________________

Ownership:________%

3. BUY/SELL SOLICITATIONS: If your firm has received inquiries or solicitations from another firm about purchasing or merging robotics operations; or, if you have offered or solicited bids to sell these operations in the last year or plan to do so in the next year, please describe below the circumstances, naming the firm(s) involved, the parts of your assets in the consideration, the purchase/selling price offered, and the reason the solicitation took place.

______________________________

______________________________

______________________________

4. R & D FACILITY: If you have a separate facility(ies) or building dedicated to robotics research and development, please provide the facility's address and current number of full time employees below.

Address:______________________ Full Time Employment:__________

______________________

______________________

PART I. FIRM IDENTIFICATION (continued)

6. DOMESTIC AND FOREIGN RELATIONSHIPS: In the space provided below, please list the joint ventures, partnerships, teaming efforts, licenses, marketing agreements, or other arrangements you have associated with your robotics operations with domestic and foreign firms.

DOMESTIC:

| Type Relationship | U.S. Partner's Name | Primary Activity |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

FOREIGN:

| Type Relationship | Foreign Partner's Name | Country | Primary Purpose of Relationship |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

## PART II. PRODUCTION CAPABILITY AND FOREIGN DEPENDENCE

1. PRODUCTION AND CAPACITY UTILIZATION. (Complete Part II for each U.S. establishment. Make copies of this page as necessary. See also definition of PRACTICAL CAPACITY.)

Establishment: ______________________________

| | 1989 Unit Production | 1989 Production Value ($000) | 1989 Capacity Utilization | Estimated 1989 Market Share | Estimated 1989 Import Penetration |
|---|---|---|---|---|---|
| **WELDING** | | | | | |
| Spot/Resistance | ________ | ________ | ________ | ________ | ________ |
| Arc | ________ | ________ | ________ | ________ | ________ |
| Other | ________ | ________ | ________ | ________ | ________ |
| **ASSEMBLY** | ________ | ________ | ________ | ________ | ________ |
| **MATERIAL HANDLING** | | | | | |
| Palletizing | ________ | ________ | ________ | ________ | ________ |
| Machine Loading/Unloading | ________ | ________ | ________ | ________ | ________ |
| Storage and Retrieval | ________ | ________ | ________ | ________ | ________ |
| Other | ________ | ________ | ________ | ________ | ________ |