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THE ROBOT FACTOR: TOWARDS AN INDUSTRIAL ROBOTICS PROGRAM FOR CANADA

Zavis P. Zeman
with Balu Swaminathan

Institute for Research on Public Policy
Montreal

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"We used to kid each other about robots that build robots. But no more... it is here, it is here."

W. Winnpissinger,
President, International Association
of Machinists & Aerospace Workers (USA)

IRPP Conference, Toronto, March 1981

DEDICATION

To Karel Capek, who gave us the word robot.

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EXECUTIVE SUMMARY

This report surveys the field of industrial robotics and discusses the opportunities and challenges for Canada emerging from the recent advances in the field.

Chapter One first defines and describes industrial robots. They differ from other automatic machines in one very important respect: robots are reprogrammable and thus multifunctional. Unlike "hard" automatic which can be made to perform more than one task only with extensive retooling, a robot can be switched from one task to another within minutes by a change of program.

While it is difficult to classify all 2000 types of robots, the sophistication of the control system serves to distinguish three main types: the pick-and-place, the servo-controlled and the computer-controlled. The pick-and-place is an unsophisticated robot on the borderline of "hard" automation, merely capable of repeating a fixed number of motions with slight variations. The servo-controlled is a more dexterous robot able to control the path and speed of the movement of its parts. The computer-controlled robot is the most sophisticated type with an ability to store numerous programs and, thereby perform various operations.

A new generation of "smart" robots which can "see" or "feel" are now in the development stage. A number of vision systems have been designed and constructed, with varying degrees of success. Likewise, efforts to give robots tactile capability have advanced considerably, thus enabling them to "touch" and "feel" the parts with which they work. Beyond "seeing" and "touching", robots that can "hear" that is recognize voice and follow speech instructions, are appearing on the horizon. Such advances in robotics promise the introduction of factories where robots would join other computer-operated machines to mass-manufacture goods with minimal direct human assistance.

Chapter One next deals with current as well as foreseeable robot applications. The use of robots in the automotive industry, chiefly in welding of automobile bodies, spray-painting and transfer of bumpers and other parts, is by now well known. The second leading user-industry is metalworking where robots are used mainly in die-casting, forging and investment-casting operations. In heavy manufacturing, robots find their use in industrial finishing (sanding and polishing) and spray-painting. In light manufacture, the appliance and plastics industries use robots widely. Robots are also used for drilling and routing of aircraft fuselage panels and picking and placing of parts in the electrical and electronics industries.

Foreseeable applications include welding of 3-D structures in the ship-building industry, digging and loading in the construction industry and drilling and blasting in the mining industry. Robots may come to be used extensively for handling explosive materials in the munitions industry and radioactive materials in the nuclear industry. Among more exotic applications, (described in Appendix D), robots are either now in use or planned for use in underwater operations and space exploration.

Chapter Two describes the robotics scene in Canada. With an estimated 200 robots installed, half of which have been introduced since 1980, Canada lags far behind a number of other major industrial nations. As in the U.S., the automakers are the leading employers. On the manufacturing side, Canadian General Electric has announced plans to produce robots and a number of other Canadian companies are showing interest. The National Research Council provides modest financial assistance and McMaster University leads academic institutions in robotics research.

Chapter Three surveys the world-wide robotics industry. A number of factors have combined in the last few years to boost interest in robots. These include rising labour costs, improved robot performance, and growing concern for occupational health and safety. There are, today, 130 companies in Japan, 27 in the United States and 33 in the Common Market countries engaged in robot manufacture. Trends indicate a multi-billion dollar industry developing by 1990.

The United States robot market has grown from $21 million in 1977 to $60 million in 1979 and $90 million in 1980. While still miniscule by U.S. standards, sales are expected to reach $700 million by 1985 and $2.2 billion by 1990.

Unimation Inc., with about half the market, is the leading manufacturer: others include Cincinnati Milacron, Auto-place Inc. and Prab Conveyors. The automotive industry employs more than 700 of the 3,000 industrial robots in the United States. Westinghouse and General Electric, are also leading users: the latter plans to introduce a large number of robots as part of a major automation program. A number of research laboratories including Stanford Research Institute, Massachussets Institute of Technology and Carnegie-Mellon's Robot Institute have major projects in the field. Government's involvement is represented by the multi-million dollar ICAM (Intergrated Computer Aided Manufacturing) project.

The European market for robots is expected to grow as rapidly in the 1980s as those of the U.S. and Japan. West Germany and Sweden are the largest employers of robots, while ASEA of Sweden and Trallfa of Norway are the best known European models. Italy, Britain and France are making serious efforts to enter the robot market, and to encourage their use by industry. Among the Comecon nations, East Germany leads in research and development while Poland leads in the number of robots employed.

Japan leads the world both in robot manufacture and industrial use. In 1980 alone, 12,000 robots were produced in the country, a 50 per cent increase over 1979. The annual growth rate is expected to continue at that level throughout the eighties. Large and small industrial concerns alike have employed robots. Among the most exciting applications is the automated factory of Fujitsu-Fanuc where robots make other robots. A notable feature of Japanese efforts in this field - as in others - is the high degree of co-operation between government and industry. There are many government-industry joint projects aimed at advancing Japanese technological supremacy in industrial robotics.

Chapter Four discusses the implications and possible benefits of the "robot revolution" for Canada. Because robots are very well suited for the short production-runs of small and medium-sized manufacturers, so typical of Canadian industry, they offer the possibility of contributing towards a workable national industrial strategy. They promise substantial increases in productivity and may relieve Canadian workers from the hardships of such hazardous work environments as metalworking and mining. While the use of robots will undoubtedly lead towards some loss of jobs, in the longer run the direct unemployment effects are likely to be small. And we would argue that the failure to robatize in the 1980s could render whole industries uncompetitive internationally which would certainly entail large scale unemployment.

Chapter Five briefly describes the robotics supporting programs of some other industrial nations and argues that the Canadian government should provide similar leadership in this important area. Three possible government attitudes are compared: laissez-faire, a positive policy framework and finally a National Industrial Robotics Program. Such a program, which Chapter Six recommends and outlines, would have the following elements:

(1) Industrial Education
(2) Rapid Application of Industrial Robotics
(3) Support for Small and Medium Companies through a Canadian Robot Leasing Facility
(4) Robot software Support
(5) End Effectors and Sensors Development
(6) Robot Hardware Manufacture Scheme
(7) Research and Development Support
(8) Manpower Development
(9) Strengthening Government Programs
(10) Workplace Adjustment.

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This study is one of a number of probes into some foreseeable economic and social impacts of probable technological changes in Canada. It forms part of the Institute's Technology and Society Program, directed by Zavis P. Zeman. The study was mainly supported by a research grant under the Technological Innovation Studies Program of the Department of Industry, Trade and Commerce, Government of Canada. The Canadian National Limited has also contributed towards the cost of the study. The report was edited by R. Miller. Professor Gunter R. Rao and Professor J.V. Svobada, both of Concordia University, Montreal, read the technical sections of the report.

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The views presented in this report should not be interpreted as those of the Government of Canada, Canadian National or the Institute: they represent the views of the authors alone.

INTRODUCTION

THE ROBOT CHALLENGE

Throughout the industrialized world, the robot is going to work. At last count, the world robot population had grown to over 25,000 from about 3,500 only five years ago. What explains the dramatic increase? There are both economic and social reasons.

Economically, robots are attractive workers. They can do work that humans would "rather not" and they are well suited to short production runs which now account for some three quarters of all manufacturing. They can work three shifts a day without slowing down: their "up time" on the job averages around 95 per cent compared to 75 per cent for the average industrial worker. They can be "employed" for as little as $5.00 an hour and, with the benefit of inexpensive micro-computers, easily retrained.

Socially, the robot is utterly indifferent to the monotony and discomfort of manufacturing. By contrast an increasingly well-educated human work force in the industrialized countries is unwilling to accept such jobs. There is, in general, a greater awareness of health hazards and safety risks in the work place. In some cases human operators cannot be employed to perform the tasks they once did.

It is not surprising, then, that may industrialized countries see the robot as an answer to their productivity problems. Japan, the U.S., and a number of West and Eastern European countries are moving rapidly to exploit the promise of the robot, to arrest declining productivity and to increase international competitiveness. The Japanese lead the world with about 15,000 robots currently in operation: the U.S., with 4,000, is a distant second.

Canada lags far behind these countries with a little more than two hundred robots installed. There exists only one robot manufacturer in the country. More fundamentally, Canada does not have a national robot program as do Japan and some other nations. Research and development activities are focused more on basic research than on commercial development.

This state of affairs should concern those charged with responsibility for developing Canadian industry and technology. Robots present immense possibilities and a promising solution for many of Canada's persistent manufacturing production problems, especially those associated with short production runs. Robots ensure more reliable production and better utilization of plant and materials: they are found to increase output by anywhere from 25 to 100 per cent. Given the relatively short pay-back period, use of robots in manufacturing can be expected to yield large savings. Finally, unless robots and other flexible automation systems are widely used, Canadian competitiveness in the international market is bound to be adversely affected.

The purpose of this report is to look into these and other possible consequences for Canada arising from robotics. Chapter One of the report will describe what robots are, their general characteristics and types and the range of current and foreseeable robot applications. Chapter Two will deal with the robotics industry in Canada, and Chapter Three will contrast it with the world-wide developments in robotics. Chapter Four will focus on the consequences of encouraging or discouraging the use of robots in Canada. Chapter Five will discuss the public policy options and Chapter Six will recommend and outline a National Industrial Robotics Program.

CHAPTER ONE

ROBOTS: WHAT THEY ARE, WHAT THEY DO

The popular image of a robot is a mechanical man with superhuman powers. In fact robotmakers today have little interest in building a machine that looks or acts like a human being. Instead, they are building hulking, powerful, one-armed machines with computer memory, and hydraulic, pneumatic or electric musculature. These robots are destined, not to leap tall buildings in a single jump, but rather to perform dirty, dangerous, backbreaking, and boring jobs, oblivious to heat, fumes, noise or radiation. These are the industrial robots.

What distinguishes an industrial robot from other automatic machines commonly in use is its ability to perform multiple functions. A robot is readily adaptable, through computer re-programming, to a broad range of job assignments. Conventional automatic machines, by contrast, are usually "programmed" by mechanical stops or by gears or cams, a far more time consuming and inflexible process. The adaptability of the robot is easily illustrated. In machine tool operations, for instance, the robot can load, unload, operate with lathes, chuckers, drilling machines, grinders and so on: it can engage in palletizing, and effect machine-to-machine transfer.

Unlike such devices as prosthesis, exoskeletons and locomotion systems, robots have a capability to operate on their own because of their built in "intelligence." To put the matter in the formal language of the Robot Institute of America, a robot is "a reprogrammable, multifunctional manipulator "arm" designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks."

Robots are of course no more than one subclass of automation. However, because they carry out their multiple tasks in a way that resembles the human worker, industrial robots have acquired a certain mystique. For this reason, the authors thought it easier to communicate their views about the broader subject of computer aided manufacturing, supported by computer aided design (CAD/CAM) by focusing on more easily visualized robotics. It should be understood, however, that our views about robots reflect our views about the field of CAD/CAM as a whole.

Current Hardware

A robot consists of a hand-like device (gripper) connected to a mechanical arm, serviced by control and power sources. The arm may have from 3 to 7 "joints" or "degrees of freedom". A robot with seven degrees of freedom will have the capacity for three primary arm movements, and three end-of-arm movements. The seventh movement is the axis of motion of the entire robot (see figure 1.1). All of these freedoms endow the robot with its tasks in life: to manipulate tools or move materials. It needs to be emphasized however that there are many distinctions among the present generation of robots. Some 2,000 individual robots have been developed worldwide, though not many have survived industrial application. Among the survivors, one can discern three levels of sophistication having to do with their control: the simple pick-and-place robots, the servo-controlled, and the computer-controlled.[1]

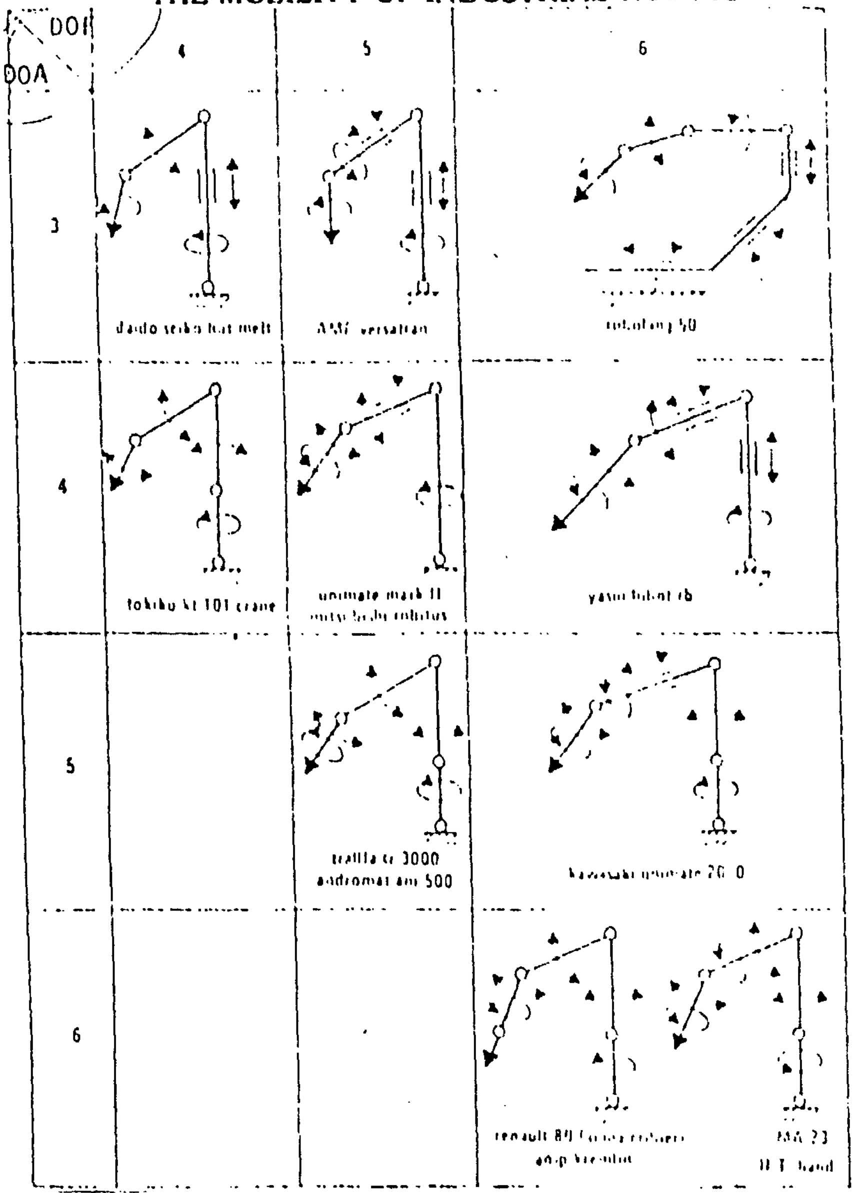
Pick-and-Place Devices

The pick-and-place robot is closely related to hard automation equipment which performs repetitive jobs at a faster than human pace. But whereas automated systems, such as those that fill bags, cap bottles, or roll cigarettes, cannot be changed easily, the pick-and-place robots have some programming capacity that enables them to alter the stops, speed and sequence of operations.

In its simplest form this robot is an arm with a gripper which can move up and down, back and forth, or sideways, to pick up an object, place it in a new position and return for another. The cycle continues, provided the geometry and placement of the parts remains the same. Means must be provided for moving parts to and from the robot.

FIGURE 1.1

THE MOBILITY OF INDUSTRIAL ROBOTS



Source: Revue des Automatismes.

Note: DOF=Degrees of Freedom
DOA=Degree of Articulations

The arm of the pick-and-place unit may operate either mechanically through bell cranks and cams or with air, hydraulic or electric actuators. The control, generally, is by means of an electronic unit - a common example being a microprocessor. At design speeds of up to 200 cycles per minute, this robot is a high-performance example of fixed automation. Commonly, a pick-and-place unit can handle no more than a 5-pound object and move it at most six to twelve inches although some can support loads of 30 to 40 pounds with an arm extension of 12 to 18 inches.

Servo-Controlled Devices

These are robots with devices which sense the positions of the various links and joints and transmit the information to a feedback control mechanism which provides adjustments to maximize the results from every operation. It is this feedback mechanism which distinguishes a servo-controlled robot from a Pick-and-Place.[2] Another feature of the servo-controlled is its memory capacity which is large enough to store many more positions than a simple Pick-and-Place robot. The feedback mechanism and memory permit control of the velocity, acceleration and deceleration of the various "joints" as they move between programmed points. This, in turn, facilitates smooth motions, regulated movement of heavy loads and considerable flexibility.

There are two types of servo-controlled robots: Point-to-Point and Continuous Path. Point-to-Point systems control the robot's movement from one distinct point in space to another with a number of stopping points in between[3]. (By contrast, a Pick-and-Place robot moves from one distinct point to another without any stops in between.) But point-to-point operation tends to be jerky because there is no provision for controlling the path and velocity of the end-effector from one stopping point to another. For this reason, point-to-point control is used for applications where only the final position is of interest and the path and velocity between points are not prime considerations.

The Continuous-Path system differs from the Point-to-Point in that positions are measured with respect to time and not merely as discretely determined points in space. Every motion taught by the operator is recorded and played back in the same manner and at the same speed.[4] Robots using this type of control are therefore capable of smooth, coordinated motion of their "joints" and, for this reason, higher end-of-arm speeds are achieved. In the point-to-point mode, the pattern traced by the robot's arm is craggy while in the Continuous-Path type, the traced curves are smooth. This smooth tracking permits application to such jobs as spotwelding, cutting or piercing by burning, and painting. On the other hand, the maximum load capacity is only 10 Kgs.

Both types of servo-controlled robots have their limitations. Many applications require characteristics of both. To achieve greater application flexibility, it is necessary to combine the smaller memory requirements and greater load capacity of the point-to-point control with the path control and ease of teaching found in the continuous path unit.

Computer-Controlled devices

The limitations of these systems and the capability of the computer provided the motivation to develop a new control system, commonly known as Controlled Path. It uses the computer to gain maximum control of the coordinated motions of the "joints". The computer also controls total position, velocity, and acceleration of the end-effector along a desired path between programmed points. The controlled-path system is an advancement over continuous-path system in two respects. First, the "joints" are coordinated in a manner which allows the operator to position and orient the end-effector at desired points without having to individually command each of the "joints". This feature permits teaching without having to physically lead the robot by hand. Second, the operator is not required to generate the desired path: he only programs the end-points. The computer then generates the controlled path at the desired velocity.[5]

The New Generation: Learning to See and Touch

We have briefly described the generation of robots already at work but a new generation of "smarter" robots is being born at various research and development centres throughout the industrialized world. Some of these are now straining to enter the industrial plant.

The present generation of robots suffers from the limitation that they cannot "look" for a part. They require that the pieces to be handled be of an expected size and shape and precisely located. They are very poor at adapting to the unexpected. The new generation of robots are being fitted with sensory systems to locate and orient parts as required. By means of a memory device linked to TV eyes, some are acquiring an ability to select, sort and remove wrong or broken parts: yet others can "feel" the differences between various sizes or orientations of parts.

The new generation of robots will be of two "sensory" types; one fitted with a force and tactile system and the other with sensory feedback control based on vision.

Both force and tactile sensing would enable the robot to measure the size, shape, temperature, softness or vibration of the object held by the "arm".[6] Optical sensing or vision is also aimed at building a robot's capability for recognition of parts. In addition, it aims at providing such abilities as orientation of parts on feeding equipment, inspecting parts for defects, and monitoring the assembly process. One vision system, already developed, uses back-lighting for recognition and inspection of parts. Another system is attempting to solve the problem of visual identification of parts in a "heap" and the acquisition of a recognized part from the heap.

None of these systems has been successful in developing robot vision beyond simplified image processing. Once a degree of sophistication is achieved, humans may be relieved from performance of those tasks which cause strain to the eye and pose health hazards. Robots with improved vision capability may perform such varied tasks as soldering of microcircuits or mining and working in the deep sea.

Foreseeable Advances in Robotics

Beyond the new generation of "touch" and "see" robots, we can foresee machines that will understand spoken commands or convert printed language into operating instructions. The capacity to "hear" will, for example, enable the robot to recognize the sound of a drill bit breaking or identify and understand the voice of a human operator. Robots are also being fitted with chemical sensors that can "smell" smoke in the air and infra-red sensors to "see" in the dark. Also under development are ultrasonic or sonar sensors which will enhance greatly the robot's potential for underwater applications. Increased capabilities such as these could be combined in the robot with an elementary intelligence that would enable it to change programs on its own to meet new situations.

The recent trend in size differentiation of robots away from larger than human size only (Unimate 2000) to all sizes, including the mansize (PUMA), minirobots (Seiko or Mobots) and microrobots (Texas Instruments) is likely to continue. As far as robot price is concerned, unit prices are expected to decrease from the current average of some $59,000 to $90,000 in 1980 to the $10,000 to $20,000 range by the end of the decade.

Such advances in specific areas of robotics apart, there have already been significant developments in incorporating robots into integrated manufacturing systems. One such development is "group technology", where the parts to be manufactured are classified into families and the machine tools to create the parts are assigned to these families. In this technique, parts are never placed into bins for storage or transferred to other areas but maintain their flow thoughout the manufacturing process in what is sometimes referred to as a flexible manufacturing system.

This technique, plus an automated programmable assembly system, has theoretically opened the way for a highly automated factory. In a simultaneous development, computers have assumed product and plant design functions. The new activity is known as computer-aided design (CAD). With CAD, it is now possible to design not only the products manufactured but also the plant layout best suited to computer aided manufacturing (CAM). The computer combined with communications technology is, as we know, bringing automation to the office. Now, the computer is combining with robotics technology to create a new stage of factory automation.[7]

WHAT THEY DO

The picture of a line of 10 or 20 robots welding car bodies in unison is by now familiar. Almost any write-up on robots cites the example of the automotive industry which tends to obscure the fact that there are literally hundreds of robots employed in non-automotive industries as well. They perform tasks such as die-casting, investment-casting, and forging in the primary and fabricated metals industry. They will soon assemble parts and products in light industries such as appliance and manufacture. In heavy industries, they assist in the manufacture of engines and turbines. Table 1.1 lists present robot applications according to whether they handle parts or tools.

TABLE 1.1

APPLICATIONS OF INDUSTRIAL ROBOTS

A. Part Handling Applications

1. Die Casting
2. Injection Molding
3. NC Machine Tool loading/unloading
4. Forging
5. Foundry
6. Investment Casting
7. Press loading/unloading
8. Palletizing
9. Loading heat treatment furnace
10. Gauging

B. Tool Handling Applications

1. Spray Painting
2. Spot Welding
3. Routing
4. Drilling
5. Arc Welding
6. Deburring
7. Flame cutting
8. Applying glue
9. Ladling
10. Mold Lubrication

Present Applications

It is not without reason that the automotive industry has been the centre of attention. It is, after all, the leading employer of sophisticated robots. Automobile manufacture calls for a very complex, high technology machine to remember three or four different body styles, each with a different pattern to be welded. The machine must also be able to wield heavy weld guns in and out of car bodies, continuously, with high speed and accuracy.

Typically, a robot in the automotive industry is computer-controlled and usually has six "degrees of freedom". The computer controls the total positions, velocity and acceleration of the robot's end effector. The most common application is spotwelding of car and truck bodies, followed by transfer of bumpers and machine tool loading, parts retrieval and storage. Robots are also being used or intended for use in a number of other areas such as spray painting, material handling, stacking and trimming. Widespread use of robots for assembly is for a more distant tomorrow.

Next to automobile manufacture, robots are most widely used in operations involving metals conversion. Robots have increased the speed of production in casting and forming of metals by two or three times compared to a human operator. They are used mainly in die-casting, forging and investment casting applications.

As mentioned earlier, the appliance industry has made considerable headway in setting up robot-operated motor assembly lines as part of efforts to automate the manufacturing process. Next to the appliance industry, it is in plastics that robots are now widely used. At a number of plastics products manufacturing plants, general-purpose industrial robots are tending compression-molding and injection-molding machines.

Although robot-use is uncommon in other light industries, there are a number of applications where robots can be employed to good advantage. In the rubber industry, ball decorating, packing, and inspection are only some of the tasks being performed by robots. In the chemical industry, they might be used for jobs such as material handling, quality checks and automatic furnace tapping.

In the printing industry, robots can be used for material handling, while in the paper industry, they may be used for warehousing. In the furniture industry, applying spray finishes, material handling and automatic welding are some of the tasks robots can perform. In the textile industry, they can be employed in moving product from finishing line to shipping, product packing and material transfer.

In the aircraft and aerospace industry, robots are being used to make investment casting molds for turbine engine blades. Recently, a number of other jobs in the industry such as drilling and routing aircraft fusilage have come to be performed by robots. Worthy of special mention is the use of robots to spray ceramic coatings on high temperature reusable surface insulation tile for space vehicles. This is expected to improve substantially the accuracy and control of coating thickness. The development of Integrated Computer-Aided Manufacturing (ICAM) techniques for airframe production is now considered feasible in view of the advances made in computer linked robots.

In electronics and electrical industries, pick-and-place devices are already being used for a variety of jobs, such as transferring glass funnels to the coating lines in picture tube production. In semiconductors manufacture, they locate, track and pick off an assembly from a moving belt and place it in a fixture for a computer-monitored test sequence, then transfer it either to a rework line or to a conveyor for packaging. More advanced robots with sensors and vision capabilities are being introduced in consumer electronics production to assist in stamping dates and serial numbers on housings.

New and Foreseeable Applications

Advances in robotics technology are likely to have their major impact on the way heavy manufacturing is performed. Automation of industrial finishing is one area where the robot revolution is being felt. Today's robots can paint nearly any product that humans can: their anthropomorphic abilities enable them to handle most types of spray guns, including electrostatic guns.

Another area, where robots are expected to influence heavy industry is in flexible automation of assembly, which is particularly important for reasons of economy and scale of operation. At present, robot-assisted assembly techniques are being developed for manufacture of small motors typically used in appliances. These techniques may well be adaptable to the production of all engines. While still not advanced for practical operations, assembly by robots is expected to reach that stage by the mid-1980s.

While simple pick-and-place robots are most commonly used in light manufacturing today, introduction of larger programmable robots is not far into the future. One way of introducing such robots is through a tie-in with hard automation. The benefits of using more complex robots in light manufacturing are considerable. Since much of the production in light industries is batch manufacturing, it has not been possible so far to match the volume of production of parts with the speed of assembly. Parts are usually run in large lots and then sent to a central assembly area where they are stored until needed. With robotics assembly it is possible to pace parts production to assembly speed and, thus, little inventory need be accumulated. That in turn would reduce stock and personnel requirements.

The feasibility of robotics application is under consideration in many other industries. In shipbuilding, studies have been undertaken to examine the use of robots in welding, cutting, grinding, blasting and paint-spraying tasks. Research is focused on arc-welding of three dimensional structures by robots. In the construction business, robots are being designed to perform two or more tasks presently carried out by a number of single-function devices such as fork lifts, cherry pickers, and front-end loaders. More advanced work is being done on walking robots, able to navigate obstructions common at construction sites.

Robots are being considered for a variety of land-mining operations. In drilling operations, robots might monitor the height of the ceiling, use reference targets placed at the stope entrance to determine its own position in the stope, and guide itself along a fixed path while drilling holes. The drilling robot can also paint the opening of each hole, as a guide for a fuse-ramming and explosives-packing machine. The fuse joining operation may be performed by a small remotely controlled vehicle. In blasting operations, a remote-control scoop would pick up muck on the floor and dump it into an automatically controlled truck.

Robots have a similarly dramatic application in the nuclear industry. Remote systems technology (robotics) is seen as an answer to problems relating to radiation hazards in nuclear power plants. Trained robots are already being employed to plug leaks and repair malfunctioning units. One such device, already in use, moves under its own power using two TV cameras as eyes and a mechanical arm for handling radioactive material. The device moves about on tracks and is attached by wires to a control trailer. The technology has now opened the possibility of robots and remote manipulators to replace human workers inside nuclear plants. As a result, nuclear fuel reprocessing plants and breeder reactors could be permanently sealed. The threat of sabotage or possibility of theft of nuclear materials could thus be significantly reduced.

The types of feasible robots are limited only by our imagination, our engineering capability and by robot cost effectiveness. More exotic applications are summarized in Appendix D. Simply stated, robots are being used ... in all shapes and forms.

FOOTNOTES

CHAPTER ONE

(ROBOTS: WHAT THEY ARE, WHAT THEY DO)

1. The classification of present day industrial robots and their average characteristics are summarized in the tables below. We wish to point out that classifications based on criteria other than sophistication of control are not only possible but may be equally valid.

INDUSTRIAL ROBOTS

Type of Control	Examples of Applications
Point-to-Point	Spot Welding Paletization
Continous Path	Transfer of Workpieces between Machines
Continuous Path and Control of the Speed	Arc Welding Painting
Synchronization with a Conveyor	Spotwelding of a Moving Piece Painting of a Moving Piece
Environmental Information	Assembly

Source: Kawasaki Heavy Industries.

AVERAGE CHARACTERISTICS OF INDUSTRIAL ROBOTS

Parameter	1970	1980	1980-1990
Weight Handled	10 kg	Unchanged	150 kg
Volume	1-10m^3	Unchanged	Unchanged
Linear Velocity	0.5-1m/sec	1-1.5m/sec	2-3m/sec
Angular Velocity	90°-180°/sec	180°/sec	180°/sec
Positioning Accuracy	± 1 to 2.5 mm	± 1 mm	± 0.3 to 0.5 mm
Degrees of Freedom	4	5-6	Unchanged

Source: BIPE; Engelberger.

2. The position-sensing devices may simply be limit switches activated by the robot's arm, or they may be encoders, potentiometers, resolvers or tachometers. Depending on the devices used, the data required for feedback may either be in digital or analog form.

3. The reference position of each stopping point in a Point-to-Point robot constitutes an input. The inputs are normally stored in the memory as a series of reference voltages. These inputs control a position-feedback mechanism or servo-mechanism. The programmability of a Point-to-Point servo-controlled robot depends on the method of teaching and operation and the type of feedback control employed. There are two types of feedback control - "record-playback" control and sequencer/potentiometer control. With those employing the "record-playback" method, initial programming is relatively fast and easy. However, modification of programmed positions cannot be readily accomplished during program execution. On the other hand, programming of those robots employing sequencer/potentiometer controls tends to be tedious. The advantage, though, is that programmed positions can be modified easily during program execution by adjusting the input potentiometers and altering the reference voltage levels.

4. The Continuous-Path robot generally employs a mass storage system to retain spatial position data in its memory. Magnetic tape or disk storage means are usually used. In a system using magnetic tape, more than one program may be stored but the program cannot be randomly accessed. In a disk-storage system, more than one program can be randomly accessed.

5. A feature that greatly enhances the application flexibility of computer-controlled robots is ease of interfacing external devices. This involves transmission of information in two directions - between the computer and the input-output or memory devices and vice versa. There is, thus, a continuous flow of position and velocity information. As a result, the robot is able to synchronize its movements with that of the workpieces it handles. This ability is crucial in operations involving multiple line tracking or pacing of the line.

6. Research efforts focused on force sensing have taken various directions. Among these are sensing of reaction forces on the end-effector and wrist-force sensing. The capability of force sensing is expected to resolve problems relating to part misalignment. Tactile sensing involves the feedback of information on objects touched by a contact sensor. It provides a relatively simple means of determining the location of objects, and possibly, recognition of objects.

7. Advances in computer and data processing technology began to affect industrial operations in a major way with the introduction of computer numerical control (CNC) systems which added considerable versatility to the punch tape-controlled numerical control (NC) machines common to industrial practice since the 1950s. More recently, the CNC system has led to a more revolutionary direct numerical control (DNC) system. In this, a central computer, serving many machine tools, directly transfers the required computer program to the local machine tool computer. The DNC has thus made flexible, multistation machinery centres possible. By intergrating the "smart" industrial robot into the DNC system, it is now possible to run a manufacturing operation almost entirely by means of computers. Such an operation has come to be called a flexible manufacturing system, which is one aspect of computer-aided manufacturing (CAM).

CHAPTER TWO

ROBOTS IN CANADA

Many of us were proud to learn that "Canadarm" will be used by the U.S. space shuttle for the vital work of placing new satellites in orbit and removing defective ones. This demonstrates clearly the Canadian capability in advanced robotics. Viewed in the context of the applications made by a number of other industrialized countries, however, Canada's robotic power is very poorly developed. With a single exception, no Canadian-built robot is on the market and robot use is both uncommon and highly concentrated in large manufacturing companies.

The reasons for Canadian "lag" in applications of industrial robots are rather complex. As with any other investments, the decision to implement robot technology is affected by a range of economic consideration including the relative cost of inputs to the production process and scale of operations. (Some rule of thumb criteria for introduction of robotics are listed in Table 3.1.) So far, most industrial robotics users in this country and for that matter abroad have been relatively large scale producers, characterized by long production runs, whereas most of Canadian manufacturing industry consists of very small firms, usually employing less than 50 workers.

TABLE 2.1

CRITERIA FOR INTRODUCTION OF INDUSTRIAL ROBOTICS

		Chances of Success of Robotization
o Company's Market Share	$>60\%$	Good
	$<25\%$	Poor
o Proportion of New Products in Total Production	$<1\%$	Good
	$>10\%$	Poor
o Unionization	$<20\%$	Good
	$>65\%$	Poor
o Capacity Utilization	$>85\%$	Good
	$<20\%$	Poor

Source: Courtesy of Strategic Planning Institute, Cambridge, Mass., U.S.A.

Whatever the reasons for the rather lukewarm attitude of Canadian manufacturers towards industrial robotics, it is clear that Canada does not have the 4 per cent share of the world robot population (about 1,000) which one might expect. Of the 200 or so robots reportedly in use,[1] close to half are accounted for by the automobile industry. However, there are signs of improvement. Since the beginning of 1980, the number of robot installations has increased rapidly. A hundred and twenty-five robots were installed in 1980 alone, with sales estimated at \$8 to \$10 million. Sales volume is expected to reach \$40 million by 1985 and, by 1990, yearly sales could reach the \$100-200 million range. The latter figure, incidentally, is the market required by one manufacturing company.

Current Industrial Uses

General Motors of Canada, which has installed 37 robots so far, plans to add 71 more to the assembly line by 1983. The 29 at Ford's Ontario plants consist of 26 welding robots and three pick-and-place devices that handle bumpers. Chrysler Canada Limited has not employed a single robot to date but the company plans a changeover to robots in 1983. American Motors has one welding robot currently in use. The automotive industry as a whole expects to have close to 300 robots installed by 1985.

Next to the automotive industry, the electrical equipment industry is the largest user in Canada. Canadian General Electric employs 14 Seiko robots in switch assembly operations. At Westinghouse of Canada, two robots are used for heavy lifting at the motor division of the Hamilton, Ontario plant while two others spray paint at the London, Ontario plant. Installation of 10 more robots is planned.

At the International Harvestor's farm machinery plant in Hamilton, Unimation-built Mark-11 robots make discs for farm plows and harrows. The robots form part of a system which combines depalletizing, feeding, loading and unloading. The system, devised by A.F. Mundy Associates (Canada) , is claimed to be the first of its kind.[2] Early in 1973, a long-reach Unimate robot was installed at the Weston Shops of Canadian Pacific Railroad in Winnipeg. It is reported that the robot has more than tripled productivity of the milling machine it serves and at the same time has markedly improved quality control.[3]

The Bombardier Company in Valcourt, Quebec, has a robot that assists in the making of snowmobiles. Northern Telecom has two robots in use and plans to add three more of which one would be an advanced robot for assembly operation. Kindred Industries Ltd. of Midland, Ontario, employs a robot to help shape stainless steel sinks and another to shear half-finished sink edges. Amcan uses four two-axis robots in die-casting and machine-loading operations. American

Standard, CAMCO, Crane Canada, Electrolier, GTE Sylvania, Hotpoint, North-American plastics, Poly Rim and Solar Ware are known to have, at least, one paint spraying robot in use. Those using welding robots include Atomic Energy of Canada, Douglas Aircraft, Glitsch Canada and National Steel Car Ltd.; Canadian National Railways, Burlington Die-Casting, Canadian Machinery and Monsanto are a few of the companies reportedly using robots for material handling operations.

The above account covers the general industrial robot applications scene in Canada. An interesting fact to note is that almost all robots are used in plants in Ontario and Quebec.

Robot Production in Canada

Most robots currently in use in Canada have been imported from such firms as Unimation of the U.S. with its Japanese licencee Kawasaki, though a number of robot-makers have set up offices in Canada. Among them are ASEA Ltd. of Sweden, and Binks Manufacturing, Cincinnati Milacron, and Nordson Corp., of the U.S. A number of others have appointed Canadian representatives.[4]

As far as indigenous manufacturing is concerned, half a dozen companies are in various stages of seeking financial assistance from the National Research Council to design and build industrial robots within Canada. Dr. Strong, formerly with Leigh Instruments, now with Bata Engineering, has developed two systems. One is an automatic shoe stitching machine that can be directed to perform operations on a variety of different shaped shoe parts. The second is known as Arm/Vision System (Arvis) which picks up an object, moves it in front of an "eye" (video camera), adjusts its orientation and then accurately places it on another part. By changing hand shapes and inserting new programs, this machine will recognize and assemble a wide variety of items and will then feed the units into machines which glue, rivet, stitch, punch, package or whatever the next manufacturing stage might be. While an apparently promising technology, plans for developing a production model have stalled and may have been abandoned altogether. Other enterprises receiving NRC assistance include Lamb Canada and Difracto Ltd.[5]

Among individual Canadian efforts, the following five could be cited. Glen Rosin of CKGP Productions Ltd. in Regina, has designed an industrial robot and expects to produce them commercially. Difracto of Windsor, Ontario, markets both tactile and visual sensors for industrial robots. Engineered Robotics Implementations of Canada of Saskatoon and Applied Robotics of West Vancouver, B.C., are engaged in research activities related to the development of computer programs for robots and Jarvis Clarke Co. of North Bay, Ontario, has developed a robot - the remotely controlled scoop - for use in mining. These efforts notwithstanding, robot manufacturing in Canada has, until recently been practically nonexistant. However, in the spring of 1981, Canadian General Electric announced plans for large scale manufacture of the MANMATE industrial robots. The launching of this Canadian venture, together with the purchase in 1978 of Hall Automation, Britain's leading robot manufacturer, establish U.S. General Electric as a major force in the robotics field.

Although, from this brief account, it is obvious that robot technology is not widely diffused in Canada, relevant expertise is not totally lacking. Worthy of special mention are the Toronto-based Spar Aerospace of Canada and CAE Electronics of Montreal. The Montreal company developed and built three control systems on behalf of Spar Aerospace of Canada which received a NASA contract for a remote-controlled "Canadarm" for the second mission of the U.S. shuttle spaceship.

The 365 kg arm designed for zero-gravity will be used by the spaceship to place new satellites in orbit and remove defective ones. A similar arm suited for earth's environment is being developed for Ontario Hydro's use in nuclear reactors to move containers of radioactive wastes. Atomic Energy of Canada, in the meantime, has developed a "robot plumber" - a system based on remote control techniques and robotics. The system is meant to carry out repair and maintenance operations in a nuclear plant.

As with space applications, Canadian technology is well advanced in underwater explorations. International Submarine Engineering (ISE) of Port Moody, B.C., has been designing and constructing remote-controlled submersibles since 1975. The company has sold its devices to the U.S. Navy, several oil companies and middle eastern countries like Kuwait and Abu Dhabi. It is presently working on a submersible for the Canadian Armed Forces which can be either manned or operated by remote control.

CAD/CAM

To date, the less complex forms of CAD/CAM techniques such as automated design and numerical control have found greater acceptability in Canadian industry than robotics proper. Northern Telecom is foremost among these companies going ahead with design automation in its Brampton facility. Through Bell-Northern Research of Ottawa, it is developing an integrated CAD/CAM system.

Another company which utilizes CAD/CAM techniques is De Havilland Aircraft. The technique, under development for more than ten years, was designed to replace manual creation of an aircraft's envelope lines by means more suited to computerization and display; in other words, automatic drafting. The company's engineering department and scientific computing department prepared a general purpose drafting program which was used in the production of the Dash-7 aircraft. The CAD-created engineering drawing contained some 60,000 details which facilitated both ease of assembly and configuration control. The company has plans to broaden the scope of its in-house developed computer aided design and manufacturing system to cover its entire manufacturing operation. Computer assisted design is now used in a number of other Canadian companies. Canadair Ltd. of Montreal made extensive use of CAD techniques to develop its Challenger business jet aircraft.[6]

Numerically-controlled tools manufacture is another manufacturing technique which has achieved a foothold in Canada. Standard-Modern Tool of

Toronto represents many of the advances made in Canada and Bata Engineering is one company keen on using these tools.[6] The company's plant at Batawa, Ontario, has some twenty NC tools, each set up as an independent work centre. With the contemplated change to an in-house computer, complete automation of the plant should become possible.

Research and Development

Among educational institutions, McMaster University, the University of Waterloo, the University of Saskatchewan, McGill University and the George Brown College of Applied Arts and Technology, are notable for their research work on CAD/CAM and NC machines.

McMaster University offers training in robotics as part of a new program in manufacturing engineering. The program was begun with an initial grant of $26,000 from the U.S. Society of Manufacturing Engineers and relates to the use of robots in repetitive or risky manufacturing. The engineering department of the University has three robots, a PUMA, a Seiko and an Unimate 2000, the last of which has been completely redesigned by the 6 research engineers currently involved in the program. The approach of a research group led by Professor J. Tlusty, is to develop both teaching and research in production engineering within the university. As part of that work, there are research interests which closely parallel the interests of the Canadian Institute for Metalworking (CIM). CIM articulates and defines the problems and the research group, using university resources, tries to solve them.

The University of Waterloo Engineering departments have developed programming techniques for robots controlled by mini- and microcomputers. The University of Saskatachewan has been engaged for some time in developing a robot for agricultural use, but with reportedly poor results. The focus has recently shifted to remote control devices for operating farm implements.

The Computer Vision and Graphics Laboratory of McGill University, under the leadership of Professor M.D. Levine and Professor S. Zucker, has worked on development of sensors and software suitable for "seeing" robots. The Laboratory's work has attracted the interest of Bell Northern Research, which finds the system useful in assembly/repair operations in electronics. Robot relevant know-how also exists in the National Research Council of Canada, where several experts such as N. Burtnyk and Dr. T. Kasvand are working in areas contributing to Canadian research on robotics.

Robot consultancy is also appearing on the Canadian scene. For example, a former SPAR engineer, H. van Deudekom has recently set up an industrial automation firm called Vadeko International offering specialist services in the planning and application of industrial robots, remote handling equipment and flexible manufacturing systems. Among other things, the firm conducts feasibility studies, designs systems and supervises installation. A few new companies, such as the Canadian Advanced Production Consultants Ltd., Applied Robotics Inc. and Associated Consultants Group, are reported to offer similar services.

Among Associations and Societies, Computer-Aided Manufacturing International and Numerical Control Society are dedicated to the application of computer and numerical control technology to manufacturing.

While there exists no government program specifically oriented to industrial robotics in Canada, there has been a more general government concern for upgrading production processes in secondary manufacture. The federal department of Industry, Trade and Commerce established the Canadian Institute of Metalworking (CIM), in 1971, to serve the metalworking industry in the application of numerically-controlled tools and computer-aided manufacturing equipment. CIM promotes CAD, NC and CAM technology by carrying out development work in machining and software and offers services in the areas of programming and consulting to evaluate, justify and orient plant facilities and personnel in computer integrated manufacturing. Programming facilities include the rental of university computers and support equipment. CIM has its own special edit terminal and plotting equipment to complement the programming service. A CAD/CAM Technology Advancement Council, a government-industry co-operative agency, was set up in 1978 to spread awareness of available new technology. It is the same group of enthusiastic supporters of CAD/CAM who have come to recognize the emerging importance of robotics.

FOOTNOTES

CHAPTER TWO

(ROBOTS IN CANADA)

1. It is next to impossible to obtain an accurate picture of how many robots are actually in place in Canada, as no national survey of robotics has been conducted and some robot manufacturers are rather reluctant to provide their complete sales data. Two rather incomplete lists of robot installations have become available recently: one by Robertson Nickerson Ltd. in August 1980 and another by the Canadian Institute of Metalworking in March 1981. They are presented in Appendix E.

2. The system was introduced when a new heat-treating and forming method called aus-tempering was adopted in 1975. Under the system, one robot loads blanked steel discs onto the entry conveyor of a surface combustion furnace which operates at 1650° F. Another robot transfers the hot discs emerging from a salt-bath quench - another heat treatment of 550° F. - into heated dies of a 400-ton press. After the press dishes the discs, a third robot removes the discs from the die area and transfers them to the entry conveyor of a washer and dryer.

3. The increased productivity is achieved in just two shifts while the milling machine used to run three shifts when it was loaded manually. With a floor-to-floor time of about one minute, CP now completes 275 to 300 cuts per shift for an annual volume of 40,000 turn-out plates. Loading alone accounted for four or five minutes before the robot was introduced. Attainment of better quality control is particularly significant in view of the fact that a turn-out plate is a key component of a rail that enable trains to switch tracks.

4. Unimation has appointed CAE-Morse of Mississauga, Ontario. Autoplace has appointed A.F. Mundy Associates of Rexdale, Ontario, Hall Smith of Burlington, Ontario, represents Fanuc, General Numeric Corp. and Seiko Instruments. Can-Eng. Manufacturing of Niagara Falls, Ontario, represents Prab Conveyors and Versatran. Trallfa Nils Underhaug of Norway is represented by Devilbis Canada.

5. Lamb Canada is reported to be researching the possibility of developing a general robot while Difracto is developing an automated inspection system. Currently, the Physics Division of the NRC is collaborating on the Difracto project in fabricating optical devices for the system.

6. Other applications of CAD/CAM in Canada include: Pratt & Whitney Aircraft in Longueuil, Quebec, uses CAD for jet engine impellers. DOMGLAS in Hamilton, Ontario finds CAD useful in designing bottles. Alcan's design center in Kingston, is a heavy user of CAD as well. Within the government, the federal department of public works is using a computer-aided design system. Among Canadian suppliers, Systems Approach Ltd. (now in receivership) supplied an automated drafting system employing a computer, now provided by Phoenix Graphics and Omnitech. CADSYS Ltd., formerly a division of West Steel Industries of Edmonton, has developed an extensive system for building architectural and engineering design. Digital Graphics is specializing in computer generated art work for printed circuit boards (PCBs). Bell Northern Research Circuit Pack System is another computer-designed PCB. It is marketed by Digital Equipment Corporation. IBM Canada has recently obtained rights to market the BNR circuit board design system worldwide.

7. Bata's CNC-driven double-ended lathes are used in an automated production process at a Xerox Corporation plant in the U.S. The Standard-Modern lathes operate with a pair of Unimate robots in the production of parts for a Xerox duplication system.

CHAPTER THREE

THE WORLD-WIDE ROBOTICS INDUSTRY: PRESENT AND FUTURE OUTLOOK

In its first decade, beginning in the mid-60s, the robot market experienced sluggish growth principally because of the failure to develop awareness of the technology's potential. In the past five years this situation has begun to change dramatically. Though the market remains small, its potential is seen to be very promising. This prospect has persuaded corporate giants like General Motors, General Electric, IBM, Texas Instruments, Digital Equipment in the U.S., Volkswagen, Fiat, Renault in Europe and Mitsubishi, Fujitsu, Toyota and Hitachi in Japan to invest heavily in the field. These manufacturers might well take over the market from the dedicated pioneers such as Unimation or Trallfa.

A number of factors are contributing to this growth in robotics. Stricter regulation of the worker's environment and safety conditions have persuaded manufacturers to reconsider robots. Rising labour costs for hazardous and monotonous blue-collar jobs made the robot an attractive alternative. In the meantime, robots have grown "smarter" and, thus, more efficient, cost-effective, and productive. Finally, advances promised by robotics technology, such as automated manufacture have generated more broad based enthusiasm.

There are now over two thousand different types and sizes of robots currently being manufactured and marketed world-wide. One hundred and thirty companies in Japan, 27 in the United States and 33 in the Common Market countries of Europe are engaged in robot manufacture. Among the Comecon nations, Poland and East Germany are leaders in the field. It has been estimated by various authorities that industrial robotics will be a multibillion dollar world market by the end of the decade.

While American and West European manufacturers have leaned towards sophisticated, universal and thus more expensive robots, the Japanese (now imitated by the Soviets) have preferred building simpler, lower cost machines, before moving to their sophisticated cousins.

During the summer of 1981, the first transnational coalitions of leading robot manufacturers were announced. A seven-year comprehensive tie-in between Japanese Hitachi and U.S. General Electric (in which technology know-how for three robot models will be transferred to GE together with shipments of hundreds of units, manufactured by Hitachi and marketed by GE under its own brand name) represents a new stage of competition for the world-wide robotics industry. West German Siemens has also reached an agreement with Japanese Fujitsu Fanuc, to become its major EEC distributor. Planned to be forged in October, a coalition of Kawasaki Heavy Industries of Japan, U.S. Unimation Inc., and Swedish ASEA will go far beyond the thirteen year old licencing and technology exchange tie-in between Unimation and Kawasaki. It will also involve joint development of intelligent vision robots for mid 1980s. If and when the trio start to work together, their combined production would be some 2000 units per year, 30 per cent of the current global market.

THE UNITED STATES

The United States robot market has grown from $21 million in 1977 to $60 million in 1979. The figure quoted for 1980 is $90 million, which represents some 1500 to 2000 units. It is expected to reach $600-700 million by 1985 and $2 to $3 billion by 1990. Several factors account for this rapid growth. When robots first appeared in the market two decades ago, their cost was about $4.00 an hour, slightly more than the hourly wage of an average worker. Today, the robot can be paid for and operated at about $5.00 an hour, while worker's wages have risen to three or four times as much. In addition, advances in technology have made robots increasingly applicable in a variety of industrial functions.

The U.S. industries most active in employing robots are the automotive, fabricated metals, both heavy and light manufacturing, electrical industry and electronics. At present, the automotive industry and fabricated metals industry each share roughly 27 per cent of the market. Heavy and light manufacturing each account for 20 per cent, while the electrical/electronics industry's share represents 5 per cent. The aerospace industry, which accounts for a little more than 1 per cent of the market at present, shows the greatest growth potential. Its share of robot use is expected to grow at an annual rate of about 40% in the current decade to reach a share of 8.5 per cent by 1989.

Robot Manufacturing

Presently there are nearly 30 manufacturers and distributors of robots in the U.S. Unimation Inc., now owned by Condec Enterprises, is the No. 1 robot maker and supplier with annual sales of $35 million and over 2500 of its Unimate robots in operation throughout the world. In 1977, the company acquired Vicarm, which manufactured small electric robots specifically designed for delicate assembly operations. With further refinements, the robot was developed into a model called PUMA, now being marketed in a model that weighs 120 pounds and has an arm with a three-foot reach. Still in development is PUMA 250 which will weigh 15 pounds. Chrysler Corporation's order for 100 PUMAs is the largest recorded sale of robots in the U.S.

Unimation presently controls close to half the U.S. market but, in the projected fast-growing market, its share is expected to decline. Growing competition and the resultant fall in prices are expected to leave the company with about 30 per cent of the market. Hard on its heels is Cincinnati Milacron, America's premier machine-tool maker. The company has been growing so fast that soon after completing a new 48,000 sq. ft. robotics plant last year it began work on a 30,000 sq. ft. addition. Its prize catch to date is an $8 million order from Volvo for its "Tomorrow-Tool" robots.

Other established American names are Auto-Place Inc., and Versatran which is marketed by Prab Conveyors Inc., who bought the robot line in early 1979 from AMF Inc. The acquisition has led to the merger of high technology robots of AMF Inc. with Prab's medium technology robots. Prab's combined business in robots is in excess of $10 million. Versatran robots are manufactured under licence by Daido Steel in Japan and Hawker Siddeley Corp. in England.

Binks Manufacturing Co. is strongly established with its Universal Spraying Machine and Systems 90, a solid state control unit for the sprayer. The company has branches and sales offices all over North America and Europe as well as in Mexico, Australia, South Africa and Japan. The spraying machine is made by Hall Automation, U.K., and supplied to Binks Manufacturing Co., through Binks-Bullows, U.K.

More than half a dozen new suppliers have sprung up in the past three years. The most promising of these is Automatic Inc., which will specialize in turnkey robot systems built around a vision capability. The latest development will see big electronics companies entering the market. Both International Business Machines (IBM) and Texas Instruments Inc. (TI), have developed sophisticated assembly robots for their own use. TI has 24 robots equipped with "eyes" that have been assembling, testing and packaging such products as calculators. Another electronics company reportedly waiting to enter robotics is Digital Equipment Corporation. Entry of these and other companies is expected to touch off a "learning curve" price decline. The projected drop in price of a $50,000 robot to some $10,000 by 1990 would undoubtedly generate a vast demand.

Not all of U.S. robot production is by large companies. There are, as well, several interesting smaller manufacturers, such as Modular Robots of San Diego, California. At the lower end of the scale are companies that offer robot kits for the hobbyist or laboratory segment of the market, such as Gallagher, a North Carolina-based company.

Industrial Application

Many U.S. companies have already introduced robots in their manufacturing processes. We will give a few examples of important or innovative applications. The "Big-Three" auto-makers employ robots to do much of their spot welding and painting. Chrysler has recently installed 116 robots to work on its new K-cars, in addition to the 80 robots already in use. Ford, the earliest among the three to install robots, now employs nearly 250.

In response to the Japanese car challenge, GM is attempting to use robots to cut the man-hours needed to make a car. It has increased its number of robots installed from 270 in 1979 to 1200 by the summer of 1981 and it has another 4000 on order. The GM plant in Oklahoma City is now the most "robotized" in the U.S., with close to 200 of the machines at work. The company has developed a vision system, CONSIGHT, that enables robots on the assembly line to recognize and choose objects.[1] While the system is fast, processing images at the speed of light, it still has trouble dealing adequately with objects at different depths.

Aerospace firms are not far behind the automakers in their use of robotics. Lockheed Corp. is installing a painting and processing line, operated by robots and controlled by computers. Hughes Aircraft Company has introduced a semiconductor-chip imaging system, called Omneye. Developed originally for military targeting applications, it operates in thousandths of a second, using the digital process. Robots are building ceramic molds for engine turbine blades at Pratt and Whitney's automated casting factory and at the General Dynamics plant, robots make sheet metal parts for fighter planes.[2]

Some companies are concentrating on other apsects of robots. The Lord Corporation is developing a touch system using a spongy material for the hand of the robot.At a Chesebrough-Pond thermometer plant, a robot is employed in an operation involving removal of air bubbles from the mercury inside a thermometer.[3]

Westinghouse, the electrical goods maker, is developing a robot assembly line to put together five different types of electric motors.[4] General Electric Company, the other major electrical company, uses over a hundred robots and the company is about to launch a sweeping automation program that may eventually replace nearly half of its 37,000 assembly workers. The company's

Major Appliance Business Group, the U.S.'s largest appliance manufacturer, plans to have a robot work force numbering over 1000 within a decade. Two years ago, the group had only two robots.[5] In 1980, GE spent \$5.1 million for 47 new robots, expecting to save \$2.6 million annually in labour and materials. The company has also invested in research and development of a vision system for the robots.[6] Of great interest is the GE robot demonstration facility in Schenectady, New York, where robots are made available to individual users within the company.

The current rate of diffusion of robotics in the U.S. will be substantially accelerated when it finally spreads from large companies to small and medium-sized entreprises. For this reason, the appearance of Thermwood, a company that offers to lease robots for \$1,000 a month or the equivalent of \$1.90 per hour for three shift operations, is extremely important. Such a development will allow small companies to use robots without having to tie up capital in their purchase.

The New Generation of Robots

The new generation of robots is being developed in a number of research laboratories in the U.S. Stanford Research Institute (SRI), has developed a part identification system that produces two-dimensional profiles of parts from video scans.[7] Although accurate, the system is judged slow. Researchers at the Robotics Laboratory of Stanford University are working along similar lines to build abstract models of common objects which the computer will store in its memory. The plan is to use a single building block, a three-dimensional cone-shaped image, that can variously represent different objects.

Yet another vision system has been developed by a new company called Machine Intelligence Corporation. The system uses a black-and-white TV camera that scans objects against a brightly lit background.[8] A refinement of this system is being attempted at the Lockheed Missiles and Space Company where engineers have developed a technique called "gray imaging". Based on grading the dots in a TV picture from pure white to pure black, it will give the robot much clearer three-dimensional vision.

Researchers at the Massachusetts Institute of Technology (MIT) are working on a robotic skin made of thin sheets of rubber lined with wire. The sheets form layers on the robot's fingers and hand. A power source on the robot supplies a steady flow of electric current through the layers to the points where the fingers contact the object while a microprocessor measures the voltage and enables the robot to relate to the part. The system's unique feature is its ability to project an image of the part that is touched on a computer screen.

The Charles Stark Draper Laboratory has developed force sensors to control the robot arm. Three springy cylinders and three tiny light detectors constitute the sensors. When the hand exerts force on an object, the cylinders contract or stretch allowing light to pass across the face of the light detectors. Based on the information sent by the light detectors, the control computer calculates the force exerted, and accordingly gives orders to the motor that drives the hand. The robot at the Draper Laboratory uses the force-sensor to assemble parts or follow the contours of a curve, making it ideal for welding or painting.

In December, 1980, Carnegie-Mellon University dedicated its new Robotics Institute, which is working on exotic autonomous underwater mobile robots and robots for space exploration, a "smart" industrial robot that will be able to adapt to changes and solve problems as they arise. Westinghouse Electric Corp. has provided the Institute with U.S. $2 million for a "factory of the future" project making heavy use of robots.

Government Programs

The determination of the last two U.S. administrations to "reindustrialize America", is being reflected in higher attention given to robotics by the U.S.

government, especially since the Industrial Innovation Domestic Policy Review of 1979.

Apart from the many remarkable efforts in U.S. private industry, there are also some impressive government robotics projects. The U.S. Air Force is spending $125 million on its Integrated Computer Aided Manufactor (ICAM) Program. The U.S. Navy is experimenting with underwater tele-operators. At the Rocky Flats plant of the Department of Energy, a robot-like remote manipulator is used to transport reprocessed plutonium. The National Aeronautics and Space Administration (NASA) has already used a robot in one space mission, the Voyager I which travelled 1.3 billion miles to Saturn. At the Jet Propulsion Labortory, a robot called the Mars Rover is being built. It will propel on its own, scan the landscape and dig up samples on the planet. At the Marshall Space Flight Center, research effort is focussed on a robot to carry out repairs on orbiting satellites. A similar robot is being built by the Naval Research Laboratory.

The National Science Foundation (NSF) and the National Bureau of Standards (NBS) spend between them about $2.5 million in support of robotics and automation research. Among projects funded are the earlier-mentioned ICAM project of the Air Force Materials Laboratory, the Westinghouse project on automated batch-assembly line for the manufacture of motors, and the Boeing-General Electric Co. IGES Project to develop initial graphic exchange specifications for parts and shapes.Besides those specific developments, robots are reportedly being used in the manufacture of tanks, aircrafts, guns and ammunition. The Department of Defence, spends a total of $150 million each year on robots-related work.

To sum up, the use of robots in the U.S. has begun to expand rapidly. It is expected that this will continue and, as a result, that U.S. manufacturing will change dramatically. According to a recent survey by the Society of Manufacturing Engineers, it is estimated that by 1995, 50 per cent of automobile assembly will be done by robots. Another SME study has forecast that between

1982 and 1985, the proportion of assembly systems in the U.S. using robotic technology will increase from 5 to 15 per cent. In the case of small component assembly, the SME predicts that 50 per cent of labour will be replaced by machines by 1988. Looking still further ahead, Dr. Charles Rosen estimates that by the year 2000, the human manufacturing work force will be reduced to only 5 to 10 per cent of the total workforce, largely as a result of the use of robots.

EUROPEAN EFFORTS

The potential robot market of Europe over the next 10 years is seen as comparable to those of the U.S. and Japan. Despite that, European countries seem, on the whole to be trailing Japan and the U.S. in the production of robots. This situation is somewhat ironic since some of the important early efforts in the field originated in Europe. Mitsui and Company and its affiliated pneumatic equipment maker, Shoku Corp., recently launched exports of industrial robots for diecasting to Europe though this pneumatic robot was actually developed by the West German aircraft manufacturer, VFW, some ten years ago. Finding no customers at the time, the German firm transferred its patents, design and production know-how to Shoku

Currently, the EEC market is estimated at U.S. $55 million, with annual sales of some 1200 units, twice the level of 1979. The total number of robots in Europe is estimated to be 3600, roughly divided as follows: Federal Republic of Germany, 35 per cent; France, 20 per cent; U.K. and Italy, each 15 per cent; others 15 per cent.[9] A trend worth noting is that European manufacturers, such as Italian Robogate, Norway's Trallfa, Sweden's ASEA, Germany's Kuka and France's Renault-Cybotech, are striving with some success to penetrate the North American markets.

West Germany, though the earliest to develop a robot in Europe, now lags behind the U.S. and Japan in robot use. The latest count places the number at about 1200, of which about a quarter are used in the auto industry. Among the makers, Kuka, Keller and Knappich Ltd. has made a strong showing in international markets and has reported impressive growth in sales. A recent comer is Jungheinrich of Hamburg, one of Europe's leading manufacturers of fork lift trucks.[10] There are as well about a dozen other German makers including Robert Bosch GMBH, Felss, Koenig, and Volkswagen.[11] Nor are research efforts lacking in Germany. The Institute of Production and Automation in Stuttgart is probably the most active in robotics research in Europe and the West German software effort is outstanding.

In Sweden, robots are seen as an ideal solution to the country's problem of labour shortage. Not surprisingly, therefore, it leads the rest of Europe in the employment of robots. About twelve hundred units are in use in various industries. Allmanna Svenska Electriska Aktiebolaget or ASEA, the national leader in robot manufacture, has a sizeable share of the export market. Its models are in use all over Europe and are selling well in the U.S. and Canada where the company has subsidiaries. ASEA sold its entire 1980 production capacity in the first quarter, despite its equipment being the most expensive in the world. It has developed an adaptive control for the robot which, in conjunction with a tactile sensory system, eliminates the need to instruct the robot in precise detail.[12] Using an ASEA robot, ESAB, a machine tool manufacturer, has introduced an automatic arc welding robot station which has been found to be 2.5 to 3 times faster than manual welding. There are 60 installations of ESAB welding stations in the automotive and equipment manufacturing industries. Magnussons i Genarp AB, which makes stainless steel elbow tubing, has installed two ASEA robots that feed parts into the polishing machines. The robots work without an overseer during weekends.[13]

In France, the automaker Renault is emerging as a leading robot maker. It has developed a robot with a television camera that can identify each of 200 parts presented to it at random. Two hundred of the company's robots are already in use and it has recently joined forces with Ransburg Corp., U.S.A., to make and sell robots in the U.S., Japan, the Far East and Australia. Comex-Seal, in cooperation with Thomson-CSF, has developed the TOM-300 unmanned submersible for operation up to about 300 metres. DCAN Centre has produced ERIC (Engin de Recherche et d'Intervention a Cable) and ERIC 2. Designed for survey and salvage operations underwater, ERIC has a robot arm with five degrees of freedom and a depth capability of 700 metres. ERIC 2 has two arms and a depth capability of 6000 metres. More recently, the French company Kremlin has set up a new subsidiary called AIOP Robotique which has installed 20 spraying robots. It has 40 more in production and has plans for expanding production to 200 robots a year by 1985. Research on vision systems and other aspects of robot are carried out at the Laboratoire d'Automatique de Montpellier. The Automation Laboratory of the University of Science and Technology, Languedoc, and the Centre of Nuclear Studies, Scaley, are working on the MA-23 manipulator developed by the Centre with an aim to minimize response times in adaptive control.

Britain is sixth in the world robot league, according to the British Robot Association. The Association, formed in 1977 with financial support from the Government, has 150 members made up of industrial user companies and equipment suppliers. According to its estimates, Britain presently has 371 robot systems with an anticipated 30 to 40 per cent increase in the next year.

Hall Automation was, until recently, Britain's only robot manufacturer. It makes three types of robots: Magic Dragon, the spray-paint robot; Bochal, the arc welder; and Little Giant, the all-purpose robot for general component lifting and manipulation. Spray-paint robots made by Hall are marketed world-wide by Binks Manufacturing Co., U.S.A. Hall has recently introduced its latest paint-spraying robot called Comparm, a light and agile sprayer which has the ability to reach behind itself and paint into corners over its shoulder. Comparm is claimed to be as versatile as a human operator. It was developed in consultation with Volvo which has ordered one for spraying under wheel arches. Besides Hall, the London-based B Elliot group of machine tool manufacturers has now entered the market with a general purpose robot and Unimation of the U.S. has opened a manufacturing base with British government assistance totalling $1.5 million.

New arrivals in the British robot market include GKN, Haden Drysys, Lansing and Sykes. GKN, which makes a range of welding equipment, has linked with Yasukawa of Japan for making welding robots. Haden Drysys, which specializes in metal treatment and mechanical handling equipment for the automobile industry, will soon be selling Hitachi's paint-spraying robot in Western Europe. Lansing Limited has entered into an agreement with Hitachi for selling Hitachi's arc-welding robots in Britain, and, it is reported, may enter into a manufacturing agreement with Hitachi if sales are sufficiently promising. Sykes, one of Britain's largest private companies in the coal and oil business, has started a new venture, Dainichi International, which will manufacture Dainichi's pneumatic robots in Britain targeted for U.K. and Western Europe markets. Started on an investment of 2 million pounds, the new company will manufacture a range of seven high precision microprocessor controlled multi-purpose robots. The company's future plans include a fully automated robot assembly line similar to the one in Dainichi's factory in Japan where robots build robots.

The National Engineering Laboratory carries out Britain's major robot research program, including a project on the automated factory. That project is being funded by the Mechanical Engineering and Machine Tool Requirement Board as part of a $35 million program to increase British industry's use of automatic techniques in small batch production. This is considered a crucial project because some 40-50% of British manufacturing is small batch production. Hewlett-Packard's newly-introduced industrial data capture terminal could be a significant contribution to the project. The British Government, through the new Robots for Industry scheme, gives companies grants of 25% towards the cost of installing robots and 50% towards the cost of feasibility studies. The National Research Development Corporation has invested $600,000 to help Unimation set up a European assembly plant in Telford.

Italy has registered in recent years, a marked growth in the manufacture and application of robots. The most advanced robot is Olivetti's SIGMA, a computer-controlled robot with visual, sensorial, and tactile capacities. It can follow spoken and written commands. Fiat plants in Turin and Casino use an advanced welding system called Robogate which consists of eight stations, each having three or four robots, and a trolley moving the auto bodies from one station to another. The system welds 800 cars a day or nearly 300,000 a year and Manpower requirements have been reduced from 125 to 25.[14] Other robot manufacturers include Basfer, Industriale Marin, Macchine Speciali Torino, Norda and Sivdeltix. Basfer robots are used in the painting systems marketed by Nordson Corp., the world's leading manufacturer of electrostic paint spraying equipment.The Milan Polytechnic has designed a software system called Multi-purpose Assembly Language (MAL) for controlling and programming Olivetti's Supersigma robot used mainly for assembly operations. The advantages of MAL are said to be its compatibility with different computers and robots and its ease of programming.

In Norway, the field is dominated by Trallfa, the manufacturer of spray painting robots. It has a significant share of the U.S. and U.K. market. General Electric, for example, uses Trallfa units at many of its appliance manufacture plants. There are two other Norwegian manufacturers in the field: Oglund and TESA.

Among Comecon countries, Poland employs the greatest number of industrial robots with about 12,006 installed. It is estimated that the number will increase four fold by 1985[15] with the greatest application in plastic forming, machining and injection molding.[16] Robotics research is carried out at the various institutes of the Technical University of Warsaw, the Institute for Biocybernetics and Biomedical Engineering of the Polish Academy of Sciences, the Industrial Institute of Precision Mechanics, the Machine Technology and Construction Basic Research and Development Center and Machine Tool Research and Construction Centre.

According to some reports, East Germany may be ahead of the U.S. and even Japan in the large scale application of sophisticated robots. At the Fritz Heckert machine tool factory in Karl-Marx Stadt, the Prisma II system integrates six machine tools, two inspection stations and automatic manipulators and transporters into a single system for producing highly precise machine tool parts. An on-line computer automatically schedules parts to maintain a 75 per cent overall utilization rate for the machine tools. In tests where one machine was taken out of service, the computer was able to resume full utilization in as little as half an hour. The PC-3, their robotized system, can handle 24-ton components of heavy presses.

The most significant East German accomplishment is the production of integrated systems using modular machine tools. The Rota FZ 200, another robotized system, produces up to one million gears per year in small batches. It involves 52 work stations and is itself composed of standardized robots and machine tools.

In the U.S.S.R., practical work on robotics was started at colleges and scientific research institutes of the Academy of Sciences in the late sixties. The first experimental prototype of a computer-controlled robot with sensors was developed in 1968 by the Leningrad Polytechnical Institute along with the Shirshov Oceanology Institute of the Academy of Sciences and some other higher educational establishments. By 1971 the first programmable industrial robots had appeared - mainly point-to-point control. By 1973, a general robotics program had been drawn up involving all the main branches of industry, the Academy of Science and establishments of higher education. More than 30 types of industrial robots had been developed by 1976 and 19 new types including some with adaptive control were to be ready by 1980.

The E.O. Paton Electric Welding Institute is concerned with development of control algorithms for welding robots using a MINSK-32 Computer. The Leningrad Polytechnical Institute has developed a high level hierarchically organized language, called Rocol, which facilitates adaptive control. The control has been used for the Institute-developed ROBIN robot and also for a deep-water manipulator. The Institute is also working on a general purpose robot system, called LPI-2, consisting of two handling manipulators, a tool manipulator, TV camera system, and other sensors.

The Leningrad Institute of Aviation Instrument Making has developed a high-level language, LAROT, for robotic control with a command system based on movement of microelements. The Institute has also developed a flexible manufacturing system for the production of turbine blades consisting of a conveyor belt, a dozen robots, and several types of machines. As for automated production systems, the Experimental Science Research Institute for Cutting Machine Tools (ENIMS), Moscow, has been concentrating on the use of group technology concepts in conjunction with different types of programmable automated manipulators. Laboratory research is focused on multi-purpose robots, manipulator movement, motional redundancy and sense development. Finally, at the Shirshov Institute of Oceanology, an underwater manipulator has been developed for gathering of geological specimens.

It is recognized by the Academy of Sciences and the State Committee for Science and Technology, which coordinates robotics efforts, that the only way towards the complete and economical automation of all manual tasks in industry is to create a new generation of robots which do not require their environment to be fully predetermined. To this end, work is proceeding on the development of robots with sensors (especially in the grippers) to allow adaptive control. This also requires the development of the appropriate algorithms, a knowledge of hierarchical self-organising systems and computer control. Although none of these advanced robots are in production as yet, there are numerous experimental examples.

Western observers estimate that the Soviets are from 5 to 10 years behind the OECD leaders in robotics technology, although in terms of installed robots they have 6,000 to 7,000 units in place. While most are simple pick-and-place devices, perhaps 2,000 are truly reprogrammable. This year, at the 26th Congress of the Communist Party an all out campaign to catch up with the West was launched. The ambitious plan aims to build 40,000 units over the next 5 years. Some forty different models are to be mass-produced, with the installed base expected to grow at 50 per cent rate annually through 1985.

JAPANESE LEADERSHIP

Japan, dubbed "The Robot Kingdom" is the undisputed world leader in the use of industrial robotics. Some 70 per cent of the world's robots are concentrated in Japan. Sales of Japanese robots were placed at $90 million in 1977, $125 million in 1978, $190 million in 1979, $350 million in 1980 and are expected to reach $500 million in 1981. At the end of 1980, it was estimated that the volume would grow at an average annual rate of 24 per cent and swell ten times over by 1990. In only six months, this estimate was revised upwards and the volume of sales was expected to grow to almost fifteen times the present level to reach a figure of $2.7 - $3 billion by the end of the 1980s. The Ministry of International Trade and Industry (MITI) is talking about an incredible figure of $2.5 billion by 1985 and of $5 billion by 1990. The revision is only one more indication of the rapid takeoff of the Japanese robotics market. In 1980, 19,000 new robots were produced, up nearly 50 per cent over 1979. Forecasters anticipate the fastest growth for arc welding (up 211 per cent in 1980), assembly and inspection (up 340 per cent in 1980) spot welding and painting (up 85 per cent in 1980).

Japan's first industrial robot was developed in 1967, five years after the first industrial robot was born in the U.S. Commercial production started soon afterwards and the industry has achieved an impressive growth year after year since 1971. There are, today, as many as 130 manufacturers in the field compared to less than half that number in Europe and the U.S. combined. Although the Japanese Industrial Robot Association (JIRA) places the number of units in Japan at 30,000, most of these are simple manipulators and, hence, cannot strictly be classified as robots. There is no doubt, however, that there is a rapid and wide-ranging shift to production of sophisticated robots. As a result, the share of the Japanese market accounted for by "intelligent" robots is expected to grow from 5 per cent in 1980 to 15 per cent in 1985.

Exports are an important element driving Japanese robot production. By 1985, exports are expected to reach 20% of production, a three-fold increase over the present share. Japanese robot makers are also establishing production facilities abroad. Fujitsu Fanuc, which has an NC machine tool service center in Los Angeles, intends to produce robots there in the next year or two. It already sells its robots to Westinghouse Electric Corporation. Hitachi reportedly has made arrangements with Otto Durr, the German paint specialist, to sell its paint spraying robots in Europe and Mitsubishi Heavy Industries has a licensing agreement with Scaiky, the French welding machine maker, to produce Mitsubishi robots in France. Nissan's new Tennessee pick up truck plant will be the most robotized plant in the world, with some 200 robots and nearly 95 per cent of all welding jobs being done by robots.

Because Japanese robot manufacturers have more business than they can handle, companies from other diverse fields are moving into the industry. These include not only large corporations such as Matsushita Electric and Sumitomo Heavy Industries but also the "odd" ones such as Pentel and Sailor Pen. Okumura Manufacturing, a large furniture manufacturer has started to actively solicit orders for a robot originally designed for its own use. Another furniture producer Okamoto Seisakasho Co. has developed three different models of industrial robots, including an inexpensive RC-04 ($13,000) which loads metal workpieces into press machines. In the Big League, Matsushita Electric Industrial Co. has recently entered the market with its welding robots and other Matsushita robots are hard at work in the manufacture of TV sets. Sumitomo Heavy Industries has revived its dormant robot division.

At the same time, pioneers in the field are consolidating and expanding their production. Kawasaki Heavy Industries, the biggest builder of industrial robots (some 700 units a year) plans to increase its production in fiscal 1981 by 30 per cent. It has a complex agreement with Unimation for sharing world markets for upgraded versions of Unimate and PUMA type robots. The second largest builder, Yasukawa Electric, plans to double its output to around 600 units in 1981. Yasukawa has arranged a sales tie-up with Hobart Brothers of the U.S., and thereby established a sales base in North America.

At Hitachi, Japan's leading general electric machinery producer, five hundred of its top technological experts in its Central Research Laboratory are developing an "intelligent robot" system that will take over 60% of assembly production by 1985. The ultimate objective, once again, is to realize complete plant automation. The plan envisages a 70% reduction of manpower on the assembly line and a comparable increase in productivity. Efforts to date have resulted in the Hitachi Integrated Intelligent Robot which is capable of assembling a finished product from a jumbled assortment of parts.[17] While probably the most advanced robot system in the world today, the operation is still slow when compared to human assembly and, hence, current efforts are focused on increasing the speed of operation. Other Hitachi research is directed towards automated semiconductor manufacturing, arc welding and paint spraying robots. Only this summer, Hitachi announced a doubling of its robot output to a level of 60 to 100 units per month. The company exported 30 units to Europe in 1980 and expects to export about 200 in 1981. It has established marketing arrangements with Automatix Inc. of U.S.A., Lansing Limited of the U.K. and, very recently, with General Electric.

The production plans of Fujitsu Fanuc is even more dramatic. Already one of Japan's most technologically advanced companies, Fujitsu Fanuc is about to bring the "workerless" factory closer to reality. A new $38 million plant employs robots and numerically controlled (NC) machines to turn out other robots and computerized tools. Currently in the first year of operation, the factory produces 100 robots a month with just 100 workers, one-fifth the work force of a conventional factory. Employees work an 8 hour daytime shift assembling parts made by the robots and the machines around the clock. During the night, one worker tends the shop while a single guard patrols the plant. With only 10 robots in the plant and monthly production of $10 million, yearly productivity works out to an amazing $1.2 million per robot![18]

A specialized company that is determined to become an industrial robotics leader is Dainichi Kiko, a small company capitalized at a mere $250,000 and employing 100 workers. The company is widely known among specialists for its superior robot manufacturing technology. In 1980, the company completed a new plant where forty robots are engaged in manufacturing robots. The company's present output stands at 15 units but production is expected to rise to some 50 units by the end of 1981. Some 70 per cent of production would go to overseas clients. As mentioned previously, the company has set up a joint venture in Britain with Sykes.[19]

Several other companies deserve special mention. Yamaha is pioneering in use of robotics in the manufacture of motorcycles and Nippon Electric has used its semiconductor automation experience to develop an ultra-precision (16 sensors) robot which it will market in a year or two. The robot can handle components up to 2 kg. in weight. Toyota Motor Company has announced that it will develop its own assembly robots in cooperation with its parts suppliers. One striking feature of Japanese industrial robotics is that many companies are making robots for their own use but not selling them to competitors. Yamazaki Engineering, a large machine tool exporter, will open in the autumn of 1981, a factory that includes a superflexible system with 18 machines and two robots linked by computer. The line will work three shifts daily, one of them without any workers at all. As a result of all this extraordinary activity, plants throughout Japan are undergoing revolutionary change. Unmanned plants are appearing one after the other. Sumitomo Electric, Toshiba, Yamazaki Machining, and other plants combining NC machinery with industrial robots have only skeleton crews of overseers.

Efforts in the direction of full-scale automation are giving rise to new technologies and processes. Because it is impractical to string together a series of computer-controlled machines which are otherwise conventional, new machines, highly flexible and modular in construction, capable of performing several manufacturing operations at once, have been introduced. One complex production system has been developed to carry out forming, heat treating, welding, finishing and assembly, each operation linked to the other by programmed transfer mechanism. Each of the operations has, in turn, given rise to new technologies. For casting or welding the conventional permanent mold approach has been found unsuitable and a new complex forming system using sectional molds has been developed. An alternative being tried is free-forming or moldless systems, using helical rolls and disc mills or even powerful magnetic fields. In metal working, lasers have been found to have the advantages of high speed great flexibility, and easy linkage to computer systems. As a result, high-power lasers are being used to accelerate cutting, welding and heat treating.

Government - Business - Academic Cooperation

All the above successes and advances owe a great deal to promotional efforts by both the government and the government-assisted industry association, Japan Industrial Robotics Association (JIRA). Established in 1971, JIRA is now vigorously engaged in a wide variety of activities including public relations, promotion of technological development, and diffusion of industrial robots. In addition, it facilitates international exchange of robot technology through symposia and exhibitions. It has a membership of about 400, of which corporate members account for roughly one-fourth.

JIRA is only one of a dozen national associations subsidized by the Japanese government through the Ministry of International Trade and Industry (MITI) and its semiautonomous Agency of Industrial Science and Technology (AIST). AIST is responsible for providing a promotional, educational, and financial basis for the co-ordination of robotics work. While figures for total AIST allocations are not readily available, its normal practice is to jointly fund projects with the more than 130 robot manufacturing firms in Japan. Besides its national projects, 1977 AIST granted $20 million to 70 laboratories and 300 researchers working on pattern recognition, sensory control and robot mobility.

At the moment, Japan is spending some $50 million on research and training programs for automation of production and for developing efficient manufacturing systems. The Ministry of International Trade and Industry reportedly plans to introduce a seven year $150 million national research and development project to began April 1st, 1982. Its main purpose is to develop intelligent robots (including assembly, clothing, space and ocean robots) with the initial emphasis on vision, touch and other sensors as well as speech recognition and synthesis. To this end, a special research and development group is to be created by MITI.

Among the many projects involving government, industry and academia, several merit special mention. In 1980, encouraged by the Ministry of International Trade and Industry, some 30 industrial robot manufacturers launched a leasing company to encourage medium and small-sized companies to switch to flexible automation. The company expects to lease robots worth $200 million by 1985, with half the financing coming at low rates from the Japan Development Bank. It is hoped that this subsidy scheme will be as successful as another started by Japan Electronic Computer Company in 1961. Under that scheme, over $500 million worth of computers were bought from fledgling robot manufacturing companies and leased to users.

An excellent example of academic initiative was that taken by Professor Y. Makino of the University of Yamanaski when he invited 13 manufacturing companies to a two-year seminar to put his laboratory findings into practice. The result is the SCARA (Selective Compliance Assembly Robot Arm) family of robots. Their main feature is the ability to adjust arm positions to fit slightly displaced workpieces.

The Electrotechnical Laboratory is the best known of AIST's sixteen research institutes. The ETL has a staff of 800 researchers concerned with advanced designs for a variety of machines including robots. Among its projects are a two-armed cable-driven robot programmed to use tools like a carpenter's drill and a multi-fingered prototype arm that can tie knots and use chopsticks! No doubt an application for a chopsticks using robot will be found. The Environment Teaching System - a machine to teach robots to do complex jobs -is ETL's latest achievement. The device learns about any object to be worked on and its surroundings in a matter of a few minutes from a human operator and transmits the memory information to the robot. It includes a laser pointer, a TV Camera, a display device, a keyboard and an information processor.[20]

The Mechanical Engineering Laboratory is another of AIST's research institutes. It has designed many kinds of robots including an ultra-precise robot with vision capacity using light pipes; a two-armed robot (MELARM) that resembles human arms in their motions and freedom of action; a mobile robot with vision and intelligence that can move from one work place and task to another; an intelligent car that uses TV cameras and a micro-computer to drive automatically; a guide dog robot (MELDOG) to help the blind; and prosthetic arms with tactile sense that has use in industrial applications.

The aim of MUM - the Methodology for Unmanned Manufacturing - is to produce an automated plant where two or three workers would supervise a volume of output that 50 workers would produce in a conventional plant. Started in 1977 to be in operation by 1984, MUM is funded by AIST ($78 million) and is a co-operative effort involving the government, Mitsubishi Electric, Hitachi, Toshiba, and other firms. Research and development is carried out in six technological areas: integration, forming, machining, assembly, construction and total systems technology. The Japanese government has recently scaled down the overly ambitious project to design a completely unmanned factory in favour of more immediately useful research into highly productive superflexible manufacturing systems. The Japanese already claim world leadership in this area.

The Driving Force

A number of factors beyond investment considerations alone have contributed to the rapid growth of robot-use in Japan. Robotics is given high priority in university engineering courses and extensive training is offered in technical schools. Senior government and corporation executives have recognized the importance of robots in their long range economic planning, and even public awareness of robotics is quite high, encouraged by such means as the "robot a month" programs. More importantly, the Japanese corporation guarantees life-time employment and, thus there is minimal fear of job loss to robots. At the same time, younger workers are more reluctant to take up repetitious jobs, with the result of labour shortages in jobs such as welding, painting and press forming.

The steady drop in the price of robots and leasing arrangements make their use economical even for small and medium-sized firms. As a result, a radical change in the use of industrial robots can be observed in Japan. While, in Japan as elsewhere, the demand for robots first came from large enterprises such as the car makers, now the smaller firms, working as subcontractors for major companies, are embracing industrial robots. Such companies now account for some 70 per cent of all the welding robots in use. To illustrate, a small firm engaged in processing parts for a major camera maker, has installed a robot line for automating the painting process. Nearly 30 per cent of the sub-contractors in the plastics industry have switched to robots to operate molding machines. Robots have even moved to the textile industry, where they are used to splice broken thread. Partly as a result of this application, the Japanese have been able to repatriate some textile production lost to low wage countries.

Japanese export-based industries find in robots a means to strengthen their international competitiveness. Thus the chief users of robots now are the electronics industries followed by precision instruments and steel industries. While, until recently, a main motive to introduce robots was a work-force unwilling to work in unhealthy environments, the driving force now is the desire to increase flexibility in manufacturing and to improve quality control.

The year 1980 witnessed the Japanese offensive in the export of cars, a performance helped by the intensive use of robots. They will undoubtedly help again in such export offensives appearing on the horizon as construction machinery, medical electronics and small business computers. Further down the road, we might also expect a trade offensive involving Japanese robots themselves.

Have the Japanese awakened a sleeping American giant? Will we witness a battle to automate factory floors of the world? While the Japanese lead in robot applications and in superflexible manufacturing, the U.S. industry dominates the world markets in software and in Computer Assisted Design. While no one can say who the winner of the robot revolution will be, one thing is clear: the industrialized world is beginning to automate at a pace that will soon change the face of its factories. Robots are key tools in this new stage of industrialization.

FOOTNOTES

CHAPTER THREE

(THE WORLD-WIDE ROBOTICS INDUSTRY: PRESENT AND FUTURE OUTLOOK)

1. CONSIGHT scans a part with a multi element visual array, then processes the image to find the edges, combines these into a profile, and then tries to match the profile with stored images of various parts. The robot is thus able to identify one part and determine its location and orientation. The system, however, is limited to two-dimensional parts. Work is under way to extend pattern-recognition to three-dimensional parts. GM technicians are trying the optical processing method. A laser image of the part or parts is passed through a filter carrying a Fourier transform of the part image. Interference patterns are set up, and when the filter is rotated to correspond with the orientation of the part, a "match" is signified by a beam of light. This indicates the part's orientation and position.

2. The robots drill holes into panels for the wing and the fuselage at the company's Forth Worth plant.

3. The company's laboratory has developed a computerized gray-tone camera destined for the factory floor and, perhaps, for use by robots if found suitable. The camera has a "differencing" function. By comparing two pictures of an object or a scene taken at different points in time, the computer produces an image that presents the difference between the pictures. The technique is useful in determining whether or not a part on the assembly line is in the required position.

4. The Westinghouse APAS system consists of seven arms and seven camera eyes for inspection. In one of its plants, at present, a robot is engaged in swaging operation, performed with a multimillion-dollar budget and a mandate to apply robots in any and all areas of manufacturing.

5. The GE robots have been put to work in a number of operations. At the Chicago refrigerator plant, a robot is used for spraying powdered paint on refrigeration lines. At the Hotpoint dishwasher factory, spraying of porcelain enamel is being performed by a robot. In yet another appliance plant, robots load and unload a press that trims refrigerator liners. The 20 lb. liners are picked off hooks on an overhead conveyor, trimmed and punched, then placed on another conveyor. At the same plant, robots are also used for spraying refrigerator cabinet interiors with an adhesive that anchors a foam-insulation layer.

6. This research activity is centered at the company's Optoelectronics Systems operation in Syracuse, New York. The company has plans to set up a production base in Japan in collaboration with Dainichi Kiko Company of Tokyo.

7. The system measures a variety of orientation - invariant properties such as area, perimeter, length and width and thus establishes identity of the part or parts in question. SRI is also engaged in extending the system to three-dimensional objects. It is using a digital processing approach, in which a laser scans the scene, and range information is derived from the time it takes the laser pulses to return to a receiver. A three-dimensional image is thus built up in the computer which then rotates three-dimensional models of various parts, fitting these models to parts of the scene until all parts are identified.

8. The hundreds of dots that form the TV image are transmitted to a computer which converts the dots into binary code and compares the details with previusly recorded descriptions of various objects. It compares features like perimeter and area enabling it to recognize and choose among nine different objects.

9. The sources of these estimates are Quantum Science Inc. of New York and Consultronique Ltée of Paris.

10. Initial production was meant for complementing its existing range of semi-automatic high rise stacker trucks and microprocessor controlled tractors and pallet trucks.

11. Worthy of note are Robert Bosch and Wolkswagen. Bosch specializes in machinery and assembly technology. Its Bosch assembly system employs Bosch-designed robots, and Eastman Kodak has a Bosch system in its German plant where the Pocket Instamatic Camera is assembled. Volkswagen currently makes four types of robots -- L15, K5, R30 and R100.

12. All that needs to be specified are the end points and the force to be applied. The robot automatically maintains the specified pressure, following whatever variations in content it encounters. The company has a highly automated plant where its robots service four machine tools which together produce 21 different components for brake motors. Similarly, at a SAAB - Scania auto plant, two MHU robots link together four machine tools - two broaches and two drills - to form a flexible machinery system which produces 200,000 gear shift housings a year.

13. Other Swedish manufacturers include Bofors, Ekstroms Industri AB, Electrolux, Hiab-Foco, Kaufeldt and Retab-AB. Of these, Ekstroms is known for their Ecomat[C] pick-and-place; Electrolux for their MHV Series of robots and CP-10 electronic control system, and Retab for their Coat-a-Matic paint spray system. Retab robots are remarkably similar to the Norwegian Trallfa model in construction and operation. The unit itself was, however, licensed from Tokyo Keiki upon their abandoning the line. Marketing of the units has been assigned to Atlas Copco Tools, a major world manufacturer of pneumatic equipment.

14. Robogate was developed by Comau Industriale, a Fiat subsidiary.

15. The estimates are based on a study conducted by two roboticists of the Technical University of Warsaw.

16. Most of the robots presently used in Poland are characterized by 4 to 5 degrees of freedom, hydraulic activation, programmable open-loop control system with a load capacity of 50 kgs. and positioning accuracy of the order of 1 mm. Most common Polish robots are IRb and RIMP-1000. Fifteen Unimate robots do spot welding work on the body of a new Polish car called "Polonetz".

17. The robot has two arms, one for heavy lifting, the other for precision fitting, each having eight degrees of freedom. It uses seven television cameras for vision and one of the hands has pressure sensing devices for touch. In operation, the robot detects the part, recognizes it, determines its orientation, lifts it and manipulates it to fit into another component.

18. The plant is made up of cells each consisting of a robot and a NC machine tool. All cells are linked to an automated warehouse and to one another by cables. The cables guide unmanned carts which are automatically loaded and dispatched by a control computer to the appropriate cell or the warehouse. The company is hoping to create, by 1985, a robot that will undertake the task of assembly too. By 1986, the plant should produce four hundred robots a month, with only 200 employees.

    Fujitsu Fanuc is a highly innovative company, as its advanced bubble memory casette for use in NC systems can testify. The new device - a world first - eliminates the trouble of handling tapes and boosts the efficiency of all NC machines. The casette, measuring only 120 by 64 by 22 millimeters and weighing 235 grams, can memorize information equaling the capacity of a 160-meter long perforated tape. Built into the casette is a pair of bubble memory units. Unlike the perforated paper tape, the casette is capable of accepting any change or correction in instructions, regardless of the frequency, without having to repeat the input job. This contributin to an advanced NC system may not only hasten the march towards the factory of the future, but may also have a major impact on the machine industry as a whole.

19. IBM has recently ordered two Dainichi robots. Dainichi's most sophisticated robot is the Part Time 500.

20. A human operator first observes any object of work and all surrounding conditions through the monitoring TV camera and screens and feeds his findings into the system through a keyboard. The device understands the findings by comparison with the details of all basic and standard work objects shapes and positions which are already stored in its memory. The system then "feels" the object of work by its laser pointer beam hitting a single point of the object with a small bright spot, accurately understanding the location of that point from the beam's directional angle and other facotrs. Hitting with several different spots allows the system to ascertain the object's configuratin, position, and size by the aid of its memory. All surrounding conditions may be grasped by the system through its laser beams. A very complex object is conceived by putting together divided images. Finally, all that the system has understood is corrected by the operator through his display screen checks.

CHAPTER FOUR

CONSEQUENCES OF THE "ROBOT REVOLUTION" FOR CANADA

There is, throughout the industrialized world, a growing realization of the advantages of using robots in production. A few of these advantages are worth repeating here. First, robots are an effective means of automating small to medium-size production - something not achieved by the existing special purpose automatic machinery and equipment. Second, even in the case of mass production, robots can save much time and money due to their reprogrammability. They can be made to perform a variety of functions without elaborate retooling. Their average downtime is only 5% compared to 11% for an automatic, high precision machine and robots can easily be moved from one place (and job) to another in a plant. Third, because robots can usually work more than one shift, their pay back period is relatively short and they increase plant productivity such as by reducing the need for stockpiles. Their capacity for high precision and accurate repeatability reduces scrap and increases product quality. Fourth, their flexibility permits frequent changes in the volume and form of production and thus "mass customization" of products. Finally, they contribute indirectly to greater occupational safety and health in the workplace and thus help user companies to reduce costs connected with employee turnover and absenteeism.

Given these advantages, it is not surprising that many industries and governments see robots as one important answer to their productivity problems. But what of their consequences for Canada? We would argue that robot technology is uniquely suited to Canadian conditions and that the country stands to gain immensely from its widespread adoption. If, on the other hand, Canada should fail to introduce robots in its manufacturing activities - or even delay doing so much longer - the consequences for our economic performance are going to be grim.

We see six major aspects of the Canadian economy that could be influenced by industrial robotics.

The Weeding-Out of Branch Plants

Branch plants have rightly been identified as one of the major hurdles to the development of an independent Canadian industrial strategy. A recent survey of CAD/CAM activities in Ontario by the Ontario Research Foundation, revealed that an overwhelming majority of small and medium-sized companies in Canada did not produce their own engineering or product design but instead borrowed or bought these services from equipment suppliers or parent companies in the U.S.A. What is worse, almost half of these companies preferred relying on their parent companies to the establishment of a Canadian technical resource center.

Robotics might well help to break down this dependency. A government sponsored Industrial Robotics Program could establish an "East-West" information resources infrastructure geared towards building up a truly Canadian industrial complex. Unless such an infrastructure is built, Canadian industry is likely to suffer increasingly on account of its branch plant status. To take an entirely plausible example, once the parent companies have automated their U.S. plants, they might well lose interest suddenly in their "backward" Canadian children. The productivity achieved by an automated plant could be so high as to render a Canadian subsidiary uneconomical even with the protection of tariffs. Canadian industries dependent on the flow of technology from the U.S. would then be forced suddenly to develop other sources or face elimination. And even if the U.S. parent company decided to automate its Canadian subsidiary - on the face of it a better deal than bankruptcy - the outcome would almost certainly be to tighten still more the strings from Head Office. Advanced automation affords greater precision in the setting of production schedules and the attainment of targets, and thus facilitates greater integration of all parts of a company into its manufacturing strategy. In short, the impact of industrial robotics could confront Canadian companies (which do not act) with a rather unattractive choice between growing dependency on the one hand and obsolescence on the other.

Productivity Gains

Aggregate labour productivity in Canada has declined from an annual rate of 3.07% in 1967-73 to 0.16% in 1974-75. According to the latest estimates, productivity is not expected to exceed 0.5% during the first half of the decade. More worrisome is the fact that manufacturing industry's labour productivity growth has declined from 4% in the period 1967-73 to 2.66% during the 2 years 1974-76. Table 5.1 presents a clear picture of the steady, disturbing decline in productivity over the past three decades. This has contributed in turn to Canada's recent poor performance in economic growth, culminating in virtually zero-growth in 1980.

While, by world standards, Canadian manufacturing industry is relatively small, its importance to the Canadian economy cannot be denied. As a recent report by the Department of Industry, Trade & Commerce pointed out, the manufacturing sector is the most important indirect generator of employment in Canada. When manufacturing expands, demand is created both in the primary sector that supply materials, and in the consumer sector as a result of income growth. And, most important of all, it has been estimated that about 50% of the aggregate labour productivity growth in Canada comes from manufacturing industry.

TABLE 4.1

PRODUCTIVITY GROWTH BY INDUSTRY, 1947-1978

(AVERAGE ANNUAL RATE OF CHANGE OF GNP PER FULL TIME EQUIVALENT EMPLOYEE)

	1947-57	1957-66	1966-73	1973-78
MANUFACTURING	3.0	3.4	2.5	1.3
NONDURABLE GOODS	3.3	3.7	3.0	2.1
Food & Kindred Products	2.3	3.1	2.1	3.2
Tobacco Manufactures	3.6	3.5	4.2	4.4
Textile Mill Products	4.7	7.0	1.7	4.0
Apparel & Other Textile Products	2.7	2.5	3.7	3.0
Paper & Allied Products	1.1	2.7	4.7	-0.1
Printing & Publishing	2.7	2.6	1.2	0.2
Chemicals & Allied Products	7.3	4.8	5.3	0.5
Petroleum & Coal Products	3.9	7.1	3.3	2.4
Rubber & Misc. Plastics Products	-0.8	4.4	1.7	0.3
Leather & Leather Products	0.1	3.4	1.5	1.1
DURABLE GOODS	2.7	3.2	2.1	0.7
Lumber & Wood Products	0.7	6.5	1.2	0.9
Furniture & Fixtures	7.9	2.2	1.9	1.0
Stone, Clay & Glass Products	2.1	2.7	1.9	1.0
Primary Metal Industries	5.3	1.9	1.2	-3.1
Fabricated Metal Products	-4.7	3.0	0.04	0.2
Machinery (Except Electrical)	2.9	2.8	2.0	-0.4
Electric & Electronic Equipment	3.0	5.1	4.7	1.8
Transportation Equipment (Except Motor Vehicles & Equipment)	3.8	3.4	2.5	-2.0
Motor Vehicles & Equipment	5.2	4.3	3.0	5.3
Instruments & Related Products	--	4.4	0.0	0.1
Misc. Manufacturing Industries	0.2	2.7	3.4	3.1

Source: Hudson Institute, Research Memorandum, October 1979.

A number of industries in which productivity decline has been most marked (e.g., fabricated metal products, electric and electronic equipment, transportation equipment, instruments and related products) can benefit greatly from the use of robots. In turn, these industries might well recapture some share of the world market they have been losing to trade rivals. Fabricated metal production is a case in point. Surveys show that about 75 per cent of all metalworking products are manufactured in short production runs. Small companies are characteristic of the industry, accounting for almost half of total employment. Many of these companies are now uneconomic because of high labour turnover and the high wages demanded for work in hazardous environments. While the short production runs and small scale of the industry have historically inhibited the adoption of automation, robots - as we have shown - lend themselves very well to such production. Their employment would almost certainly improve productivity by increasing capacity utilization, material and manpower savings, and flexibility of operations. In some countries the use of robot diecasting machines has increased output by amounts ranging from 25 to 100 per cent.

Direct Benefit to Users

Judging by the 1980 market growth, one may assume that demand for robots in Canada will continue to be about 10 per cent of the demand in the U.S. Sales of robots in the U.S. in 1980 were estimated at $90 million, while the Canadian figure was about $10 million. Projecting this into the next decade, one might expect Canadian sales to reach $40 million by 1985 and $100 to $150 million by 1990.

Given the short pay back period, the savings accruing to robot users is bound to be significant. At present prices, robots pay back within 18 months if operated on two shifts and within 3 years if operated on a single shift. Pay back periods are even shorter - less than a year - in the best examples of current use such as spot welding, plastic injection molding and spray-painting. When spinoff benefits are taken into account, the economic returns are even greater. Chrysler U.S.A., for instance, found that the installation of robots reduced the need for heating and ventillating and, thereby, cut energy costs by $75,460 - the price of a robot! Medium-sized companies, faced with the prospect of slow growth in the 80s, could improve their situation considerably by installing robots.

The productivity benefits over the five to ten years of their expected life could add up to savings of millions of dollars.

Improved Export Performance

Canada is clearly being pushed out of markets by stronger trading nations. During the period 1970-75, Canada's share of world trade in manufactured goods dropped from 5.6 to 3.8 per cent, a decline of 32 per cent! During the same period, Japan's share grew from 10.4 to 12.1 per cent, France's share increased from 7.7 to 9 per cent and Germany's share increased from 17.6 to 18.1 per cent. To be sure, since 1975 there has been a reversal in the trend and Canadian export performance is showing some signs of improvement. However, when compared to the performance of other countries, the situation must still cause concern. A further disturbing fact is that many of our competitors are increasing their share of the Canadian market. From 1970 to 1977, the proportion of the Canadian market for manufactured goods supplied by imports grew from 26 to 31 per cent.

One of the main reasons for the superior performance of countries like Japan and France is application of the most advanced technology. These economies are constantly engaged in the modernizing of machinery of production and the improvement of manufacturing processes. It has been estimated that, over the last decade, the use of computers accounted for at least 15% of productivity growth in the U.S.A. To remain competitive, Canadian industry, with its high labour costs and small domestic market, must increase its productivity. Following the lead of other countries, Canada should move with speed and determination to increase the application of modern technology to its manufacturing industry. There is growing recognition of this fact among Canadian businessmen. A recent survey by the Canadian Institute of Metalworkers (CIM) found that about 50 per cent of executives realized that the use of advanced technology will, over the next 5 years, be a prerequisite to their companies' remaining competitive.

Safety and Health of Workers

In Sweden, the law prohibits people from working on night shifts and in Germany, women are so prohibited. The U.S. Congress has passed a law which will, by 1984, prohibit people from working in paint-spraying operations. Following in the wake of such legislation, industries in these countries are turning to robots. In Comecon countries, labour shortages and a concern to protect workers from hazardous environments are dictating the shift to robots.

Canadian workers too are increasingly reluctant to perform hazardous jobs or to work in stressful environments. Assembly lines and metal working will come to attract fewer and fewer workers and it is simply a matter of time until such concerns manifest themselves in legislation and regulation. Canadian manufacturing industry as a whole and machine tool manufacturers in particular would do well to prepare for coping with such changes.

An early, phased legislating of workers out of hazardous environments would accomplish two positive objectives. The re-employment of workers could be planned so as to minimize hardship and avoid the high human and financial price of sudden, drastic change. At the same time, the resulting increased demand for robots would act as a stimulant to domestic robot or robot-related production. Any such legislation must of course take account of the resistances built into Canadian manufacturing. The metal working industry, for example, expects very strong growth in the coming years and so may feel that it can do very well without robots.

Impact on Employment

The $64,000 question is, of course, "What effect will robots have on employment"? The most extreme estimates suggest that they might eventually displace almost 50% of workers in the manufacturing sector. Given that manufacturing accounts for 19 per cent of the total Canadian labour force, that would mean a loss of about 10 per cent of present Canadian jobs as a result of factory robotics automation. To date, however, it is estimated that no more than 500 Canadian workers have been displaced by robots. Over the next decade, assuming the installation of 6,000 to 10,000 robots, each of which (on average) displaces $2^{1}/2$ workers and creates .25 jobs in maintenance and manufacturing, we estimate that some 13,500 to 22,500 jobs will be at risk. This represents about 1 per cent of the manufacturing labour force, or 0.2 per cent of the total labour force.

Unlike office automation, which uniformly affects a large number of workers doing virtually identical jobs, robots are coming to factories in many shapes and forms, displacing a small group of welders here, or of painters there. The impact on employment would thus be far more diffuse than is sometimes suggested. And an important point to remember is that most of the jobs lost to robots are in fact the worst kinds - dirty, hazardous and monotonous.

Employment in the automotive industry will probably continue to be the most severely affected by industrial robotics. But a recent survey of ten Canadian passenger car and light truck assembly plants indicates that no more than 650 unskilled jobs are expected to be lost to robots in Ontario car plants by 1985. This will be partially offset by the creation of some 45 skilled jobs, leaving the net reduction at about 2 per cent of the labour force in the industry. However, as the nominal production capacities of plants are expected to grow, despite the net loss of 600 jobs to robots, the number of Ontario auto workers may grow by more than three times as much for the same period. If the impact in all other manufacturing industries is no more severe, the renewed automation scare on the factory floor could be put to rest.

So far we have discussed possible job loss, but what about job creation? It has been found in the U.S. that high-tech industries create employment at seven times the rate of companies using conventional technology and moreover, that new companies in the high-technology field create eight times more employment than established, high-technology firms. Similarly, a survey done in the U.K.

revealed that for every 12 to 14% increase in productivity which resulted from new technology, there was a corresponding 7 to 8% increase in labour employed within that industry. It is reasonable to assume that this would be true in Canada and that the encouragement of robotics would lead to sizeable new employment opportunities.

The most important thing to keep in mind about the employment effects of robots is that such new technology is absolutely essential to maintain Canada's international competitiveness in manufacturing. Refusal to introduce "leading edge" technology for fear of immediate unemployment, may well result in job losses far more widespread and extreme in the future. Whole plants and with them whole work forces might be eliminated. Such developments would be unmanageable because they would be brought about by external factors over which Canadian decision-makers would have no control. In short, far from being a threat to jobs in Canadian manufacturing, robots and similar new technology may be the best defense those jobs have.

All of these developments must be set against a still longer historical perspective. It is now widely accepted among policy analysts that employment in manufacturing, like employment in agriculture before it, will inevitably decline. The only question is by how much? A Rand Corporation study has projected that manufacturing will account for a mere 2 per cent of the labour force by the year 2000. Even if this proves extreme, it is not too early to begin to adjust to the post-industrial age that is now upon us. If it is realized that we are living through a major economic transition, then the concern will not primarily be to protect "existing" jobs, but rather to make sure that history does not pass us by and leave us poor in its wake. Periods of change can be viewed as opportunities for progress or as a threat to the past depending on one's perspective. It would, in our judgement, be wise to view robotics as beneficial and to begin looking for ways to maximize those benefits.

CHAPTER FIVE
POLICY ANALYSIS

Discussion of the possible consequences of the robotics revolution for Canada underscores the need for policy initiatives in a number of areas. A few of these have been detailed in the following pages. It is, however, necessary to sound a word of caution about the efficacy of these policies in bringing about the desired changes. Technology is never a panacea for poor performance. While robots can improve productivity, cut labour costs, and increase the flexibility of manufacturing operations, their ability to bring about beneficial changes is limited by the social, political and economic settings. Technology can certainly strengthen the manufacturing base of the Canadian economy. However, it does not, in itself, have the capacity to bring about a turnaround in the economy, the outcome of which rests on a variety of factors, including the whole gamut of government policies. For instance, robot-manufactured products need as much export promotion as do products manufactured without the use of robots, and enhanced quality will not automatically result in an increase of exports. Efforts in promoting robotics should therefore be seen only as a part of the industrial strategy of this country in meeting the challenges of the 1980s.

In the competitive environment of the upcoming 1980s, our trading partners are expected to remain as keenly competitive as ever. In fact, they are improving their international competitiveness by the increased use of leading edge technology. Industrial robotics plays a pivotal role in their designs. The advancement of automation is clearly the Great Industrial Bet of the 1980s. Governments of all industrialized nations now seem to support automation, with particular emphasis on robotics.

Even the conservative government in Britain has reversed its earlier stand against government-initiated support mechanisms and has quite recently announced a "Robots for Industry" scheme which provides funds to undertake feasibility studies and the actual installation of robots. In the U.S., the government is supporting manufacturing technology through the National Science Foundation and the National Bureau of Standards. In Japan, the role of MITI and its national robotics program is well known. The German Federal Republic is funding extensively a number of research programs, the most notable of which is known as the "Humanization of Working Life." The government has already spent over $50 million and has increased the robot population in the country to make Germany the third leading nation in the world in terms of robot use. In France, the state is helping robotics through its MECA scheme. It would therefore be difficult to expect that the Canadian manufacturing industry, completely unaided, could ride out the robot wave alone at a time when all our major trading partners do not hesitate to harness governments to strengthen their technological capability.

Robotics Recapitulation

When considering policy concerning industrial robotics, it is useful to recapitulate succinctly their advantages, problems associated with their implementation, their present capability, major trends and expected future capabilities.

As previously argued, industrial robots provide a useful way to eliminate human work in hostile environments (poisons, nuclear, heat, dust, underwater, space), and to reduce human involvement in dangerous or monotonous work. What is more, they provide the chance to increase productivity, especially in batch processing. For example, 25 - 100% increases in the output of die-casting machines have been claimed with robots in use. The higher throughputs, higher speed and higher flexibility should be reflected in reduced stocks, and therefore in cutting costs, resulting in a good return on investment.

Robots allow the expansion of manufacturing into three shifts, as they have no objection to working night shifts. In addition to these quantitative considerations, the higher consistent quality of production, as well as increased workers' safety, are other positive features of robotics.

There also exist, however, some problems associated with the introduction of robots. Costs of maintenance increase, and robots do have their oil breaks (but not coffee breaks). However, downtime is still less than half that of other automation equipment. Another problem often cited is difficulties connected to long periods needed for debugging the machines. The most critical problem, however, seems to be the lack of experts in industrial robotics -- both at the engineering and technician levels.

The present leading edge industrial robots provide six articulations, have teach and playback capabilities, are endowed with sizable memories, have reach positioning accuracy of one-third of a millimetre, can handle weights up to 150 kgs., can have mixed point-to-point or continuous path control, can be synchronized with moving workpieces, are compatible with microprocessors, are highly reliable, and are above all economically feasible.

Presently robots have been proven to be useful in manipulation (60% of applications worldwide) and welding (20% of applications globally, 50% in Canada). They are also used in spray painting (20% of applications globally) of parts of machines of all kinds -- cars, motorcycles, trucks, farm machinery, mining and construction machinery, electrical equipment, aerospace, armaments, textile machinery, and consumer electric appliances from calculators to TV sets. New applications are developed every day -- in medical equipment, furniture, computers -- but also in more exotic environments such as underwater, nuclear or space environments.

Some trends in industrial robotics have emerged recently. A shift from pneumatic and hydraulic actuation to electrical drive can be detected. Robots are increasingly programmable, as they are increasingly married to microprocessors and minicomputers, thus becoming smarter and smarter. They are being downsized and more and more modularized. Their positional accuracy and velocity has been increased. They also have more arms. Robots are also having more feedback -- or, in other words, control is increasingly more adaptive. Their reliability has been increased to 400 hours of uninterrupted performance and the goal of 1500-2000 hours target is appearing on the horizon. A considerable effort is exerted to equip robots with locomotion. Above all, the blind robots of today will increasingly be equipped with new senses in the future -- with rudimentary vision and proximity tactile sense.

Robots are increasingly being combined with other robots in families, and with computers and NC machinery in cells, or flexible manufacturing systems. With the robot payback period continuously decreasing, as the price of the machines drops and industrial wages climb, the robots are increasingly being used for production in small and medium batches. Finally, the use of robots is no longer limited to the large companies. Small and medium enterprises are becoming increasingly more interested.

Robots of the future will most likely have a rudimentary sense of vision to provide better recognition and orientation data. They will be equipped with tactile sensing for recognition, orientation and physical interaction purposes. They will be routinely coupled with microprocessors. Many will be mobile. They will have self-diagnostic ability. Speech synthesis and voice recognition in robots is another characteristic soon to be seen on experimental robots in leading research laboratories.

All of these characteristics are difficult to achieve simultaneously, nevertheless, it might be expected that with present drives to improve industrial competitiveness, based on improved productivity, these properties would be available in robots within a decade. In this area it is dangerous to speculate beyond 1990. However, it is to be expected that by the end of the decade the industrial robot market could be a multibillion one, transforming deeply the landscape of advanced economics, and modifying the lives of tens, if not hundreds of thousands, in the plants around the industrialized world.

Before providing policy recommendations, it is useful to comment on the desirable degree of government intervention in this area.

Random discussions with managers in the Canadian manufacturing industry clearly confirms that findings of the May 1981 CAD/CAM Report of the Ontario Research Foundation, that many Canadian companies are opposed to even the slightest forms of government intervention in robotics (or any other CAD/CAM technology), mainly as a result of deep philosophical opposition to any government intervention in their businesses.

The decision about the degree of government intervention is undoubtedly a complex and difficult one. The track record of government intervention in high technology is not very good. Nevertheless, taking into account the rapid developments abroad that involve massive help by the governments in other industrial nations, and also taking into account the contrasting very low level of robot use, to say nothing of robot manufacture in Canada, leads one to the inescapable post-Keynesian conclusion that in this area the government system of this country has to provide leadership if Canada is to be "reindustrialized."

CHAPTER SIX
POLICY RECOMMENDATIONS

National Industrial Robotics Program (NIRP)

It is with all the previously-discussed considerations in mind that we would propose the establishment of a National Industrial Robotics Program. The program would utilize the successful and transferable elements of similar programs in the U.S., Japan, France and the U.K. It would be composed of ten important building blocks, which should ideally reinforce each other. Among the elements of an effective National Industrial Robotics Program one should focus upon the following:

1. Raising the awarness of robotics;
2. Rapid introduction of applications of industrial robotics;
3. Support for small and medium companies through a Canadian robot leasing facility;
4. Robot software support;
5. End effectors and sensors development;
6. Robot hadware manufacture scheme;
7. Research and development support;
8. Technical manpower development;
9. Strengthening of existing government programs;
10. Introduction of workplace adjustment mechanism.

Individual basic blocks of the proposed program will be discussed further in this chapter.

The details of the proposed program would have to be worked out by a Task Force, composed of representatives from various departments of the two senior government levels, the private sector, and organized labour.

The National Robotics Program must take into consideration the present reality of Canada. In the absence of a comprehensive national industrial strategy, the individual provinces are already actively defining their industrial strategy programs. Furthermore, the goals of central and peripheral provinces are not identical. Provinces with a considerable manufacturing capability -- Ontario and Quebec -- are striving to keep their industrial base competitive. The strategic goal of provinces where the source of wealth is based primarily on income from resources would have a different emphasis. In this case robots would aid in increasing the speed of processing of their produce. Clearly, any sound National Industrial Robotics Program would have to be a two-tier construct. The central government would be best advised to attempt seizing on the initiatives already under wraps in various regions of the country, such as:

- The CAD/CAM and Robotics Centre in Ontario;
- Centre de Recherches Industrielles du Quebec in Quebec;
- National Institute for Manufacturing, Science and Production Technology in Manitoba;
- Productivity Centre in New Brunswick;
- Also the initiatives of the governments of Alberta and Saskatchewan in this area.

The best the central government can do is to provide the leadership "from behind," harmonizing these provincial efforts, helping to avoid duplications and filling the gaps in the field not covered. Any worthwhile achievement in one of the regional centres of excellence should be diffused to others to minimize the overall effort and maximize results. It would also be the responsibility of the co-ordinating body to facilitate development projects on a shared-cost basis between two or more centres. Handsome pay-offs could be expected to result also from co-ordinated research efforts. The most appropriate mechanism here would be an inter-departmental Task Force, with Industry, Trade and Commerce being its lead agency. The participation of experts from federal technical departments, the National Research Council of Canada and other concerned and interested provincial departments, would assure that the National Industrial Robotics Program was as broadly based as possible, and that a meaningful inter-governmental consultation was achieved, as well as that all the varied aspects of the complex issue of a major transformation of our industrial base was covered.

Basic Building Blocks of the NIRP

1. Raising the Awareness of Robotics

The previously-mentioned survey of Ontario manufacturers (1981) clearly shows that only some one-quarter of Canadian companies are fully aware of the robotics potential. The first task is to make the management and technical personnel of Canadian manufacturing companies aware of the capabilities offered by industrial robotics. Furthermore, the management of these enterprises must be educated to accept robotics.

In order to combat this lack of awareness, some information disseminating source becomes a necessity. For the sake of placating fears regarding government intervention, such a centre might be constituted as part of the recently recommended Canadian Centre for CAD/CAM, and be staffed by both industry and government experts in the field. The creation of a Robot Institute of Canada should be seriously contemplated, perhaps as an extension of the CIM. TV campaigns on the importance of robotics might help in increasing public understanding of the contributions of industrial productivity increase, and ensure well being.

The need for increasing awareness cannot be overemphasized, given the deeply ingrained conservatism of Canadian manufacturers which manifests itself in such characteristics as risk aversion and lack of innovativeness.

2. Rapid Introduction of Robot Applications

Given the head start of other industrial nations in the manufacturing of robot hardware, and having only a rudimentary manufacturing capability for producing robots, combined with the limited number of qualified design talent in this country, it is recommended that the policy priority be given to the encouragement of rapid and intensive applications of imported robot machinery which has already demonstrated its capability. While more detailed calculations would be needed, the rough estimate derived from detailed British studies of the 1990 potential for robots is given in Table 6.1. Under Alternative A, market forces alone are assumed to do the job. Under Alternative B, government intervention is expected to increase the growth/year of robot applications by 5 - 35% a year.

To this end tax incentives for the use of robotics might be desired. Tax write-offs are used in Japan, and there is no reason why this policy instrument cannot be used in Canada as well. The feasibility of a tax credit might therefore be further explored. This and another alternative such as grants to the first users could be combined with the proposed Robot Leasing Facility discussed below.

TABLE 6.1

ROBOT POTENTIAL IN CANADA 1990

		Alternative A (Market Forces)	Alternative B (Govt. Intervention)
*	Spotwelding	400	800
*	Injection Moulding	300	600
*	Pressure Die-Casting	300	600
*	Spraying	500	500
*	Forging & Extrusion	250	250
*	Metal Cutting	300	300
*	Investment Casting	50	100
*	Press Loading	850	850
*	Heat Treatment	50	100
*	Arc Welding	1,000	1,900
*	Assembly/Packaging	1,000	2,000
*	Material Handling	500	1,000
*	Other (Hospitals etc.)	500	1,000
	TOTAL	6,000	10,000

Under the government intervention scenario (b), the projected "natural" robot market of some $150 - 200 million could be increased up to some $300 million by 1990.

3. Support for Robotization in Small and Medium Companies

The introduction of robots is likely to progress faster in large companies. Small manufacturing companies, however, are apprehensive of introducing robots in view of the skills gap that exists in knowledge available to them at present and the required know-how for the future. To bridge this gap it is necessary to set up a consulting agency which would provide expert advice as well as assistance in installation of the robots. So far at least two private firms are known to offer such services. However, a governmental or, even better, a mixed agency would be a welcome initiative. It would be the purpose of this agency to provide information to the prospective user on the available alternatives and to advise on their suitability. The agency could also perform a return-on-investment analysis on behalf of the compay. The agency could thus enhance the level of technological awareness in the small manufacturing companies. It is quite obvious that the support and awareness functions could and should be combined.

4. Canadian Robot Leasing Facility

One scheme that can be expected to substantially quicken the process of roboticizing Canadian manufacturing would link the consulting agency to the Robot Leasing Facility. Under such a scheme a government - supported (jointly or exclusively) crown corporation would purchase robots from the leading manufacturers around the world, and provide the know-how in application studies and other consulting services. The leasing facility would also allow the small, inexperienced manufacturers to lease rather than purchase the robots, and, of course, the related qualified personnel. Such an arrangement would have several advantages. It would help to reduce capital requirements for automation of the manufacturing and it would also develop a considerable body of aplication expertise in one place (the facility), transcending individual companies. What is more, such a facility would, by the shear volume of its input, gain considerable clout in obtaining the best possible conditions of delivery, modifications and service. Such a facility could also be advantageously coupled with a permanent demonstration facility where robots of various makes could be seen in action by prospective customers.

The Robot Leasing Facility concept has already been tried abroad. A single large company, General Electric, has such a facility in Schenectady, New York. As already mentioned, the Japanese set up in 1980 the Japan Industrial Robot Company, modelled on a very successful similar scheme (the JECC) designed to accelerate the use of computers some years ago. A variation on the leasing scheme comes from France where L'ADEPA (Association pour le developpement de la production automatisee), and the Ministere de l'industrie, designed in 1980 the MECA procedure to help enterprises to equip themselves with automatic machines. In this system the user obtains an advantageous loan to purchase the machine. The enterprise that agrees to try the machine on a "complete satisfaction or your money back" basis, can return the machine within two years if not satisfied with it. In such a case the robot manufacturer is reimbursed from the loan fund. The scheme is modelled on a successsful 1974 MOCN scheme, which resulted in more than 500 installations of numerically-controlled machinery in small French enterprises.

Even the large companies should not be forgotten. Here, to strengthen the industries which are strategically important to the Canadian economy, they can be helped by loans to aid in setting up pilot installations using industrial robotics.

Though it is late in the robot race, such mobilization can help Canadian manufacturers to reduce the gap with the leaders in the use of flexible automation.

4. Robot Software Support

Once the most appropriate robot or group of robots are selected for a given job, their capability must be fully exploited by clever production engineering and system design. Part orientation, sequence control, analysis of the machining cycle, interlock analysis, gripping requirements, figuring out work and workplace configurations, are examples of the problems that can be embodied in the software of a computer control for robot-based groups of machinery

It is proposed that the robot design talent be channelled into developing sophisticated software packages that can be added to both the imported and the indigenous robot hardware. Similarly Canada could strive to develop orgware expertise related to robotics.

5. End Effectors and Sensors Development

End effectors are the hands at the working end of the robot. These are the moving elements that grasp, move and manipulate parts, awkwardly emulting human hands. Being less adaptable than human hands, robot effectors have to be designed for a particular industrial application.

It is proposed that the design efforts be focussed on the development of the end effectors. Effectors of particular interest to Canadian industrial users should be focussed upon. Interestingly, robot accessories could be more profitable than bare robots.

Robots have to work within the context of the larger plant. A number of sensors have to be developed to harmonize the interaction of the robot and its complementary machinery. It is therefore proposed that the robot design efforts in Canada be focussed on the development of mechanical, electrical, and above all electronic sensing devices.

6. Robot Hardward Manufacture

While on a short-term basis the need to equip Canadian manufacturers with industrial robots can be solved by large-scale importation, this is not a long-term solution. It will be necessary to develop a robot hardware manufacturing capability in this country. Given the complacency and dependency-orientation which permeats private industry, it will be necessary for the Canadian governments to help set up a major robot hardware manufacturing company, perhaps through its Canadian Investment Development Corporation. It is also essential that such an enterprise involve the participation of one of the leading robot manufacturers. The choice of the partner could be based on considerations of complex Canadian requirements. Japanese manufacturers have developed the widest variety of robot devices. Hence a team-up with a leading Japanese manufacturer could be given serious thought, and the appropriate welcome-mat package would have to be developed. Alternatively, the great resources of a large multinational company already operating in this country could be channelled in the direction of obtaining a global product mandate for its Canadian operation to produce industrial robots not only for Canada but also for export. Any of the available candidates for such a role could be designated as our national champions in industrial robotics manufacturing, and thereafter be treated as such by our governments.

It may rightly be argued that classical industrial robot manufacturing in Canada is nearly impossible as of 1981, since it is a very competitive market. Furthermore, it can be argued that Canadian robot manufacturing is not essential if the machines could just as easily be imported to meet the existing low demand. However, this demand is likely to grow explosively if the doubling of the number of robots in operation in 1980 alone is any indication. But it is the development of technological capability that is above all important. Without indigenous production there is little chance that Canadian technology can keep pace with developments elsewhere. If action on creating our own robot manufacturing base is deferred, Canadian technology will be involved in a continuous catching-up game and could fall considerably behind other industrial nations. What is more, it may be that technology available "off the shelf" would then be quite far behind, as our trading partners would safeguard the edge of their exports. Such consideration is not hypothetical. For example, the Japanese manufacturer Fujitsu Fanuc announced that its new robot technology would not be given out for sale for three years in order to safeguard their production and exports.

Japan offers a good model of the reward for developing indigenous capability. The earliest developments in robot technology did not take place in Japan. However, Japanese manufacturers were the first to recognize the robot's potential. They entered into arrangements with the developers in the U.S. and elsewhere, and used the borrowed technology to build up their national technological capability. The success of their initiative is evident by now. To illustrate, Unimation's Japanese licensee, Kawasaki Heavy Industries, already ships out as much as half of Unimation's total production.

It is still not too late for Canada to enter the field of industrial robot manufacturing. The present, virtually blind generation of robots, would have to be ignored, though. Instead, it might be possible to build up a national capability via the technology of 1985. By "leap-frogging" into intelligent robotics there is still a chance for Canada.

7. Research and Development Support

If the government endorses Canadian entry into the manufacturing of intelligent robotics, then new resources for robot research, and above all the development of future robots, will be needed.

Little of the existing research is being applied to industrial problems. This will have to change. The puddles of research talent will have to be brought into a comprehensive pool. R&D efforts will have to be focussed and co-ordinated.

The target of development could be use of robots for assembly. Pay-offs are large, as some 80% of assembly work is still done manually, and it employs about one-third of the blue-collar workforce. Because of the formidable technical problems involved, no competition exists, and assembly robots are still some five years away.

To this end, without any doubt, research on computer vision should be encouraged and strengthened. Building on the achievements of the computer vision programs of the National Research Council of Canada and McGill University, the existing effort should be more directly focussed on intelligent industrial robotics needs. Work on algorithms for scene analysis on computer interpretation of visual data (extract the features from the visual scene in 10^{-3} seconds or less) and on rationalization of the workplace are some examples of the work which promises payoffs.

The research in end effectors, focussing perhaps on more universal grippers, could lead our improved design capability in this area. Research should also be encouraged in the area of non-visual sensing -- such as tactile, chemical and electrical sensors.

In software research, the packages for interpretation of visual scenes, for co-ordination of multiple areas and self-diagnostic fault tracing, are examples of areas where the research effort could lead to exportable products. Finally, research on robot assembly proper would have to incorporate all the results of the primary research thrusts. The task is not easy, as leading researchers in Charles Stark Draper Laboratory, Stanford Research Institute, Rhode Island University, the National Bureau of Standards, Hitachi, DEA and elsewhere could attest to. Nevertheless, automatic assembly is worth a bet.

Another development target has emerged during our study. Development studies could most profitably focus on high quality production of low-cost robots (less than $1,000) coupled to a small computer (again less than $1,000). One possible avenue in this context might be to explore the production know-how of toy manufacturers for producing low-cost high-volume products. Achieving access to a leading toy manufacturer by a Canadian robot manufacturer might be a pre-emptive move in the right direction. Low cost vision, needed for such robots, could probably come from the new developments in electronic cameras, most likely made in Japan.

Yet another area of R&D that promises rich payoffs is the interface between industrial robotics and other advanced technologies, such as flexible manufacturing systems or automatic warehousing. After all, industrial robotics is an integral part of CAD/CAM technology. While the links to CAM are obvious, the link to CAD is perhaps less so. Development of robotics should also feed back even to the redesigning of products so that they can be more easily manufactured by these "steel collar" workers. The other productive area of research would be work on multiple-level hierarchical control systems for manufacturing, along the lines of the work of the U.S. National Bureau of Standards, and the ICAM (Integrated Computer Manufacturing) Project of the U.S. Air Force.

The robot research program, a combined effort by the National Research Council of Canada, Canadian universities and industry, would require the commitment of funds. A rough estimate based on recent British studies indicates that some $10 million a year for ten years, to a total of some $100 milion under Alternative A, and $16 million a year to a total of $160 million under Alternative B, would be needed if R&D capability for strong manufacturing of intelligent robots is really desired. Detailed cost calculations will have to be performed.

8. Technical Manpower Development

In order to ensure that qualified manpower is available in sufficient numbers, there is a need for focussed initiatives. Universities are one obvious area where efforts need to be made to ensure a steady supply of trained manpower. Robotics should be made part of the curriculum in engineering schools. The Carnegie Mellon University's Robotics Institute has already introduced a graduate study program leading to degrees in electrical engineering or mechanical engineering or computer science. Students are invited to choose from a variety of projects which include the factory of the future, automated mining, undersea exploration, space exploration and manufacturing, microsurgery and prosthetics. The program focusses on such research areas as intelligent systems, vision, sensors, mobile robots, flexible assembly, flexible manufacturing, speech and robot grippers. A similar program should be developed at a Canadian university, even if it need not be quite as extensive as the one offered at Carnegie Mellon. Canadian universities may concentrate on developing projects in the areas not covered by Carnegie-Mellon robotics, specializing in areas that would help specific Canadian conditions. McMaster University in Hamilton, Ontario has recently begun a program leading to a degree in manufacturing engineering, and the University of Manitoba is organizing a program on Industrial Engineering. However, no Canadian university has so far announced any teaching program based specifically on robotics. ITC could sponsor a program in one of the universities which is deemed to have the best capability, possibly under its program for Centres of Advanced Technology.

In parallel, robot technician programs should be initiated in selected post-secondary, non-university institutions across the country. To meet short-term manpower requirements the government could increse acceptance of qualified foreign nationals to work in Canada by relaxing entry requirements. Faced with a shortage of technical manpower, the government in the U.K., which was hard-pressed to restrict immigration, has welcomed foreigners to come and work in the U.K. Until Canadian colleges can confidently meet the manpower requirements of industries embarking on automation, hiring of foreign technicians might be the best temporary solution to the shortage of technicians.

But the major responsibility for ensuring the availability of adequate technical manpower will rest with the industry itself. The brunt of the job displacement will be borne by semi-skilled workers. By effectively using major programs within or outside of companies, in order to re-educate and retrain these workers for the required new tasks, the industry will not only serve its own ends -- having the capability to service robots inhouse -- but will also secure the active support of the unions and the affected workers. The American Society of Mechanical Engineers has already shown the way. The Society has contributed close to one million dollars towards the funding of a foundation which will promote training in those higher engineering skills for which demand is likely to be great in the future. A similar program for trade skills, patterned after the ASME one might be envisaged for our purposes.

Another good step in the right direction would be setting up a national apprenticeship program for skilled robot tradesmen.

9. Strengthening of Existing Government Programs

This study was not undertaken in a vacuum. A number of studies on the importance of robotics have recently been completed around the world and in Canada, as mentioned in the bibliography. The authors have relied heavily on these sources, always keeping in mind the peculiarity of the Canadian condition. In

Canada the report Strategy for Survival: The Canadian CAD/CAM (September, 1980), produced by the CAD/CAM Technology Advancement Council, identified many issues associated with the upcoming wave of automation in manufacturing, and with the rapidly emerging use of Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM). One can only endorse the Council's recommendations. The creation of a CAD/CAM Centre might be combined advantageously with the Robot Centre proposed in this report.

One could also endorse the desire of the Council to see the designation of one representative in each manufacturing company to be responsible for awareness of CAD/CAM technology. Our recommendations overlap with those of the Council. The Council's recommendations are that the universities and community colleges examine their course curriculum to ensure that CAD/CAM technology is adequately represented. This is definitely a step in the right direction.

The National Research Council identified intelligent robotics research and development as one of its priorities. The NRC now supports, or is about to support, efforts by several Canadian companies in the development of robotics. This effort should be enlarged and intensified. The NRC is also involved in the joint ventures with its provincial counterparts. It has been proposed that the Council establish an R&D Institute for Manufacturing, Science and Production Technology in Manitoba, as a joint venture with the Manitoba Research Council.

Similarly, a robotics centre has been announced in Ontario. Elsewhere, the New Brunswick Productivity Centre, and the CRIQ-NRC in Quebec are efforts which should be encouraged and endorsed. Support for university programs in robotics should be provided by the programs of the National Sciences and Engineering Research Council (NSERC).

All of these and other similar efforts unfortunately take time. It will be a while before a full-fledged applications and manufacturing capability in robotics emerges and is in place. By framing them in a high visibility, a high-priority national program would accelerate and strengthen these valuable steps in the right direction. At the same time such a program would refocus these goals, aiming them pragmatically towards practical applications.

10. The Workplace Adjustment Mechanisms

A well-thought-out program should take into account the sociological impacts of robotics. So far the job loss by robots is miniscule. However, whenever labour-displacing technology is introduced, proposals halting the advent of the technology are heard. The doomsdayers project millions of unemployed, and forebodings abound on the consequences of failure to act against the menace of technology. Very often the action is directed at slowing down the diffusion of the technology, rather than at introducing appropriate adjustment mechanisms in the society as a whole.

To be sure, robots are initially bound to displace some workers in manufacturing. However, there is no job activity concentration similar to that of office workers. Robots would enter the factories in numbers and in sufficiently different areas so that the "robot transformation" could be managed, providing that measures be taken to ease the transition of displaced workers form one income-earning activity to another. To that end, the following steps should be taken:

1. Retraining the affected workforce for tasks for which there is likely to be a growing demand. Young, educated workers could without difficulty be taught maintenance and programming tasks. At present robot maintenance is handled in many cases by the vendor. When a breakdown occurs considerable time is wasted in awaiting the technician from the suppliers to arrive. User companies could well act in their own best interest and retrain many affected workers to build up in-house maintenance capability. Another task -- programming of robots - is also feasible. At one GM plant the union local has won the right for its electricians to program computer chips -- a job that had been done previously by employees outside the bargaining unit. In another case, union members are programming robots installed in a GM plant -- again a task done previously by outside employees.

The U.K. Trade Union Congress has come up with a "checklist for negotiators" which many unions could find highly useful when working out New Technology Agreements. The checklist contains many demands calling for expansion of output to neutralize redundancies, redeployment of those displaced, retraining, reduction in working hours, etc.

Very often, though, it is only where the unions are strong that such agreements have any force. It is, therefore, essential that a government arbitration council be set up with clear guidelines to ensure smooth transition to automated shopfloors even where the unions are weak or nonexistant.

2. Increse employment opportunities in other sectors, mainly in the service industries. Jobs could be created in building robots as well. Some 150 jobs would have been created if the robots installed last year in Canada were manufactured in the country.

3. Reduce minimum weekly working hours to match the productivity increases. For instance, a 35-hour work-week could maintain the present employment levels in manufacturing industries and yet increase their competitiveness owing to the immense increase in productivity ensured by the application of robots.

The case of the automotive industry could be cited in this regard. Under a new benefit won in 1976, auto workers obtained seven "personal paid holidays" in addition to regular holidays. As a consequence, the work year equalled 52 work weeks of 4¼ days each for every worker. According to one union estimate, the benefit resulted in the creation of 11,000 jobs at GM alone. If the four-day week becomes a reality in the car industry, it could set up a general standard for all industries by 1990.

4. Lower retirement age, enabling senior workers to retire early and enjoy their retirement benefits. This particular measure could be coupled with such schemes that encourage retirees to engage in productive entrepreneurial activity. In the absence of such a scheme older workers might resist lowering of the retirement age as they could then be expected to join the already growing share of unemployed, unutilized senior citizen population.

5. To enable displaced workers to cope with short-term and medium-term dislocations, specific schemes offering financial assistance need to be developed. Care should be taken to ensure that such measures do not act as a disincentive to the introduction of automation.

6. Introduce legislation making it mandatory for employers to give advance notice of 180 days to workers of technological lay-offs or plant closings, and consult respective unions on introduction of robots.

7. A Task Force may be set up specifically for the purpose of considering the implications or organizational changes occasioned by plant automation. There are a number of issues that deserve careful review. Introduction of automation involves a new knowledge base and new forms of task-based interaction in the workplace. As a result there is bound to be less and less need for skills so far considered essential. The supervisor's job is likely to change considerably from the present function of supervision of workers, to an auxiliary role involving management of support activities such as management of materials and other resources. As a result of closer integration of design engineering and manufacturing operations, technical managers will act more and more as administrators. Most notably, the distinction between blue and white collar division of labour is slowly blurring. Consequently, direct labour will continue to decrease proportionate to indirect labour. Such far-reaching changes call for considerable planning and adequate preparation. The U.S. Federal Aviation Agency is reported to have already done some work along these lines. In 1976 the agency appointed two task forces to assess present and future problems associated with new technology and the changing composition of the agency's workforce. The reports by the task forces, called "Technology Group" and "Quality of Worklife Group," could serve as examples for futher work in this area.

An issue closely related to change in the organizational environment is job satisfaction. It is open to debate as to whether the change in the knowledge base will lead to greater or less satisfaction. While the human operator tending robots will have greater personal task control than the man on the assembly line, he has less opportunity for contact with other human beings in the workplace. Is a worker dealing mainly with machines for the better part of his work-time likely to suffer mental stress caused by loneliness? The question is not as premature as it might appear to some. Agreements incorporating assurances that job satisfaction will be taken into account in job design have been reported recently.

Conclusions about the NIRP

The proposed National Industrial Robot Program is based on the assumption that the main issue for Canada now is strengthening our technological capability, which would help us to "reindustrialize" and to remain internationally competitive. The resulting benefits of productivity, flexibility of production runs and improved quality control are far more important in the long run than the fears of labour displacement.

The core of the Program should be focussed on the establishment of one or more Canadian Robot Centres which could combine the needs of the interested companies regarding robot technology and applications (described above), while serving as the center of expertise on applications research, research into end effectors, robot software and orgware. At the same time, the Centre could serve as a demonstration facility, with its financial arm functioning as a Robot Leasing Facility.

The Canadian Robot Company should form a separate but harmonized entity. Five traditional industries could be the primary targets of intensified roboticization efforts in the near term --

* motor vehicle manufacturing
* domestic appliances
* plastic moulding
* forging
* die casting

However, rather than focussing on particular industries, it is more useful to focus on particular types of work. The traditional applications most worthy of immediate attention, wherever they are found, are:

* spot welding
* paint spraying
* loading/unloading of machines
* testing and inspection
* maintenance

Among the candidate industries which might be significantly helped by the increased applications of industrial robots one can list the following:

* farm equipment
* construction equipment manufacturing
* offshore oil rig equipment manufacturing
* aerospace manufacturing
* electronics manufacturing
* telecommunications manufacturing

* office automation equipment manufacturing
* consumer electronics manufacturing
* shoe manufacturing

The National Industrial Robotics Program would, of course, not come without expense. On a 1990 time horizon, if the targets for robot installations are 6,000 units for Alternative A (market forces alone) or 10,000 units for Alternative B (government intervention), then the total costs of the program needed for achieving the target would probably reach the following estimated capital investment requirements:

	Alternative A	Alternative B
Robots:	$240 million	$400 million
Research:	$100 million	$160 million
Total:	$340 million	$560 million

While obstacles in achieving the goals of this program are great and numerous -- costs, ignorance, lack of skilled engineering talent, to name just a few -- the roboticization of our manufacturing is the imperative move for survival. To this end, government and business have to co-operate. The private sector will have to carry the bulk of the capital robot investment. The governmental system of Canada will have to be responsible for the bulk of research funds. The government has also to act as a source of information about robots, as a catalyst, and above all as an agent of change.

Some $160 million for research, and another $160 million for government participation in the production of robots over 10 years is the price and risk commesurable with long-term success. How to raise the capital needed?

Mr. B. Danson put it best in the Globe & Mail on June 26, 1981: "If we can devise incredibly attractive incentives for the domestic film-making industry, we can provide for greater innovative investment in other areas of our industrial sector."

The robots are about to take off in a bigger way. Tenfold growth over the decade is expected. If would be sad if we failed to use the Robot Factor for "reindustrializing" Canada to cope better with the emerging challenges of the last decades of our century.

APPENDIX A

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APPENDIX B

TECHNOLOGY AND SOCIETY PROGRAM

PANEL-SEMINAR

THE IMPACTS OF INDUSTRIAL ROBOTICS ON COMPETITIVENESS AND EMPLOYMENT IN THE CANADIAN MANUFACTURING INDUSTRY

November 6, 1980

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APPENDIX C

LIST OF PRINCIPAL ROBOT MANUFACTURERS

EUROPE

ASEA
Electronics Division
S-72183 Vasteras
Sweden

Comau Industriale
Divisione Sistemi Saldatura
Strada Orbassano N.20/22-10095
Turin, Italy

Electrolux
S-10545 Stockholm
Sweden

Hall Automation Ltd.
(a GEC-Marconi Electronics Company)
Colonial Way, Watford
Hertfordshire WD2 4FJ, England

Olivetti Controllo Numerico S.p.A.
Strada Torino 603, 10090 S. Bernardo d'Ivrea
Turin, Italy

Renault
Machines - Outils
Centre Parly 2, P.B. 70, 78150
Le Chesnay, France

Trallfa Nils Underhaug A/S
Box 113, N-4341 Bryne
Norway

Unimation Europe Ltd.
Stafford Park 4, Telford
Salop, England

VW - Volkswagenwerk AG
3180 Wolfsburg
Germany

UNITED STATES

Autoplace Inc.
1401 East Fourteen Mile Rd.
Troy, Michigan 48084

Cincinnati Milacron
4701 Marburg Avenue
Cincinnati, Ohio 45029

Prab Conveyors, Inc.
5944 E. Kilgore Rd.
Kalamazoo, Michigan 49003

Unimation Inc.
Shelter Rock Lane
Danbury, Connecticut 06810

JAPAN

Aida Engineering Ltd.
2-10, Ohyamacho, Sagamihara City
Kanagawa Pref.

Daido Steel Co. Ltd
1-11-18, Nishiki, Naka-ku, Nagoya City
Aichi Pref.

Daini Seikosha Co. Ltd.
4-3-1, Yashiki, Narashino City
Chiba Pref.

Dainichi Kiko Co. Ltd.
Daini-Maruzen Bldg., 6-16-13, Nishi-Shinjuku
Shinjuku, Tokyo

Nachi-Fujikoshi Corp.
World Trade Center Bldg., 2-4-1 Hamamatsucho
Minato-ku, Tokyo

Fujitsu Fanuc Co. Ltd.
3-5-1, Asahigaoka
Hino City, Tokyo

Hitachi Ltd.
Shin-Maru Bldg., 1-5-1, Marunouchi
Chiyoda-ku, Tokyo

Kawasaki Heavy Industries Ltd.
World Trade Center Bldg., 2-4-1 Hamamatsucho
Minato-ku, Tokyo

JAPAN (cont'd)

Kobe Steel Ltd.
1-3-18, Wakihamacho, Fukiai-ku
Kobe City, Hyogo Pref.

Komatsu Ltd.
2-3-6 Akasaka
Minato-ku, Tokyo

Mitsubishi Heavy Industries Ltd.
2-5-1 Marunouchi
Chiyoda-ku, Tokyo

Nippon Electric Co. Ltd
1753 Shimonumabe, Nakahara-ku
Kawasaki City, Kanagawa Pref.

Shinmeiwa Industry Co. Ltd.
1-1, Shinmeiwacho
Takarazuka City, Hyogo Pref.

Star Seiki Co. Ltd.
2-36, Shimosakacho, Mizuho-ku
Nagoya City, Aichi Pref.

Toshiba Seiki Co. Ltd.
5-14-33, Higashi-Kashiwagaya
Ebina City, Kanagawa Pref.

Yasukawa Electric Mfg. Co. Ltd.
Ohtemachi Bldg., 1-6-1, Ohtemachi
Chiyoda-ku, Tokyo

APPENDIX 'D'

More Exotic Applications of Robot Related Technology

In addition to their current or foreseeable application in manufacturing, robots may, in the next 10 to 20 years, come to be used in a wide variety of ways. We offer a few "futuristic" examples here to stretch the reader's imagination.

Medical services are among the most promising and interesting fields for robotics. An automated cart (called Amscurs) has been programmed to move through hospital tunnels and up escalators. At least one hospital is reported to have successfully employed the device to transport tons of food, linens, ward supplies, pharmaceuticals and trash. There are also nursing and helping robots, one of which is designed to gently lift a bedridden patient while a nurse changes the bed. Another is designed to help the mentally and physically handicapped with basic tasks they are unable to perform themselves. Medical robots with applications such as physical examination are on the horizon and remote-controlled surgery can be foreseen in the more distant future.

Household chores are another application of robots that tease the imagination, though the special problems posed by the variability and complexity of the house environment have yet to be surmounted. Still robots may, in the not too distant future, clear tables, do the dishes, prepare meals, sort clothes, do the laundry and clean the house. Suitably modified, they could also be made to perform a variety of jobs outside in the yard and garden. A mowing attachment could cut and trim the grass, weed the flower beds, and sprinkle water. The same robot could also stand guard and chase away intruders with devices such as spotlight and siren. The first of these domestic robots has already appeared. "Mole" is a vacuum cleaning robot that remembers movements after it has once been guided through the house. Huggy, the "bionic butler", is a three-foot, 670 lb. robot that talks, walks, plays chess, vacuums, serves drinks and even hails cabs.

The oceans are an immense, wide-ranging area for robot experimentation and application. Efforts are underway to develop lightweight, plastic robots using hydraulic power that will eventually have the ability to walk on two legs undersea. Another development is the unmanned submersible, able to reach a depth of some 300 metres and containing equipment ranging from television cameras to temperature sensors and other transducers. These have already proved helpful in inspecting wrecks and carrying out undersea experiments. Robots may also take over many tasks in the exploration for offshore oil. One immediate possibility would seem to be inspection of drilling rigs. With further development, robots might be used in construction of rigs, or the operation of drilling and other equipment. Further into the future is the possibility of building huge robot-operated turbines to capture energy from deep ocean currents. This, in turn, might make feasible the establishment of ocean colonies based upon aquaculture. Robots are already assisting in fish farming.

Space exploration offers some of the most exciting possibilities for robot-use. Robot exploration and construction of large space structures are considered real possibilities within the next few decades. Remote sensing satellites will be used to collect data for assessing soil conditions, sea status, crop conditions, weather, geology, disasters and so on. Unlike current earth satellites, however, they will also possess the intelligence to process the gathered data and relay only that which is useful to earth. Robot voyagers will increasingly be used since they have no need of the elaborate life support and safety equipment required by human astronauts. These explorers will be sent on one-way missions into the far reaches of outer space. Where they accompany humans, robots will assist in crew and cargo transfer, perform first aid functions and carry out high risk rescue operations.

Robots will be essential for space construction. They will transport the components, assemble them at their destination, and repair and modify structures. The servicing of the system will probably be left to robots since most of the functions (calibration, checkout, data retrieval, resupply, maintenance) will be highly automated and not require human intelligence. Plans for such structures, albeit on a small scale, are already underway. The construction of an "antenna farm" in near space will begin within the next 5 years. The parasol-like structure to be built by robot crafts called "space spiders", will handle the fast growing volume of electronic mail. It will be able to accommodate up to five nationwide television channels, and service as many as 45,000 private channels. In related developments, it has been proposed to build robots to repair orbiting satellites and to build banks of solar cells on the moon or in space. One step further down the road is the automated space laboratory which would use solar energy for automated experiments in extracting volatiles, oxygen, metals, and glass from the soil and other substances mined by automated space rovers. It is believed that advances in robot replication technology will hasten the day of space colonies. Robot-built robots may be capable of developing new functions and thus be able to produce the materials needed for a self-sustaining habitat.

APPENDIX 'E'

CURRENT ROBOT INSTALLATIONS IN CANADA

APPENDIX E (1)

BREAKDOWN OF CANADIAN ROBOT INSTALLATIONS BY COMPANY NAME, PRODUCT, CURRENT AND PROJECTED ROBOT INSTALLATIONS, AND APPLICATIONS

COMPANY NAME	PRODUCT	ROBOT INSTALLATIONS CURRENT	PROJECTED	APPLICATIONS
A.E.I. Telecom			2	Material handling
American Motors	Jeeps	1		Welding
American Standard	Plumbing Fixtures	3	3	Spray painting
American Standard Industrial	Steel Fixtures	1	1	Spray painting
Asea Industries	Assemble Robots	1	2	Assembly
Atomic Energy of Canada	Nuclear Products	1		Welding
Bristol Aerospace	Aircraft Parts		1	Welding
Burlington Die Casting	Die Casting	1	1	Material handling
Campbell Soup Co.	Lead Smelting		1	Material handling
CAMCO	Appliances	1	2	Spray painting
Canada Metal Co.	Lead Smelting		1	Material handling
C.G.E. Montreal	Appliances	2		Assembly, spray painting
Canadian Industries Ltd.	Chemical		3	Material handling
Canadian Machinery	Metalworking	1		Material handling

Forward

BREAKDOWN OF CANADIAN ROBOT INSTALLATIONS BY COMPANY NAME,

PRODUCT, CURRENT AND PROJECTED ROBOT INSTALLATIONS, AND APPLICATIONS

COMPANY NAME	PRODUCT	ROBOT INSTALLATIONS CURRENT	ROBOT INSTALLATIONS PROJECTED	APPLICATIONS
Canadian National Railway	Metal Working	1		Material handling
Canadian Pacific Ltd.	Metal Working	2	1	Material handling
Chrysler Canada Ltd.	Automotives		4	Welding
Computer Assembly Systems	Printed Circuit Bds		3	Welding, Material handling
Crane Canada Ltd.	Plumbing Fixtures	4		Spray painting
Digital Equipment	Computer Parts		1	Material handling
Dome Petroleum	Oil & Gas Explor.		1	Sub-sea welding, Inspection, etc.
Dominion Engineering	Pump & Paper Machinery		1	Material handling
Douglas Aircraft	Aeroplane Ports	1	4	Welding, drilling
Enviro Glass	Glass Products		1	Spray Painting
Falconbridge	Nickel Mining		1	Material handling
Ford Motor Co.	Automobiles	21	20+	Welding, spray painting, inspection, material handling

Forward

BREAKDOWN OF CANADIAN ROBOT INSTALLATIONS BY COMPANY NAME, PRODUCT, CURRENT AND PROJECTED ROBOT INSTALLATIONS, AND APPLICATIONS

COMPANY NAME	PRODUCT	ROBOT INSTALLATIONS CURRENT	ROBOT INSTALLATIONS PROJECTED	APPLICATIONS
General Motors Co	Automobiles	37	90	Welding, Spray Painting, Inspection, Material handling
Glitsch Canada Ltd.	Diesel Fuel Tanks	1	1	Welding
General Steel Wares	Building Products		1	Spray painting
G.T.E. Sylvania	Lighting Fixtures	2	2	Spray painting, Material handling
Hayes Dana	Truck Frames & Axles		10	Material handling
Heinz Co.	Food Processing		1	Material handling
International Harvester	Agricultural Implements	3		Material handling
Jarvis-Clarke	Mining Equipment		1	Mining operations
Kindred Industries	Sinks	2	2-10	Material handling
Monsanto	Chemicals	1	1	Material handling
Noranda Research	Mining		10	Material handling
Northern Telecom	Telephones, Circuit Boards	2	3	Material handling
Olivetti Canada	Typewriters	1	1	Testing and Inspection

Forward

BREAKDOWN OF CANADIAN ROBOT INSTALLATIONS BY COMPANY NAME, PRODUCT, CURRENT AND PROJECTED ROBOT INSTALLATIONS, AND APPLICATIONS

COMPANY NAME	PRODUCT	ROBOT INSTALLATIONS CURRENT	ROBOT INSTALLATIONS PROJECTED	APPLICATIONS
Otis Elevator	Elevators		1	Spray painting
Polysar	Chemicals		1	Material handling
Spar Aerospace	High Technology Equipment		1	Material handling
Stanton Pipes	Pipes		1	Material handling
University of Waterloo	Research	1		Research purposes
Versatile Mfg.	Agricultural Implements		2	Welding, material handling
Wabasso Ltd.	Textiles		3	Material handling
Westinghouse Canada Ltd.	Electrical Components	2	10	Material handling
TOTAL		93	202-210	

APPENDIX E (2)

CANADIAN ROBOT INSTALLATION BY MANUFACTURER:

THE YEAR END 1980

Robot Manufacturer/Canadian Distributor	Total Canadian Installations	Installations Since Jan. 1980
Unimation Inc./Kawasaki/CAE Morse Inc.	75	12
Cincinnati Milacron Canada Ltd.	60	54
Trallfa/Devilbis Canada Ltd.	14	5
Seiko/Hall Smith Co. Ltd.	30	22
Fanuc/Hall Smith Co. Ltd.	4	4
Hall Automation Inc. U.K.	3	3
Versatran/Can. Eng. Ltd.	11	11
Prab/Can. Eng. Ltd.	11	11
Nordson Canada Ltd.	6	6
TOTALS	214	127

Courtesy of: The Canadian Institute of Metalworking and the National Research Council of Canada.

SELECT BIBLIOGRAPHY

In preparing this report, we have used literally thousands of pieces of information culled from reports, books, articles, newspaper clippings, annual company reports and personal interviews. We have also made extensive use of computer searches of abstracts available from a number of data bases. In order to keep the report readable, we have chosen to waive the usual academic style of carefully footnoting each statement.

The report contains very recent, event current, information. The source for much of these information can be traced to the periodicals mentioned in the following list. In particular, we found Electronics Times and Japan Economic Journal excellent sources of current information.

Books and Reports:

Abraham, R.G., et. al.

1977 State-of-the-Art in Adaptable-Programmable Assembly Systems. Bedford, England: International Fluidics Services Ltd.

Albus, J.S.

1976 People's Capitalism. College Park, Maryland: New World Books.

Asimov, I.

1950 I, Robot. NY: Doubleday & Co., Inc.

Barnett, C.J., et. al.

1978 Industrial Automation - Its nature, effects and management. Cambridge, Mass.: Centre for Policy Alternatives, MIT.

Bolles, R., and Paul, R.

1973 The Use of Sensory Feedback in a Programmable Assembly System. Stanford, California: Stanford University AI-Memo-220.

CAD/CAM Technology Advancement Council

1980 Strategy for Survival: The Canadian CAD/CAM Option. Ottawa: Technology Branch, Industry, Trade and Commerce.

Capek, K.

1923 R.U.R. (Rossum's Universal Robots). NY: Doubleday, Page & Co.

Dickson, P.

1976 The Electronic Battlefield. Bloomington, Indiana: Indiana University Press.

Dodd, G.G. and Rossol, L. (Eds.)

1979 Computer Vision and Sensor-Based Robots. NY: Plenum Publishing Corp.

Engelberger, J.F.

1980 Robotics in Practice. NY: Amacom.

1977 Robotics and CAD/CAM. Dearborn, Mich.: The Computer and Automated Systems Association of SME.

1976 Designing Robots for Industrial Environments - SME Technical Paper MR 76-600. Dearborn, Mich.: Society of Manufacturing Engineers.

Ernst, B.D.

? Economic Justification for Industrial Robots. Dearborn, Mich.: Robot Institute of America.

Forester, T. (ed.)

1981 The Microelectronics Revolution. Cambridge, Mass.: MIT Press.

Frost and Sullivan Inc.

1979 The United States Industrial Robot Market. NY: Frost & Sullivan Inc.

Ingersoll Engineers

1980 Industrial Robots, Vol. I & II. Glasgow, England: National Engineering Laboratory.

International Resources Development Inc.

1979 Industrial Robots in the 1980s. Norwalk, Conn. International Resources Development Inc.

Japan Industrial Robot Association

1978 Industrial Robots in Japan: 1979. Tokyo: Japan Industrial Robot Association.

1979 Specification of Industrial Robots in Japan: 1979. Tokyo: Japan Industrial Robot Association.

Lane, J.D.

1978 Industrial Robots in Manufacturing. SME Technical Paper MS 78-653: Dearborn, Mich.: Society of Manufacturing Engineers.

Lundstrom, G., et. al.

1977 Industrial Robots - Gripper Review. Bedford, England: International Fluidics Services Ltd.

Minsky, M.L.

1966 An Autonomous Manipulator System. Cambridge, Mass.: MIT.

Proceedings of the 1st Conference on Industrial Robot Technology (CIRT). 27-28 March 1973, University of Nottingham.

1973 Bedford, England: International Fluidics Services Ltd.

Proceedings Les Robots Industriels, 8-9 October, 1974.

1974 Ecole Polytechnique, Federale de Lausanne.

Proceedings of the 4th International Symposium on Industrial Robots (ISIR), 19-21 November, 1974, Tokyo, Japan.

1974 Tokyo: Japan Industrial Robot Association and Society of Biomechanics

Proceedings of the 2nd Conference on Remotely Manned Systems - Technology and Applications, 9-11 June 1975.

1975 Bedford, England: British Robot Association.

Proceedings of the 3rd Conference on Industrial Robot Technology (CIRT) and 6th International Symposium on Industrial Robots (ISIR). University of Nottingham, UK, March 24-26, 1976.

1976 Bedford, England: International Fluidics Services Ltd.

Proceedings of the 7th International Symposium on Industrial Robots (ISIR), 19-21 October 1977.

1977 Tokyo: Society of Biomechanics and Japan Industrial Robot Association.

Proceedings of the 9th International Symposium on Industrial Robots (ISIR), March 13-15, 1979, Wash. D.C., USA.

1979 Dearborn, Mich.: Society of Manufacturing Engineers.

Proceedings of the 1st International Conference on Assembly Automation, Brighton, U.K., March 25-27, 1980.

1980 Bedford, England: IFS Publications Ltd.

Proceedings of the 10th International Symposium on Industrial Robots (ISIR) and 5th International Conference on Industrial Robot Technology (CIRT), Milan, Italy, March 5-7, 1980.

1980 Bedford, England: International Fluidics Services Ltd.

Project Committee of Unmanned Manufacturing System Design

1974 MUM: Methodology for Unmanned Metalworking Factory - Basic System Design. Tokyo, Japan: Mechanical Engineering Laboratory.

Rao, S.P.

1979 An Econometric Analysis of Labour Productivity in Canadian Industries; Some Further Results. Ottawa: Economic Council of Canada.

Tanner, W.R. (Ed.)

1979 Industrial Robots, Vol. I & II. Deaborn, Mich. Society of Manufacturing Engineers.

Toffler, A.

1980 The Third Wave. NY: William Morrow & Co. Inc.

Mimeographs:

Binford, T.O.

Computer Integrated Assembly Systems.

Cakebread, R.F.

Robots - 15 years of Industrial Experience, Paper presented at Development and Exploitation of Programmable Automation, 29th Nov. 1977. London: Institution of Mechanical Engineers.

Charnley, C.J. and Stout, K.S.

1977 Robotic Handling Devices for use during Manufacture Manchester, England: International Fluidics Services Ltd.

Evans, J.M., et. al.

1978 Computer Science and Technology: NBS/RIA Robtics Research, Workshop held at Williamsburg, Va., 12-13 July 1977. NBS-SP-500-29.

1980 Rapporteur's Report to the Critical Issues Sub-Committee of COCAM. Los Angeles, Calif.: University of California.

Hart, D.E.

Adaptive Robots. General Motors Research Labs.

Joseph, E.C.

The Future of People Amplifiers. Sperry Univac Division, Sperry Corp., St. Paul, Minn.

Future People Amplifiers: Emerging Ethontronic Systems. Sperry Univac Division, Sperry Corp., St. Paul, Minn.

Kasvand, T.

A Preliminary Survey of the Field of Robotics. Ottawa: National Research Council.

Vision, as applied to Robotics. Ottawa: National Research Council.

The Present State of Image Processing. Ottawa: National Research Council.

The Robotics Scene in Japan. Ottawa: National Research Council.

Munson, G.E.

Integrated Machining Systems Using Industrial Robots. Unimation Inc.

Foundries, Robots and Productivity. Unimation Inc.

Nevins, J.L. and Whitney, D.E.

Exploratory Research in Industrial Modular Assembly.

Paul, R.P. et. al.

Advanced Industrial Robot Control Systems.

Rosen, C.A.

Machine Intelligence Research Applied to Industrial Automation.

Machine Vision - A major component of Intelligent Machines. Palo Alto, Calif.: Machine Intelligence Corp.

Salmon, M. (Ed.)

Robots in Italy.

Economic Commission for Europe Working Party on Automation - 5 -10 September 1977: Copenhagen, Denmark.

Scrimgeour, J.

CAD/CAM and its impact on the manufacturing industry. Paper presented at the Canadian Conference on Automatic Control, McGill University, Montreal, May 23-25, 1979.

Senker, P.

Social Implications of Automation. Presentation to Robots 79 Conference and Exhibition at the University of Nottingham, March 27-29.

Stanford Research Institute and Stanford Research Institute International.

Exploratory Research in Advanced Automation and Machine Intelligence Research Applied to Industrial Automation.

Sugimoto, K., et. al.

Industrial Robots with Linkage Mechanism. Production Engineering Research Laboratory, Hitachi Ltd., Yokohama, Japan.

Takeyasu, K., et. al.

An approach to the Integrated Intelligent Robot with Multiple Sensory Feedback: Construction and Control Functions. Production Engineering Research Laboratory, Hitachi Ltd., Yokohama, Japan.

U.S. Air Force Materials Laboratory.

Robotic System for Aerospace Batch Manufacturing.

Will, P.M. and Grossman, D.D.

An Experimental System for Computer-Controlled Mechanical Assembly. Yorktown Heights, NY: IBM Research.

Will, P.M.

Computer-Controlled Mechanical Assembly. Yorktown Heights, NY: IBM Research.

Yonemoto, K. and Shiino, K.

Present State and Future Outlook of Technology and Market on Industrial Robots in Japan. Tokyo, Japan: Japan Industrial Robot Association.

Articles:

Albus, J.S. and Evans, J.M.

1976 "Robot Systems." Scientific American, No. 234, February, pp. 76-86.

Atkey, M.

1976 "Robots can handle industry's unwanted jobs." Metalworking Production, No. 120, Jan. 1, pp. 62-67.

Bylinsky, G.

1979 "Those Smart Young Robots on the Production Line." Fortune, December, pp. 90-96.

Christner, W.A.

1978 "Anything you can do a robot can do better." Sweden Now, Vol. 12, No. 3, pp. 14-17.

Conway, A.

1973 "The rise of the robot." Management Today, June 1973, pp. 37-38 & 42-43.

Friedrich, O.

1980 "The Robot Revolution." Time, Dec. 8: pp. 50-57.

Hannam, R.G.

1977 "Industrial Robots and their place in batch production., Machinery and Production Engineering, Vol. 131, No. 3373, 10th Aug., pp. 115-117.

Heginbotham, W.B.

1973 "Industrial Robots - Future and Trends." European Review, Vol. 23, No. 1, Winter, pp. 38-42.

Holt, H.R.

1978 "Trends in Robot Controls." Agricultural Engineering, Vol. 59, No. 4, April, pp. 42-43.

Latil, Pierre de

1980 "Les Robots." Sciences & Avenir, Mars, No. 397, pp. 46-64.

Marsh, P.

1980 "Robots see the light." New Scientist, June 12, pp. 236.

Merchant, M.E.

1976 "The Future of Batch Manufacture." Phil. Trans. R. Soc., London, Volume 275 A, pp. 357-372.

Nevins, J.L. and Whitney, D.E.

1978 "Computer-Controlled Assembly." Scientific American, Vol. 238, No. 2, February, p. 62-74.

Norman, C.

1981 "The New Industrial Revolution: How Microelectronics may change the workplace." The Futurist, February, pp. 30-42.

Reed, F.

1980 "The Robots are Coming, The Robots are Coming." NEXT, May/June, pp. 31-38.

Remick, C.

1979 "Robots: New Faces on the Production Line." Management Review. May, pp. 24-28; 38-39.

Report

1976 "Industrial Robots - Manufacturers are ready to meet increased demand." Engineering Materials and Design, Vol. 20, No. 8, August, pp. 21-24.

1977 "Hitachi Hand-Eyes System." Hitachi Review, Vol. 22, pp. 362-365.

1980 "Robots Join the Labor Force." Businessweek, June, pp. 62-68.

1975 "Robots become more sophisticated and may find new jobs." Production Engineering, Vol. 46, No. 8, August, pp. 11-19.

Rosen, C.A. and Nitzan, D.

1975 "Developments in Programmable Automation." Manufacturing Engineering, Vol. 75, Sptember, pp. 26-30.

Ruzic, N.P.

1978 "The Automated Factory - A dream coming true?" Control Engineering, April, p. 58.

Schraft, R.D.

1977 "Industrial Applications in Europe - Market Applications and Development." Mechanisms and Machine Theory, Vol. 12, No. 1, pp. 45-50.

Stout, K.J., et. al.

1976 "Robots - Current Trends and Industrial Requirements." Machinery and Production Engineering, Vol. 128, No. 3309, 12th May, pp. 440-446.

Tavernier, G.

1978 "The Robots Are Coming." International Management, Vol. 33, No. 7, July, pp. 24-27.

Thornton, J.

1978 "Capabilities of Robots Expanding." American Metal Market, Aerospace Metals and Machines Supplement, 20th March, p. 3.

Various Issues

Electronics Times. Weekly, Morgan-Grampian Ltd. (Publishers), London, England.

The Japan Economic Journal. Weekly, The Nihon-Keizai Shimbun Inc., Tokyo, Japan.

The Japan Industrial & Technological Bulletin. Monthly, The Japan External Trade Organization, Tokyo, Japan.

Weinstein, C.

1978 "Robots in Industry - Too Few or Too Many." Electronics and Power, Vol. 24, No. 5, May, pp. 379-383.

Yonemoto, K.

1980 "The Growing Market Size of Industrial Robot Industry." Digest of Japanese Industry & Technology, No. 152, pp. 25-31.

1975 "Will Industrial Robots change the course of history?" Journal of Electronic Engineering, February, pp. 46-50.

Periodicals:

Robotics Age. Quarterly, Robotics Publishing Corp., La Canada, Calif.

Robotics Today. Quarterly, Society for Manufacturing Engineers, Dearborn, Mich.

The Industrial Robot. Quarterly, International Fluidics Services Ltd., Bedford, England.

Robot. Quarterly. Japan Industrial Robot Association, Tokyo, Japan.

Confidental Reports:

Barclay, S.

CAD/CAM Final Report. Ministry of Industry & Tourism Policy & Priorities Division: Government of Ontario: May 1981.

Robertson, Nickerson, Group Associates Ltd.

Study to identify Canadian industrial needs, and potential areas for National Research Council involvement in the science of robotics. National Research Council, Ottawa: August 1980.

Tlusty, J. and Crozier, J.E.

A Robotics Application Study. National Research Council, Ottawa: March 1981.

TECHNOLOGICAL INNOVATION STUDIES PROGRAM

PROGRAMME DES ÉTUDES SUR LES INNOVATIONS TECHNIQUES

REPORTS/RAPPORTS

1. Litvak, I.A. and Maule, C.J., Carleton University. **Canadian Entrepreneurship: A Study of Small Newly Established Firms.** (October 1971)

2. Crookell, H., University of Western Ontario. **The Transmission of Technology Across National Boundaries.** (February 1973)

3. Knight, R.M., University of Western Ontario. **A Study of Venture Capital Financing in Canada.** (June 1973)

4. Little, B., Cooper, R.G., More, R.A., University of Western Ontario. **The Assessment of Markets for the Development of New Industrial Products in Canada.** (December 1971)

5. MacCrimmon, K.R., Stanbury, W.T., Bassler, J., University of British Columbia. **Risk Attitudes of U.S. and Canadian Top Managers.** (September 1973)

6. Mao, J.C.T., University of British Columbia. **Computer Assisted Cash Management in a Technology-Oriented Firm.** (March 1973)

7. Tomlinson, J.W.C., University of British Columbia. **Foreign Trade and Investment Decisions of Canadian Companies.** (March 1973)

8. Garnier, G., University of Sherbrooke. **Characteristics and Problems of Small and Medium Exporting Firms in the Quebec Manufacturing Sector with Special Emphasis on Those Using Advanced Production Techniques.** (August 1974)

9. Litvak, I.A., Maule, C.J., Carleton University. **A Study of Successful Technical Entrepreneurs in Canada.** (December 1972)

10. Hecht, M.R., Siegel, J.P., University of Toronto. **A Study of Manufacturing Firms in Canada: With Special Emphasis on Small and Medium Sized Firms.** (December 1973)

11. Little, B., University of Western Ontario. **The Development of New Industrial Products in Canada. A Summary Report of Preliminary Results, Phase 1.** (April 1972)

12. Wood, A.R., Gordon, J.R.M., Gillin, R.P., University of Western Ontario. **Comparative Managerial Problems Early Versus Later Adoption of Innovative Manufacturing Technologies: Six Case Studies.** (February 1973)

13. Globerman, S., York University. **Technological Diffusion in Canadian Manufacturing Industries.** (April 1974)

14. Dunn, M.J., Harnden, B.M., Maher, P.M., University of Alberta. **An Investigation Into the Climate for Technological Innovation in Canada.** (May 1974)

15. Litvak, I.A., Maule, C.J., Carleton University. **Climate for Entrepreneurs: A Comparative Study.** (January 1974)

16. Robidoux, J., Garnier, G., Université de Sherbrooke. **Factors of Success and Weakness Affecting Small and Medium-Sized Manufacturing Businesses in Quebec, Particularly those Businesses Using Advanced Production Techniques.** (December 1973) (Available in French)

17. Vertinsky, I., Hartley, K., University of British Columbia. **Project Selection in Monolithic Organizations.** (August 1974)

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