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Robotics in Canada

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Robotics in Canada

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1.0 Purpose of Study

Contemporary society is at the crossroads of a major change (some describe it as a major upheaval) with the advent of robot applications in the manufacturing and processing industries. There will be both advantages and disadvantages because of this change, but as will be pointed out later, Canada has no choice but to adopt it if it wishes to survive in this new era.

The purpose of this paper is to familiarize and outline to the reader the field of robotics in Canada. Although certain impacts and aspects of robotics are of a global nature, the particular Canadian interest and concern is emphasized.

2.0 Definition of a Robot

There are various definitions of robots and their distinctions are often confused. A good and succinct definition of what constitutes a robot is described by The Robot Institute of America as a "reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks". (1)

In comparison, although the Japanese definition of a robot is similar, they have specified four basic levels as follows:

a) manual manipulators that perform fixed or preset sequences;

b) playbacks that repeat fixed instructions;

c) numerically-controlled robots that execute operations by numerically loaded information;

d) intelligent robots that function through their own recognition capabilities. (2)

For the purposes of this paper The Robot Institute of America's definition has been adopted.

3.0 Physical Aspects of a Robot

The robot has been defined as a general purpose tool, being programmable and able to perform a variety of tasks. It has three major components; a manipulator, a controller and a power supply, described as follows. (3)

3.1 Manipulator

It is a series of mechanical linkages and joints capable of movement through several degrees of freedom or various directions. Figure 1 illustrates the four basic movements of a robot manipulator. The more degrees of freedom such a manipulator has, the greater its flexibility. Figure 2 illustrates a robot with six degrees of freedom.

3.2 Controller

It is the "brain" of the robot, storing data and directing the movement of the manipulator and the power supply (which provides energy to the manipulator).

It can vary in complexity from simple steps sequencers to mini-computers and frequently uses feedback devices (sensors) to determine position orientation and identification information to make decisions.

It has three basic functions:

(a) initiate and terminate motions of the manipulator in a desired sequence and at desired points;

(b) store position and sequence data in memory; and,

(c) interface with the robot's local environment.

3.3 Power Supply

It provides energy to the manipulator's actuators and is usually in an electrical, pneumatic or hydraulic form. Pneumatic drives use compressed air to drive the robot manipulator. They are lightweight, fast and relatively inexpensive but do not provide much strength. The hydraulic drives use compressed fluids to drive the robot "arm". They are more expensive and messy than pneumatic drives, but are considerably stronger. Electric motor drives can provide the greatest power for the least energy cost but at the greatest expense (of all three types) both to buy and maintain. (4)

3.4 Classes of Robots

There are basically two classes of robots, servo-controlled and non-servo-controlled. The former can be usually programmed to stop at any point within its range of motion allowing for acceleration or deceleration of the tool's center point. These movements are usually controlled by oil flowing through servo valves or by DC electric motors. In the case of the

Figure 1

Basic Manipulator Movements

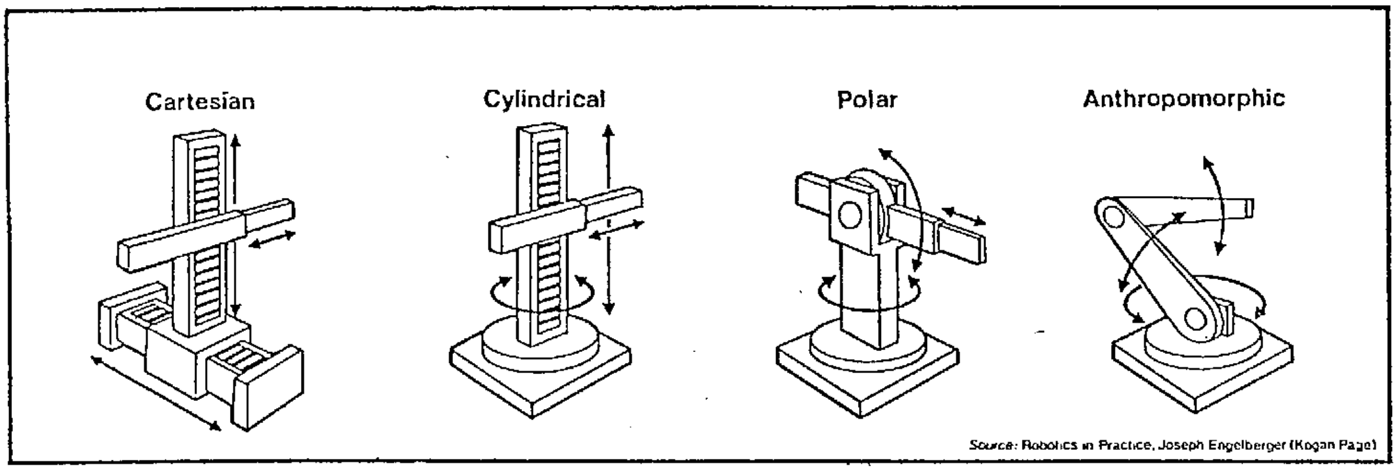
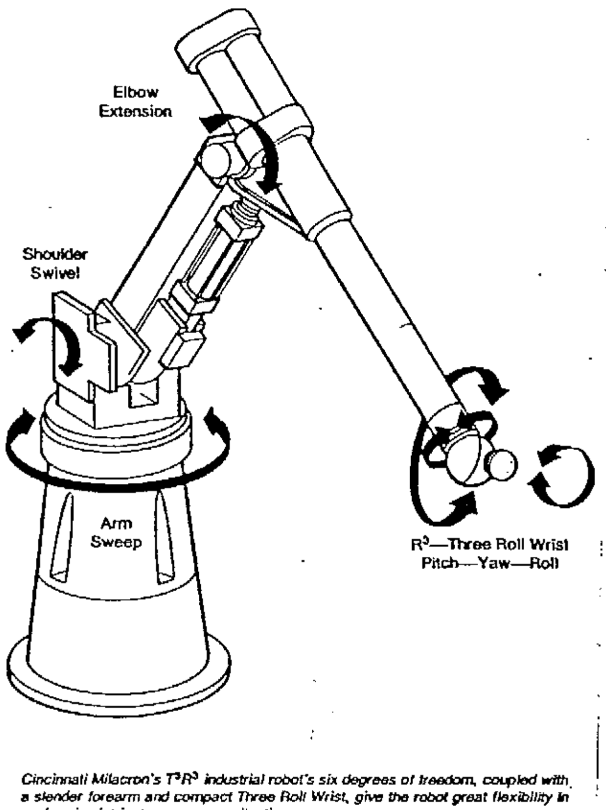


Figure 2

Robot with Six Degrees of Freedom



Cincinnati Milacron's T^3R^3 industrial robot's six degrees of freedom, coupled with a slender forearm and compact Three Roll Wrist, give the robot great flexibility in performing intricate process applications.

latter, the tool's center point can only stop at the fixed end points of each access. There is limited provision for acceleration or deceleration but can offer greater accuracy of repeatability because of their fixed stop end point positioning. Servo robots, because of their feedback systems, are typically not as accurate.[5]

3.5 Robot Programming

There are three primary programming methods for the robot:

a) lead through - here the operator directs the robot through the desired positions and locations by means of a remote teaching control;

b) walk through - the robot is physically manipulated through the desired motions (which are recorded and then played back by the robot) and usually poses less of a debugging problem;

c) plug-in - the robot operates via a prerecorded program without manual intervention which also facilitates fast reprogramming.[6] Robots controlled from remote computer facilities fall into this category.

3.6 Current State of the Art

The design of contemporary robots has reached the point where further refinement for mechanical and economic reasons have limited justifications. They are well suited to the tasks for which they are designed for, but still could offer a greater flexibility and adaptability. At this point, the intelligent robot (I.R.) comes into existance and is currently the focus of considerable R &D activity in the U.S., Japan and Europe.

For a robot to be more flexible, it needs greater "thinking" or computational capacity which now can be provided by contemporary micro-computer technology. It also needs accurate sensing capabilities,these having three components: force, with application in fitting operations; tactile, with application in both positioning and orienting; and vision, with application in positioning, inspection and monitoring.[7]

Vision sensing is receiving considerable R & D emphasis and is considered the terminal impediment to a truly universal programmable robot. Current vision systems usually require a contrastingly lit background, a controlled work place and non contiguous parts. The major problem of feeding a robot with disarrayed workpieces could be solved with a refined vision system. The intelligent robot is the next step in the robot evolutionary ladder.

4.0 Economic Aspects of Robotics

A programmable robot offers both flexibility (the ability to do process work in a wide variety of configurations with minimal effort and cost) and adaptability (the ability to conform or adjust to changing environmental conditions). The economic aspects and impact of robotic technology entering our society are outlined in the following paragraphs.

4.1 Productivity

"Productivity" is the output of a unit of labour. A common measure is the dollar output per hour of labour, however, it is also measured reciprocally rather than directly as:

a) hours of labour per dollar of production;

b) hours of labour per unit of production;

c) cost of labour per dollar of production;

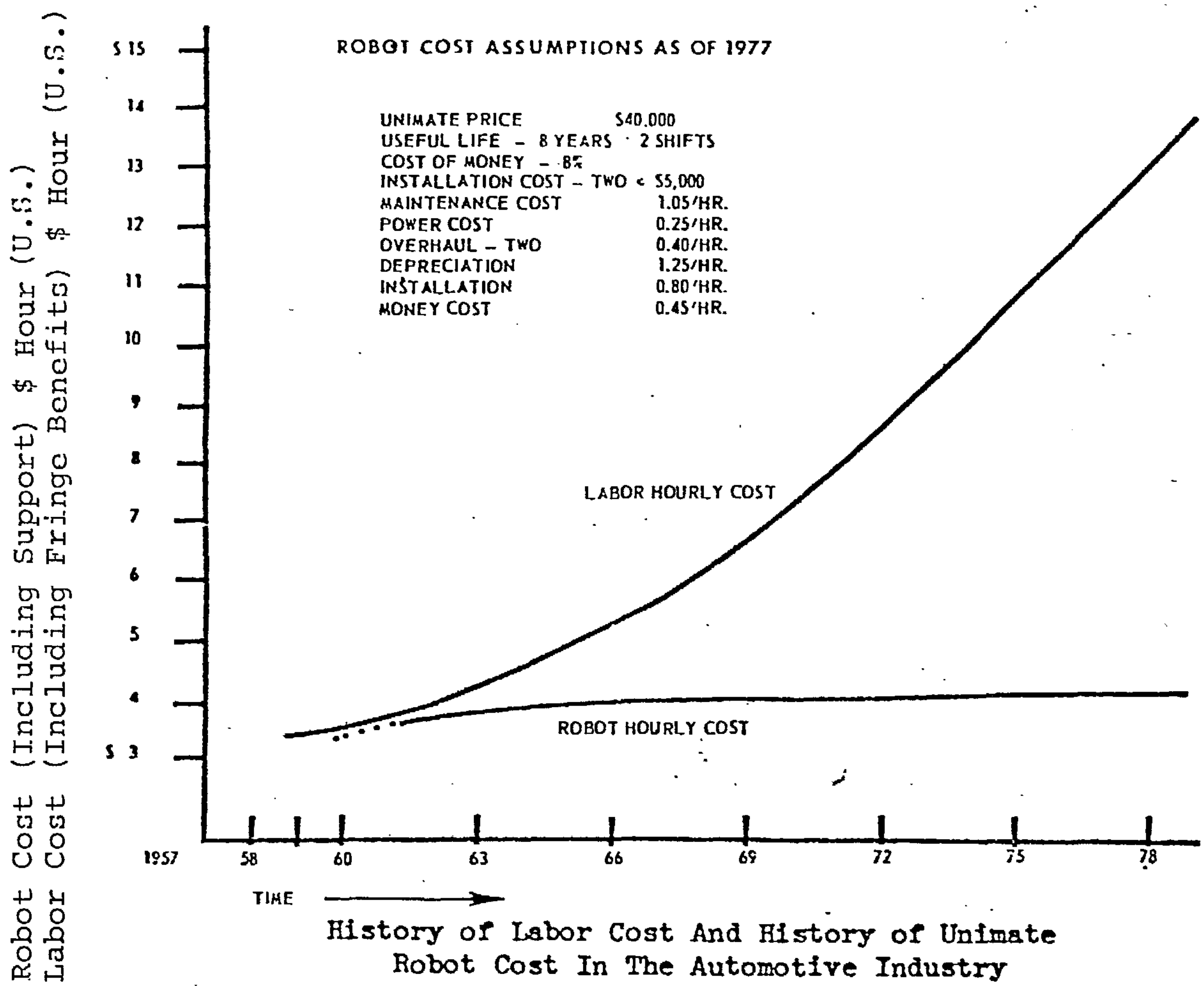
d) cost of labour per unit of production. (8)

Properly applied and managed robot applications are currently much more productive than their manual labour counterparts. As an example, Figure 3 illustrates the history of labour and robot costs in the automotive industry. As the graph indicates, robot costs have remained fairly constant over the last twenty years whereas labour costs have risen rather sharply. Thus the cost of "robot labour" per dollar of production or per unit of production is significantly less than that of "human labour" costs.

4.2 Cost and Return on Investment

Capital costs of robots vary considerably with the task to be performed and thus the type of machine. The current major users of robots, the auto, foundary and die-casting businesses, spend anywhere between $ 30,000

Figure 3



History of Labor Cost And History of Unimate Robot Cost In The Automotive Industry

Source: G.E. Munson, "The Industrial Robot's Future in Manufacturing Systems", Chicago: April 9-12, 1978, p. 254.

to $ 150,000 (U.S.) for each machine.(9) Since introducing robots in the manufacturing and process industries can be quite expensive, the return on investment is fairly important. Current payback time on these units depend greatly on the utilization time but frequently range between one and two years. This is usually a much faster return on investment than other types of comparatively expensive equipment. Figure 4 illustrates the return on investment considering the average labour hours replaced per day. It indicates a greater return for the robot investment with higher labour costs and longer working hours.

> " *A $30,000 robot working two shifts a day can pay for itself in a year. 'Studies indicate that a human arc welder performs to capacity only 30% of the time he is on the job. A typical robot works at 85% capacity all the time. The difference over 4,000 hours would be the cost of the robot'".* (10)

Maintenance and repair costs will run about 5% the initial cost, around $ 1,500 for a unit costing $ 30,000. It should last about 10 years on two shifts per day or between 40,000 and 50,000 hours, before it will have to be replaced.(11)

4.3 Potential Savings

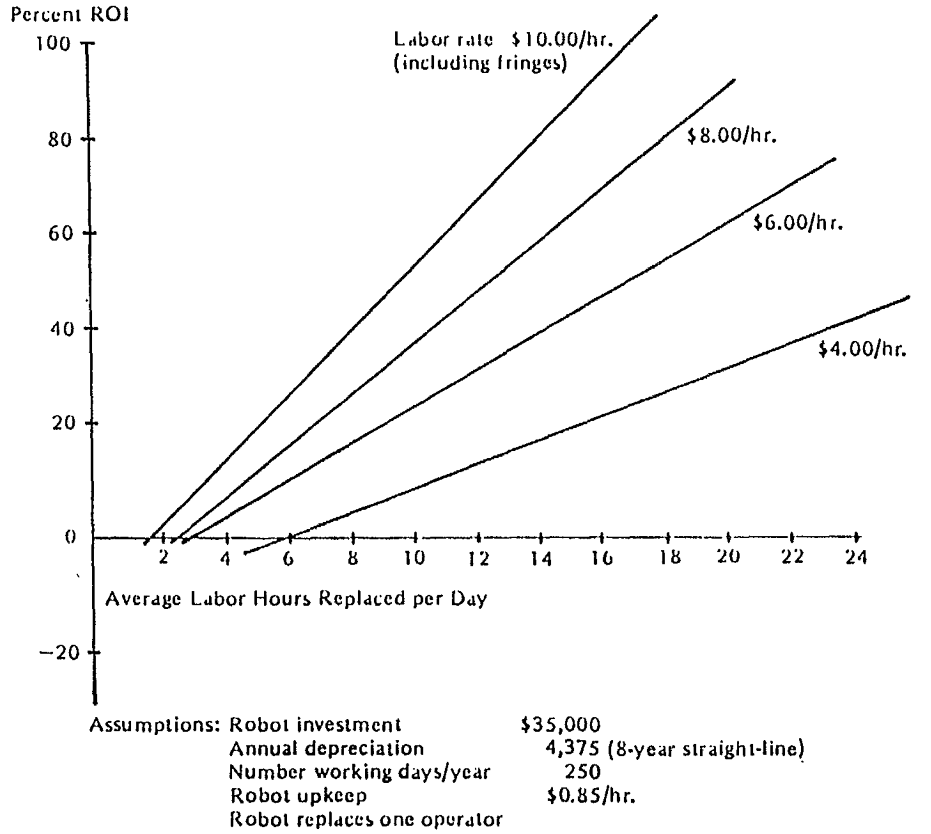
Significant savings can be brought about through the use of robot labour in a number of areas. For example: increased productivity, human labour savings, material savings, reduced need for capital investment, lower process times and safety. The savings through increased productivity have been indicated in previous paragraphs.

Material savings will come about through reduced waste in the operation. Reduced capital costs can be achieved by rationalization of existing and expected equipment requirements. Also, increases in automation tend to increase the rate of capital utilization thus contributing to capital savings. Lower process times can be expected in some applications since the robot can execute motions and tasks repeatatively in shorter periods of time than the equivalent human operator(s).

The savings in human labour, also previously mentioned, is basically through displacement. Until now, the introduction of robots in a manufacturing or processing operation has not caused any actual worker lay-offs. Job losses have been handled through normal attrition and retraining/reallocation of the surplus labour. Some automation experts

Figure 4

Return on Investment



Adapted from: Engelberger, J.F.
Robotics in Practice, 1981.

have claimed that robots could displace as much as 65% to 75% of today's factory workforce - a rather significant savings in wages but possibly at a rather expensive social cost. (12)

Although some of these lost jobs will be recaptured in the new robot service industries, the impact could be astonishing if appropriate measures are not taken and the adoption of robot technology occurs too rapidly.

Robot applications have produced positive results in the area of safety both towards cost savings and work place/job enhancement. In fact, most robots are currently concentrated in tasks that are either hazardous or monotonous. Robot application in these areas are the primary reason why labour (and management) have not resisted their introduction although they are a significant potential threat to human workers' future employment status.

One can see then that there are a number of motivating factors for the implimentation of robots, but all relate to some form of savings over conventional practices. These factors may be summarized as for the following reasons:

a) the production of goods and services which could not have been produced by conventional methods of production;

b) the development of process-capacity to meet anticipated increase in demand;

c) increase in efficiency of operations;

d) shortening of lead time--faster response to customer requests;

e) easier and more effective inventory control;

f) greater consistency in product quality;

g) the precise duplication of product over long periods of time;

h) health and safety in the work environment. (13)

4.4 Robot Market Potential

Although the robot manufacturing industry has been around for more than 20 years, it is only now on the verge of becoming widely accepted and applied by the manufacturing and process industries and society as a whole.

In Canada, the present rate of robot installations is relatively the same as in the U.S. (with respect to the size of the industrial economies; i.e. - about 10 times less); about 125 being installed in 1980 and approximately 200 units altogether. (14) A conservative estimate of the total volume of robot sales in Canada is $ 10 million. Future sales could quadruple in five years time, then representing a $ 40 million per year investment (in 1980 dollars). (15)

The robotics industry is considered by many to be at the point where the microelectronics industry was 5 years ago. Figure 5 illustrates a rather optimistic market potential for 1980 to 1990. The interesting point it indicates is a potential for the industry if the computer companies enter the market - an order of magnitude increase in production! It appears that most of the major computer hardware firms are developing and possibly even using robot assembly lines for their products. Digital Equipment, Texas Instruments, IBM and Olivetti all appear prepared to introduce their own line of robots. (16) At present, there are no Canadian robot manufacturers although this will likely change in the near future. This is further discussed in section 7.

4.5 Robot Applications

The number of robot applications are limited only by one's imagination. A few industrial application examples which would provide significant savings as discussed previously are outlined below.

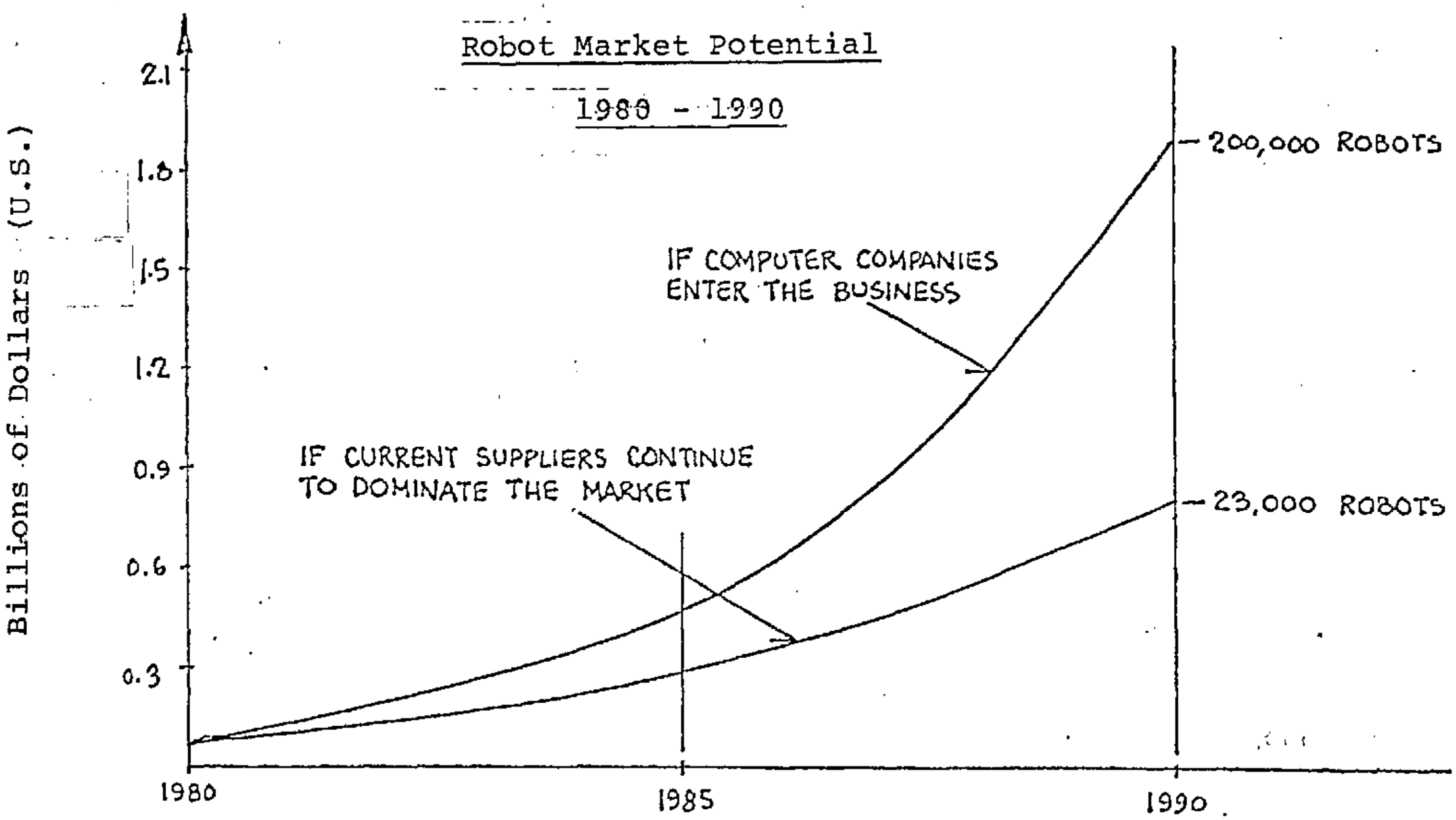
4.5.1 Parts and Material Handling

- Machine tool - loading and unloading
- Investment casting - mold preparation
- Die casting - removing parts
- Powdered metallurgy - furnace charging
- Injection molding - (plastics parts)
- Press loading & unloading (metal forming)
- Forging
- Pallet loading and unloading
- Conveyor - loading and unloading
- Packing

4.5.2 Tool Handling

- Spot welding
- Arc welding
- Spray painting
- Furniture sanding & polishing

Figure 5



Source: Business Week, June 9, 1980, p 82.

4.5.3 Inspection

- measurement of object size
- sorting of parts

4.5.4 Assembly

- electronic products (i.e. PCB boards)
- mechanical products (i.e. appliances, machinery)

5.0 Employment Impact of Robotics

Justifiably, one of the major concerns of labour is the impact of robot applications on employment, with particular reference to predictions of widespread technological displacement and possibly even widespread permanent unemployment. One reason this has been brought about is through the concerns of foreign competition. In order for many Canadian firms to remain competitive with foreign imports, they must look for ways of reducing labour costs. This pressure is mounting from other industrialized nations already adopting robots technology and from less expensive third world labour.

Other reasons for concern are labour-related to particular Canadian factors such as the scarcity of skilled manpower, seasonal variations in production, problems of inexperience and lack of work discipline. They all contribute to low productivity, waste, defective output and high unit costs and add up to non competitiveness. (17)

A recent report prepared for NRC indicates that the impact of robot applications in Canada will have widespread implications concerning the existing industrial structure. There will be a shift in labour requirements from low level operations labour to higher level engineering functions; from "blue collar" to "white collar" jobs.(18) The effect on non-production workers - management, production planners, systems analysts, and other scientific professional and technical workers - is generally expected to be positive. (19)

The suggested predictions for the robot market potential indicate widespread applications throughout industry by 1990. Another factor to consider is the difference in the present wave of technological change from those of the past. Due to technological and cost achievements in microelectronics (to which robot control and sensing is very closely attached), computer application and automation (i.e. robotics) are now diffusing 7 to 10 times faster than any previous technology. (20) Experiences of the last 5 years show that microprocessors have the potential to cause a tremendous acceleration in the rate of technology change, robotics not excluded.(21)

This all points to labour's concern with job security. As a result of this new wave of technological change (mostly due to the current microelectronic revolution), 2.5 million Canadians could be unemployed by 1990. (22) This could be through direct job displacement here in Canada by robot applications, or because of international competition which Canadian manufactures may not be able to meet.

It would seem that Canada has no choice but to adopt robotics technology if it wishes to minimize the potential unemployment problem. Unfortunately, even this basic decision is confounded by the facts that Canadian industry appears to be handicapped by a lack of long range planning in the introduction of automated processes and is almost totally reliant on foreign sources of supply of automated equipment. (23)

Applied robotics technology "will give birth to a range of new supporting positions including such roles as maintenance and servicing, programming, productivity analysts and CAD/CAM and automation specialists". (24) However, studies in West Germany suggest that for every job created by robots, between five and seven jobs are eliminated. (25)

One might take some consolation from past experiences though; the employment upheavals from newly adopted technologies have not been as disastrous as predicted. This has been most likely due to their gradual absorption into the economy. The speed of transition may be the key factor which will indicate the severity of an employment upheaval. If robotics can be adopted over a longer period of time, then the reemployment/ retraining of workers and acceptance of this technology will be "uneventful" to Canadian society.

There is a good likelihood that this is the case that will probably evolve as one sees from the past experience of numericaly controled machine tool adoption in Canadian manufacturing industries. NC machines have been around for more than 20 years, although in some areas of industry, they are just being adopted. Manufacturers will be reluctant to replace such expensive capital equipment without first realizing a profit by them. Robots are also capital intensive machines and thus the costs will also inhibit the wholesale adoption/replacement of them. The fact that presently, robots are limited to certain applications and cannot be built fast enough to meet even these demands (or the demand of the robot service industry), indicate the unlikely introduction of this technology overnight.

The robot is not necessarily the best answer to a manufacturer's problem. Other forms of automation may be better suited and thus the demand for robots could be lower than expected.

One final point; it is unlikely that the manufacturing and the robot industries could or would be able to handled a jump in the evolutionary ladder of automation, thus robot adoption could in all likelihood be a slow methodical process as experienced with NC machines.

Another factor must be considered with reference to the future interrelationship of robotics and Canada's labour force; that of the work force's significant slowdown in growth in the next decade. The "Labour Market Task Force Report" prepared for Employment and Immigration Canada, indicates that by 1990, the work force will be growing at only half the rate at which it grew in the 1970's. A decline of 100,000 workers in the 18-24 age group is anticipated.

There are other changes expected in the labour force also; an increase in the female and native participation rate and an increase in the demand for highly skilled "blue-collar" and "white-collar" workers.

As these changes in the labour force become more pronounced, greater emphasis on industrial robot applications could be expected in hopes of overcoming some of these labour deficiencies.

5.1 Robot Implementation in the Workplace

Safety and health (which includes mental boredom) have been the major accepted reasons for introducing robots into the manufacturing and process industries. More frequently though, these reasons are becoming superficially attractive excuses, particularly when employers rather than the employees define the unsafe and dirty jobs that robots take over. Consequently, some jobs are eliminated as an "unintended" outcome of an employer's desire to reduce absenteeism or shopfloor militancy through new technology. (26)

Two basic approaches have been adopted by industries implementing robots. One approach is where the company restructures its production processes and redefines manual tasks to make them more interesting. In the other, more common approach, jobs (and workers) are selectively replaced by robots. At the same time, the production processes (and the workers) are coordinated to work at a pace set by the new equipment. (27)

Sometimes companies fear repercussions from employees and thus plan their robot installations secretly. This approach may be short sighted and suspicious from the workers point of view, but it indicates the caution that makes companies introduce robots slowly, thus decreasing the chances of industrial disputes. (28) This fear goes as far as having equipment redesigned so that employees using the robot controls will not have justification for reclassification and higher wage demands! Some unions have also drawn up strategies to influence the way the new technologies such as robotics, are applied and influences their members' work. A firm may be resistant to such infringements of their control.

One phenomena which will have interesting repercussions is in the plant run by robots whose programming will often be done by staff in computer departments away from the shop floor. This will happen with increasing frequency as robot manufacturers perfect techniques that connect the robot to central computers. The eventual scenario along this line of thought is the robot-run factory that will be programmable from hundreds of kilometers away. (28) The remaining factory workers will have minimal input into the working operation of the plant which could in turn cause discontent and job dissatisfaction.

Increased demands by unions over robot implementation in the workplace, plus the increasing international competition that is forcing firms to automate, will put a strain on the relationships between management and unions. (29) A coordinated effort on both sides would seem necessary to avoid potential conflicts.

6.0 Interrelationships with other Disciplines

The field of robotics is an integral component of the CAD/CAM technologies. Although as a machine, it can work alone, the robot will attain its greatest usefulness in concert with the other technologies. Appendix 1 outlines the CAD/CAM technologies and their interdependencies. These relationships will vary depending on the level of robot equipment used and the work needed to be performed.

The field of robotics is at the point where interfacing with computer and electronic technology are the next steps along the evolutionary ladder. Thus, it is beginning to, and will very much so in the future, rely heavily on computer technology for sensing, controlling, pattern recognition, etc...as it becomes more "intelligent". With this advance in intelligence will come increased flexibility and adaptability and thus robots will have greater multifunctional capabilities. One will be able to look forward to greater cost effectiveness of these machines also.

7.0 Canadian Research, Development and Applications

A report prepared for NRC (in the summer of 1980) indicates a general low level of awareness of robotics in Canada-in the government sector, industry and academic fields. It found not one government department actively promoting robotic technology to Canadian industry. [30]

There is current research and development activity in the robotics field in Canada, but as the research for this preliminary report indicates, and as was found in the reports prepared for NRC, there is no overall organized structure or effort to it. Most research is in peripheral areas of robotics - like vision systems, pattern recognition etc... and very few firms were found to be actually contemplating the design and manufacture of a robot. Only a few universities are actually involved in robot R & D activity and apparently are often funded from American industrial sources. [31]

The following paragraphs outline robotics activity in government, industry and academic circles. It should not be considered conclusive as this report is of a preliminary nature and other reports (done for NRC) examine the subject more comprehensively, particularly for industrial activities. (32)

7.1 Government

7.1.1 Federal

There seems to be limited activity in the encouragement and funding of robot R&D by the federal government. Besides the projects undertaken by NRC (and dealt with in section 7.2), the CAD/CAM Technology Advancement Council working out of Industry, Trade and Commerce is the only body actively supporting (indirectly) such research. This support is tempered by the fact that the field of robotics is only one technology of CAD and CAM, and that the council's objectives are limited to:

a) providing a focal point for the acquisition and dissemination of information concerning the CAD/CAM technologies;

b) identifying general areas where Canadian industry can successfully utilize these technologies and to make these opportunities known to both potential users and suppliers;

c) recommending possible actions to encourage the rapid adoption of these technologies. (33)

At this point in time, federal government has no specific policies or strategies oriented to the field of robotics.

7.1.2 Provincial

Of the ten provinces, the Ontario government is the only one currently known to be contemplating involvement in the robotics field. Before the last provincial election (spring of 1981), the Ontario government announced a $ 750 million economic program that included major high technology initiatives. (34) One of these initiatives is the establishment of a development and testing installation for CAD and CAM (including robotics) systems. From this initiative a robot application centre patterned after General Electric's robot centre in Schenectady New York is planned. Its primary function is envisaged to be a corporate consulting service for industry in Ontario providing demonstration and "hands on" training, seminars and workshops on robots. It will not be a facility for research and development. (35)

7.2 National Research Council

Currently, the NRC has no defined robotics research and development program, but is in the process of organizing one.(36) Intelligent robotics has been proposed as a new initiative by them requiring $ 4 million and 25 person years over the next five years, but has yet to be authorized. (37)

The research and development with the highest profile to date has been the Remote Manipulator System (RMS) Program also known as the "space arm" which is planned for it's first test in space this fall along with the launching of the second space shuttle.

By some definitions, it may not quality as a robot itself, but certainly could qualify with some additional intelligence and reduced human supervision. It does fit the definition requiring flexibility and adaptability. Spar Aerospace Limited is the major contractor on this project (which is now almost complete).

The RMS project is the closest device NRC has developed (under contract to Spar Aerospace Limited) which could be classified as a robot. Other activities in this field are aimed at particular aspects of robotics - such as sensing systems, pattern recognition and control systems. Some have developed as a spinoff from the RMS project.

One is a "machine vision" system which has a very fine resolution capability and high accuracy through geometric measuring techniques rather than through conventional pattern recognition. (38)

Another is the "arm" dynamics and control aspect which the people in Mechanical Engineering have and are pursuing. Some thought is being given to a program examining the operational consequences of the "arm" in an assembly line. (39)

A problem that Stelco has come to NRC with is the welding of the holes made in the bottom of their poring laddles after repeated use. They are considering the purchase of a welding robot and modifying it for the particular task that they have in mind. (40)

NRC also supports research and development activity in the robotics field through the PILP and IRAP programs. Unfortunately, they are not being inundated with proposals . (41)

7.3 Industry

A breakdown of Canadian robot installations for 1980 by company, product, application, current use and projected need is included in Appendix III. This listing indicates the purchasing activity in this field. Approximately 125 robots were installed by 1980 and more than another 100 robots by May 1981. A list of the thirteen most current robot suppliers in Canada is found in Appendix IV.

The two reports prepared for NRC (by Robertson, Nickerson Ltd. and Crozier and Tlusty) are suggested references for a more complete listing of the companies involved in robotics activity. From them approximately 20 to 25 firms have been noted to be pursuing research, development, production and/or application of robots in Canada.

The automotive industry (in particular GM) is the biggest user of robots. Additional examples also exist in other companies (such as International Harvester, Crane Canada, National Steel Car and others) but the application of robots in Canadian manufacturing and process industries is really just beginning. Also, research, development and manufacturing is covering a wide array of robotics applications in Canada. It includes industrial and mining robots, sensory systems, robotic submersibles, the "space arm" technology and computer software for robots.

7.4 Universities

In all likelihood, most universities are undertaking some form of related robotics R & D through their mechanical engineering departments, although few are known to have strong expertise in the field itself. The following universities outline three of the more noted schools in which robotics R & D have been identified.

7.4.1 University of Saskatchewan

The Control Systems Laboratory of the Agricultural Engineering Department at this school is involved in a "master-slave" type agricultural robot for field work. They have also done extensive work with sensors and control systems on tractors [43] and other automated agricultural equipment, and have sensor experience in grain loss monitoring.

7.4.2 University of Waterloo

There is a small group at this university headed by Professor French which has or is undertaking some research in the robotics field. Repeated attempts failed to make contact with him, but it is understood that the expertise of the Waterloo people in this field is nowhere near as strong as that found at McMaster.

7.4.3. McMaster University

This school is the home of the Canadian Institute of Metal Working and of the Manufacturing Research and Design Group. It is the latter organization, composed of five mechanical and two electrical professors, three full time and four part-time staff members, that concern themselves in the area of robotics research.

Five major projects in this field have been identified at McMaster and there are various stages of completion. Three of these projects include actual laboratory work and testing and cover the following areas:

1) mechanical and electrical hardware development for the rebuilding of a Unimate robot;

2) teach and playback software for three modes of control using a Puma robot;

3) sample assembly system using a Seiko assembly robot (the project is expected to be undertaken by an undergraduate student this year).

This group at McMaster headed by Dr. Tlusty, indicated their current capability to design a robot system that is superior to those now on the market. They have spent considerable time examining the weaknesses and strengths of contemporary robots and are actively searching for an industrial partner who can put up the development money and pursue the marketing to get this project under way.

One of their major projects now being conceptualized examines the performance of kinetic design in robots. This type of research would lead to the optimization of robots for different parameters such as size, speed, etc. This project has no funding as of yet.

The Manufacturing and Design Group also undertakes R & D in the numerically controlled machine field. They have an exceptionally strong background in this area.

7.5 Overview

At present, there are no commercial Canadian made robots available on the market. Foreign sources are supplying the Canadian market through distribution networks. [44] The research and development in this field is varied ranging from the work on the high profile RMS program to the application of robotics in the shoe manufacturing industry. [45]

Since the robot is going through its next evolutionary step - becoming intelligent - a whole new field of R & D requirements arise which offer Canadian researchers and manufacturers an opportunity to capitalize and meet these future needs. There are however, problems with contemporary robots that do not receive as much attention, possibly because some of them involve only simple mechanical engineering solutions. These problems and needed developments include:

a) easier and more flexible programming (Teach Mode);

b) larger memory for holding programs;

c) improved reliability (reduced 2nd and 3rd shift maintenance);

d) improved reliability and fewer failures (joints, gears, bearings, seals, hydraulic cylinders and hoses);

e) simpler interface with external equipment (sequence initiation, time delay, velocity and acceleration);

f) reduced susceptibility to plant electrical noise;

g) improved tracking of moving conveyor lines;

h) ready availability of spare parts and service;

i) greater load carrying capacity;

j) improved accuracy and repeatability (high speed, arm extented or full load);

k) reduced vibration or over shoot;

l) reduced cost;

m) improved safety in event of malfunction;

n) improved gripping of parts (location variation). (46)

These problems can also offer some opportunities in development and services for robots in Canada and abroad.

8.0 Future Needs and Prospects

As mentioned earlier, the market potential for classical robot sales is conservatively estimated at $ 40 million in Canada by 1985. This would represent about 600 jobs just building robots. (47) Considering the spin-off effects, the number of jobs will be greater.

An excellent example of this is the RMS program which was funded by the federal government for $118 million. Spar, being the major contractor, let 20 sub-contracts to Canadian firms (and 5 to U.S. firms). At the peak of operations, about 650 people were employed working on this project. Spar itself has already picked up about 30 contracts on the basis of their "space arm" experience valued at about $350 million. They are now talking about $2-4 billion worth of business by the year 2000, again just on the basis of the RMS program experience. (48)

Just as significant as the number of jobs that will be created, are the effects that robotics will have on the Canadian economy and society. As indicated, major labour upheavals could occur if robotics technology is absorbed at a too rapid pace. The rate of adoption will be controlled in part by normal market forces such as the availability of capital, supply of materials and peripheral parts, demand for robots and the availability of skilled people for installing and operating them.

Obviously, to minimize the potential negative impact and yet clearly try to maintain Canadian competitiveness in the foreign trade markets, leadership and a plan of action are required. It is inevitable that the leadership role be taken up by the federal government as the effects of this technology will impact the whole of Canadian society and economy. As time is of the essence in this particular case, quick action is required.

The state of knowledge about the robotics field and its impact on the economy is rather limited. A comprehensive study is suggested which should include market surveys and studies, and social impact studies. Some of the questions that need to be answered before government policy is defined are:

a) What is the current state of the art in robotics and future expectations ?

b) What are the short and long term robot problem areas? Are these areas endeavors that should require Canadian R & D effort?

c) What is the real market potential of robotics in Canada and the world, for various robot applications and peripheral equipment?

d) Is the Canadian market capable of supporting indigenous robot manufacturers?, or should manufacturing licenses be obtained or subsidiary companies encouraged so that Canada will at least have manufacturing experience in this field?

e) What particular savings and advantages and conversely disadvantages are there associated with the adoption of robotics technology in Canada?

- how will it affect the Canadian trade balance (exports/imports)?

- how will it affect Canadian international competition?

- will the adoption of robotics provide Canada a self-sustaining new growth industry?

- what will be the ripple effect throughout the economy?

- does the import savings from an indigenous robotics industry justify the capital investment and use of people?

f) What areas in the robotics field should Canada specilize in (for example - arm design and control)?

g) Will we be able to capture a certain percentage of the world robotics market if we pursue such a specialized course of action?

h) What areas could we specialize in with respect to the applications of robots in Canadian industries? (for example - as a world leader in the mining industry, should we not pursue particular R & D efforts in robotics to maintain this lead, i.e. - robot miners?)

i) How should robotic R & D be undertaken and then disseminated throughout the economy? Should it be via the Japanese example of coordinated industrial - governement R & D? left to NRC to set the pace and take the lead? How should university R & D be pursued - NSERC Strategic Grants Program?

j) Could pilot projects and case examples open to industrial scrutiny help sell Canadian expertise in robotics to Canadian manufacturers' and to potential foreign buyers?

k) At what level should the government support robotics R, D & D and how much emphasis should be placed on this field by the government?

l) How will the necessary qualified people be found for the research, development, application and maintenance of this technology ?

   - what will the universities and colleges teach (definition of robotic courses and content) ?

   - how long will it take to get qualified/ competent workers trained?

   - when will qualified/competent workers be needed ?

   - what will public acceptance be for robotics and is there a need for public education in this technology ?

m) How will retraining/re-employment of displaced workers occur?

n) What financial incentives will be required (if any) to promote Canadian robotics implementation ?

o) Should a central agency be organized to serve as a data resource base and liaison for interface between government and industry ?

p) Would a similar organization such as the CAD/CAM Technology Advancement Council, for robotics serve a useful function (i.e. - technology radiation) ?

q) How will robotics R & D be interfaced with the other CAD/CAM technologies ?

The answers to these and many other questions need to be considered in the development of Canadian policy on robotics. It is important to move expediently on the robotics subject if Canada is to technologically and economically survive (and maintain some semblance of sovereignty) in todays world. The opportunity to make technological contributions towards the state of robot knowledge is still within our grasp. At the same time, the opportunity to improve our economic base is also still available. The dividends earned in the not to distant future will be determined by the speed of the policies and actions taken today.

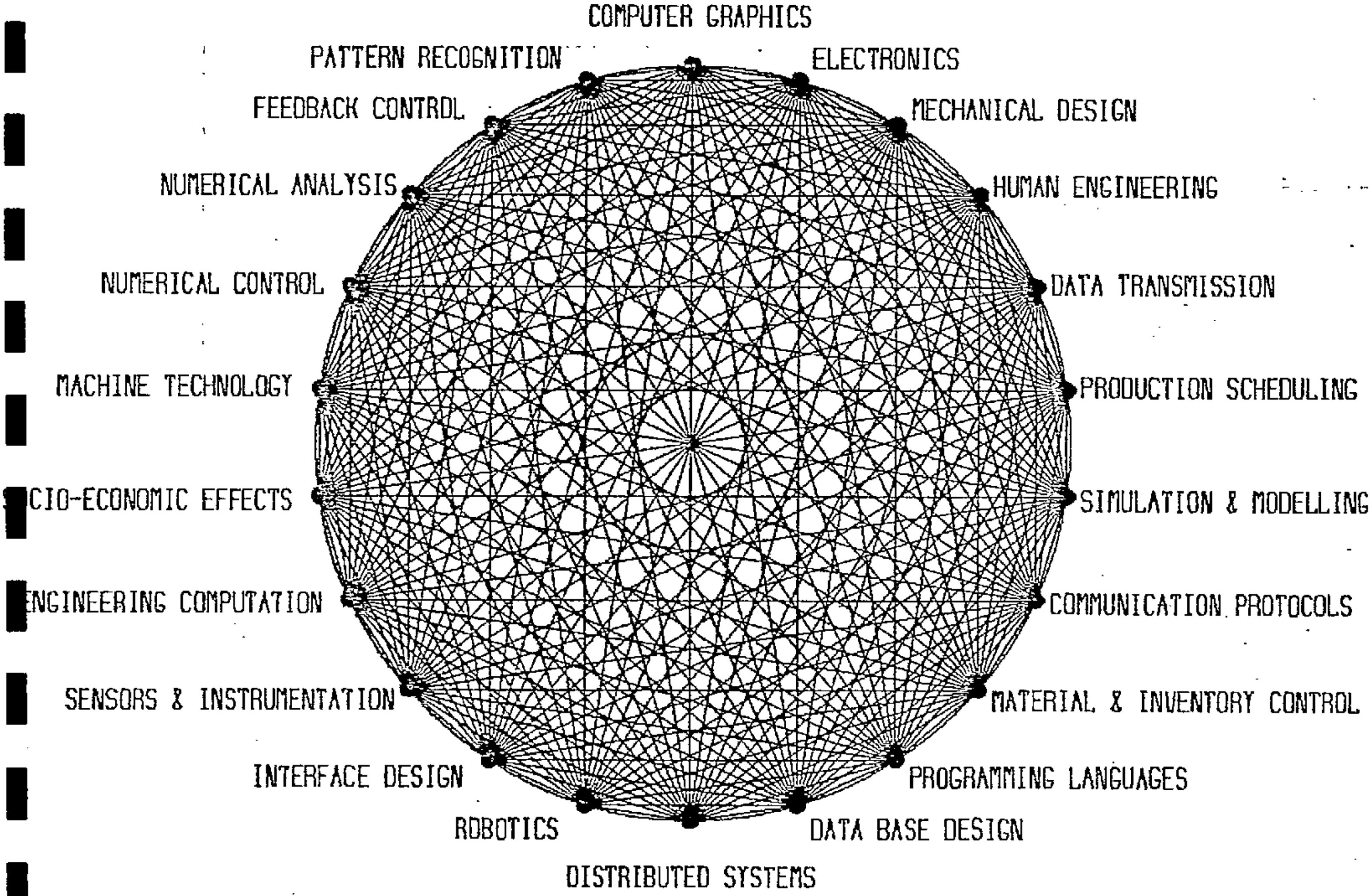
9.0 Appendix I

SUMMARY OF CAD/CAM APPLICATION AREAS

Computer Aided Design	- Production design and analysis including graphic design, functional analysis, stress strain analysis, heat and material balances, simulation and modelling, data reduction and analysis and cost estimating of the proposed product or system to determine fitness of purpose and economically optimized production.
Customer Order Handling	- Record keeping, tracking and reporting on the status of individual customer orders, particularly when part of an integrated on-line system.
Production, Material & Inventory Control	- Scheduling and information handling pertaining to material requirements planning, inventory control, facilities planning and order scheduling, particularly when related to an integrated on-line system.
Automated Production	- Numerical and computer control of machine tools, lathes, milling, boring machines, pattern and fabric cutting, welding, brazing, plating, flow soldering, casting, flame cutting, spray painting and automated assembly (all of these exist and are under further development).
Automated Material Handling	- Integrated materials handling using computer operated conveyors, robotic units, etc.
Automated Testing	- Automated inspection of machined parts, testing of electronic components, circuits and products, automated material inspection and grading using sensor based computer systems, pattern recognition.
Automated Packaging	- Computer implemented coordination of material and information in packaging, bottling, labelling and weighing systems.
Automated Warehousing	- Computer implemented order picking and material handling for both work in progress inventory and finished goods inventory. Automated label reading, routing of packages, parcels, baggage in shipping, sorting and distribution centers.

Notes: - CAD/CAM technology will yield its greatest economic and productivity gains when all or most of the above application areas are married or joined together to form an integrated system. Hence there is a strong development trend in this direction.

FIGURE 6 CAD/CAM TECHNOLOGIES & THEIR INTERELATIONSHIPS.



Source: Strategy For Survival: Ottawa: CAD/CAM Technology Advancement Council, September 1980.

COMPUTER GRAPHICS BY -CADSYS LTD- VANCOUVER*

10.0 Appendix II

LIST OF CONTACTS

Jack Scrimgeour	I, T&C	593-7861
Arthur Hunter	NRC	993-2110
Linda Ploeger	Ministry for Industry & Tourism (Ont.)	965-7196
Jack Cole	Ministry for Industry & Tourism (Ont.)	965-7196
Nestor Burtnyk	NRC	993-0261
Lloyd Pinkney	NRC	993-2469
Phil Hammil	NRC	993-2834
Bill Coderre	NRC (PILP)	993-0695
D.R. Strong	Bata Engineering	398-6106
Tony Kasvand	NRC	993-2003
Karl Doetsch	NRC	993-2110
Prof. French	U. of Waterloo	885-2802
Dr. Tlusty	McMaster University	525-9140 Ext. 4817
G.M. Lindberg	N.A.E.	993-2427
Frank Cairns	N.R.C.	993-2557
Peter Young	McMaster University	525-9140 Ext. 2066

11.0 Appendix III

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
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.	Food Processing		1	Material handling
CAMCO	Appliances	1	2	Spray painting
Canada Metal Co.	Lead Smelting		1	Material handling
C.G.E. Montreal	Appliances		4	Welding, Spray painting
C.G.E. Toronto	Appliances	2		Assembly, Spray painting
Canadian Industries Ltd.	Chemicals		3	Material handling
Canadian Machinery	Metalworking	1		Material handling
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
General Motors Co.	Automobiles	37	90	Welding, Spray painting Inspection, Material handling

Forward

COMPANY NAME	PRODUCT	ROBOT INSTALLATIONS CURRENT	ROBOT INSTALLATIONS PROJECTED	APPLICATIONS
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 & Inspection
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	-

Source: Nickerson, M.L. & Robertson, G.M., Study to Identify Canadian Industrial Needs and Potential Areas for National Research Council Involvement in the Science of Robotics, Ottawa: Robertson, Nickerson Group Associates Limited, 1980.

12.0 Appendix IV

Robot Suppliers in Canada

(1980)

Unimation Inc./CAE Morse Inc.	4500 Dixie Road Mississauga, Ontario L4W 1V7 (416) 625-5161
Cincinnati Milacron Canada Ltd.	122 North Queen St. Toronto, Ontario M8Z 2E4 (416) 233-3216
Trallfa/Devilbis Canada Ltd.	1 Wood St. Barrie, Ontario L4M 4V6 (705) 728-5501
Seiko/Hall Smith Co. Ltd.	3505 Mainway Burlington, Ontario L7M 1A9 (416) 335-6008
Prab/Can-Eng Ltd.	Can-Eng Mfg. Ltd. 6800 Montrose Road Niaraga Falls, Ontario L2E 6V5 (416) 356-1327
Versatran/Can Eng. Ltd.	Can-Eng Mfg. Ltd. 6800 Montrose Road Niaraga Falls, Ontario L2E 6V5 (416) 356-1327
Nordson Canada Ltd.	849 Progress Ave. Scarborough, Ontario M1H 2X4 (416) 438-6730
ASEA Ltd.	P.O. Box 700 Postal Station Cartierville Montréal, Québec H4K 2J8 (514)332-5350

Brinks Mfg. Co. Of Canada Ltd.	14 Vansco Road Toronto, Ontario M9Z 5J4 (416) 252-5181
Martonair Canada Ltd.	3067 Jarrow Ave. Mississauga, Ontario L4X 2C6 (416) 625-4060
Fanuc/Hall Smith Co. Ltd.	3505 Mainway Burlington, Ontario L7M 1A9 (416) 335-6008
Auto-Place/A.F. Mundy Assoc. Canada Ltd.	Rexdale, Ontario
Sterling-Detroit/J.S. Bulmer	Oshawa, Ontario

Source: Crozier, J.E. & Tlusty, J., A Robotics Application Study for the National Research Council, Hamilton: 1981, and Peter Young, McMaster University.

13.0 Footnotes

1. Industrial Robots: Volume 1, Fundamentals, (Dearborn Michigan, Society of Manufacturing Engineers, ed. - W.R. Tanner, 1979).

2. L. Froehlich, "Robots to the Rescue?", Datamation (New York: January 1981), p.86.

3. Industrial Robots: Volume 1, Fundamentals, (Dearborn Michigan, Society of Manufacturing Engineers, ed. - W.R. Tanner, 1979).

4. "Robots are Coming to Industry's Service", The Economist (August 29, 1981), p. 72.

5. L. Froehlich, "Robots to the Rescue?", Datamation (New York: January 1981), p.86.

6. *Ibid.* p. 88.

7. *Ibid.* p. 90.

8. J.P. Kornfeld and E.L. Magad, "Robotry and Automation -- Key to International Competition", Proceedings on the Second International Symposium of Industrial Robots, (Chicago: ITT REsearch Institute, 1972), p. 31.

9. C. Sinclair, article from: Financial Times of Canada March 3, 1980.

10. *Ibid.*

11. *Ibid.*

12. L. Froehlich, "Robots to the Rescue?", Datamation (New York: January 1981), p. 86.

13. S. Peitchinis, The Introduction of Computer-Aided Design (CAD)/Computer-Aided Manufacturing (CAM) Systems and Their Employment Implications, (Ottawa: IT & C, September 1980), pp.11 and 12.

14. J. Tlusty and J.E. Crozier, A Robotics Application Study for National Research Council, (Hamilton: Canadian Institute of Metal working,1981), p. 24.

15. *Ibid.* p.24

16. L. Froehlich, "Robots to the Rescue?", Datamation (New York: January 1981), p. 90.

17. S. Peitchinis, ... p. 10.

18. Robertson, Nicherson Ltd., Study to Identify Canadian Industrial Needs, and Potential Areas for National Research Council Involvement in the Science Of Robotics, (Ottawa: Robertson, Nickerson Ltd., August 1980), p. 3

19. S. Peitchinis, ... p. i.

20. "The Impact of Computer/Communications on Employment In Canada: An overview of current OECD Debates", Z.P. Zeman, Project Leader, Institute for Research on Public Policy, Montreal 1979, Contract No. 12 SV 36100-9-0017. Department of Communications, Ottawa. Synopsis of this report can be found in: Strategy for Survival, (Ottawa: CAD/CAM Technology Advancement Council, September 1980), Appendix IV, p. 2.

21. *Ibid.*, p. 15

22. *Ibid.*, p. 2

23. S. Peitchinis,... p.i.

24. Robertson, Nickerson,... p. 43.

25. H. Scarborough, "Working with Robots is a Bore", New Scientist, (May 28, 1981), p. 554.

26. *Ibid.*, p. 554.

27. *Ibid.*, p. 555.

28. *Ibid.*, p. 555. This has in part been practiced by Digital Equipment Co. of Kanata for many years.

29. *Ibid.*, p. 555.

30. Robertson, Nickerson..., p. 20.

31. *Ibid.*, p. 21.

32. See the reports done for NRC by Robertson, Nickerson Ltd. and Crozier & Tlusty.

33. Strategy for Survival,... Appendix ii, p.1.

34. "Report on Business", Globe and Mail, (Toronto: July 13, 1981).

35. Personal communications with Linda Ploeger and Jack Cole both of the Ministry for Industry and Tourism, Ontario.

36. Personal communication with Nestor Burtnyk, NRC.

37. The Urgent Investment, (Ottawa: NRCC, 1980), p. 44.

38. Personal communication with Lloyd Pinky, NRC.

39. Personal communication with Phil Hammil, NRC.

40. *Ibid.*

41. Personal communication with Bill Coderre, NRC.

42. Personal communication with Jack Scrimgeour, I.T.&C.

43. Robertson, Nickerson..., p. 39.

44. *Ibid.*, p. 34.

45. Personal communication with D.R. Strong, Bata Engineering Department. Formerly with Leigh Instruments in Ottawa where he developed an arm-vision system (ARVIS), Strong has gone to Bata Shoes to set up a robotics R & D group. He hopes to start his project in January 1982, have the robot system developed in one year, have the system applied in the shoe factory by the next year and the robot commercially available in the third year!

46. Personal communication with Jack Scrimgeour, I,T&C.

47. J. Tlusty and J.E. Crozier,... p.26.

48. Personal communication with Arthur Hunter, NRC.

14.0 Bibliography

Barrow, H.G., Bolles, R.C. & Tenenbaum, J.M. — "Prospects for Industrial Vision", Computer Vision and Sensor-Based Robots. New York: Plenum Press, ed. - George G. Dodd & Lothar Rossol, 1979.

Cousineau, D.T. — "Robots are Easy...It's Everything Else That's Hard", Robotics Today, Spring 1981.

Crozier, J.E. & Tlusty, J. — A Robotics Application Study for the National Research Council. Hamilton: 1981.

Crozier, J.E. — A Study to Identify the Attitudes and Awareness of Numerical Control Users to CAD/CAM Technology and The Technological and Economic Strengths and Weaknesses of Machine Tool Part Programming. Ottawa: Industry, Trade and Commerce, Technology Branch, Technological Innovation Studies Program, Research Report, November 1980.

Dixon, J.K., Salazar, S. & Slagle, J.R. — "Research on Tactile Sensors for an Intelligent Naval Robot", 9th International Symposium on Industrial Robots. Washington D.C.: 1979.

Heer, E. — "Robot and Automation Technology Requirements for Space Industrialization", 9th International Symposium on Industrial Robots. Washington D.C.: 1979.

Hon, R.W. & Reddy, D.R. — "Computer Architectures for Vision", Computer Vision and Sensor-Based Robots. New York: Plenum Press, ed. - George G. Dodd & Lothar Rossol, 1979.

Horn, B.K.P. — "Artificial Intelligence and the Science Of Image Understanding", Computer Vision and Sensor-Based Robots. New York: Plenum Press, ed. - George G. Dodd & Lothar Rossol, 1979.

Kasvand, T. — A Preliminary Survey of the Field of Robotics. Ottawa: Computer Graphics Section, National Research Council, March 1979.

Kasvand, T. — Image Processing in Japan. Ottawa: National Research Council.

Kasvand, T. — "The Present State of Image Processing", Graphics and Imaging. Ottawa: National Research Council.

Kasvand, T. — The Robotics Scene in Japan. Ottawa: National Research Council.

Kasvand, T. — Vision, As Applied to Robots. Ottawa: National Research Council.

Kornfeld, J.P. & Magad, E.L. — "Robotry and Automation --Key to International Competition", Proceedings of the Second International Symposium on Industrial Robots. Chicago: ed.- IIT Research Institute, 1972.

McGhee, R.B. — "Future Prospects for Sensor-Based Robots", Computer Vision and Sensor-Based Robots. New York: Plenum Press, ed. - George G. Dodd & Lothar Rossol, 1979.

Nickerson, M.L. & Robertson, G.M. — Study To Identify Canadian Industrial Needs and Potential Areas for National Research Council Involvement in the Science of Robotics. Ottawa: Robertson, Nickerson Group Associates Limited, 1980.

Peitchinis, S.G. — The Introduction of Computer - Aided Design (CAD)/ Computer-Aided Manufacturing (CAM) Systems and their Employment Implications. Ottawa: Industry, Trade and Commerce, Technology Branch, Technological Innovation Studies Program, Research Report, September 1980.

Rosenfeld, S.A. "Robotics Research A Program for Industry", Proceedings of the Second International Symposium on Industrial Robots. Chicago: IIT Research Institure, 1972.

Scarborough, H. "Working with Robots is a Bore", New Scientist. May 28, 1981.

Thring, M.W. "Telechiric Mining", Theory and Practice of Robots and Manipulations Proceedings. New York. Elsevier Scientific Publishing Company & PWN-Polish Scientific Publishers, ed.- A. Morecki & K. Kedzior, 1977.

____________. CAD/CAM and Canada. Ottawa: Department of Industry Trade and Commerce, 1981 (a collection of CAD/CAM reprints)

____________. Computer Vision and Sensor-Based Robots. New York: Plenum Press, ed. - George G. Dodd & Lothar Rossol, 1979.

____________. Industrial Robots, Vol. 1, An Industrial Appreciation. Glasgow: Ingersoll Engineers, DoI/National Engineering Laboratory, 1980.

____________. Industrial Robots: a World Wide Literature Survey, Vol.2, Applications R & D Bibliography. Glasgow: Ingersoll Engineers and DoI/National Engineering Laboratory, 1980.

____________. Industrial Robots, Vol. 1, Fundamentals. Michigan: Society of Manufacturing Engineers Marketing Services Deppartment, ed. - William R. Tanner, 1979.

____________. Proceedings of the Second International Symposium on Industrial Robots. Chicago: IIT Research Institute, 1972.

____________. Proceedings of the 4th International Symposium on Industrial Robots. 1974.

Thring, M.W. ________. 5th International Symposium on Industrial Robots. Chicago: IIT Research Institute, 1975. TJ 211. 1. Automata - Congs Manipulators (Mechanism) -

________. Strategy For Survival. Ottawa: CAD/CAM Technology Advancement Council, September, 1980

________. Theory and Practice of Robots and Manipulators Proceedings. New York: Elsevier Scientific Publishing Company & PWN-Polish Scientific Publishers, ed.- A. Morecki & K. Kedzior, 1977.

________. The Urgent Investment: A Long Range Plan for the National Research Council of Canada. Ottawa: NRCC, October 1980.

________. "Report on Business", Globe and Mail. Toronto: Monday, July 13, 1981.

________. "Highlights of Labour Market Task Force Report", news release from Employment and Immigration Canada. Ottawa: July 7, 1981.

________. "Robots are Coming to Industry's Service", The Economist. August 29, 1981.

________. "Industrial Robots - The Next Generation", Compressed Air Magazine. August, 1981.

________. "Robots Join the Labour Force", Business Week. Hightstown, N.J.: McGraw-Hill, Inc., June 9, 1980.