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SECTORAL WORKING PAPERS

In the course of the work on major sectoral studies carried out by UNIDO, Studies and Research Division, several working papers are produced by the secretariat and by outside experts. Selected papers that are believed to be of interest to a wider audience are presented in the Sectoral Working Papers series. These papers are more exploratory and tentative than the sectoral studies. They are therefore subject to revision and modification before being incorporated into the sectoral studies.

This paper was prepared by Messrs. J. Chabrol and A. Laffaille (France) as consultants to UNIDO. The views expressed do not necessarily reflect the views of the UNIDO secretariat.

Preface

In the work programme on capital goods UNIDO's Sectoral Studies Branch has identified and analyzed the new technological trends affecting the development of the capital goods industry in developing countries. The new technologies can be described as microelectronics-based technologies and industrial automation.

This paper explains systematically the different stages in the introduction of industrial automation, namely CNC machine tools, CAD/CAM systems, industrial robots and flexible manufacturing systems (FMS) and the possibilities offered by these technologies for developing countries.

A first version of this study was presented as background paper to the UNIDO/JUNAC Technical Working Group for the formulation of a work programme on microelectronics in the capital goods industries of the Andean Pact countries (project UC/RLA/86/230), which was held from 8 to 13 March 1987 in Paipa and Bogota, Colombia. The final report of this meeting is available in Spanish as UNIDO document PPD.36.

The present revised version is primarily a discussion paper for the Seminar on Machine Tools in Selected Developing Countries (project US/INT/87/061) organized by UNIDO jointly with UCIMU (Italian Machine Tools Manufacturers Association) from 14 to 22 October 1987 in Milan, Italy, during the 7th EMO (International Machine Tool Exhibition).

This study was prepared in collaboration with Messrs. J. Chabrol and A. Laffaille as consultants to UNIDO. Tables and graphics without specific mention of the source were prepared by the consultants.

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EXPLANATORY NOTES

References to dollars ($) are to United States dollars, unless otherwise stated.

A slash between dates (e.g., 1980/81) indicates a crop year, financial year or academic year.

Use of a hyphen between dates (e.g., 1960-1965) indicates the full period involved, including the beginning and end years.

The following forms have been used in tables:

Three dots (...) indicate that data are not available or are not separately reported.

A dash (-) indicates that the amount is nil or negligible.

A blank indicates that the item is not applicable.

Totals may not add up precisely because of rounding.

Besides the common abbreviations, symbols and terms and those accepted by the International System of Units (SI), the following abbreviations and contractions have been used in this report:

Economic and technical abbreviations

AGV	Automatic guided vehicule
AI	Artificial intelligence
AMH	Automatic material handling
APT	Automatically programmed tool (programming language for NC machines)
CAD	Computer aided design
CAM	Computer aided manufacture
CAP	Computer aided planning
CECIMO	Comité Européen de Coopération des Industries de la Machine Outil
CMM	Coordinate measuring machine
CNC machine	Computerized numerically controlled machine
DC motor	Direct current motor
FMC	Flexible manufacturing unit
FMU	Flexible manufacturing unit
GT	Group technology
IR or MIR	Industrial robot or manipulating industrial robot
ISO	International Organization of Standardization
LAN	Local area network
MAP	Manufacturing automation protocol
MRP	Material requirement planning
NC machine	Numerically controlled machine
PA	Programmable automation
PC	Programmable controller
R and D	Research and Development
ROM	Read only memory
2D, 3D	Two dimensional, three dimensional

1. INTRODUCTION

1.1 Historical review of automatic manufacturing

In this study consideration will be given to advanced manufacturing technologies and the flexible manufacturing systems in order to assess the advisability of introducing these techniques for the production of capital goods in developing countries. A brief historical review of the steps of automation will help understand the benefits, both technical and economic, brought about by programmable automation (PA) in engineering industries.

Until recently automation had been more or less synonymous with mechanization which had given rise to spectacular effects on productivity and production volume. Continuous improvement of machinery and other technical devices had made it possible to replace many workers undertaking physical manual operations with machines. However mechanized production processes required large investments, and as there was hardly any built in flexibility in the production process, strict product standardization as well as very large-scale production were prerequisites : before the manufacture of a new product or product variant, the whole production line had to be rebuilt.

For small batch production which in metalworking manufacturing accounts for something in the order of 75 % of all manufacturing, mechanization never made any significant in roads. The only way to achieve the necessary flexibility was through manual operations. Thus mechanized or hard automation has been typically very efficient, very expensive and best for mass production ; its main disadvantage is its lack of flexiblity.

Some 17 years ago, a new step in technology revolutionized the manufacturing process : it was the advent of the industrial electronics materialized by the programmable controller (1) and the digital computer as well as their hardware components, the integrated circuit and the microcomputer. These two innovations opened up radically new possibilities in the rationalization of production processes. Indeed microelectronics has brought an enormous potentiality in the sophistication of the control of the machines operated in the engineering industry and also the

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1/ Programmable controllers (PCs) are small dedicated computers used to control a variety of production processes. Until the late 1960s PCs were comprised of mechanical relays and were "hard wired" - one had to physically rewire the device, to change its function or order of processes. Modern PCs are computerized and can easily be reprogrammed ; they are also able not only to control production processes but also collect information about the date. PCs and NCs for macnine tools are very similar in concept - essentially NCs are a specialized form of a PC designed for controlling a machine tool.

materialization of the flexibilty (1) concept in their control. So automation through computerized digital control has generated changes of the same magnitude as were previously brought about the mechanized production technology.

Through microelectronics and data processing not only the engineering processes have made a tremendous leap forward but also the management of production have been radically changed to a better efficiency and more rationalized organization. Now besides the material processing system, the information processing system can be added which can be thought of as the "nerve system" in the production system : in the former system, raw material is processed to finished goods through a series of mechanical operations such as metal cutting, forming, joining, surface treatment, etc., while the latter system receives information regarding status in the material processing system and transmits back orders and control information concerning individual machine operations as well as the material flow between work stations.

Due to its high power of logic decision making and its capability to handle complex organizational and integrational problems far more rapidly than humans could do, the computerized manufacturing technology offers a solution to the problem of small batch production which has become technically and economically possible to automate. Now flexibility in the production process is a reality.

1.2 Scope and organization of the study

The aim of this report is to study the impact of new emerging technologies on selected engineering products of interest in developing countries.

Section 2 reviews the past developments and current situation of industrial automation in the engineering industries of industrialized countries. This presentation includes description and assessment of each of the most usual modern tools used in the engineering industries, i.e. numerically controlled machine tools, industrial robots, computer aided design and computer aided manufacture and flexible manufacturing systems. This presentation is practical and explanatory ; it describes only

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1/ The word "flexibility" is often used in this study and so deserves a clear explanation. Flexibility is defined as the range of products and the range of volumes of a specific product which a plant can economically produce. It can be thought of as the case with which a production system can be reset to process a variety of parts and its ability to change over to produce a new set of products very economically and quickly. It is also understood as the system ability to operate different production volumes.

functional points of view ; no technical concepts are developed ; only the state of the art and its current capabilities are presented with a fair appraisal of every tool considered.

Section 3 deals with the technological developments under way and expected in the engineering industry and their main implications, i.e. the constraints of training the staff and the production personnel of the company as well as the complex management of how to prepare and conduct the installation of the new manufacturing tools, from organizational and financial points of view ; this latter aspect is of such a paramount importance that it was deemed necessary to give it a special consideration. Furthermore a survey shows how the new manufacturing tools are well adapted to produce capital goods products of interest to developing countries, not only machine tools, electric power equipment, diesel engines, and accessories and spare parts for the automative industry, but also a wide and diversified range of products not related to those manufactured by the engineering industry.

Section 4 deals with policy strategies and policy options to facilitate the introduction and application of industrial automation in developing countries. If industrial automation is viewed both as contributing to problems faced by the economics and as part of the solutions to those problems, it often received a mixed welcome. So, before formulating any strategic and policy suggestions and/or recommendations, the knowledge and assessment of industrial automation international framework and industrialized countries recent experiences are very useful.

2. REVIEW OF PAST DEVELOPMENTS AND PRESENT SITUATION OF INDUSTRIAL AUTOMATION IN THE ENGINEERING INDUSTRIES OF INDUSTRIALIZED COUNTRIES

2.1 NC machine tools

The most common sequence of process for 3D metal parts is casting and forging followed by machining. This machining is carried out by metal cutting machine tools: lathes, boring, milling and grinding machines tools. The machining for 2D metal parts obtained from rolling mills is carried out by metal forming machine tools : presses, punching, stamping, shearing and bending machines. This present study is rather concerned with the manufacture of 3D parts.

Numerically controlled or NC machine tools are devices which machine pieces of metal according to programmed instructions about the desired dimensions of a part and the steps for the machining process. They consist of machine tools, specially equipped with motors to guide the cutting process, and controllers which receive numerical control commands.

Machine tools for cutting and forming metal are the heart of the metal working industry. Using a conventional manual machine tool, a machinist guides the shapping of a metal part by hand. He moves either the workpiece or the head of the cutting tool to produce the desired shape of the part. The machinist controls the speed of the cut, the flow of coolant, and all other relevant aspects of the machining process. In ordinary NC machines, programs are written at a terminal which, in turn, punches holes in a paper or mylar plastic tape. The tape is then fed into the NC controller. Each set of holes represents a command, which is transmitted to the motors guiding the machine tool by relays and other electromechanical switches. Although these machines are not computerized, they are programmable in the sense that the machine can easily be set to making a different part by feeding it a different punched tape ; and they are automated in that the machine moves its cutting head, adjusts its coolant, and so forth, without direct human intervention. However, most of these machines still require a human operator, though in some cases there is one operator for two or more NC machine tools. The operator supervises several critical aspects of the machine's operation :

1) he overrides control to modify the programme speeds (rate of motion of the cutting tool) and feeds (rate of cut). These rates will vary depending on the batch of metal used and the condition of the cutting tool ;

2) he watches the quality and dimensions of the cut, and listens to the tool, replacing worn tools (ideally) before they fail, and

3) he monitors the process to avoid accidents or damage, e.g. a tool cutting into a misplaced clamp, or a blocked coolant line.

Since 1975. machine tool manufacturers have begun to use microprocessors in the controller, and some NC machine tools come equipped with a dedicated minicomputer. Those called computerized numerically controlled (CNC) tend to be equipped with a screen and keyboard for writing and editing NC programs at the machines.

So the operator can edit the program at the machine, rather than sending a tape back to a programmer in a computer room for changes. In addition, by avoiding the use of paper or mylar tape, CNC machines are substantially more reliable than ordinary NC machines. CNC machines, througn their computer screens, mays also offer the operator more complete information about the status of the machining process. Some CNC machine tools are equipped with a feature called "adaptive control" which tries to automatically optimize the rates of cut to produce the part as fast as possible, while avoiding tool failure. Closely related to CNC is direct numerical control (DNC) in which a larger computer is used to program and run more than one NC machine tools simultaneously. As the price of small computers has declined, DNC has evolved both in meaning and concept into distributed numerical control, in which each machine tool has a microcomputer of its own, and the systems are linked to a central controlling computer ; one of the advantages of such distributed control is that the machines can often continue working for same time even if the control computer "goes down". Typically, NC programs are written in a language called APT (Automatically Programmed Tools), a number of modified versions of which have been released. Some of these are easier to use than the original. But the essential concept and structure of the numerical codes has remained the same, and practically APT has become a de facto standard for machine tool.

Intricate mechanical part shapes, such as those found in the aerospace industry, are nearly impossible for even the most experienced machinists using conventional machine tools. With NC the parts can be more consistent because the same NC program is used to make the part each time it is produced. A manually guided machine tool is more likely to produce parts with slight variations, because the machinist is likely to use a slightly different procedure each time he makes a part. This mav not be a problem for one-of-a-kind or custom production, but can cause headaches in batch production. The advantages in consistency due to NC are seen by many manufacturers as an increase in their control over the machining process.

NC machines have a higher "through put" than conventional machine tools, and hence are more productive. They are operating (i.e. cutting metal) more of the time than conventional machine tools because all the steps are established before the machining begins and are followed methodically by the machine's controller. Further, on a complex part that takes more than one shift of machining on conventional machine tool, it is very difficult for a new machinist to take over where the first left off. The part may remain clamped to the marchine, and the part and machine tool lie idle until the original machinist returns. On NC machines, operators can substitute for each other relatively easily, allowing the machining to continue ininterrupted.

Furthermore the capability of guiding machine tools with numeric codes opens up possibilities for streamlining the steps between design and production ; the geometric data developped in drawing the product on a CAD system can be used to generate the NC program for manufacturing the product.

2.2 Computer aided design (CAD)-computer aided manufacture (CAM)

- "A CAD system is a system which incorporates one or more computers for carrying out some of the calculations and actions involved in product design and analysis" (1).
  Hence CAD increases drawing office productivity by its automated drafting. The computer calculates dimensions and can recall drawings of standards components. The computer can also produce drawings in standard projections. Current claims are that CAD can cut the time for designing and draughting by at least a factor 3. CAD encourages designer creativity. The video display screen can display 3D (3 dimensional) models, which can be rotated at any angle and enlarged as well. This allows easy visualisation ; its also greatly decreases the cost and time associated with evaluating alternative designs. CAD in its simpler form is an electronic drawing board for draftsmen and design engineers ; in its more sophisticated forms CAD is the core of computer aided engineering, allowing engineers to analyze a design and maximise a product's performance using the computerized representation of the product.

- A CAM system is a system which incorporates one or more computers for carrying out some of the tasks involved in organization, scheduling and control of the operations involved in the manufacture of the product. Where machining is involved, a CAM system will usually involve CNC machine tools and means for producing part programs for them, and it may also involve a central computer for schedulling, planning and control of the operation of the system. It may involve a DNC system using either the control computer or a separate computer, as well as computer control of stores, orders, etc." (2).
  This manufacturing process is therefore concerned with the programming of the direct activities of manufacturing (cutting, forming, machining, assembling, etc) as well as indirect activities (production planning, scheduling, warehousing, etc).

- "CAD/CAM system is a system in which computers are used to carry out some of the tasks involved in designing and manufacturing a product. In particular, computers are often used to produce part programs for the CNC machines in the system directly from the design data". (3).
  Therefore CAD and CAM systems are combined into CAD/CAM systems which have to support design analysis and testing as well as product production, testing, inspection, production planning, inventory control, purchasing, material requirement planning, product database and quality control.

These design and production processes make use of computers, printers, graphic terminals and dedicated softwares to carry 2 or 3D designing and computer aided engineering.

1/ Definition established by the CECIMO Working Party on Standardization.

2/ Idem.

3/ Idem.

Today CAD/CAM systems are commonly used to design and manufacture parts, such as automotive parts or computer chips : they are increasingly being used to analyse and test designs, and later test the finished parts. CAD/CAM systems are currently used to design and produce aircraft, automobiles, heavy equipments and in shipbuilding. Mechanical and electronics industries were and are still the first users of CAD/CAM techniques.

An important aspect of CAD/CAM is its ability to program IR as well as CNC machine tools and simulate the running of their programs. The programmer can intervene during the whole process usually through the keyboard of the screen, which permits him to vary the place of the robot or the tool relative to its peripheral and environment, and watch a computerized simulation of the whole work cycle.

Group Technology is another field to CAD/CAM. This is a system to classify and code parts according to their geometric properties, component materials and manufacturing methods. These are stored in a database and then can be retreived and scrutinized. this allow the manufacturer to find opportunities for design and production economies by locating existing parts that may serve in a new design.

Building a group technology database is a monumental task but extremely useful and can dramatically reduce costs and cycle time. It also eliminates the need to keep many engineering drawings in file.

2.3 Industrial robots

According to the ISO definition a "manipulating industrial robot (MIR)" commonly called "industrial robot (IR)" is an "Automatically controlled, reprogrammable, multi-purpose manipulative machine with several degrees of freedom, which may be either fixed in place or mobile, for use in industrial automation applications". The manipulator definition and some comments are necessary to entirely understand what an industrial robot is and is not.

"A manipulator is a machine, the mechanism of which usually consists of a series of segments jointed or sliding relative to one another, for the purpose of grasping and moving objects usually in several degrees of freedom. It may be controlled by an operator, a programmable electronic controller, or any logic system.

"Reprogrammable" means : capable of changing the programmed motions or auxilliary functions without physical alterations.

"Multi-purpose" means : can be adapted to a different application with physical alteration.

"Physical alteration" means alteration of the mechanical structure or control unit except for changing programming cassettes, ROM's, etc.

So an IR is a CNC manipulator whose main features are :

- its ability to move its end effector along 6 degrees of freedom : 3 of position and 3 of orientation (although not all robots have 6 degrees of freedom),
- its working volume may be very large : several cubic metres -or small, some cubic centimetres-,
- if equipped with a tool changer, at the same working station several operations can be sequentially executed during a same work cycle ; e.g. a robot whose end effector is a gripper picks up a part of a car body from a container and puts it on a working table, then automatically changes its end effector into a spot welding gun and after several spot welds changes again its end effector into the gripper to pick up the part and put it away in another container.

- its ability to be equipped with external sensors -often optical- the outputs of which give its control unit a knowledge of its environment and the changes or evolutions of this environment : this permits the robot to decide its own motions necessary to carry out its task.

One of the characteristic of an IR is that according to the sophistication of its control system, it can operate :

- either in a blind, purely repetitive, but always accurate way,
- or in a repetitive way, but according to real time information on its near environment the motions of the end effector and/or the forces exerted by the end effector can be adapted to the current state of the environment,
- or in a more autonomous way with only one goal : to carry out a designated task (for instance to empty a bin loaded with intermingled parts which are a positioned and oriented at random).

The flexibility of use of an industrial robot can be considered at two levels :

- control level : for a given application, spot welding for instance, by simply changing the task program, either manually (changing a cassette) or through teleloading, the work cycle of the robot can be entirely modified.
- end effector level : the simultaneous changes -either manual or automatic- of the end effector and the task program can completely modify the type of application : material handling to spotwelding, or vice versa for instance, as in the above example.

There are three main parts of a typical IR : the controller, mechanical structure, and end effector. The controller consists of hardware and software -usually involving one or several microcomputers- which steers the motions of the robot and through which the machine is programmed. The mechanical structure consists of a base, usually bolted to the floor (or travelling along a fixed track in the floor or on an overhead or vertical support), an actuation mechanism (generally electric, hydraulic for heavy load robots and unusually pneumatic) which moves the mechanical structure, and the mechanical structure itself ; this latter, consisting of the arm for positioning and the wrist for orienting, can be configured in various ways to move through particular patterns. The number of different joints -generally the number of degrees of freedom- determines the robot's dexterity as well as its complexity and cost. Finally, the end effector, very often customized for particular application, is the tool which the IR uses to perform its task (gripper, welding gun, paint spraying gun...).

There are essentially two methods of programming an IR. Ten years ago the method was "teaching by guiding". The worker either physically guides the IR through its path, or uses switches on a (portable) control panel to move the arm and wrist ; the controller records the path as it is "taught". In "off line" programming the programmer writes a program in computer language at a computer terminal, and directs the robot to follow the written instructions. Teaching by guiding is the simplest method and is actually superior for certains applications such as paint spraying where it is useful to have the operator guide the robot through its path because of the continuous curved motions usually necessary for even paint coverage. However tracking by guiding offers minimal ability to "edit" a path -i.e. to modify a portion of the path without re-recording the entire path- and to use sensory information. Off line programming is useful for several reasons :

- production need not be stopped while the IR is being programmed ;
- the factory floor may be an inhospitable environment for programming, whereas off line programming can be done at a computer terminal in office ;

- computer aided manufacturing technologies will increasingly be able to automatically generate robot programs from design and manufacturing databases ;

- an off line written program can better accomodate more complex tasks, especially those in which "branching" is involved (e.g. "if the part is not present, then wait for the next cycle"). These branching decisions require some kind of mechanism by which the robot can sense its external environment.

Industrial robots can be thought to be mechanisms that duplicate human ability in movement and adaptability especially in a well definite limited space like a shop floor. Generally speaking IR properly fitted with adequate end effectors can carry out nearly all the operations executed in the mechanical engineering industry except for those operations carried out by numerically controlled machine tools.

The main fields of application of IR may be divided into four application categories depending of its mechanical structure size and the type of its end effector :

1) manipulation : all material handling, picking up, moving fast, positioning and orienting with accuracy ; e.g. bin picking, piece sorting, loading and unloading of presses, die-casting machines and machine tools, tool handling (handling a portable drilling machine accurately positioned and oriented before every operation), plastic moulding, palletizing... especially in hazardous work conditions.

2) machining :
   - grinding, deburring, fettling ;
   - paint or enamel spraying, sealant or adhesive application ;
   - waterjet or laser cutting ;
   - surface treatement, sanding, finishing ;

3) assembly : spot welding, arc welding, insertions and fastening screws, mounting of small apparatus : electrical motors, type writer keyboards, home appliances... Mounting of electronic components and chips on printed circuits boards.

4) Test and inspection : dimensional tests automatically carried out on finished or non-finished products.

The advantages of IR depend on whether one is comparing them to hard automation devices or to human workers. Clearly the flexibility and programmibility of IR is prominent in the first case, while in comparison with humans the advantages are likely to be the IR's greater consistency, endurance and ability to tolerate hostile environment.

The disadvantages of IRs also depend on whether they are compared with other automation devices or humans. In the former case, robotic devices are sometimes more expensive than a hard automation device which is not programmable, and they are not as fast : a typical IR moves as fast as a human, while dedicated automatic part-transfer devices can operate at considerably greater speed. The clear advantage of human workers over IRs, on the other hand, is in situations where extensive sensing, judgment, or intelligence is required, and/or where situations change so frequently that the expense of programming an IR is uneconomical. For these reasons it is often suggested that humans, IR's and hand automation equipment are best suited for low, medium and high production volumes respectively.

2.4 Flexible manufacturing system (FMS)

"A flexible manufacturing system (FMS) is an integrated computer controlled complex of numerically controlled machine tools,automated material and tool handling devices and automated measuring and testing equipment that, with a minimum of manual intervention and short change over time, can process any product belonging to a certain specified family of products within its stated capability and to a predetermined schedule" (1). So, in short, an FMS is a production unit capable of producing a range of discrete products with a minimum of manual intervention.

Pratically a FMS consists of production equipment workstation (machines tools or other equipment for fabrication, assembly or treatment) linked by a material handling system to move parts from one workstation to another, and it operates as an integrated system under full programmable control.

An FMS is often designed to produce a family of related parts, usually in relatively small batches, in many cases less than two and even as low as one. Most FMS include at least four workstations,and some have up to 30.

There are a wide variety of formats for Automated Materials Handling (AMH). AMH systems store and move products and materials under computer control. They include conveyors, monorails, towlines, motorized carts riding or tracks, automated carriers which follow wires embedded in the floor of the factory and automatic guided vehicules (AGV) which move "freely" in the workshop ; the common characteristic of all these devices is that they are controlled by a central computer.

The first application for AMH is to shuttle workpieces between stations of an FMS. For example, when the controller receives a message that a machine tool has finished work on a certain workpiece, the controller orders the AMH system to pick up the workpiece and deliver it to the next workstation in its routing. The material handling portion of the FMS is one of the trickiest element-part transport needs to be logistically complicated -and the HMS system must place the part accurately and reliably for machining. If some AMH systems, such as conveyors or towchains, are serial in nature, and in case of failure of an element, cause the FMS to ease operating, other AMH systems have backup paths, or use wire guided vehicules or automated guided vehicules which can be routed around disabled carts or other obstacles.

The second major a application for AMH is automated storage and retrieval systems. These systems are often very tall in order to conserve space and to limit the number of automatic carrier devices needed to service the facility. Advantages for such systems include lowered land needs, fewer (but more highly trained) staff and more accurate inventory records.

For mechanical parts, the most prominent such device is the Coordinate Measuring Machine (CMM) which is a programmable device of automatic and precise measurement of parts. A great variety of automatic inspection and test equipment is also used for electronic parts, which sometimes makes use of robot style machines.

1/ Idem.

Using NC programs and often computer-aided process planning, workers develop the sequence of production steps for each part that FMS produces. Then, based on inventory orders, and computer simulations of how the FMS could run most effectively, the FMS managers establish a schedule for the parts that the FMS will produce on a given day. Next, operators feed the materials for each part into the system, typically by clamping a block of metal into a special carrier that serves both as a fixture to hold the part in place while it is being machined, and as a pallet for transporting the workpiece. Once loaded, the FMS essentially takes over : IR's, conveyors, AGV's or other automated materials handling devices transport the workpiece from workstation to workstation, accordingto the process plan. If a tool is not working, the FMS can reroute the part or other tools that can substitute.

Machine tools are not the only workstation in an FMS ; other possible stations include washing or heat-treatment machines, automatic inspection devices and even involve machines for grinding, sheet metal working, plastic handling and assembly.

The amount of flexibility necessary to deserve the label "flexible" is arguable. However, in the current state of the technology, a system that cannot produce at least 20 different parts is not flexible.

The essential features that constitute a workable "part family" for FMS are :

- a common shape : in particular, prismatic (primarily flat surfaces) and rotational parts cannot be produced by the same set of machines ;

- size : an FMS will be designed to produce parts of a certain minimum size, e.g. 600 cm^3. Parts larger or much smaller than that size cannot be handled ;

- material : titanium and common steel parts cannot be effectively mixted, nor can metal and plastic ;

- tolerance : the level of precision necessary for a set of parts must be in a common range.

For a manufacturer with an appropriate part family and volume to use an FMS, the technology offers substantial advantages over stand-alone machine tools. In an ideal FMS arrangement, the company's expensive machine tools are working at near full capacity. Turn around time for manufacture of a part is reduced dramatically, and computer simulations of the FMS helps determine optimal routing paths. Most systems have some redundancy in processing capabilities and thus can automatically reroute parts around a machine tool that is down. Because of these time savings, work-in-process inventory can be drastically reduced. The company can also decrease its inventory of finished parts, since it can rely on FMS to produce needed parts on demand.

Finally, FMS can reduce the "economic order quantity" for a given part, the batch size necessary to justify set up costs. When a part has been produced once on an FMS, set up costs for later batches are minimal because process plants are already established and stored in memory, and materials handling is automatic. If an FMS could theoretically produce one part batch almost as cheaply as it could produce 1000 in cost per unit, in practice there are unavoidable set up costs for a part, and a one-part batch is uneconomical. Nevertheless, the FMS's capability to lower the economic order of quantity is particularly useful in an economy in which manufacturers perceive an increased demand for product customization and smaller batch size. FMS is mainly used for drilling, milling, testing, storage-and-retrieval.

The chief problems related to FMS arise from its complexity and cost. Several months and even years of planning are needed for such a system, and installing and maintaining an FMS is likely to require a higher degree of technical expertise than manufacturers may have available. Finally, because FMS is a system of interdependant tools, reliability problems tend to magnify.

3. TECHNOLOGICAL ISSUES, PRESENT SITUATION AND TRENDS OF THE PRODUCTS UNDER ANALYSIS

3.1 Technological issues : present situation and trends

While the possibilities for application of existing programmable automation tools are extensive, the technologies continue to develop rapidly. There are five themes in the directions for development in each of the technologies. They are :

- increasing the power of the technologies, i.e. their speed, accuracy, reliability and efficiency ;
- increasing their versability, the range of problems to which the technologies can be applied ;
- increasing the ease of use, so that they require less operator time and training, can perform more complex operations and can be adapted to new applications more quickly ;
- increasing what is commonly called the intelligence of the systems, so that they can offer advice to the operator and respond to complex situations in the manufacturing environment ; and
- increasing the case of integration of programmable automation devices so that they can be comprehensively coordinated and their data bases intimately linked.

3.1.1 NC machine tools

Although machine tools are a well established technology, there continues to be a need for substantial improvements in the tools and their controllers. Table I lists improvements thought necessary :

Table 1. Technological improvements necessary in machine tools and their controllers

Area of improvement	Hardware (H) or software (S) Development	Objective
Toolsetting	H/S	Reduce setup time, improve accuracy
Diagnostics and sensors	H/S	Allow more of the important parameters to be sensed and monitored for failure indentification.
Fixturing/clamping	H	More versatility of fixture and less setup time.
NC programing and instruction	S	Develop improved new computer subroutines to simplify and reduce time for programing.
Programmable controls	H	Integrate machine processes into computerized system ; enhance conventional machine operations ; provide interfacing devices and flexibility.
Interface standards	H/S	Improve upgrading and growth-retrofit potential ; interchangeablity.

Source : Machine Tool Task Force - Technology of Machine Tools, October 1980.

Many of the development needs for machine tools involve devices which facilitate the use of the tools under computerized control. For example, chip removal -disposal of metal shavings that accumulate in large volume during machining- is a big problem in industry, a problem that gets bigger as machine get more efficient and automated. Though various and more or less successful, schemes have been used for chip control and disposal, many engineers believe the answer is not to create the chips in the first place, for instance by forging the part close to its final shape or machining with lasers instead of cutting tools. While "near net shape" forging is becoming more prevalent, laser machining is just emerging.

Another problem in machine tool is tool wear. A drill bit or grinding wheel has a fixed useful life, after which the quality of cut begins to decline and the tool eventually fails. The traditional solution to tool wear is simply for an experienced machinist to listen to the machine tool, and ideally, sense when noise and vibrations become abnormal. In situations where that is not possible, particularly on CNC machine tools some machinists replace the tool after a specified period of tool life; others run their machines at slower speeds in order to minimize tool failure during unmanned machining. However, tools can fail at almost any point in their use : a drill bit may fail after it only drills a few holes, or it may last for hours. This variability makes prescheduled replacement difficult and inefficient. There has been some progress in developping devices that can sense tool wear and report when tool change is needed : some devices listen to the vibrations produced by the tool and can be taught to recognize abnormal vibrations.

The rate at which a machine tool can cut metal depends on many factors : the type of metal, the depth of cut, the condition of the tool and so forth. Controlling the speed of cut or the feed rate so as to cut metal at optimum removal rates has been a continuing research and development problem in the industry. As with sensing tool wear, the traditional answer has been for experienced machinists to adjust a cutting speed or feed rate dial on the machine. Also, various "adaptive control" devices have been developped which vary the "speeds and feeds" of the machine tool based on motor load, for instance.

Finally, a great deal of effort is now being devoted to increasing precision in machine tool : a long term goal for machine tool technology involves measurements of parts during machining. With such a scheme, quality problems could be identified and corrected during manufacturing rather than afterwards.

There is also a continuing demand for and research on simplifying programming of NC achine tools ; the same holds true for the need to simplify and set standards for interfaces, between machine tools and their control system, between machine tools, and between machine tools and other automation devices. A critical issue is the development of effective interfaces between CNC machines and other computerized devices, so that, for example, CNC machines can derive their cutting instructions from the stored dimensions of a design produced with CAD ; this is now possible but has to be developped.

3.1.2 Computer aided design - CAD

So far the first generation of CAD equipment has been the 2 D computerized drafting systems which streamline the process of drawing and, especially, editing the drawings of parts, plans and bleueprints ; the second generation are 3D CAD systems which allow the user to draw an image of a part using either wireframe models or "surfacing" i.e. displaying the surfaces of objects.

The third generation commercially available within the past few years, are the so-called solid modelers. Such systems -actually an expanded 3 D capability- can be used not only to draw an object in three dimensions but also to obtain a realistic vizualisation of the part. Users can rotate, move and view the part from any angle, with all hidden lines removed, and in same cases, derive performance characteristics. Because the system "constructs" a sophisticated solid model of an object, it can be used to vizualise such design issues as component clearance problems, or to "pull out a drawer" to make sure it does not hit a cable, for instance.

There seems to be three related themes in current CAD research work :

- improving algorithms : Representing shapes in computer memory and manipulating power and complexity of CAD systems increase, their computing needs grow rapidly. Nevertheless, generating an image of an irregular part from a different viewing angle takes one minute of computer processing time. Although the system is still useful, clearly quicker response is needed for the designer to have optimal flexibility from a CAD system : a shorter response time can come from a faster computer or from more efficient way of representing and manipulating shapes in computer memory. One scheme called "constructive solid geometry" involves assembling images by combining simple shapes, such as blocks, cylinders and spheres. The other is boundary representation, in which an object is constructed as a set of individual surfaces. In another one the designer manipulates on the screen the equivalents of thin metal strips used in models of boats or planes ; he or she can expand them, cut them, curve them, and so forth to create a model.

- adding "intelligence" to CAD. In the industry there is much discussion of "smart" CAD systems which would not permit certain operator errors. For example, they would not permit the design of an object that could not be manufactured : a case without a handle or a faulty printed circuit board. Further, they would facilitate the designer's work by such functions as comparing a design to existing designs for similar objects, and storing data on standard dimensions and design sub-units such as standard shapes. Such systems might also increase the ability of CAD system to simulate the performance of products. There is much concern over "bad design" in industry, and intelligent CAD systems are considered one way to improve the situation. Some researchers feel it will be possible to use an "expert" system (see Artificial Intelligence section) for developing a "smart" CAD system.

- CAD as part of computer integrated manufacture. This area of research is mentioned for the record, because full integration of computer aided design to other computerized systems in a factory still seems at least a decade off, all the more as movement toward design-manufacturing connections is impeded by a strong tradition of separatism among design engineers and manufacturing engineers. However such connections would mean that design information could be forwarded directly to machine tools that make the part, that designers could draw on previous designs as well as data on their performance and cost, and that designers would have up-to-date information on the manufacturability and cost of their design.

3.1.3 Industrial robots

In part because robotics is a complex and interdisciplinary technology, there are many discrete areas of research and possible directions for extension of capabilities:

- improved positioning accuracy for the robot's wrist : increased accuracy and repeatability are essential for many applications, particularly in assembly operations and other cases where a robot is programmed offline. Though the traditional answer has been to increase the stifness and mechanical precision of the mechanical structure, such approaches can greatly increase the weight and cost of the unit. Software calibration, which is new technique only used by the most advanced IR manufacturers, involves adjusting the robot control parameters of its kinematic model to compensate for inaccuracies in its movements.

  Also new types of electric actuators are emerging which, due to their improved power /mass ratio, give the robot better capabilities. The "direct drive motors" need no reduction gears to be connected to the rotating elements of the robot mechanical structure. The so-called "brushless DC motors" are actually alternating current motors that, through a sophisticated electronic control circuitry, can be controlled in the same easy way DC motors are usually controled, but their use is not handicapped by the drawbacks of ordinary DC motors used in servomechanisms.

- increased "grace, dexterity and speed". The physical structure of the robot-its material, actuators, and joints- is about to change. Work on lighter structures are likely to lead to the use of composite fibre materials (similar to those now used extensively on aerocraft) whose density is one-sixth of that of steel. Another direction for progress in robot structures includes fundamentally different designs for the structure : a Swedish manufacturer has developed a structure in some ways like a human spinal column ; another one has developed a pendular robot whose mechanical structure includes a universal joint pivoting subassmbly which allows the end effector to be moved at a high speed.

  Cost is not the only drawback to the use of lighter structural materials ; in addition, the robots's controller must become more sophistacated in order to direct the motions of a lightweight and inherently somewhat flexible structure. For instance, computer scientists and mathematicians must develop control algorithms that will prevent backlash or vibrations that occur when the end effector is moved quickly from one position to another.

  Finally, end effector design needs to be made more efficient and the use of automatic end effector changes must expend to give the robot more flexibility.

- software methods for programming robots are becoming easier and more efficient ; the trend is towards more "user-friendly" and interactive high level languages which could suit every brand of robot.

  At the same time, teaching-by-guiding programming is becoming less practical for complex applications : it delays production and has very limited capabilities for editing the program or using sensory information. CAD programming is becoming the most suitable way of programming robots ; indeed, as their is still much progress to be made in human interfaces with robots, one technique for improving human-interfaces is the use of CAD to program robots and simulate their operation. The ability to visualize the robot's path may permit more effective planning and debugging of programs so that production need not be stopped in order to test a robot program. Dynamic Control is a new sophisticated and computer time demanding method of IR control which takes into account dynamic parameters (speed and acceleration) to improve the positioning accuracy of the robot.

3.1.4 Flexible manufacturing systems

FMS for the machining of prismatic parts are becoming more prevalent and are a relatively established technology. FMS for rotational parts are now available, while the range of other possible applications for FMS -grinding, sheet metal working, or assembly- are at early stages of development.

Many of the chief R and D problems for FMS involve logistics : design and layout for the FMS, and computer strategies that can handle sophisticated combinations of powerful machine tools. In addition, there is a need for more sohistication in simulation systems for the FMS so that their efficiency can be optimized.

There are a variety for enhancements to FMS hardware ; these include automatic delivery and changing of cutting tools and systems for automatic fixturing and defixturing of material to be processed. There is a trend towards the increased use of automatic guided vehicules (AGV's) in FMS. Besides the perfection of AGV's with respect to control system, speed, mobility and sensor interactions, it is likely that they will be used for carrying robots between workstations, or that, while transporting workpieces and tools, they will perform certain operations such as quality control, cleaning, etc.

Improving the reliability and versatility of material handling systems is also an important need for FMS. However, the level of sophistication of material handling technology often does not match that of other programmable automation technologies, and the automatic material handling system maybe the "weak link" of FMS.

3.1.5 Material trends

Plastics, ceramics and composites are replacing metals in a wide variety of products at an increasing rate. This trend is both complementary to and problematic for increased use of certain programmable automation devices.

These new materials technologies, on the whole, fit well into an environment of FMS. Injection molding of plastics, for instance, is by nature an automated process and adapts easily to integration with other computer-controlled devices. It is thus possible to create an FMS for plastics at least as easily as for metals (one hitch in creating an FMS for plastics is in developing dies -the metal forms into which molten plastics is injected- which are programmable or easily changed). Similar systems are also possible for producing parts from new technology "fine grain ceramics" which have strength comparable to that of metal, at a fraction of weight, are immune to corrosion, and do not have the brittle qualities that one expects from ordinary ceramics.

These trends mean that the amount of metal-removing activity is going to decrease. Thus, there is some chance that use of plastics and ceramics will eventually render obsolete some new metalcutting equipment. However, IR because of their flexibility, are less likely to be affected than machine-tools. New materials tecnnologies will reduce the amount of metalworking, but it is expected to take one or two decades for ceramics to displace a significant amount of metal working.

3.1.6 Sensors

Many programmable automation devices are limited in their capabilities because they are "unaware" of their environment ; they do not "know" what they are doing, exactly where the parts are, or whether something is wrong in the manufacturing system. This problem is especially accute when manufacturers hope to use PA devices to perform tasks normalled performed by people. A minor adjustement or observation which would be easy and obvious for a human -e.g. righting a part which arrived upside-down- is nearly impossible with most current manipulators.

Many machines have internal sensors -e.g. IR and machine tools have sensors which provide feedback on the positions and speeds of their joints- ; but here we are concerned with those sensing devices that can acquire information about the environment and can be used in conjunction with robot systems or other CAM equipment such CNC machine tools or AMH handling systems, of which they are an integral part.

There are roughly three categories of application for sensing devices :

- inspection, in which parts or products are examined and evaluated according to pre-established criteria ;
- identification or pattern recognition, in which part, products or other objects are recognized and then classified for further processings ;
- guidance and control, in which sensors provide feedback to IR's or other CAM machines on their tool environment or the state of the part under process.

The simplest sensors provide binary information, e.g. photocell, simple electrical switch, weight sensor that can indicate whether a part is or is not present.

At a moderate level of complexity, the information sensed is analogue (continuously varying) ; for example, a proximity sensor can determine the distance of an object : a popular proximity sensor used on robots calculates distance by emitting inaudible ultrasonic waves and by measuring how long they take to bounce off the closest object and return. Other devices can electromechanically sense force and torque, e.g. in a robot wrist or a machine tool spindle ; these can be used, for example, to allow a gripper to apply just enough force to a delicate object. Optical sensors can ben used to monitor the diameter of a driveshaft on a lathe, or for non contact sensing of the dimensions of hot metal as it emerges from forging processes. Most of these moderately complex sensing techniques are fairly well developed and currently used ; however there is some R and D work under way to increase their sensitivity, speed and range of applicability (development of sensors for measuring arbitrary prismatic shapes on machine tool).

At the most sophisticated end of the sensign techniques, visual and touch sensors deal with information that is not only analogue but also needs substantial processing to be useful. Of the two, vision, by far, has received the most attention, but both have begun to have practical use in the factory. Besides the problem of interpreting the pictures generated by a videocamera, this device provides only 2D characteristies ; so, often, it is necessary to use in addition to the camera either another camera or some other sensing device (light stripping, for instance) to obtain 3D information. If successful applications of current machine vision technology tend to be very specific, ad hoc solutions, often using clever tricks or manipulations of the environment, make useful applications possible and machine vision is currently a rapidly growing field. In certain specific applications, especially very tedious tasks such as inspection of electronic circuit boards, machine vision systems can out perform humans. Touch sensors based on a carbon impregnated rubber pad which changes its electrical conductivity under pressure, can send to the computer processor an "image" or "footprint" of an object being grasped ; once this image has been obtained, interpreting it involves virtually the indentical process used for vision processing. Touch sensors can also act as a slipping alarm for object carried by a robot gripper equipped with such a sensor.

3.1.7 Artificial intelligence (AI)

It would not be fair to close a subchapter on current technological issues without mentioning, at least briefly, the artificial intelligence and one of its most powerful tool, the expert system.

The purpose of AI is to design machines which can perform tasks generally regarded as requiring intelligence. It may be a key to automate parts of the manufacturing process heretofore thought to be too complex for automation.

So far, AI techniques have successfully been used for image processing (deciphering images from video cameras or touch sensors) mainly in robotics applications, where a simplified aspect of AI techniques is an important factor of the adaptive control of the IR's. Work in progress is mainly concerned by the computer processing of natural language (e.g. English as opposed to computer languages as Fortran), both written and spoken, which will allow people to give commands and communicate with computer controlled machines in every day languages when they do not have a hand free to use a keyboard ; various other uses have been proposed or such systems, from directing the motions of a IR to operating a CAD system.

Experts systems are programs which can, through a sophisticated network of rules, advise and make decisions in specific situations much as human experts would, e.g. to mimic the performance of a human mechanics, to advise designers and prevent design errors, to act as a linkage between manufacturing and design data bases.

3.1.8 Standards, interfaces and communication networks

The need for standards in both languages and interfaces is strong and consistent throughout programmable automation technologies.

Without standards it is very difficult to combine equipment of different vendors, and it is still more difficult to proceed incrementally toward a more integrated system.

The demand for standardization in languages is particularly strong from users of automation devices, because of the increased confusion and need for additional training that result from the many different programming languages.

Furthermore standards for interfaces between computerized devices will greatly facilitate integrated PA systems. The recent development of standards for "local aera networks" (LAN) helps define the hardware connections for linking devices together, as well as the "protocols" that ensure that different systems can interpret each others'messages conveyed by this data exchange systems. Such a "nerve system" must take into consideration the different levels of control and the kind of information it is necessary to communicate and also must be open to further developments of the manufacturing system.

The most efficient way to overcome this problem of data exchange is likely to follow a strict policy of implementing a well known communication system such as MAP (Manufacturing Automation Protocol).

3.2 Constraints of skill, education and training

Implementation of flexible or programmable automation in the engineering industries is not only a technical change of the production operations but also a thorough change of the mind and skill or competence of all those who participate in the process.

If strong basic skills in mathematics and science serve as the foundation for instruction for programmable automation :

- instruction for semiskilled and skilled production line workers in automated facilities must emphasize conceptual and problem-solving skills as much as motor skills,
- instruction for technician level occupations common to automated facilities must focus on the development of multiple skills (broader training) and on an understanding of how programmable equipment interfaces with other components of the manufacturing process,
- instruction for engineers who work in automated plants must emphasize a broader based knowledge of engineering operations and stronger management skills.

Experience in industrialized-countries has proved that a key ingredient in successful programmable automation instructional programs is close cooperation between industry, educators, labour and government in such areas as skill assessment, curriculum design, equipment acquisition and training of qualified instructors.

3.2.1 Training requirements for production line skills

For jobs common to production work in automated facilities there appears to be a greater need to developp the ability to apply conventional manufacturing skill in new, more conceptual ways. Operators have to learn to interact with the control panel and to monitor rather than constantly interact with the equipment. While students, especially older machinists, need to learn to use their knowledge of traditional machining operations more than they may have in the past, their knowledge of traditional machining operations will enable them to anticipate CNC machine motions and functions. Overall, electronic control of production machinery of all types is expected to reduce demand for motor skills and increase the demand for conceptuals skills.

Instruction for some technician-level occupations is quite similar in some instances to instructions for skilled trade occupations (e.g. electrician and electronic technicians), given the similarities between certain skilled trades jobs and selected technician-level jobs.But where distinctions can be drawn -e.g. for robotics, programmable equipment field service and NC part programming technicians- the focus of technician level instruction is now on the development of multiple skills (greater skills breadth) and of an understanding of how programmable equipment interfaces with other components of the manufacturing process.

Often, limited employer-provided instruction has been made available to semi-skilled and skilled production personnel beyond apprenticeship and/or entry-level training. If the plant has no formal mechanisms for delevering in-plant class-room and laboratory training to shopfloor workers, training can take the form of on-the-job training or be provided by the equipment vendors.

Production personnel responsible for equipment systems operation, and/or maintenance and repair most often receive their training from vendors of programmable equipment and systems. Through these programs, production staff, along with other types of manufacturing personnel are oriented to general equipment system features and operation. Rarely is the training designed to address the unique applications within a particular plant or facility. However some vendors offer formalized customer training courses for NC and CNC machines and IR's, but also develop instruction geared to particular customer applications and provide training design consulting services on request. Lastly some producers of programmable equipment provide informal on-the-job training to customers on an as-needed basis to supplement instruction provided at installation ; formal training programs range from 3 days to 3 weeks.

In some instances, PA related training for skilled production personnel with some previous exposure to electromechanical technology is broader in scope ; presumably these workers are graduates of apprenticeship programs and have broader skills on which to base instruction. Some organizations provide training to electricians on the installation and maintenance of programmable controller ; the training is designed to develop in enrollees who possess a background in electricity an understanding of electronics technology, which is a related but separate discipline.

It seems that, where possible, the most appropriate and efficient way is to develop at the college level, a standardized curriculum for technician-level occupations with the field of programmable automation. The advantage of the core curriculum is that it develops a broad foundation of knowledge on which to base subsequent programmable automation instruction during the same instructional period, or at a later date. So students leaving technical high school follow courses to which components for robotics, computer aided design and laser technology can be added to the core curriculum that develop interdisciplinary skills such as : electrical, electronic, mechanical, fluidal, thermal, optical and microcomputer technology. Such 2 or 3 years programs may produce technicians qualified to operate in today's automated manufacturing facilities and who can cope to future workplace change. Indeed programs that develop a broad interdisciplinary knowledge base that emphasizes computer technology and that impart a broad understanding of the system as well as its components are essential if individuals are to have the flexibility future programmable automation change in the workplace.

3.2.2 Training requirements for engineers

Design and production engineers who works in computer automated facilities are required to have a broader based knowledge of engineering operations and stronger management skills than those who work in more conventional manufacturing plants. There is also much greater emphasis placed on understanding how programmable automation may be most effectively applied. In keeping with these new skill requirements, engineering schools are placing greater emphasis on hands-on experimentation and project-oriented instruction in addition to the more traditional theory-based instruction. Engineering students are offered the opportunity for contacts with practicing engineers and with practical problems and situations in the form of industrial projects where CAD/CAM technologies are widely used.

Attempts are being made in engineering schools to familiarize design engineers with manufacturing requirements and, conversely, to familiarize production engineers with design procedures. In addition, there is more emphasis being placed on developing the ability to take the entire design-manufacturing process into account, e.g. through the system approach, which focuses on the integration of computerized systems with more traditional forms of automation. Some time students enrolled in master's program in engineering manufacturing are required to have at least one year of industrial experience.

Note that training an NC programmer up to speed may require as much as two years.

3.2.3 Training requirements for managers

Traditional engineering programs have not stressed the need for the development of management competencies, nor have traditional management education programs offered special courses geared to the needs of technical and engineering operation managers.

Now business schools are recommended not to overemphasis on finance and marketing in their curricula by giving equal weight to production processes and productivity. The need for managers of automated manufacturing facilities and other complex operations to possess an understanding of the total manufacturing system and all of its components had led some universities to create new master's degree programs in technical management. Continued industry pressure for more effective technical managers leads to greater emphasis on the development of management skills in industrial engineering and computer science programs.

As an example, the followings are included in the programme of a seminar which is a step-by-step approach to managing a CAD/CAM project :

- consideration for purchasing hardware,
- methods to ensure efficient system use to achieve maximum productivity,
- procedures for defining requirements for implementing a training programme,
- procedures for choosing proper systems applications for a particular environment, and
- procedures for establishing a data management system.

Conversely have emerged the interest in and need for technology management courses for engineers and non technical personnel employed in automated manufacturing facilities.

3.3 Infrastructure, management, planning and financing

A company which is about to decide on CNC machine tools, IR or FMS investment for the first time is confronted not only with a decision involving primarely the use of certain advanced pieces of manufacturing equipment, but rather with a policy decision concerning the long term technological, organizational and managerial structures of the firm.

The following present study refers to an FMS implementation which corresponds to the most complex situation, but the installation in a workshop of any simpler PA system must be conducted in a similar way making due allowances.

3.3.1 Implementing an FMS : a major strategic decision

The designing and installation of a FMS is a lengtly -one or two years- and complicated process requiring not only multidisciplinary skills and financial ressources, but also a new way of thinking as regards the management and the production.

The decision to implement an FMS must enclose an investment plan which includes all requirements, including the cost of the training process as well as that of the plant building or rebuilding. The ressources needed for developing new skills, reorganizing production departments and introducing the FMS way of thinking should, however, be subject to depreciation not only in connection with the first FMS investment, but as regards all subsequent ones. Implementing an FMS represents a major strategic decision, which, if successful, will enhance the company's capability of meeting increased competition.

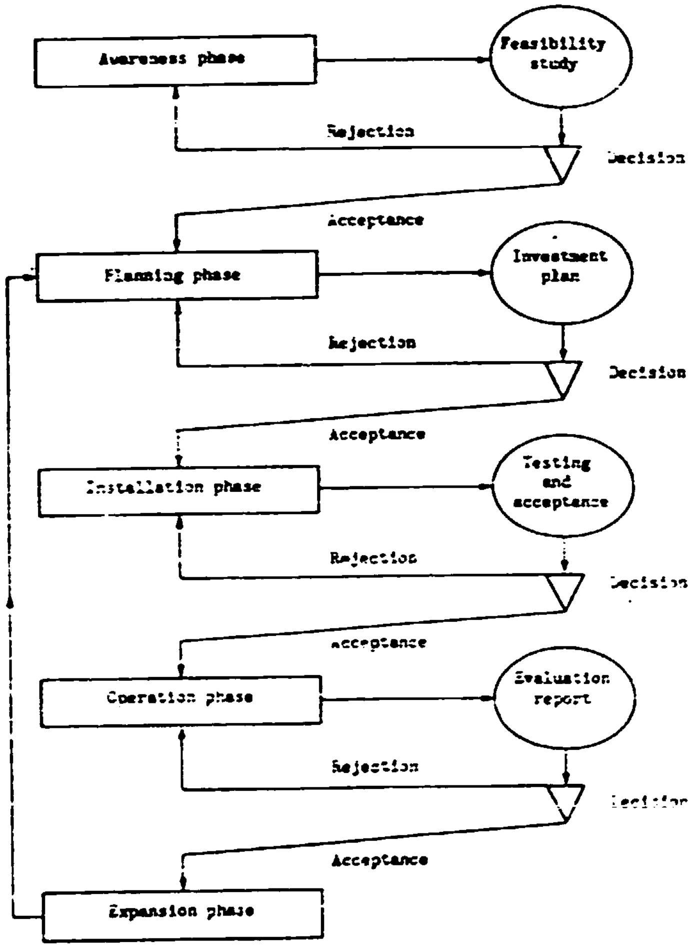
Having decided to go ahead with an FMS investment, the company should be aware that there are significant potential benefits to be reaped provided that certain preconditions are fulfilled and that, at the same time, it is exposing itself to considerable technical and commercial risks. Any delay in the implementation of the system -and delays are generally the rule rather than the exception- or if the system does not operate as efficiently as anticipated, would result in serious disturbances in the whole production system, leading to reduced revenues and possibly even financial difficulties : an FMS investment represents a major capital outlay, and at worst the survival of the company may be at stake.

Another type of risk has to do with the level of market demand and the resulting degree of utilization of the system. Normally, an FMS must run at least a two-shift operation in order for the investment to be paid back within the two or three year period expected by the management. As profitability of FMS is very sensitive to variations in the degree of utilization, any slackening in market demand could lead to an under-utilization of the system, and give rise to serious financial problems.

The more all the technical, productional, organizational and managerial problems -and not all of them will not be anticipated- are forseen and solved before the system is designed and installed, the more the chances of the investment's success.

One or two years of feasibility studies and planning work usually precedes the decision to invest in an FMS ; moreover before the system is designed, developed, assembled, tested and finally put into full operation, another one or two years has usually elapsed, depending on the complexity of the system and its application as well as the experience of the usier and of the supplier. The process of implementing an FMS is thus very protracted ; it can be broken down into five phases, each leading up to a result on which a decision is based. The process of implementing stand -alone CNC machine tools or IR's is not so long, two to four months- but the sequential phases and decisions are the same. Table II illustrates these implementation phases.

Table II. The phases of implementing an FMS



Source: ECE secretariat.

The awareness phase starts when someone in the company takes the initiative of investigating the possibility of applying FMS. In this phase information is collected from various sources, such as technical journals, relevant courses and symposia, and visits provide opportunities of evaluating FMS in actual industrial operation -in contrast to the design schemes of supplies and limited demonstrations at exhibitions- and, above all, of hearing the experiments of users having first-hand knowledge of the problems involved in implementing an FMS.

Of course the start of this awareness phase depends to a large extent on the general policy of the company in promoting new technology and encouraging its employees to investigate technological alternatives in the production system.

At the end of this awareness phase, some form of feasibility study containing a project proposal is submitted to the appropriate decision-makers at the company. If this project proposal is accepted, the planning phase follows.

3.3.2 The planning phase

In the course of this planning phase several technical, economic, organizational and managerial issues must be identified, analyzed and dealt with ; many of the issues must be solved simultaneously and often the solutions must be continuously revised during the whole planning phase.

a) Appointment of a project team and a project manager responsible for the planning and the eventual installation of the FMS ; funds should be allocated to the project organization from a budget set up for the planning phase. The project team should include systems engineers and also production managers, operators and maintenance personnel and make close liaison with representatives of other departments in the company to ensure a smooth integration of the FMS. Consultations with possible contractors prove to be helpful during this early stage of implementation.

b) Definition of technical and economic objectives and analysis of their relation to an overall long-term FMS strategy for the company : as a decision to invest in FMS is one of strategy, it is essential to ensure the involvement and full support of top management which should regard FMS as a fundamental part of the corporate strategy. This commitment of the management involves its recognition of the importance of starting the training of all personnel.

   One important task when defining the technical and economic objectives of the project is to ascertain carefully whether there is really a need for a full FMS or whether an smaller size version fo FMS, for instance a flexible manufacturing cell, FMC (1) or a flexible manufacturing unit FMU (2), would suffice to begin with ; a thorough assessment of the needs on the one hand and of the complexity of an FMS on the other hand should be done carefully.

1/ FMC : comprises two or more machines, usually at least one machining centre or turning centre, multi-pallet magazines and automatic pallet and tool changers for each machine. All machines, as well as the operations carried out by the cell, are controlled by a DNC computer.

2/ FMU : is a one-machine system, usually a machining centre or turning centre, equipped with a multi-pallet magazine, an automatic pallet changer or robot and an automatic tool changing devices. The unit is able to operate partly unattended.

c) Identification of parts and processes most suitable for the current FMS project as well as those which might be applied in future projects.

As regards the part families identified, the relevant manufacturing processes of both the old and the new systems must be analysed with respect to a large number of variables : machines and equipment to be used, cycle times, lead times (1), the routing of parts, tools and fixtures, the order or process sequences, the number of set-ups of parts and tools, and the corresponding time required, the number of tools and changing devices needed.

The design of the parts to be processed by the FMS should receive careful investigation, because it is at this stage that 80 to 90 % of the components' cost is defined. Judicious changes in the design of a product and its components, with out impairing their performance and reliability, can greatly facilitate not only the machining process in FMS but also subsequent assembly operations. Furthermore the redesign of a product may also result in a reduction in the number of parts and processes required for the product, a fact which in itself might lead to considerable saving in production costs.

d) development, in co-operation with vendors having the capability of acting as main contractors, of alternative system designs with respect to machine configuration, material fixture, tool and information flow, control structure and its fundamental aspect, the software requirements.

Software is often the critical factor : it is not only the user who might lack software knowledge ; sometimes the main problem has been insufficient software knowledge on the part of the main contractor. Or the software is at a prototype stage and written for a specific application, which results in high costs when updates are required due to application alterations or where there is a need to interface a specific software module with other modules.

e) Simulation, either with small-scale models or with computer models, of alternative system design with respect to key production factors, e.g. machining arrangements, cycle time for various operations, number of set-ups required, number of fixtures, routing of parts, capacity utilization.

f) Analysis of the FMS design to achieve the system's optimal integration as a part of the existing production system that, otherwise, could become unbalanced : the production section containing the FMS might function very efficiently, while preceding and subsequent work stations formed bottle-necks. In such a situation, the FMS makes no real contribution to the production process as a whole.

A successful implementation requires prior analysis not only of the production section where it will operate but also of the whole production process : it is necessary to identify any necessary changes in the production organization with a view of obtaining balanced production : these changes might concern machine configuration, material flow, work assignments of operators, information flow etc. Often it might be necessary to establish closer production planning and technical co-operation with subcontractors delivering raw materials and components as well as customers ; in particular subcontractors might be required to follow new and more timely delivery schedules.

1/ Lead time : defined as the processing time plus the waiting time (in buffer storage at machines and during transport between machines).

Furthermore, the subcontractors are also expected to apply a production system which can be linked to that of the manufacturer who is receiving their output : for instance a component designed on a CAD system by the manufacturer should be able to be transformed into a NC program and transmitted to the subcontractor, together with other relevant production data concerning batch sizes, delivery schedules, quality, etc.

Following this policy will decrease the number of subcontractors who will to be chosen from their human and financial ressources to match the technology requrements but also from their geographical location in order to minimize transport time, and risk in deliveries : this organization complies with the just-in-time manufacturing principle.

g) Strong emphasis on efforts aimed at standardization of the products to be manufactured and their components, as well as the production system : material handling, tools, fixtures, machines and their control systems, communication systems and over-all planning and control systems. For instance, as tools are a major cost item in FMS, reducing the variety of dimensions of holes to be drilled can represent a considerable saving.

Concerning process standardization the major problem is the incompatibility of various pieces of equipment and subsystems. Companies investing in FMS for the first time can start from scratch in setting up an over-all production-information strategy ; others, with equipment purchased from various vendors at different times often as stand-alone systems, have to start anew by creating a common database system for the company and to rebuild existing control systems or to buy new ones, so that they can communicate with each other.

The most efficient way to overcome these problems of equipment compatibility is to implement a well known data exchange system or local area network such as MAP, both at the manufacturer's and its main contractors' plants.

h) Selection of vendors. Usually several vendors, each having the capability of serving as the main contractor for the whole project, are asked to analyze and bid on the project and prepare system proposals, including cost/benefit calculations. When finally selecting the vendor for the project, the following factors should be decisive, bearing in mind that years of close co-operation with the vendor is ahead :

- Will the vendor be able to act as main contractor ?
- Does the vendor have sufficient capabilities in software development, defining and developing common databases, system interfaces and system engineering ?
- Can the vendor provide standard interfaces to CAD/CAM, material requirement planning (MRP) and other systems supplied by the others vendors ?
- Will the vendor ensure compatibility between the system he designs to day and those implemented subsequently ?
- Is the vendor able to provide sufficient operating support (during the initial period of operation) and maintenance ?
- Does the system design proposed by the vendor include the use of some of the machines already in existence at the user's site ?
- What degree of reliability of the whole system can the vendor assure ?
- Does the FMS "philosophy" of the vendor coincide with that of the customer company ? Is his approach part-oriented as that of the user, or machine-oriented, if he is a machine tool producer ?

- What is the competence of the vendor's project team and how this team is likely to cooperate with the in-house project team ? A mutual knowledge transfer between the two project teams is essential ; and
- What are the capabilities and promptness of service, maintenance and trouble-shooting on the part of the vendor ?

i) Manpower and skill requirement is probably the main critical factor in the implementation of FMS. Some compagnies do not have sufficient skills or manpower ressources for the necessary project management, installation, operation and maintenance. The many disciplines on which FMS is based require new types of skills which should be built up long before the FMS is installed. So before adopting the FMS technology, companies should invest in far reaching training schemes involving project and installation personnel, operators, maintenance personnel and key personnel in other departments linked to the FMS production section, as well as management in order to implant the FMS way of thinking throughout the company.

The outcome of the planning phase is a project report, prepared jointly by the project team of the user and the selected vendor. Besides proposals for an investment decision, this report should contain :

- an analysis of the cost/benefit implications of an eventual FMS investment, as well as of alternative solutions,
- simulation of the economic results of the various proposals, and a risk and sensitivity analysis with respect to fluctuations in market demand,
- the proposals of the vendors, or alternatively, the main contractor,
- detailed system description,
- specifications of necessary changes in product design, in production organization and in the over-all production system,
- specification of requirements as regards skill and financial ressources,
- proposals concerning the financing of the FMS, including a cash-flow analysis,
- a detailed timetable for the development and installation of the system.

One must keep in mind that most of the problems that might appear during the installation or the operation of FMS can be traced back to the planning phase. The planning phase ends with a management decision to go ahead with the investment, to continue planning or to stop all further preparation.

3.3.3 The installation phase

A purchase contract for the system is signed with the selected vendor, followed by the start of development work for the various components of the system, and, eventually, the final assembly of the system at the user's site.

There are several tasks for which the user normally takes main responsibilities :

- rebuilding of the plant or workshop to accomodate the FMS : floor reinforced, adequate wiring installed, electricity expanded, etc;
- reconfiguration fo machines, material handling and information flow in other departments of the plant, and perhaps a change of the total production organization ;
- design and development of certain peripherals to the system, purchase of tools and utilities for the system ;
- preparation of a plan for the production stoppage which is normally unvoidable during the physical installation of the system which has to be scheduled to take place during a vacation period ;
- preparation of a testing and acceptance protocol for the system ;

- preparation of operation schedules to be applied when the system goes into operation ;
- implementation of previously planned training schemes adapted to various catagories of personnel ;
- readiness to tackle the unexpected : for instance departure of one or several key persons from either the user company or the vendor, delays in equipment delivery and testing as well as software avaibility, etc.

Software developments deserve special attention owing to the fact that delays and malfunctions can often be traced to this area. Normally system software, including databases as well as utility programs, is developed and supplied by the vendor on the user's specifications. When it comes to part program for part families which have been identified to be processed in the FMS, the responsibility is disbrituted between user and vendor, but a sufficient number of part programs should be developed, tested, debugged and approved before the system is installed, and when the system is scheduled to go into operation, all part programs should be ready and accepted otherwise the profitability of the investment would be greatly reduced.

If the user has contracted the vendor to do the part programming, the system should not be accepted, no matter how well it operates, before the part programs have been accepted.

The final step of the installation phase consists of testing, normally including some form of pilot production, and a decision of acceptance on the part of the user.

3.3.4 The operation phase

The relationship between the user and the vendors continues : usually agreements have been made concerning service and maintenance, further training, some form of operation support, and may be also a feasibility study covering possible future expansion of the system.

During the first part of the operation phase adjustements are made in the system : the time required to reach the stage of full operation varies between one to six months.

For the continuous techno-economic monitoring and evaluation of the system a scheme should be set up to collect data concerning :

- the operation rate for the whole system as well as its warious subsystems in order to find out whether the system is optimally balanced : inefficient routing of parts, process sequences etc. can keep some machines too often idle ;
- lead time and cycle times ;
- machine process time, time for set-ups and tooling ;
- batch sizes and number of batches ;
- number, time and causes of stoppages or breakdowns ;
- product quality ;
- maintenance operations ;
- unplanned human interventions in order to solve process problems ;
- production costs, broken down in the greatest possible detail, for the system itself and also for the whole production system ;
- revenues resulting from FMS ;

When the system has been in operation for a period of one or two years, an evaluation report should be presented to management, this report should contain :

- an account of the result obtained, concerning the variables mentioned above, for the first operation period ;

- a comparison with the ex-ante techno-economic evaluation made during the planning phase and an analysis of causes of eventual deviations, and
- a forecast of future operation periods.

An evaluation report is essential whatever the appraisal of the system operation might be ; it is the basis for decisions concerning :

- future extension of the system, as well as investments in new systems ;
- the diffusion of FMS experience throughout all departments and plants in the entreprise ;
- action to be taken to overcome problems or deviations from plans occuring during the first operation phase.

3.3.5 Financing

(a) Justification of investments

In the past, production rationalization was focused mainly on the reduction labour-per-unit cost. Beside this strong motive, the greatest potentials in investing in PA are :

- increased capital efficiency,
- flexibility in the production system,
- streamlining the production system, which operates with a high degree of utilization, while, at the same time, producing goods in the right amount and at the right time for a constantly changing market demand, and
- the synergetic effects of bringing disparate processes into an integrated system.

The economic return on a PA system comprises the aggregated benefits derived from a more rational use of all production ressources employed in the production process; but the major problem facing entreprises contemplating investments in PA is the quantification of these benefits and their acounting in the investment justification either in ex-ante or in ex-post evaluations.

Having recognized the importance and potentials of PA one the one hand, and the problem of its economic justification, the logical solution is to use one of the traditional methods for investment calculations, bearing in mind their relative applicability to the appraisal of PA systems.

- The pay back period method is defined as the time period needed in order to recover the original investment cost through the net profit generated by the investment.

- The return on investment method is defined as the rates of net profit during a year of full production to the total capital outlay of the investment.
  Both these methods can be used for quick management orientation when making a preliminary evaluation of competing projects but are not suitable approaches in attempting to justify the investment.

- The net present value (NPV) method is a discounted cash-flow technique. It takes into account the time value of money.

- The net-present-value method adjusted for capital utilization is an improved variant of the previous method in which the NPV is amortized over the calculated life of the investment. Its mathematical formula expresses the ratio of the average annual profit of the project to the average amount of capital tied up by the project. The result is a measure of the profitability of the project charged at the discount rate fixed by the company.

  This last method of investment calculation is mainly used in connection with large PA projects.

Concerning the application of the above methods, as many of the numerical input data inserted in the equations are estimates, the larger the period for which the calculation is made, the less precision in the estimates ; so, since PA investments are normally calculated on a long term basis, it is advisable to make both a pessimistic and an optimistic estimates of input data in order to identify those variables most critical for the outcome of the economic return. Furthermore the economic return on investments should be calculated taking into account taxes and grants where applicable.

The major shortcomings in the above methods of investment calculations, including the input data on which they are based, can be said to be :

- "the impact of the investment is limited to the immediate environment of the equipment" (1) ; since large PA projects like FMS have the capability of integrating various processes in the production system, these benefits will therefore appear in many departments of the plant ;

- "The capabilities of the equipment and technology are assumed to be well known and will not change after installation, except, eventually to decline " (2) ; the situation is usually the reverse. After some time of adjustments and experience, the operating efficiency and the gains which were not known at the beginning of the project are likely to increase as the capabilities are being realized.

- "The investment costs and benefits, i.e. savings, can typically be estimated with reasonable accuracy" (3). This does not usually apply in the appraisal of PA system investments.

(b) Costs/benefits - problems of their quantification

The various items of cost, expenditure, income and revenue originating from a PA investment can be grouped under three headings.

Total investment costs/benefits should include :

1) basic investment costs : all the equipment, spare parts, software, system engineering ; usually these costs can be estimated fairly accurately if no major changes are made after the contracts with the vendors are signed ;

1/ From "Economic justification - Counting the strategic benefits" by Abrey and Young.

2/ idem.

3/ idem.

2) project design, development and installation costs : in-house work, outside assistance (fees to consultants), changes in the plant necessary to accomodate the PA system, part programming ;

3) design and manufacture or purchase of dedicated tools (pallets, robot end effectors, etc) costs ;

4) modification costs of the design of products and their components with a view to facilitating the process carried out by the PA system ;

5) costs of methodological work and implementation of new production planning systems ;

6) costs of modifications undertaken in other departments ;

7) costs of training of the personnel -course fees, loss of revenue owing to the absence of personnel attending courses-, but not the continuous training costs ;

8) costs of rebuilding and retrofitting existing machines which are to be used in the PA system ;

9) revenues resulting from the sale of existing machines which are not to be used in the PA system ;

10) savings arising from a deferred or replacement investment should the PA system not be implemented.

Cost items 2-8 are frequently underestimated.

Operating expenditures and incomes relating to input factors should include :

11) labour cost savings : direct and indirected labour costs in the department where the PA system is installed and in the other departments which are linked to the PA system. Evaluation of labour savings should not be based only on the first years of operation but also on the following years, when full rationalization potential is attained ;

12) reduction of capital tied up in inventories (raw material, intermediate goods and finished goods) and in work-in-progress ; lead time can be reduced drastically by PA system ;

13) materials : in those companies where, owing to far-reaching rationalization, labour input had been reduced to a minimum, material costs account for 40-60% of the output value of companies and should be given special attention. PA system, and mainly FMS has the potential of reducing direct material costs through :

. higher yield from input material : stock entry and pre-machining inspections, preferally computer aided, can detect defective input material ; higher yield for a given sheet of metal can be reached through CAD and CAP (computer aided planning) systems ;

. higher product quality following a reduction in the nomber of defective parts and products being manufactured ; a defective part gives rise to losses corresponding to the value added. The later in the manufacturing process the defect arises, the greater the loss -a loss whose value must be added to over-all production costs and, hence, to the prices of the output of non-defective goods ; and

. a reduction of material overhead and other indirect costs relating to materials : a defective part or product has to be replaced which leads to additional costs for administrative work and causes disruption in the production process ;

14) factory supplies such as maintenance materials, lubricating oils, grease cleaning material and tools -the latter being and important cost item when appraising PA systems. By means of computer controlled optimum cutting speeds and tool monitoring systems, tool life can be extended and thereby tooling costs reduced ;

15) utilities, such as electricity, water, fuel, effluent disposal etc ; some savings in electricity consumption result from a better ratio of processing time to operation time ;

16) floor space : PA systems require substantially less floor space than traditional machinery ;

17) maintenance : even though PA systems include sophisticated diagnostic subsystems, the total maintenance costs will increase when compared with conventional systems ;

18) continuous training of personnel whose know-how must be expanded, results in higher expenditures when compared with conventional systems ;

19) working conditions : besides social and human considerations, improvement of working conditions is motivated also by economic considerations ; poor working conditions often lead to a high degree of labour production distrubances and increased costs for the recruitement and training of new personnel. Furthermore, since PA systems require less manpower, the remaining operators are more than ever key operators ; so the psychological working conditions -motivation of the labour force- are as necessary as the physical working conditions ;

20) flexibility : although flexibility is one of the major motives for investing in PA systems, it is difficult to appraise its benefits in quantitative terms. Some of the benefits are credited in the calculated savings resulting from lower capital costs of inventory ; but it whould be wise to take into account of the avantages of having a manufacturing system which can rapidely respond to changes in market demand.

In accounting in an investment appraisal for the considerable but unquantifiable synergetic effects of PA systems, the savings realized from extending the calculation period can be taken as a proxy for the above mentioned synergetics effects because this would lead to lower annual average capital costs.

Companies should apply cost and accounting systems which not only give a more accurate basis for investment appraisal, thus reducing the associated risks, but also provide an important tool for monitoring the effectiveness of production. A wide range of computer-aided tools are now available, not only for the rationalization of various process activities but also the monitoring of variables (e.g. costs, time required, etc) determining the efficiency of these processes.

Deficiencies in cost accounting systems and difficulties in quantifying many of the benefits of PA systems give rise to a rather high degree of incertainty in ex-ante investment calculations. It is therefore essential that PA systems be evaluated at regular intervals and compared with the ex-ante assumptions, in particular with respect to those benefits which have been stated in qualitative terms.

3.4 Relationships between the production of the metalworking industry and the new technological developments

So far this report has explained how :

- on a technical point of view, the advent of programmable automation techniques in the engineering industry has now lead to a more flexible use of the production machinery for producing goods of a high and steady quality ;

- on an economic point of view, while mechanization was mainly concerned with the decrease of labour cost per produced unit, computer controlled automation is aimed at reducing all items that make up total production cost, i.e. :

  - reduction of labour cost per unit of production ;
  - reduction of capital cost through a higher degree of machine as well as plant utilization ;
  - saving in energy and raw material ;
  - faster product development, and
  - higher and more even quality of products.

The current technological trends in the industrialized countries in the production of the following engineering products :

machine tools, electric power equipment, diesel engines, accessories and spare parts to the automotive industry,

can be summarized as optimization and standardization of both the tools and the products as well as a growing utilization of new non-metalic meterials.

3.4.1 Machine tools

- In the machine tool industry one can note two main trends :

  - firstly more than 60 % of all machine tools built are NC controlled, whatever may be their function and their degree of sophistication,

  - secondly the tendency is to build the so called flexible special transfer machines or FMC with several working stations for simultaneous and consecutive different machining operations : each station is equipped with automatic tool changing systems, manipulating devices and testing systems so that different parts can be machined simultaneously. Operational optimization is reached as a consequence of the concentration of the machining operations at the same working site and of the drastic decrease of transfer times between the working stations. Such machines will soon be commonly used in the automotive industry where, for instance, cylinder heads, connecting rods and cylinder blocks can be machined by the same special cell which has a high and flexible output capacity. Of course all programs are CAD/CAM prepared and the production is CAM controlled and managed.

3.4.2 Electric power equipment

. For the last decade most of the electric power equipment (generators and transformers) used to generate and distribute the electric current has been designed through CAD systems in order to optimize their performance and their manufacture : for those mass or batch produced electric apparatus, namely medium and low power generators, transformers, circuit breakers, contactors -CAM techniques and mainly machining NC machine tools are widely used.

Electrotechnics attained its highest technical level some twenty years ago, and no breakthrough is expected for the next decade, especially after the hopes arisen by researches on supra-conductivity failed to result in industrial products.

In the electric equipment field, the current trend is to provide a function more than only a piece of equipment, e.g. not a motor alone, but a whole assembly including both the rotating machine and its electronic control circuitry -variable speed drive, for instance- which is often very sophisticated and whose cost price is growing as an important part of the total cost.

Furthermore, mains distribution networks, at least the smaller ones, are microprocessor controlled.

3.4.3 Diesel engines

. In the diesel engines fabrication there are two main trends :

- firstly all main parts -namely cylinder blocks, cylinder heads, crankshafts, connecting rods, pistons and rings, water and oil pumps- are CAD designed for optimization ;

- secondly the trend is to use new materials, such as ceremics for parts working at high temperature inside the combustion chamber. Indeed the excellent high temperature stability and heat insulating characteristics of ceramic materials -mainly titanium nitride based ceramic- give these parts great durability especially in engines working in hard conditions. The last years have brought dramatic improvements in ceramic composition, and processing technologies such as shape forming, sintering machining, ceramic-to-metal joining have been developed. Nevertheless, to day, ceramic parts are more expensive than metal parts but their use will be felt necessary for heavy duty engines ; furthermore some traditional machining operations, such as grinding, water jet or laser cutting, have to be adapted accordingly.

3.4.4 Spare parts for the automotive industry

. Due to the high cost of their development and testing operations, automotive accessories and spare parts are common to two or more car makers. Whatever may be the material -metal or plastic or composite fibres- used, these parts and accessories are usually CAD designed by the car makers and CAM manufactured by one or more subcontractors. Because of their excellent mechanical characteristics, their lightness and their cost price, composite materials are now widely and often exclusively used for bumpers, dashboards, front seat frames, steering wheels, etc. These parts are manufactured through extrusion or molding; their machining requires specially adapted tools.

Besides the traditional electrical equipment (head lamps, alternators, windscreen wiper motors, etc), another trend is the ever wider use of electronic subassemblies, often microprocessor controlled, such as fuel injection, electronic ignition, automatic transmission systems ; more and more of these subassemblies, as well as electronic cloks, electrical motors for windowglasses, electromagnetic door locking devices are now more or less automatically manufactured.

3.5 Final remarks

The manufacture of all the above products highlights the need for organized systematic use of CAD techniques for their optimum design. Optimum refers both to their functionality and lower cost price. Standardization of these products can be considered as a consequence of their CAD/CAM fabrication and of the use of data-bases which will reduce development and time costs for different models of a same basic product. And a special consideration should be given to the consequences of the growing use of non-metallic parts in the engineering industry.

As shown so far, and due to their powerful characteristics, the new technologies of programmable automation are quite fit for their use in well-known industrial sectors, such as manufacture of capital goods, electric power generation and distribution equipment and means of transport, all the more since some developing countries have already the necessary industrial structures and the technical mastery of these processes in their traditional ways. However the modernization and optimization of yield of these industrial means should not be considered as a finality: they are an efficient way to attain proficiency in the handling of these techniques, and they should be thought of as a training phase.

Indeed according to the international environmental evolutions and to the national industrial policies chosen, the know-how and experience acquired in programmable automation will prove a valuable asset to developing countries in the development of other diversified industrial activities such as, for example, consumer goods and home appliances, electronics (for telephone and data exchanges), bio- and agricultural techniques, chemical products, textiles, etc.

Expertise in programmable automation can be regarded as a passport to any type of optimized and well managed production.

4. FORMULATION OF STRATEGIC OPTIONS AND INDUSTRIAL POLICIES TO FACILITATE THE INTRODUCTION AND APPLICATION OF INDUSTRIAL AUTOMATION IN DEVELOPING COUNTRIES

The new wave of industrial automation, the technologies and general economic and social effects which have been analyzed in previous sections, received in the industrialized countries a mixed welcome. Indeed, industrial automation is viewed both as contributing to the problems faced by the economies and as part of the solution to some problems.

Industrial automation is a reality to day : an increasing number of firms and research laboratories are more and more deeply concerned and involved in industrial automation supply. Most of the industrialized nations support the development of PA to some extent and more and more manufacturing firms, in the current climate of international competition, plan to invest in PA or still automate their production. Therefore, markets for PA are strongly international, and various forms of interfirm cooperation blur distinctions among firms by nationality.

Regarding this general trend, involving industrial and economic strengths which show themselves directly on the international scene, any PA technologies benefits and risks appraisal and any appropriate policies determination should take into account the PA international framework.

This statement does not mean, there is no room for national or regional initiative ; but, if the distinctive cultural, social, political and economic characteristics of each nation shape its policies, the formulation of such an initiative must consider the international context of PA.

Therefore, before formulating strategic options and industrial policies to facilitate the introduction and application of industrial automation in developing countries, the main features of PA markets in the industrialized countries are explained.

4.1 PA in the industrialized countries

The purpose of this section is neither to write down the current history of PA since the beginning of the sixties, nor to analyze for itself the development of PA in the industrialized countries. But as mentioned previously, at least two reasons justify to bear some attention to the situation of PA in the industrialized countries :

. Firstly, the PA markets are strongly international ;

. Secondly, any expert emphasizes PA technologies contribution to economic growth and greater employment by making domestic manufacturing more efficient and competitive. Nevertheless, the complete economic benefit achievement of PA requires deep changes in production organization, work structure, managerial methods. And the experience of the industrialized countries is to some extent a first relevant basis for specific proposals.

Therefore, the three following points are developed:

- The main features of the PA economy are considered and four PA firms strategies patterns are pointed out ;

- The analysis shows that, in spite of large PA markets growth forecasts, PA diffusion through manufacturing industry follows a rather slow pace. The main reason for such a paradoxical situation consists of neglecting PA impacts on work environment ;

- Public initiatives and national programmes, dedicated to those various fields, set up by the industrialized countries are analyzed. Main impacts of PA on manufacturing processes are listed and developed.

4.1.1 The industrial economy of PA : the case of robotics

CAD, IR, NC machine tools, flexible manufacturing systems, and other PA equipment and systems are supplied by industries that are currently more or less separate. Of the principal PA industries, the NC industry is the oldest and largest, dating from the 1950s ; significant markets for these technologies did not emerge until the 1970s. But a separate PA system market does not exist. No one yet sells PA systems as a total product nor has any vendor fully implemented computer integrated manufacture systems.

The PA supply among myriad firms of different types and sizes may even impede development of a PA system market, especially in the absence of standard equipment and interfaces. This feature should suppose to analyze each market. Assuming information and reports on the machine tool industry is easily available, and the main concern is manufacturing, only the robotics industry in under consideration.

At the end of 1984, four main trends could be pointed out :

. hastening technological improvement ;
. opening of US and European markets ;
. beginning of IR mass production ;
. launch of price competition.

In 1987, these trends are strengthening :

(a) Price competition : a static warfare. IR average prices are presently slowering. On the US market, the IR average price was in 1985 of US$ 51,700 vs US$ 64,430 in 1984. Three facts explain this first trend:

. increase of low cost light robotics share ;
. launch of new low-cost designed IR ;

. suppliers price strategies oriented more to maintain prices in nominal money than to drastically cut them down.

The price competition did not happen because :

. suppliers, after losing lots of money in 1981 and 1982, prefer to strengthen their profit margins ;
. competition occurs more in the field of commercial networks and post-sales services, than in that of prices ;
. yen revalorization prevents aggressive price strategies from Japanese suppliers.

Nevertheless, with the development of IR mass production, price custs in the near future are likely.

(b) IR manufacturing : from craft methods to automated production. If the 1986 low market profile postponed IR suppliers investments, automated IR manufacturing remains a deep trend : longer production ranges, production equipment flexibility allowing manufacturing automation for medium ranges and necessary production cost lowering aim at the emergence of this trend.

(c) World-wide markets. Since 1982, every month new commercial and/or industrial agreements are announced. Licensing, outsourcing, mergers, and takeovers, limited equity investments and joint ventures are common, and usually occur between firms from different countries. For instance, in 1983, General Motors, the first US automaker, launched with FANUC, the first NC equipment manufacturing company in the world ; this joint venture, GMF Robotics, is to day the leader on the US market. IBM settled down an agreement with a Japanese IR manufacturer to market Japanese IR mechanical structures controlled by IBM built control units. Lastly, in the medium term, international cross-fertilization may abate in favor of direct foreign investment.

(d) Technological evolution. More and more innovations, designed in research laboratories, are now industrialized. Nevertheless, their diffusion remains very slow. Off-line programming, high level languages, local area networks consist only of 1 % of new PA applications.

Despite sluggish end-user markets, suppliers R and D effort is consistent and even increasing : the average R and D rate is over 10 % of turnover. And the technological competition remains sharp and relates to :

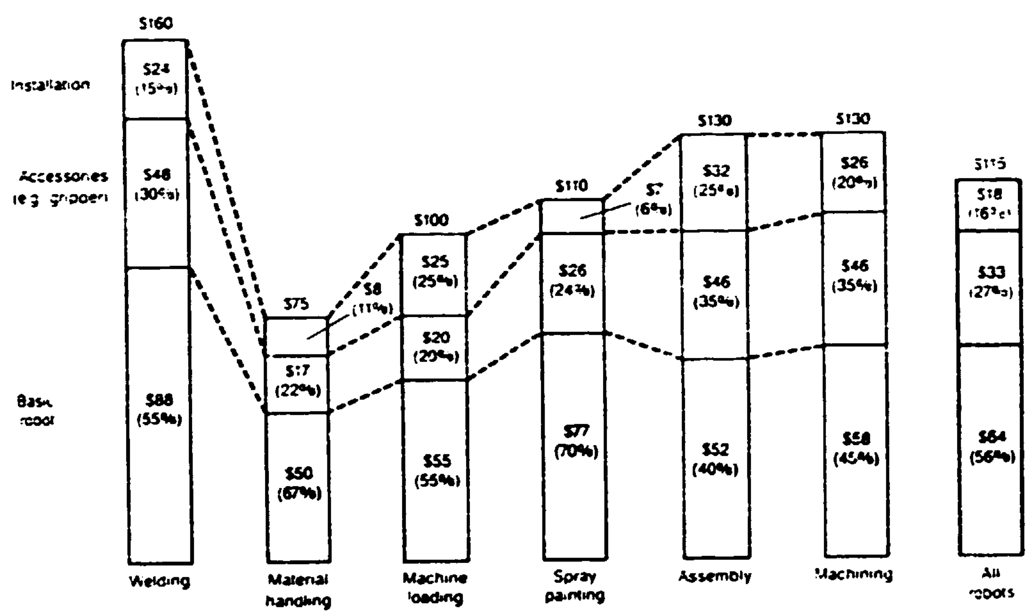
. the establishment of a high level language standard ; for instance, IBM promotes its standard, called AML2, and GMF, KAREL, another high level language ;
. the design of new programmable controllers ;

. the compatibility with the communication interface network, called MAP (Manufacturing Automation Protocol) proposed by General Motors.

(e) <u>Increasing role of "system houses"</u>. For both simple and complex applications, pre- and post-sale support and service are increasingly considered essential by both vendors and users. One indicator that service and support have been inadequate is the fact that buyers occasionally abandoned robots, a situation that did not occur with CAD systems and other types of programmable automation.

A lot of pre-sale support planning, training, facilities preparation, etc., are often needed for a couple of reasons : IR has yet to be viewed as the only alternative for certain tools ; and there are no single, correct approaches of applying robots in given situation. Because IR technology is still developing, and because users often adopt their first IR as a preliminary to broader process changes, post-sale support -software updates, service contracts- is also important. Table III illustrates the cost breakdown.

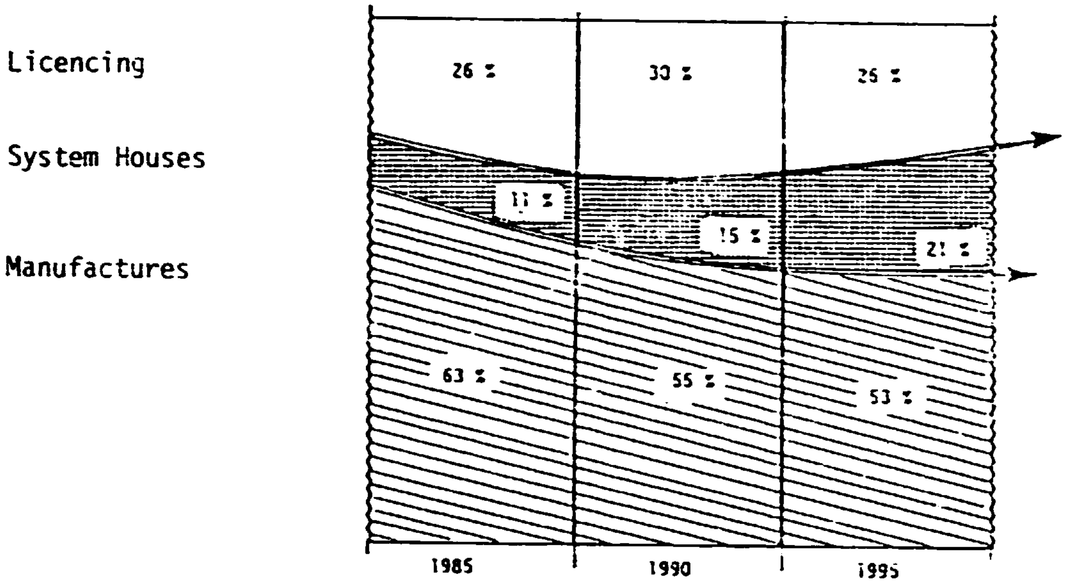
Table III. Typical robot system cost breakdown



Source: Tech Tran Corporation

Lastly, with IR diffusion in the small -and medium- sized firms, system houses companies are playing an increasing role in robotics markets (table IV).

Table IV. IR diffusion patterns in the US market



(f) <u>Increasing of minimum production capability size</u>. At the beginning of the 1970s, a two hundred units annual production was sufficient to be an IR supplier. Today, the required production level to be profitable is much higher. Market leaders manufacture about 1.500/2.000 units a year and set on a 5.000 units production level goal for the 1990s. The increasing gap between leaders production volumes and other firms ones is upsetting for the latter.

Table V. IR production in 1986 (assuming the same IR definition is used by all manufacturers)

Leaders :	MATSUSHITA (J)	3.500 robots
	GMF (USA)	2.000 robots
	ASEA (S)	1.500 robots
Others firms :	KUKA (G)	850 robots
	COMAU (I)	450 robots
	RENAULT AUTOMATION (F)	450 robots.

Finally, during the past years, the foreseen trends grew stronger. And if technological diffusion and price evolution proved less than expected, this does not question the deep tendency to the emergence of an oligopolistic structure in the robotics industry.

(g) The emergence of four patterned supply strategies. It is obvious, the world market is more and more structured. On the US market, where competition is keener than elsewhere, a double trend can be stressed out :

. relative fall of the traditional firms ;
. rise of new firms, as GMF, the market share of which increased up to 30 % in three years.

Table VI. IR manufacturers sales on the US market

	1986	1987	1983
GMF	235	180	102,8
Cincinnati Milacron	66	59	52,5
Unimation	53	45	44,5
Asea	48	39	30,0
De Vilbiss	28	33	30,0
Automatix	26	25	17,3
GCA	25	35	13,5
American Robot	25	19	8,0
Adept Technology	25	15	1,1
Kuka	24	27	13,5
Graco Robotics	23	20	9,3

Source: Prundential Bache

The Japanese market, with more than 200 vendors, is always ruled over by some large firms : MATSUSHITA, FANUC, TOSHIBA.

Table VII. The first ten IR Japanese Manufacturers

Rang 85	Rang 84	CONSTRUCTEURS	C.A. 85	C.A. 84	PREVISION 86
1	1	MATSUSHITA ELECT.	45.0	32.0	48.0
2	2	FANUC	19.9	12.6	20.0
3	3	YASKAWA ELECT.	13.0	10.0	16.0
4	4	KAWASAKI	10.0	8.0	12.5
4	7	TOSHIBA	10.0	6.0	12.0
6	4	HITACHI	9.0	8.0	10.0
7	8	NACHI FUJIKOSHI	7.2	5.9	9.0
8	6	FUJI Machine Mfg	6.6	6.3	8.5
9	9	MITSUBISHI	6.5	5.5	8.5
10	11	DAIHEN	5.7	4.2	6.5
11	15	FUJI ELECTRIC	4.8	3.3	7.7
12	13	KOBE STEEL	4.7	3.8	4.7
13	15	STAR SEIKI	4.5	3.3	6.0
14	14	CITIZEN WATCH	4.0	3.6	5.0
15	12	SANKYO SEIKI	3.7	4.0	4.3
16	17	NEC	3.5	3.0	4.5
17	23	KOMATSU	3.2	2.0	5.4

Source: Nihon Keizai Shinbon

On the European market, the leader is the Swedish group ASEA, with 30 % of the market. The other firms are the German company KUKA (15 %), COMAU, a FIAT subsidiary, (8 %) and RENAULT AUTOMATION (8 %).

Four patterns could be stressed out :

- specialized market niche strategies : some firms design and develop specific automated devices, dedicated for today very narrow, but profitable expected markets (personal robots, service robots for cleaning, agriculture, mining...) ;
- functional package strategies : they consist of selling not only a wide range of IR, but also a range of robotic turnkey systems for industrial applications ;
- standard IR mass production strategies ;
- PA system strategies : robot is viewed as a peripherical device of the control system. In this case, suppliers aim at selling computer integrated manufacturing systems, including IR.

Table VIII. PA manufacturers strategy-patterns

STRATEGIES	ADVANTAGES	DISAVANTAGES	CONSTRAINTS	COMMERCIAL NETWORK	AGREEMENTS
NICHES	- Limited competition - large potential market increase - weak market entry cost	- if market growth be confirmed, new firms enter the market	-growth funding	- not important at the beginning	- agreements with users
APPLICATION TURNKEY SYSTEMS	- better assets if prices war - expertise in application areas	- expensive strategy - hard implementation for new intrants	- large implemented IR population	- internal commercial network development	- system houses with complementary expertise
MASS PRODUCTION	- manufacturer may concentrate its efforts on products development and manufacturing	- access to new markets through partnerships	- investments in R-D and manufacturing	- agreements required	- system houses
PA SYSTEMS	- IR could be a mean to promote solutions designed in industrial data processing	- strong competition with IR manufacturers	- to design integrated automated systems	- agreements required	- system houses

Indeed, the industrial strategy developed by vendors is not so one-patterned.

Table IX. Strategic positionning of some leaders

Specialized strategies	Functional packages strategies	CIM strategies	Mass Production strategies
	XXXXXXXXXXXXXXXXXXXXXXX GMF XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX		
	XXXXXXXX ASEA XXXXXXX		XXXXX ASEA XXXXXX
		XXXXX IBM XXXXXX	
XXX ADEPT XXX			(*) XX JAP.VENDORS XX
		XXXXXXXXXXXXX FANUC XXXXXXXXXXXXXXXX	

(*) outside Japan.
Source : Lettre 2000, Basic : Robots industriels, une crise, la croissance -Nov. 1986.

4.1.2 Slow PA adoption : the neglected dimension

At the end of the 1970s, manufacturing industries, experts and politicians discovered the new wave of automation. Technologies began to be available ; beyond the mixed welcome, PA was viewed as a panacea for problems in manufacturing. It was argued that PA can improve product quality by raising consistency and control in production. And it can be used in producing a range of products because of its programmability. This trait, in particular, lies behind claims for PA "flexibility". These features had to make PA economical in production of much smaller quantities than hard automation, which is largely restricted to large quantity or mass production. Product life cycles shorten, consumer needs require to be satisfied by the market segmentation (several types of the same model). PA technologies are applicable accross a wide range of industry, whereas the applicability of conventional hard automation is much more limited.

Shortly, PA had to help many companies to produce better and cheaper. If all these features are right, the way how they were dealt with is quite inappropriate : PA is not a panacea, but it is an important and powerful set of tools, as it was demonstrated in the previous chapters.

This misunderstanding in the industrialized countries about what PA really means, is one of the main reasons for the slow and uneven growth seen in markets for automation. Another is also the unfavorable economic conditions to investment.

Because the prestige of manufacturing engineering is low relative to other engineering fields, companies have devoted relatively little effort to improve manufacturing processes in the past few decades. And as a result, underating the PA impact on workstructure was -and still is- the first reason of the gap between the expected and achieved benefits of PA investment.

If through technical magazines, one could feel impressed by the described realizations, it must be said these emphasized realizations remain marginal. Throughout the world, only 240 FMS are in use, and in some cases, full benefits realization is not obvious at all, likewise the national IR populations do not grow at the expected rates.

Then the current underassessment of interconnections of technological, social and economics concerns surrounding the spread of PA in manufacturing requires to better understand the key impacts of PA on workstructure. The analyse of the industrialized countries experience is very fruitful.

Among the broader work environment issues, one could quote organization and nature of work, occupational safety and health, labor-management relations, changing skill levels and training.

Only the first three issues are developed. Concerning changing skill levels, one must know, the ways in which work is organized and jobs are designed will determine both the skills needed to do a particular job and the overall level of skills required in a workplace using PA. In general, PA gives rise to greater need for conceptual skills (e.g. programming) and a lesser need for motor skills (e.g. machining) than are required for conventional equipment.

(a) Organization and nature of work

The ways in which work is organized, together with the specific design features of PA technology, will help to govern the effects on the work environment. In the short term, the new and emerging technologies will be adapted to traditional structures of work organization ; over the long term, the structures will change to reflect the characteristics of the new technologies. While it is too early to predict how these changes will develop, the experience to date may offer some insights.

One of the most vivid examples of how the organization of work in automated manufacturing can affect the quality of the work environment, comes from the allocation of programming in an NC shop. The introduction of NC machinery is usually accompanied by the development of a new programing departement and a new division of labour. The planning of work becomes more centralized and is moved off the shop floor, so that planning and execution become increasingly separated. From the point of view of management, this results is increased efficiency and control over the production process. However, whether or not production workers are permitted to edit programs on the shop floor, or in general engaged in planning, can determine whether their jobs are routine and relatively boring or involve, instead, an element of challenge and decision-making. The assignment of work is a function of managerial choice.

It is generally agreed that there is nothing inherent in automated technology that makes a particular form of work organization "imperative". There are opportunities for enlarging the scope of jobs with PA.

With appropriate training, workers could be involved in a greater variety of tasks by rotating jobs ; however, this would require cooperation between labour and management in agreeing to increased flexibility in work rules. Another opportunity for workers to perform a wide rande of tasks rather than narrow, fragmented ones is in the application of group technology, through the use of manufacturing cells producing families of parts grouped on the basis of similar shapes and/or processing requirements.

The flexibility of PA provides the potential to achieve a better balance between the economic considerations that determine technological choices and the social consequences of those choices in the workplace. There are cases where organizational and technological changes have been combined successfully to yield dramatic improvements in productivity and effectiveness. While these changes generally were motivated by factors other than improving the work environment, organizing work in ways that improve the work environment should result in economic payoffs as well through better worker morale and productivity.

Many of the concerns about the introduction of PA revolve around the changes it will bring about in the organization and nature of work. The choices made by those who design and manage automated systems will have a profound effect on how these systems influence the work environment.

(b) Occupational safety and health

The various forms of PA have both positive and negative effects on the safety and health of workers. In general, the introduction of PA tends to have a favorable impacts on the work environment, although some new physical hazards associated with the lack of immediate worker control over system operations may emerge. However, PA will create new situations, or perpetuate old ones, that may have negative psychological effects on the work force.

Overall, the potential physical hazards appear to be more amenable to solution than some of the psychological ones because they are more easily recognized and are less subject to the subleties of individual personalities. The relief of such symptoms as boredom and stress is more challenging because they are not as well measured or understood, affect different people in different ways, and are often complicated by other factors not directly related to the workplace. In addition, a commitment to alleviating monotony and stress in the workplace usually involves major changes in the way work is structured that can pose problems for both managers and other workers.

A common event in shop floor illustrates the difficulties to correctly assess these safety and occupational considerations : the breakdowns. While they are technological in nature, the pressure to meet quotas in spite of equipment failure is organizational. This situation is not unique to PA, but the problem is exacerbated by a system designed in such a way that equipment cannot be pulled to one side for repair, and by the complexity and automatic nature of the equipment. In addition, the high capital cost of the equipment increases the desire to use it to the fullest extent. This may entail operating the line faster to make up for time when the machine is down, in order to meet production goals.

(c) Labour-management relations

The effects of PA on the work environment will be determined in part by management's motivations for automating and by the nature of labour-management relations. Management might decide to introduce PA for a variety of reason, such as :

1) to improve productivity ;
2) to reduce costs ;
3) to standardize production methods ;
4) to enable the use of workers with fewer skills ;
5) to increase control over the pace and quality of production, and
6) to get on the technological bandwagon.

Who makes the decision in the organization will also have an important effect on the results. Research suggests that managers often lack the background to assess the technological options, while staff familiar with the new technologies are less able to appreciate associated strategic dimensions.

Once the decision is made, the strategies employed by management for introducing PA are key in determining its impacts. Prior experience seems to be an important factor in how an organization copes with additional automation. Also, the introduction of new technology may be facilited by good intra-company communications and a "participative" management style. Where the knowledge and expertise of workers is factored into the decisionmaking surrounding new technology, and information is shared, implementation problems may be minimized somewhat.

The nature of labour-management relations will affect the implementation of new technology and its consequences for the work environment. Cooperation between employers, workers, and society in determining the design, implementation, and pace of change would tend to minimize potential negative effects of technological innovation. Such cooperation, however, will require mutual trust among the parties involved.

In response to changing worker expectations, management increasingly has been forced to pay greater attention to the needs of its work force, beyond the traditional ones of fair wages and benefits. This trend has been growing since the 1960's and 1970's, and is not limited to either new technology or PA. In addition to such provisions as profit-sharing and job security, workers have been demanding a greater say in matters that directly affect their workplace ; where management has begun to tap into this knowledge and experience they have often discovered a new source of support and insights.

Any discussion of restructuring work in automated environments in ways that would enhance the workplace needs to be framed in the context of how the work rule issue evolves. Management's ability to take innovative approaches to implementing PA maybe constrained by work rules that are outmoded and difficult to change. In return for increased flexibility in deploying workers, management may need to be more responsive in such matters as increased labour involvement in decisions concerning the implementation of new technology or job security.

Finally, a number of factors determine the impacts of programmable automation (PA) on the work environment, such as how the technologies are designed and applied, the strategies employed to introduce [illegible] and management's goals for automating. In general, the introduction of [illegible] tends to improve the work environment. However, it has the potential to create new situations that are stressful or monotonous, resulting in negative psychological effects on the work force. PA offers a wide rande of choices concerning its use -choices that, if made well, will help to ensure that PA is applied in ways that will maximize its potential for affecting the workplace positively.

But the persistent mismatch between commercially available technologies and the willingness -PA creates new situations- and ability -PA sets new problems to manufacturing engineers and management- of users to implement them remains one of the major stakes for manufacturing today.

4.1.3 National support for PA

Regarding the PA markets as a whole (e.g. production and utilization) and considering the strategic stakes of the PA technologies either for economic recovery and industrial competition of each nation positionning in the world economic and political hierarchy, most of the industrialized countries set up policies and programmes which are directed at the development and use of PA.

The case of two countries are developed : Japan and Sweden. This choice is determined by their success. The analysis stresses out the public initiatives regarding the topics developed previously.

(a) Japan

Given Japan' scarcity of indigenous natural ressources and its reliance on others nations for imports of food, energy, and raw materials, the Japanese strive to maintain a high volume of exports. Thus, international competitiveness and the ability to sell abroad is of crucial importance to the Japanese economy.

Since the Meiji Restoration in 1868, there has been a tradition of Government-industry cooperation, and the Government has historically been able to interverne effectively in the economy. Thus, industry has traditionally tended to view Government as a partner, rather than an adversary or regulator.

MITI, which stands for Ministry of International Trade and Industry, was organized in the late 1940's from the Commerce and Industry Ministry, and its name reflected a new emphasis on international trade. MITI works closely with industry associations, and other Government agencies. The agencies set broad industrial policies, collect information on relevant research in other countries, and promote special studies where information is lacking.

Even if this cooperative relationship has appeared in recent years to break down to some extent, beyond the ebbing role of MITI, the Japanese Governement has developed long-range plans.

Namely, long-term economic plans call for reducing the importance of country's agricultural and manufacturing sectors, and expending the economic role to the less energy-consuming, knowledge-extensive service sectors, MITI encourages this shift by promoting productivity and quality control gains and reduction in labour, energy, and material costs. PA is one means toward this end.

(i) Direct government role

* Mechanisms

The instruments of industrial development policy include :

- Visions : These are Government-sponsored papers elaborating on current economic challenges facing Japan, and discussing strategies to meet these challenges. MITI writes these documents in collaboration with industry, labour, and political interest groups. The visions are intended to aid business and Government agencies in strategic planning.

- Government Assistance : The Japanese Government provides small amounts of financial support for R and D in private firms in order to serve as "a catalyst to stimulate private sector support of mutually agreed upon industrial development policy goals".

- Rationalization Cartels : In the late 1960's, in order to promote the development of internationally competitive firms in Japan, MITI guided the restructuring of Japanese industry by encouraging corporate mergers.

- Tax Incentives : Special depreciation allowances exist for designated plant and equipment, in order to encourage development of targeted industries.

- Monetary Policies : Throughout the postwar period, up until the early 1970's, the Japanese rationed credit. The Bank of Japan controlled the discount rate to influence microeconomic decisions. Typically, this ability was used to bias flows toward investment in productive infrastructure and capital-intensive manufacturing and away from consumer spending, housing and social infrastructure. This control eroded in the 1970's as Japan joined the International Monetary Fund (IMF) and the Organization for Economic Cooperation and Development (OECD), and its capital market became more internationalized for a number of reasons.

* Concerns for social impacts of technological change

The Japanese Government has strong concerns about the social impacts of increased application of PA and other new technologies in the manufacturing sector. The Japanese Ministry of Labor released a report in May 1983 entitled, "Microelectronics and Its Impact on Labour". The report focuses on the employment effects of IR and microelectronic products and processes in Japanese firms. In response to the employment effects of changes in production technologies in Japanese industry, the Ministry of Labour has requested funds for the establishment of a "policy department" within the ministry. This department would monitor employment trends and allow the ministry to develop recommendations which would be considered in the development of national economic policy.

(ii) Government support to industry - the machine tools industry

The Japanese Government encouraged broad industrial application of new machine tool technology. The Japanese approach included government-funded research institutes. These institutions were particularly responsive to the suggestion and experience of commercial end-users of the technology.

Japanese competitiveness in the low end of the world machine-tool market reflects the widespread application of the technology in the domestic economy. The Japanese Government provided technical information and assistance to small and medium-sized firms to encourage the application of machine-tool technology industrial production. Governement-sponsored technical centres provided cost-benefit estimates, customized software, and training to firms interested in numerically controlled (NC) machines. By reducing user uncertainty and costs, the Japanese have been able to develop both domestic and international markets for small NC machine tools.

. The Robot Industry

The Japan Industrial Robot Association : founded in 1972, JIRA, was initially a Government corporation financed by the proceeds of sports events sponsored by the machinery industry. In 1973, JIRA became an incorporated private association. This configuration allows MITI to deal with robot producers as a group. One-third of Japanese robot producers belong to JIRA, as do many Japanese and foreign robot users. JIRA's function is to promote the development of the robot industry through market surveys, the monitoring of technological advances, public relations, and development of new applications for robot systems. JIRA has been much more advanced in the collection and dissemination of information about robots and their uses than the abroad equivalent associations.

Japan Robot Leasing Co : Established in april 1980 with MITI encouragement in order to promote the use of industrial robot throughout the economy, JAROL leases robots primarily (90 per cent) to small and medium-sized enterprises. JAROL is jointly owned by 24 major robot producers and 10 life insurance companies. The company initially received no Government funding, but now receives 60 per cent of its financing from the Japan Development Bank in the form of low interest loans. The remaining 40 percent of JAROL financing comes from the Long-Term Credit Bank, the Industrial Bank of Japan, and various citybanks. These favorable capital rates allow JAROL to lease robots at more favorable rates than ordinary leasing companies can offer.

Through the development of several fiscal and financial incentives (low interest loans, special depreciation allowance) MITI has promoted robot installation.

. Research and Development

The Japanese Government, like the United States and European governments, is modestly subsidizing R and D projects on robotics. MITI's Agency of Industrial Science and Technology has two laboratories in which a considerable amount of research on robotics is carried out -the Electrotechnical Laboratory and the Mechanical Engineering Laboratory. MITI has also developed cooperative projects among competitive robot manufacturers, who contribute researchers to the joint efforts. These joint research efforts have sought to avoid duplication of research efforts by the producer firms. In addition, MITI, in conjunction with JIRA, sponsors the wide dissemination of resulting research data.

Beginning in April 1982, MITI was to carry out a 7-year, 30 billion yen ($128 million) robot research programme. It was intended to develop robots suitable for wider application (agriculture, mining, underseas, nuclear, space...), as well as to develop indigenous Japanese robot technology in order to reduce reliance on American and Western European innovations. The program was postponed for a time due to budgetary constraints, but work began in fiscal year 1983, and is still expected to be carried out over the envisioned 7-year period with full funding.

Today, this programme takes place in the international cooperative framework defined by "Technology, Growth and Employment" Working Group, set up at Versailles Summit in June 1982. It gathers 10 countries, among which Canada, France, Germany, Japan, United States and United Kingdom.

Another of Japan's large-scale technology development schemes involves "developing complex production systems in which mechanical components for small-batch production of diversified products can be flexibly and rapidly produced from metallic materials in an integrated system". Under this scheme MITI provided 20 per cent (Y 13 billion - US$ 55.5 million- over fiscal years 1977-83) of the funding for the development of a Flexible Manufacturing Complex Utilizing Laser. The programme did not finish on schedule, and was extended through 1984 with an extra Y 1 billion (US$ 4.3 million).

The project has become something of a "show case" for advanced Japanese technology. It was presented during the International exhibit at Tsukuba in 1985.

(b) Sweden

The Swedish Government has traditionally played a very strong role in the Swedish economy. Nearly half of all Swedish industrial products are sold abroad, while almost all of the Swedish energy supply is imported. Machinery and mechanical equipment also make up a larger share of Swedish imports. Given Sweden's dependence on external trade, international competitiveness is vital to its economy.

In the end of 1970's, the Swedish Government recognized that production of PA equipment might be strategically desirable, and it was concerned about a possible shortage of skilled labour.

The main Government support for industry was the initiatives taken in the framework of the Swedish Commission on Computers and Electronics (Data-och Elektronik Komitten, or DEK). In april 1981, DEK reported to the Ministry of Industry on the promotion of PA in Sweden : then, the Swedish Government has placed a high priority on promoting the development of CAD. In 1982, DEK introduced new legislation which included the allocation of Skr 14 million (US$ 1.7 million) during 1982-83 in part for the formation of three CAD centers. A DEK report lists the following motives for promoting the diffusion of these technologies throughout the economy :

1) to increase productivity and, thereby, profitability ;
2) to improve the conditions of work ;
3) to improve precision and tooling complexity ;
4) to acquire experience with new technologies, and
5) to reduce consumption of energy and raw materials.

DEK recommended that the Swedish Government coordinated activities promoting new production technologies, and, in particular, that it promoted long-term technology development and skills development at technical facilities. It recommended enlarging the vocational training program at the Swedish Institute for Corporate Development (SIFU), and establishing a training programme for vocational instructors on computer-based production technologies.

On April 1, 1983, DEK announced the Programme for Diffusion of Industrial Robots and Computer Controlled Production Techniques. In order to promote wider use of PA in small and medium-sized firms that have little or no familiarity with PA, DEK proposed the following measures :

1) An information campaign revolving around the 14th Annual International Symposium on Industrial Robots (ISIR), was held in Stockholm in October 1984.

2) Support for production technology development projects.

3) Educational programmes for project personnel.

4) Development of a consultancy program.

5) Regional educational programmes which would include demonstration programmes, including robot-assisted lathes and automated materials handling, robot welding and automated materials handling, and flexible automated machine loading.

On Research and Development side, the Swedish Board for Technical Development (STU) operates under the auspices of the Swedish Ministry of Industry, and provides funding for advanced R and D in universities, research laboratories and industry. Between 1972 and 1979, STU funding for robotics and CAD accounted to US $ 4 millions.

The degree to which such support has been effective is not easy to determine. It is confounded by other factors, including technological sophistication, industry characteristics, and cultural differences. However, what must be emphasized is that, the national efforts which prove to be most successful are those which conform to, and build on existing social and economic traditions.

From the analysis achieved above, the principal findings are :

1) PA markets are strongly international. Competition among PA industries to increase market shares is very keen and vendors earning money the exception.

2) The non-profitable feature, at least on the short term, of PA industries is to due mainly to market narrowness : PA is not a panacea, but an important and powerful set of tools, the social and economic effects of which must be mastered. Among most significant impacts of PA, is its impact on work environment, a largely neglected issue.

3) All the major industrialized countries support the development and use of PA. Beyond the amount of money spent to that purpose, it appears the more initiatives are conformed to and build on existing social and economic tradition, the more effective they are.

4.2 Policy strategies and policy options

From this assessment on PA technologies the central policy question that emerges is "what policy strategy should be implemented for the development and use of PA ?"

Although such a strategy could take many forms, the fact that the opportunities and problems posed by programmable automation are interconnected makes it appropriate to consider a policy strategy combining actions in several areas. PA may well become an important factor in national productivity growth and improvement in economic performances, but the spread of this technology can aggravate existing social and economic problems as well as create new ones for developing countries, as a whole. While the potential for PA to benefit industry and the economy counteracts arguments for slowing its spread, the risks inherent in rapid diffusion raise questions about whether, and how, the spread of PA should be accelerated. Among the principal motivations for policy are :

- The immaturity of PA technology and limited experience with its application. Although current technology is applicable in many situations, further development and applications experience are needed before its potential for improving productivity, work environment, and product quality can be fully realized.

- The competitive environment in which PA development and use are taking place. Governments, in industrialized countries, are encouraging the development and use of PA, while markets for many goods and services, including PA equipment and systems, are becoming increasingly international. Both situations militate against complacency.

- The risk of growth in unemployment. In the absence of growth in production levels, PA may be associated with unemployment.

- The risk of adverse effects on the psychological aspects of work environment. These effects, arising from the combined influences of new technology and job design, may not only diminish productivity gains from PA, but may constitute new health problems. Collective bargaining will allow only a fraction of the labour force to resolve these problems on their own. Because PA and structural changes in the economy will limit the number and range of manufacturing jobs available, many workers will become less able to move out of disagreeable situations.

- The ramifications for education, training, and retraining at all levels. The appropriateness of the mix of skills within the labour force governs both the rate at which PA can be developed and used, and the extent of adjustement (through retraining or relocation) that may be necessary given changing skill requirements.

As the above list indicates, there are factors that motivate policy promoting PA (technological immaturity and international competition) and factors that militate against accelerating PA adoption or that support complementary policy in other areas (the risks of worsening unemployment and work environments and the need to assure appropriate instructional capacities). Furthermore, concerns raised by PA are also aspects of larger policy problems. Competitiveness and unemployment, for example, reflect many circumstances, not just use of new technology. Assuaging these concerns, in particular, requires a healthy economy -something that PA can influence but not guarantee.

A policy strategy for PA would have to balance the interests of a large and diverse group of stakeholders :

- The developers and producers of PA are primarily concerned with funding and facilities for R and D, as well as general economic policies which affect markets for the technologies.

- The users of PA focus on competition in their product markets. While they tend to resist governenment intervention in production and personnel areas, they call for improvements in tax and trade laws and other policies which influence the business climate.

- Members of the labour force care about whether they can get and keep jobs, what kind of jobs are open to them, and their relations with management.

- Finally, Government have broad interests in the development and application of PA, including its effects on productivity, economic growth and external accounts.

4.2.1 Policy strategies

The orchestration of policy initiatives in different areas may be considered a policy strategy. If Governments choose to coordinate activities in the areas of technology development and use, employment, work environment and instruction, they can pursue one of four basic strategies :

1) laissez-faire ;
2) technology-oriented -emphasis on programmable automation development and use ;
3) human resource-oriented -upfront attention to education and training, work environment, and job creation ; or
4) both technology- and human resource-oriented.

Besides, Governments may perform the chosen strategy at different levels, either 1) national level, or 2) regional level.

The outcomes of Government action can be evaluated according to likely effects on industrial output, employment, work environment, and change in adjustement assistance programs. The principal uncertainties that cloud projections of change are :

1) the rate of advance of the technology, i.e. the likelihood that the state of the art will advance far beyond what is currently expected during this decade ; and

2) the relative success of efforts abroad to develop or apply PA and to increase sales penetration in domestic and foreign markets.

Another major uncertainty is the economic growth. A stagnant economy creates numerous problems which are best addressed directly, rather than through "PA policy".

The success of some industrialized countries in international competition can be a principal cause of lower industrial output and employment for a specific country. A strategy with at least some orientation to new technology development and use can reduce that risk, because it can contribute to improvements in productivity and competitiveness. However, a strategy that is strictly technology-oriented will probably increase the incidence of labour market problems associated with shifting employment demands, aggravating needs for retraining and other adjustment services. Also, a strictly **technology-oriented strategy** is likely to aggravate potential work environment problems. In sum, a strictly technology-oriented strategy would entail upfront costs for technology development and use, but it would also entail other, postponed costs such as increased adjustment assistance spending.

A **human resource-oriented strategy** would involve investments in evaluating skill requirements ; tailoring education, training and retraining activities ; and assisting in the matching of people with jobs. Ideally, it should avoid growth in adjustment assistance spending due to extended unemployment that might occur in the wake of PA, and it may even diminish such spending. Human resource development does not preclude and may well facilitate the use of PA and otherwise improve productivity. However, its effects on industrial output levels may not be as measurable as the effects of technology-oriented policy. Although human resource and technology initiatives may complement each other in influencing output and employment, explicit human resource efforts may be needed to address work environment concerns, regardless of whether initiatives are taken to accelerate PA applications.

A **combined technology- and human resource-oriented strategy** could draw on the complementarity of equipment and humans in production, assuring technology development without compromising work environment concerns. Also, it lends itself to long-term job creation initiatives. Thus, a combined technology- and human resource-oriented strategy could assure that human impacts are explicitly considered in the processes of PA development and use. While this type of strategy is the most comprehensive and balanced, it may be the most difficult to design and implement because it explicitly affects the broadest range of interests.

Whatever policy strategy chosen, successful policy regarding PA must mesh actions in several areas. According to areas and topics considered, some actions could be run more fruitfully on a regional basis. For instance, regarding research and development effort, the settlement of dedicated research laboratories or centres has to be defined on a regional level. Indeed to perform the necessary research and development work to master PA technologies, a critical mass of researchers and equipment is required. And the cost of such a centre amounts at least to US$ 2-3 millions. Likewise, to perform technological forecast and assessment, information on various realizations in different industrial sectors and firms must be gathered, processed and then diffused to any organism and firm interested. Lack of information is one of the main barriers to new technologies diffusion. So the creation of an information centre, dealing with technical, economic and social aspects of PA, could be acutely needed, but the more such a centre can gather, process and diffuse information, the more it will be efficient. And to cover the overall field, it requires means. Nevertheless to this unique information centre, could be associated a network of more specialized industrial sector information centres, according to their industrial capabilities for instance.

4.2.2 Policy options

The strategies outlined above are based on policies. In the areas of technology development, use, work environment, and education and training, a set of options for possible policymaking is proposed. They could be continued to develop one of the strategies suggested.

(a) Technology development and diffusion

Fund research and development

Governments could act to increase PA R and D by influencing both the overall level of funding and its distribution to various agencies and research topics. Governments may also wish to increase funding for standards and human factors research, which would facilitate the application of programmable automation across a wide range of industries. Nevertheless, to make quickly PA equipment available for national industry, Government could favour foreign PA suppliers settlement by setting up specific industrial areas such as offshore zones.

Facilitate standard-setting

In addition to bolstering R and D in standards, Governments may wish to consider legislation to facilitate standard-setting as a means of increasing the ease of use of the technologies and encouraging their application. The principal disadvantage of standard-setting is the risk that a more rapid adoption of standards may provide short-term benefits for users but hinder future innovations which could be inconsistent with the standards.

Encourage use of the technologies

The appropriate rate for adoption of PA is a subject of contention. It depends on the rates of adoption among trading partners, the extent of delay between invention and adoption of new technology, and the ability of the labour force and industries to adjust. There is probably a degree to which PA adoption can be facilitated by national efforts without incurring excess costs. Beyond some indefinite point, however, encouragement of the use of PA may lead to ill-considered applications and excessive problems for employees and communities.

Options for facilitating application of PA primarily involve removing barriers. These options include assistance in providing capital for the purchase or lease of automation equipment, and providing information about PA to manufacturers.

Measures to encourage adoption of PA, however, are only a partial and short-term solution to manufacturing problems. A longer-term solution involves redressing the inattention to manufacturing processes, organization, and management. Though there is some evidence that the private sector has begun to address this need, Governments could play an important role in fostering the development of engineering curricula in universities which combine manufacturing, design, and human resource management activities ; as well as encouraging research in manufacturing engineering topics. Further, Governments could establish some form of manufacturing institute to provide a focus for manufacturing technology, organization, and management issues. Such an institute could serve as an information clearing-house for manufacturers, as well as a think tank with rotating fellowships for people from all parts of the manufacturing sector.

(b) Work environment

Because PA will eventually affect the work environment of most manufacturing personnel, especially in metalworking manufacturing, and because it poses potential new problems pertaining to the psychological aspects of the work environment, this technology raises questions about the adequacy of existing mechanisms for studying, monitoring, and regulating workplace conditions.

No increased Government role

Although no single policy instruments specifically address the impacts of PA on the work environment, various mechanisms must be already in place at the national and local levels that cover workplace concerns in general. And finally, it may be too early in the development and application of Pa to devise an appropriate Government role. All the above concerns might argue for retaining the status quo.

However, work environment issues are similar in some ways to other problems, such as pollution, which are not easily solved by the private sector on its own. With current estimates of union membership in various industrialized countries totaling about one-fifth of all workers, there is a large segment of the population that will not have a focused way to articulate work environment concerns. Finally, there is a great deal to be learned about the effects of PA on the workplace, and such research must begin immediatly in order to help improve the workplace as adoption of PA accelerates.

Increase overview and monitoring

Governments could increase the emphasis placed on the workplace effects of computerized manufacturing automation through their overview and monitoring activities. While overview could inform Governments and the public about workplace concerns and cover a wide rande of settings, it might result in a piecemeal effort with little or no coordination of activities or sharing of information.

Increase support for work environment research

Governments could support research, through agencies and Departments of Labour, on both the short- and long-term social impacts of PA on the workplace. Potential areas for research might include the physical and psychological effects of PA, management strategies and policies in introducing and using PA, worker participation, identification of hazards and how to control them, changes in work content and organization, and changes in organizational structure, among others. Research would be particularly valuable for identifying techniques to measure nonphysical problems in the workplace. Demonstration projects, seminars, and experiments would enhance understanding of the effects of Pa and the extent to which it can be shaped to improve the work environement.

Current research on the social impacts of PA on the manufacturing work environment is modest in scope and support, reflecting the limited amount of interest and funding available for this purpose. Nevertheless, study of the impacts of new technology on the workplace is more common in some industrialized countries, as Western Europe, where the subject has historically received more attention across sectors.

Set new standards

New safety and health standards may be required to address problems associated with the use of PA. Reliable information would be needed on the numbers of people at risk, the nature of the risks, and the potential costs and benefits of establishing and enforcing new regulations.

Promulgate omnibus work environment legislation

Other aspects of the introduction of new technology into the workplace, beyond safety and health concerns, suggest that a broader approach to work environment policy may be desirable. These aspects include the potential for excessive surveillance of workers and the disparity in worker and management understanding of both the choices available in adopting PA and their workplace ramifications. In addition, a broader approach would ensure that the interests of all workers would be protected.

A number of European countries have taken an omnibus approach to workplace concerns. In Norway and Sweden, for instance, work environment legislation has been in effect since 1977. One purpose of this legislation is to protect workers'mental as well as physical health in the workplace, particularly in the context of technology change ; another is to give employees an opportunity to influence the design of the work environment.

(c) Education, training and retraining

No increased Government role

As in other areas affected by PA, it may be too early to assess the appropriate Governmental role in education, training, and retraining related to PA.

Increase support for facilities, equipment, and qualified instructors

Governments could consider options such as tax incentives for the purchase of state-of-the-art equipment for training, and funding to establish selected educational facilities and maintain them for use in periods of intense demand for PA instruction.

Encourage industry-based instruction

Few users of PA equipment currently have or plan to establish in-house instructional programmes. Governments could choose to encourage users of programmable equipment to establish or enhance in-house technical training programmes through the creation of tax incentives that help defray the costs of instructors, equipment, expansion of instructional facilities, and curriculum development.

Encourage curriculum development

Governments could enact a grant programme to fund the development of curricula geared to the development of PA-related skills. Encouraging comprehensive curriculum design and the establishment of voluntary guideliness for curriculum content at various levels would guarantee some degree of standardization to both enrollees and employers.

Encourage renewed emphasis on basic skills and problem-solving skills

Governments could choose to encourage at all levels of instruction a renewed emphasis on strong, basic skills in reading, math, and science. Special emphasis could be placed on the development of individual problem-solving skills, since these are important prerequisites to training for careers in computerized manufacturing, as well as for non manufacturing occupations.

Intensify research efforts

Governments could choose to increase central sponsorship of research to identify changing skills requirements within manufacturing occupations, and to provide for broad-based dissemination of the findings to better equip educators and trainers for curriculum development. Governments could also use a research programme to encourage the development of instructional standards that are in keeping with PA skills requirements.

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Industrial automation in the production of capital goods. Issues for developing countries

	(please check appropriate box) yes	no
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