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TECHNOLOGICAL REQUIREMENTS FOR THE MACHINE TOOL INDUSTRY IN DEVELOPING COUNTRIES

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SECTORAL WORKING PAPERS

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This paper was prepared by Mr. E.J. Wightman as consultant to UNIDO. The views expressed do not necessarily reflect the views of the UNIDO secretariat.

Preface

At the recommendation of the 9th Session of the ESCAP Committee on Industry, Technology, Human Settlements and Environment held in Bangkok from 10 to 16 September 1985, UNIDO, Sectoral Studies, and the ESCAP/UNIDO Division for Industry, Human Settlements and Technology will organize a meeting on "Production and use of machine tools in the engineering industry of ESCAP developing countries". This meeting, to be held in Singapore between 17 and 21 November 1986, will be a direct follow-up of the UNIDO/ESCAP project on "Review and appraisal of industrial progress at regional level".

The meeting should formulate concrete recommendations to be followed by industrialists and policy-makers in the countries concerned and by UNIDO and ESCAP to assist in developing the use and production of machine tools in the engineering industry in the ESCAP developing countries. This study will be one of the background documents for this meeting.

The study was prepared by Sectoral Studies in collaboration with Mr. E.J. Wightman as consultant to UNIDO. Tables without specific mention of source were produced by the consultant.

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1. INTRODUCTION

This study attempts to define industrial strategies adequate for the formulation of practical measures for the development of the machine tool industry in developing countries.

The prime objective is to identify the technological requirements for entry of developing countries into the machine tool industry and/or to upgrade it into DNC-CNC machine tools, as well as to propose ways and means of setting up machining centres so as to take advantage of the latest state-of-the-art in machine tool technology.

This study comprises three main aspects:

(a) Definitions and main characteristics of the machine tool industry;

(b) Technological requirements for entry into the machine tool industry by developing countries; and

(c) Technological requirements for upgrading the existing machine tool industry in developing countries.

The first step is to establish a frame of reference to specify what is meant by different terms describing the technology in the machine tool industry and which are the salient characteristics of modern machine tool computer control systems, particularly since the latter are seen to play a predominant role in shaping the industry.

The second step is to establish why machine tools have been developed the way they have, in addition to defining how machine structures have developed. In the long term it is recognized that market forces will play a significant role in shaping the industry and much attention needs to be directed towards these issues.

The third step is to analyze the technological characteristics of the machine tool industry - the effect of linkages with control technology, tooling, mechanical, electrical and hydraulic disciplines - and not least the impact of computer aid in the control of machines and in computer aided design and manufacturing.

In addition to these analyses of technological and operational criteria are the governmental industrial and fiscal policies which provide the starting point for change. Projects management systems are discussed in the context of two objectives:

(a) Government administration of the machine tool industry; and

(b) Project co-ordination of a pilot scheme to evaluate the benefits of modern technology.

These two main objectives are supplemented by a step-by-step progressive strategy for updating existing, conventional manually operated machines towards full computer numerical control and the potential benefits of flexible machining systems.

From the results of this study a development policy emerges which may be tailored to suit the needs of developing countries, irrespective of their state of technological advancement.

This study concludes with a step-by-step checklist of factors which should contribute to technological advance, taking account of experience in the industrialized countries in the field of computer aided design and manufacturing and a recommendation that a project team representing governmental fiscal, industrial and educational interests is necessary to spearhead the proposed programme.

2. DEFINITIONS AND MAIN CHARACTERISTICS OF THE MACHINE TOOL INDUSTRY

2.1 Overview

Until recently the popular conception of the machine tool industry has been one of large workshops populated by noisy machines operated by men in blue overalls cutting up metal bars. Metal cutting machine tools still tend to dominate the industry but automation is reducing the manual content and less conventional methods are being used for metal removal. The machine tool industry comprises mainly:

- Drilling machines - pillar and radial types;
- Milling machines - vertical and horizontal;
- Turning lathes - centre lathes and turret lathes;
- Grinding machines.

The application of mini computers has enabled developments of these machines in automated form to be computer numerically controlled:

- Drilling machines;
- Vertical and horizontal machining centres;
- Turning lathes, two axes, three axes, four axes and power driven tool options for milling and drilling;
- Grinding machines for automatically profiling and gauging during the process;
- Automatic inspection is available by means of special probes mounted on the CNC machines;
- Automatic tool changes are available for drilling, milling and turning;
- Automatic work handling is available for loading raw material and unloading finished components;
- For sheet metal work there are manual and computer controlled versions of guillotines, presses, turret punches, welding machines.

2.1.1 Mechanics of machine tools

The mechanics of machine tools have changed little in concept but greatly in detailed engineering as cutting technology has improved, enabling higher power to be utilized and the technology for bearings has advanced enabling higher spindle speeds to be achieved. Twenty years ago, 2,000 RPM was considered a typical maximum speed for a centre lathe. Speeds up to 6,000 RPM are now possible.

Machine tool structures are principally made from cast iron, steel welded fabrications or concrete filled steel shells, depending on availability and choice of a particular designer. Cast iron tends to be the preferred material because it can be easily cast, machined to provide good wear resistance and hardened locally if required. Above all it possesses good sound and vibration dampening characteristics matched only by concrete filled structures pioneered by the German machine tool industry.

In addition to the components produced by traditional machine tools described above for metal removal by drilling, milling and turning, there is the need to produce at economic prices a great variety of complex parts in small quantities, from more and more diverse materials - a need for a high degree of versatility in manufacturing processes and equipment. Furthermore this need must be met in the face of requirements for closer tolerances, higher strength in work materials, less wastage of material, more frequent design changes and shorter product lives.

2.1.2 Non-conventional machining processes

There are a number of methods of machining metals other than by removing large portions by cutting tools. These less well known means of machining and metal forming by special purpose metal cutting, abrasive machining, electrochemical and electrical methods include:

(a) Skiving. This technique is used for the internal finishing of long tubes such as hydraulic cylinders for example. A boring bar equipped with a special tungsten carbide faced tool 300mm long removes 0.5mm at up to 20mm per minute in one direction and burnishes the bore in the reverse direction.

(b) Deep hole boring. This is a specialized field of metal cutting for the production of bores in which the length is greater than the diameter. The technique was pioneered in the 1930s by Gebrüder Heller in Germany, the salient feature of which is that swarf is no longer carried away along the surface of the bore as in conventional drilling, but is disposed of through a hollow boring bar. For this purpose the coolant is fed from a pressure head to the boring head by way of an annular space between the boring bar and workpiece. The coolant returning through the hollow boring head continuously picks up swarf and carries it back to the swarf trolley.

(c) Abrasive machining. Many of the very hardest materials can be machined using special grinding wheels which can remove up to 600 cm^3 per minute. Abrasive-belt grinding machines can be used for flat or slightly curved surfaces, but obviously are not suitable for complex shapes.

(d) Ultrasonic machining. This is now established, particularly for glass, ceramics and other hard, brittle and electrically non-conducting materials which are difficult to machine in other ways. Applications of ultrasonic machining include drilling of non-circular holes; production of small blanks from glass sheet, semiconductors and so on; shaping of ferrite cores; drilling of fine holes and slitting of diamonds.

(e) Electro-chemical machining (ECM). This is currently used in the production lines of the aero industry. The greatest value of the technique lies in its ability to machine the very hard alloys now in use in this industry. Applications in this field seem to be unlimited. The motor industry is also using this method, notably for deburring operations on gears, connecting rods and splines. Some users have found the method economically attractive for replacing conventional machining on materials that are not particularly tough. The accuracy of the process is good; the surface finish is excellent; the removal rate is high (up to 16 cm^3/min. with a current of 10,000 amp) and there is practically no tool wear.

(f) Spark erosion of electro-discharge machining (EDM). This is used particularly in the tool room. The technique has been adopted mainly to manufacture dies and moulds in hardened material, thus eliminating subsequent hardening operations which often produce distortion. It has also been used to drill fine holes in high-strength alloy steel and to produce complex shapes in nimonic alloys. The tooling problems are not as severe as those for ECM although there is some wear of the electrode during machining. The capital cost of the machines is not high and the process is finding increasing application in general engineering.

(g) Plasma machining. By injecting water into the nozzle of a plasma torch using nitrogen as a plasma gas, up to nine times the cutting speed of flame torches are possible.

(h) Electron-beam machining. This provides extremely good accuracy and is thus suitable for many precision applications; its use so far has been limited to the drilling of very fine holes. There are many possible applications but the capital costs are high.

(i) Laser machining. This is still very much in the development stage. The efficiency of the laser is low and its accuracy for cutting is poor. Lasers have so far been used in the micro-electronics and precision welding fields, two areas in which considerable use can be made of the laser's special characteristics. The application of lasers as machine tools would seem to be a long way off; current applications are found in the field of accurate dimensional measurement, e.g. calibration of machine tools.

(j) Electro-hydraulic and explosive forming. These are used primarily for the bulging of tubes and certain types of metal forming and embossing. The capital cost is comparatively low but setting up is somewhat slow - they are mainly for large forming operations. Both processes give good accuracy.

(k) Electro-magnetic forming. This is limited to materials of high electrical conductivity such as copper and aluminium; for these materials it has a high potential. It gives good accuracy and is rapid in operation; with suitable automatic mechanical handling arrangements, high repetition rates are possible, making it particularly attractive for mass production operations. The process can also be applied to the swaging of tubes and the forming of thin flat sheets into one-piece dies.

Although it is unlikely that electro-magnetic, electro-hydraulic, or explosive forming will replace existing methods, they are all valuable additions to current forming techniques.

2.1.3 Production engineering

Associated with developments in machine tools are the technological requirements, which will be discussed in some depth in chapter 4.

It is significant how computer aids are being rapidly developed for all aspects of manufacturing be it the control of machines, the workhandling or the management systems from design to production process.

The first most powerful stimulus for the current trend towards the use of the computer aids in manufacturing is the need to reduce costs.

The second incentive is to only produce for the market, when the need arises, to minimize the cost of funding stock.

The third requirement is to respond quickly to change, either because of technological advancement or because of improvements in quality or lowering of cost by competition, providing the capability exists to quickly respond by change to design and production process. To this end the trend towards small specialist units with computer aids enabling quick changeover is becoming increasingly evident in manufacturing companies of the industrialized countries.

Because of the importance of computers in manufacturing, an explanation will be made of the developments in control systems in section 2.4 and associated manufacturing aids, beginning with definitions of the current abbreviations in use, in section 2.2, up to and including computer aided design and computer aided manufacturing. These will pave the way towards planning for modern machine tool manufacture by taking advantage of available technology and leapfrogging the conventional manual techniques of previous years. The development of computer numerical control (CNC) is seen to be a catalyst which has precipitated the present technological wave in the use of computers in production engineering, consequently much of the following text will be devoted towards CNC and the attendant benefits. In chapters 3 and 4 it will be shown how step by step progression may be made in developing countries by incorporating CNC machine tools and their associated computer aids in production engineering, for manufacturing industries, without necessarily incurring long programmes of education, training and funding.

2.2 Definitions

Throughout this paper there is frequent reference to the abbreviation n.c. in relation to what may be loosely described as a family of control systems, in association with various types of machine tools. It is, therefore, necessary to define a little more precisely what is meant by n.c., both in general terms and in the context of this paper, progressing to Computer Aided Design (CAD) and Computer Aided Manufacture (CAM).

(a) Numerical controlled machining (n.c.). An n.c. system may be summarized by stating that it is a manufacturing process controlled in a fixed repetitive way by numerical form of input.

(b) Computer numerically controlled machining (CNC). Individual machine tools which use computer controllers to store and perform operating instructions (e.g. selection of cutting tools, speed and feed rates) with manual loading and supervision (one operator may attend more than one machine). These machines can process accurately a sequence of different batches with low changeover time between products.

A CNC system is basically an n.c. system which is flexible because a computer replaces the fixed logic which forms the heart of an n.c. system and it may thus be programmed to accommodate a variety of changes relevant to the machine type or machine use.

(c) Direct numerical control (d.n.c.). A d.n.c. system relates to the linking of a number of n.c. machines to one central computer, which in its simplest form may be little more than a sequencer and data bank for storing part-programmes and in its most complex form may be extended to include the house-keeping and control functions of individual machines.

Each of the above n.c. or CNC control systems can control one machine or several different machines, but for multiple machine control and supervision the d.n.c. system is relevant. Early examples were Mollins systems 25, the Sunstrand system and the Okuma parts centre. In these the various shop operations such as turning, milling, hardening, grinding and measuring are performed in a matter of minutes by locating specific machines to each stage, linking them by means of conveyor and automatic work changers and controlling them through one central CNC system based on a mini-computer.

(d) Flexible machining system (FMS). Two or more machine tools, linked by an integrated parts handling system and operating under the control of a computer. The control system can route parts between machines so as to achieve, for example, maximum spindle utilization or minimum lead time.

FMS is a development of d.n.c. whereby the use of computer numerical controlled machines enables parts to be machined in groups, changeover between one type of component and another being carried out automatically under control of a central machine tool controller.

(e) Computer-aided design and draughting (CAD). A computer based facility for the design of engineering components and assemblies, using specialized software packages and data files. Applications are currently applied to general assemblies and layouts, perspective views and diagrams used in tendering, subassembly design, detailed piece-part design, jig and fixture design, parts lists, engineering calculations and improved standardization of components and tooling.

(f) Computer-aided manufacture (CAM). A system which supports production engineering by defining operating sequences and part routing, creating control tapes for CNC machines, establishing requirements for fixtures, tooling, etc. and simulating operations prior to first-off machining.

(g) Computer-integrated manufacture (CIM). The concept of a totally automated factory in which all manufacturing processes are integrated and controlled by a CAD/CAM system. CIM enables production planners and schedulers, shopfloor foremen and accountants to use the same data base as product designers and engineers.

Additional computer aids for the management of a manufacturing operation comprise:

(a) Computer aided process planning (CAPP). An off-line computer system operating from a common data base handling set-up and run process times for individual operations.

(b) Computerized inventory control. An on-line computer-based system operating from a common data base and handling bills of materials, materials requirement planning, inventory recording and control and purchase ordering and control.

(c) Computer-aided production management (CAPM). An on-line computer-based system operating from a common data base and handling manufacturing instructions, operating sequences, shop loading and scheduling, work-in-progress monitoring and despatch procedures. The more advanced systems incorporate product costing and variance analysis. Together with computerized inventory control, this forms a complete computerized manufacturing control system.

(d) Automated stores and parts issue. A control system which, under computer management, places parts and materials in storage locations and later delivers them to work stations in the machine shop or assembly area. In most companies, these systems include conveyors, high rise automated stores, stacker cranes or robot trucks and automated routing.

(e) Automated assembly and test. Unlike the machining technologies, which apply specific solutions to industry-wide functions, this category covers a range of assembly and test aids in which specialized equipment and techniques are used in different sectors of industry. In some cases relatively simple improvements in assembly and component handling are appropriate; in others, major investments in mechanized assembly and automated test equipment are needed. Some companies may include robots; others may need large automated test-cells.

2.3 Tooling technology

Tooling technology embraces materials, mountings and the attendant physics relating to the interaction between tool tip and workpiece.

Equally important to basic machine tools are the tools themselves. Originally the simplest metal cutting tools were made of high carbon steel which could be re-ground and reset by the operator, indeed manually operated machines still rely on this method. With the advent of semi-automatic, sequence control, numerical control and computer numerical control systems the tooling technology has progressed from simple re-usable tools, pre-set tooling, qualified tooling with sintered throwaway tips, to qualified automated replaceable tooling systems for unmanned operation.

2.3.1 Materials

Modern tools are based predominantly on sintered technology and include:

- Tungsten carbide
- Ceramic
- Boron nitride
- Diamonds.

These materials enable high metal removal rates to be achieved on high strength steels. The first hard metal was pioneered by the Federal Republic of Germany with the development of tungsten carbide.

2.3.2 Tool holders

The simplest tools used on machine tool lathes, drills and milling machines were made from carbon tool steel, to be followed by chrome molybdenum alloys or high speed steel. These tools were re-ground and reset as they developed wear. With the advent of sequence controlled machines and in an effort to reduce set-up time and changeover time necessary to obtain economical small batch manufacture, a system of pre-set tooling was pioneered by Alfred Herbert of Coventry. In this system, secondary tool holders were used in which the tool proper was set accurately in a special jig and shadowgraph to position the tip to an accuracy of 0.02mm. This enabled sets of tools, for example for a turret lathe, to be prepared away from the factory floor and held in readiness for a particular component.

The development of numerical control heralded a further development, the concept of qualified tooling using standard tool lengths and special tips secured by a single screw fixing, which could be rotated to one of several positions, each with a new cutting face.

Finally there is the current development of quick change tooling for unmanned machining. One of the most widely publicised is the Sandvik block tooling system which incorporates means for clamping a tool in a special holder which may be operated on demand from a CNC system, a new tool being supplied from a tool-changer.

2.3.3 Milling cutters

The clamping systems on milling cutters equipped with hardmetal indexable inserts in most cases are relatively complicated. They require superstructures which hamper a free chipflow (clamps, sharp edges etc.) and which considerably reduce the space needed for a smooth chip formation. The operator may therefore have to reduce either the cutting speed, the cutting depth or the feed rate in order to obtain satisfactory results.

There are two fundamental concepts around which cutting tools for milling are structured - positive geometry and negative geometry.

2.3.4 Upmilling/downmilling

Upmilling or normal milling is normally applied when using light duty machines, for a given workpiece. Upmilling requires more horsepower than downmilling but, due to the resistance of the cut, no snatching or pulling of a cutter into the workpiece occurs. Small light duty machines generally have no lead screw backlash elimination, hence the necessity to use conventional or upmilling methods.

This method of machining gives an inferior surface finish, necessitating fine feeds with high speeds to overcome the cutting resistance. A tendency to lift the workpiece from the table occurs.

Downmilling or climb milling necessitates rigid machines equipped with backlash elimination to the lead screw, alternatively, CNC machines with the ball screw arrangement. The cutting operation presents less resistance than conventional milling, the rotation of the cutter aiding the cutting by pulling into the workpiece. The swarf starts at the maximum thickness then diminishes, whereas conventionally it starts small and then increases.

2.3.5 Effect of tooling on machine design

Undoubtedly the developments in harder cutting materials have influenced the design of modern machine tools in terms of:

- Mechanical stiffness
- Anti-backlash axes drives such as ballscrews used in CNC machines
- Variable speed spindle drives as used in CNC machines to keep the cutting surface speed constant
- Tool changing facilities for continuous, semi-manned and unmanned operation.

The main conclusion to be drawn from this appraisal of tooling technology is that manual machines, designed for use with solid high speed steel tooling cannot compete in terms of stiffness and spindle power with modern computer controlled machines equipped with automatic tool wear, monitoring and tool changers which are designed for continuous heavy duty operation. It is questionable if the automation of conventional machines can be economically justified but limited semi-automatic aids may be considered effective.

2.4 Machine control systems

There are three groups of automated machine tools requiring control systems:

(a) Semi-automatic. The role of the operator is reduced by supplementing manual tasks by electric hydraulic or pneumatic assisted operations.

(b) Fully automatic, including sequence controlled machines. Further to the above power assisted functions there are means of sequencing the machine automatically. Such machines tend to be special purpose machine tools built to carry out a specific sequence of operations, making the maximum use of fixtures and tooling. They are very expensive and can usually be justified only for the mass production of consumer durables.

(c) Numerical control, including computer numerical control. To meet the need for a versatile machine tool which can quickly and economically produce a few components of a particular kind, numerically controlled machine tools have been developed in which there is virtually no tooling at all. All the necessary movements required to machine the component are performed automatically by the machine itself, in response to numerical information fed to it in coded form on punched paper or magnetic tape.

The development of numerically-controlled machine tools has made it economically possible to produce a wide range of components in batch quantities by completely automatic methods. The advent of the mini computer has enabled such machines to be even more versatile.

2.4.1 Types of control systems

Irrespective of the level of automation required in the three groups above, to automate operation of a metal cutting machine such as a lathe, miller, drill and so on, it is necessary to:

- Control each individual operation; and
- Control the sequence of operations.

Increased productivity from conventional machine tools can be realized by introducing quite cheap electrical, hydraulic, or pneumatic devices to act as substitutes for manual operations.

The most versatile and productive machines in use today are computer numerical controlled machines.

There are many advantages of introducing sequence control:

(a) There is invariably a reduction in the time required for a whole operation; operations can overlap, a tool can be changed at the same time as the spindle speed and both the turret and cross slide can operate simultaneously. If several machine tools are fitted with sequence control then inevitably there will be a saving in labour.

(b) Controlled speeds, pressures and feeds result in improved accuracy and finish and reduce the number of rejects.

(c) Tool life is increased.

In general the saving of time on lathe work is often from 25 to 50 per cent.

In recent years considerable advances have been made in the field of part-programming techniques, the use of microcomputers for simulation and prove-out tapes and the move towards even higher-level programming languages which enables interpretation of drawing information and makes conversion to machine language more simple. The advent of computer numerical control leads to even greater scope in this direction, with the objective of linking design with the manufacturing process through the medium of CAD.

Part programming problems are a combination of multiple axes considerations, e.g. machining centre, geometrical considerations of a component and machine, tooling configurations and cutting technology. Much work has been done to simplify part-programming languages and much useful work in recent years has been directed towards formalization of terminology and procedures for compiling part programmes. The most advanced techniques require only the specification of the finished part dimensions and type of material used; thereafter special computer programmes generate step-by-step cutting data even to the point of deciding how many rough cuts should be taken and to what roughing sizes.

2.4.2 The use of micro-computer for numerical control - CNC

Although CNC systems were originally developed for metal cutting machine tools such as machining centres and turning lathes, they are applied universally now to all types of machine and work handling systems:

- Metalcutting, forming, punching, drilling
- Welding
- Painting
- Robots
- Conveying systems.

There are several points to remember:

(a) While the problems of positioning mechanical devices can be solved by standard electro-mechanical or electro-hydraulic servo mechanics, the computer does not know whether it is driving a machine tool or a robot. It is the executive programme of the computer which describes how the machine has to be powered.

(b) The executive software programme is designed by the machine tool control system supplier and stored permanently in the memory of the computer, whereas the part programme is compiled by the user and may be stored, edited, replaced or destroyed at the discretion of the user.

(c) In general, a computer accounts for 30 per cent of the total system in terms of hardware complexity. The remaining 70 per cent is made up of interfacing, power supplies, cabling transducers, etc. If one excludes machine tool positioning and feed drive system, the computer accounts for about half of the control system and the interface accounts for the greater part of the remaining half.

(d) The computer can be programmed to detect faulty conditions on the machine in addition to controlling the machine and indicates such faults by means of a special code number or error message which is flagged on the visual display to tell the operator where the fault is. It can be deduced which part of the control is faulty and the decision can be made whether to replace the defective part or to change the control system for a new one: the system can be unplugged from the machine if required.

2.4.3 Interactive graphics - CAD aids

The use of a standard system of coding for part programming has influenced recent developments in applying computer graphics to aid the programmer. Such systems are referred to as interactive graphic systems because the operator may now programme the CNC system by reproducing a drawing on a visual display and entering the dimensions, tool stations and material. The computer does the rest. On early systems, the CNC system was equipped with a secondary graphics computer which processed the drawing information in terms of roughing and finishing cuts, tooling technology such as feeds and speeds and communicated with the CNC system at the tape reader interface in ISO code in the usual way. On more recent systems, however, a high level language is used which enables part programmes to be edited and corrected and a new tape to be produced in ISO format if required.

2.5 Manufacturing systems and production engineering

This section reviews how computer aids assist the principal functions of a manufacturing business:

- Controlling the business
- Engineering the product
- Computer-aided production management
- Production quality control and test
- Data storage and communications.

All manufacturing businesses require a master schedule. The master schedule is the key document for the executive management of the company. It represents the strategical links between the chief executive and principal functional heads, showing what is going to be achieved and when. Strict disciplines must be established to determine who can make changes to the master schedule and when. The master schedule is one of the two key drivers of the business. The other is the Bill of Materials (BOM) which determines what has to be made for each product or individual order.

In an integrated system, all production management data held in the system are available on-line and in real-time. They will show the BOM at its current correct status. Recording each shop operation will indicate also the current state of completion of all components. Work-to lists for production shops, or assembly shortage lists will be available on-line and can be issued in document form if required.

For these reasons, it is essential to locate terminals at convenient points throughout the shopfloor, stores, purchasing and quality control departments, as well as graphics terminals in the engineering and CAM departments. Systems with these capabilities will permit levels of management control to be established which were inconceivable ten years ago.

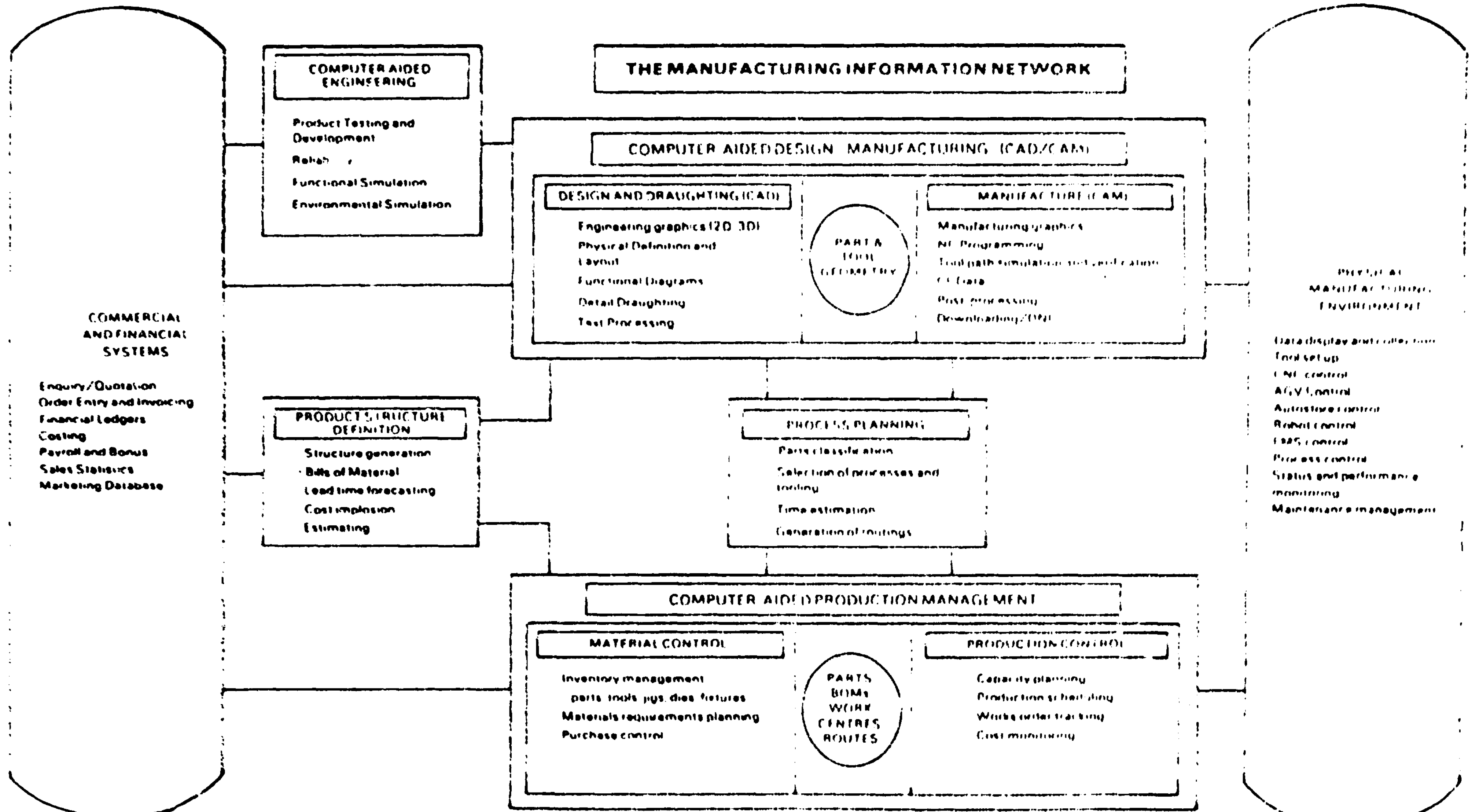
The engineering of a product to meet a customer's requirements is a complex process involving many skilled and experienced specialists. In addition to extensive opportunities for work processing, the principal areas in which computer aids have been developed to assist the engineering function are:

CAE - Computer aided engineering
CAD - Computer aided design and draughting
CAM - Computer aided manufacture
CAPP - Computer aided process planning
CAPM - Computer aided production management.

The fundamental point which makes integration of the first three so beneficial is that they all require a geometric model of the product or components. At present the graphical model is first created in the drawing office as a paper drawing; it is then used by the others for their own work. This usually involved redrawing the same item many times. If the original model can be created on a computer then it can be accessed by the many users.

Figure 1 refers to the areas where computer based systems are available.

Figure 1. Computer aided manufacture



3. TECHNOLOGICAL REQUIREMENTS IN DEVELOPING COUNTRIES FOR ENTRY INTO THE MACHINE TOOL INDUSTRY

3.1 Criteria for the selection of machine tools

Generally speaking, workshops may be divided into three categories:

(a) Small job shop. E.g. small business employing up to twenty persons.

(b) Light mechanical engineering. Company employing up to one hundred persons making one or more product lines.

(c) Large company. Autonomous manufacturer or divisions of an international group of companies making large capital goods.

Mention has been made in section 2.2 of the important role played by the modern CNC machining centre. Requirements for such a machine and the technical features required are illustrated in table 1.

Where favourable conditions exist for the manufacture of machine tools which are technically and financially competitive in world markets there may be a strong incentive to set up high volume manufacturing facilities. The high capital cost of these and the attendant risk would have to be balanced by other forms of returns on investment.

The factors influencing the strategical issues outlined above may therefore include:

- Raw material supplies
- Specialized equipment supplies
- Power
- Designs and standards
- Licence deals
- Technical and management staff

Table 1. The structure of machining centres

	Small job shop	Light mechanical engineering	Large company
Products	Low accuracy parts	Own products e.g. pumps, valves	Complex parts e.g. dies, turbine blades, contoured parts. Making sets rather than individual components
Volume	Low to medium	Medium	High
Machine utilization	Low	Medium	High
Key requirements	Low price (low cash requirements)	Co-ordinated production engineering and manufacturing	Off line programming and testing
	Shop floor programming	Ability to produce difficult features and tolerances	Standard tooling
	Low tooling-up costs	Operate with simple production control systems	High accuracy
	Quick response time (simple tools, quick programming)	Bed type	Controls ability to deal with complex features
	Knee or bed type	Integration into a cell	Large tool changer, pallet changer
	Stand alone		Integration into a system - D.N.C capability

- Marketing
- Transportation
- Funding.

3.2 Inputs required

The primary input requirements are raw material, specialized equipment and power.

3.2.1 Raw material and specialized equipment

The most popular raw material for making machine tools is cast iron. This must either be produced locally, imported or some alternative form of construction be designed to minimize the cast iron content. To produce castings of adequate quality and quantity is a major undertaking because in addition to supplies of iron ore or pig iron large amounts of power are needed for heating the furnaces in terms of electricity, l.p. gas or oil.

Specialized steels for moving parts of the machine such as spindles and slides are required in small quantities but to strict quality standards.

Modern machine tools (and indeed the early conventional manually operated machines) are heavily dependent on electrical equipment such as main motors, axes feed drives, pumps, contactors, switch gear and electrical wiring.

3.2.2 Power

In addition to the power required to operate furnaces there is the need to supply sufficient power to run the machine tools which are required for manufacturing. It is not generally realized that a modern CNC tool such as a lathe or machining centre for example will require anything from 20-100 kilowatts - sufficient to light a small village in many developing countries. To be fully productive, a modern factory should be capable of running three shifts for 24 hours a day, thus the power supplies are required to be dependable and on tap whenever the occasion demands.

3.3 Designs and standards

3.3.1 Designs

Designs of machine tools have evolved during the last two decades into two broad groups:

- Traditional manually operated machines
- Modern CNC machine tools.

In the case of the manually operated machines they are characterized by their inherent simplicity e.g. rigid structure, usually cast iron, incorporating a constant speed maindrive motor with gearbox for speed selection and manually operated lead screws for actuating the tool slides.

The modern CNC machine tool, on the other hand, while appearing to be superficially similar in configuration and using a similar rigid structure, is radically different in the drives and control area because of the complete dependence on electric actuation. The main drive motor is a sophisticated D.C. or A.C. variable speed drive, the multi-range gearbox is reduced to two speeds or eliminated entirely and the axes are powered by variable speed D.C. or A.C. drive motors driving precision ball screws to eliminate backlash.

3.3.2 Standards

(a) Requirements

The majority of machine tool builders (excluding American manufacturers) make machines to metric dimensions and:

- European I.S.O.
- English B.S.
- German D.I.N.
- Japanese J.M.T.B.A. standards.

There are universally recognized I.S.O. standards for:

- Main spindle power rating
- Chuck sizes
- Spindle nose sizes
- Tool holders (square section and tapers).

Additionally, there are Safety Standards and/or Codes of Practice relating to machine safety and electrical performance and construction of which the most significant in the United Kingdom are issued by the Machine Tool Trade Association (MTTA).

When exporting to foreign countries it is important to study specific standards for approval of electrical equipment for example:

- Canada - Canadian Standards Association (C.S.A.)
- United States of America - Underwriters Laboratories (U.L.).

(b) Legislation

Considering the importance of all these standards, which of necessity have been compiled over many years, it is essential to institute a national means of establishing a standard compatible with international requirements for materials, manufacture, electrical equipment and health and safety as a minimum pre-requisite to the manufacture of machine tools. Experience in the industrialized countries suggests that it is one thing to set up or adopt existing standards and publish them - it is quite another matter to enforce them and it may take several years of legislation and persuasion to take effect.

3.4 Licence deals

Undoubtedly the quickest way to enter the machine tool industry is through agency arrangements, progressing from sales to service and then to licence for assembly (knock-down kits) and further full manufacture.

In the case of licence deals, there are a number of ways in which these may be structured:

(a) Straightforward assembly from kits. Limited technological transfer on existing (frequently dated) designs.

(b) Manufacture and assembly to existing designs:

(i) For sale in country of licensee;
(ii) for sale in export markets by licensee and/or licensor.

(c) Joint venture company with full technological transfer and design/development content.

Because of continually changing technology and market forces, the best deal is undoubtedly a joint venture company in which the participants share the investment, profits and risks of the enterprise.

On the question of patents - there is a move towards honouring patent arrangements between trading countries. Fees for licensing vary considerably depending on the scale of involvement by the principal and may range from one or two per cent to ten per cent of sales value. In practical production terms, a set of manufacturing drawings, planning sheets, tools and fixtures is more valuable in the short term.

3.5 Human resources

Human resources are probably the most important factor to establish a machine tool industry because of the continuing process of innovation and application engineering which typifies the industry, coupled with purchasing flair for sourcing specialized equipment from suppliers worldwide.

With the advent of modern CNC machine tools and computer aids now used for manufacture of the main components of machine tools, many of the traditional skill dependent operations have been eliminated - even down to inspection and test. The machine tool operator for example, now tends to be superseded by a part programmer, save for changing tools, material and unloading finished components. Modern CNC machines, once correctly programmed and set up, machine components to tolerances barely obtainable from hand operated machines twenty years ago.

3.5.1 Semi-skilled workers

Basic requirements for semi-skilled workers in machine tool construction include:

- Material movement
- Machine operation
- Loading and unloading operations
- Fitting and assembly
- Wiring and test.

As a minimum they require skills in working hand operated machines, measuring instruments and reading engineering drawings.

3.5.2 Skilled workers

Tasks normally associated with skilled workers include:

- Machine calibration
- Tooling set up and machine demonstration
- Preparation of n.c. tapes
- Part programme preparation on interactive CNC systems
- Customer training
- Commissioning of electric drives and CNC systems including diagnostics
- Production planning including the use of computer aids for process planning
- Conceptual design including detailing for production, including the use of CAD.

As a minimum they require to be educated to technician grade, be capable of reading, preparing drawings and specifications, carrying out mechanical/electrical calculations and be conversant with tooling technology as appropriate to their speciality. For programming and operation of CNC machines training is required to familiarize the technician with the machine functions and programming language.

3.6 Repair and maintenance

3.6.1 Repairs

Repair and maintenance of machine tools require similar aptitudes and skills to those of the machine tool builder. There are three main elements of resources which are essential.

(a) Data

- Complete documentation for the product including handbook;
- Recommended spares, part schedule, diagnostic (trouble shooting) handbook.

(b) Skill

- Qualifications (technical and practical) in related subjects;
- Aptitude for troubleshooting;
- Ability to work without supervision;
- Competent to completely service the machine, test and calibrate to original specification.

(c) Equipment

- Standard tools of trade for mechanical, electrical and hydraulic desciplines as required;
- Specialist tooling as required for the dismantling of a particular component;
- Test and calibration equipment.

3.6.2 Maintenance

It is customary for machine tool builders, in collaboration with specialist control system and drive suppliers, to offer annual service contract facilities. These involve the payment of a lump sum to cover a fixed number of service calls per year on a 24 hour call basis for home based machines.

With the high productivity obtainable from modern CNC machine tools, a breakdown has a more direct impact on the production programme for a company than that of a conventional hand driven machine where a substitute machine can more readily be utilized while the fault is rectified. Coupled with the mechanical failure, which can be rectified by the traditional mechanical maintenance engineer, is the problem of servicing several complex electric, electronic drives and a CNC system.

Where more than one machine of a given type is purchased there is a strong argument for self-sufficiency in terms of trained human resources and spares stocking but the economics of self service need to be carefully weighed against the cost of a service contract where specialists and parts can be made available on demand and only paid for when required.

3.6.3 Service strategy

The importance of service is fully recognized by major machine tool suppliers, who offer single source service for both machine tool and CNC system. In the case of exporting machines, the usual route is through agencies handling similar types of machines and systems.

3.7 Economics of machine tools

The growth of CNC machine sales and their vital role in cost effective manufacturing, particularly for metal cutting operations, make it natural to examine the rationale behind the purchase and/or manufacture of this class of machine.

Economic aspects of machine tools include:

- Justification of purchase
- Depreciation
- Finance.

3.7.1 Justification of purchase

The classical method used to justify the cost of purchase of a machine tool is to assess the productivity of the new machine in terms of numbers of parts produced and compare the result with the replacement cost of the machine and the productivity of that machine. However, this method ignores two powerful strategic issues which go beyond productivity.

(a) Market

Market forces require deliveries to be made in a shorter time than the deliveries offered by the competition. There must be the capability to literally make parts to order in the shortest possible time. It must be possible to quickly break down machine tools from one job and re-tool a new job, frequently in small lot sizes. Quick delivery can mean the difference between receiving orders or not, a situation which can directly affect the survival of the business.

(b) Inventory costs

The high cost of inventory - typically 15 per cent in the industrialized countries - means that economic batch quantities necessitated by the volume of parts required to justify the long set up time of traditional machines can no longer be afforded in a highly competitive world market. Thus a new CNC machine tool which offers the capability to make parts on demand, as economically for 1 off, 10 off or 100 off will enable inventory and more importantly, the cost of funding inventory to be minimized.

In view of the above considerations, it is not uncommon nowadays for the purchase of CNC machines to be justified on the basis of savings made in the reduction of inventory and work in progress alone.

Additional arguments in favour of computer controlled machines are sometimes based on savings in operators. This is because a modern CNC turning lathe is capable of the output equivalent to four manually operated lathes, saving 2 operators. This is mainly because the machine can run largely unattended for 2-3 shifts with consistent quality and dimensional tolerance. Similar arguments favour the use of CNC machining centres which combine conventional milling and drilling operations. A modern CNC machining centre equipped with tool changer operating 2-3 shifts may replace four conventional milling/drilling machines, thus saving two operators.

3.7.2 Depreciation

Attitudes are changing when calculating the payback/depreciation of modern CNC machine tools. Capital plants depreciate at a relatively slow rate, typically 5-10 years. In the case of a high performance machine there is a move towards working them to maximum capacity and dumping them when their useful working life is approached, albeit accelerated by high usage. In industrialized countries it is quite common for a maching to pay for itself in two years and a one year payback is not uncommon.

3.7.3 Finance

One increasingly popular way of financing the capital purchase of machine tools is through leasing companies who specialize in funding the capital purchase of machine tools and leasing them to the user in the form of a rental. There are two significant benefits to the user:

(a) Capital is not tied up in plant and machinery and may, therefore, be deployed in funding work in progress or profitable business ventures.

(b) The rental payments may be treated as revenue expenditure by taxation authorities and are deductible as a legitimate operating cost from the profit and loss account.

3.8 Strategy for forming a machine tool company

Before discussing the strategy for the formation of a machine tool company having the capability to make CNC machines, it is appropriate to review the basic characteristics of conventional machines versus CNC machines. These are illustrated in table 2.

A typical breakdown for works cost of a CNC machining centre is shown by means of a pie chart in figure 2. Clearly the high bought in content comprising specialized electrical equipment demonstrates the shift in emphasis between the conventional machine tool factory and a modern factory making CNC machine tools - the latter may comprise little more than a fitting, assembly and test department - all mechanical items may be sub-contracted to non-machine tool job shops, reserving only final machining for the parent company. Thus the capital investment for starting up a modern CNC factory may be considerably less than the capital required to create a conventional machine tool company with predominantly mechanical engineering disciplines, but the working capital may be greater. The chief buyer can exert a powerful influence on the cash flow by negotiating favourable credit terms with suppliers of bought out equipment, in particular the drive systems and CNC system.

There are a number of preparatory steps which require to be taken to implement the creation of a new factory. These steps are explained in the next points.

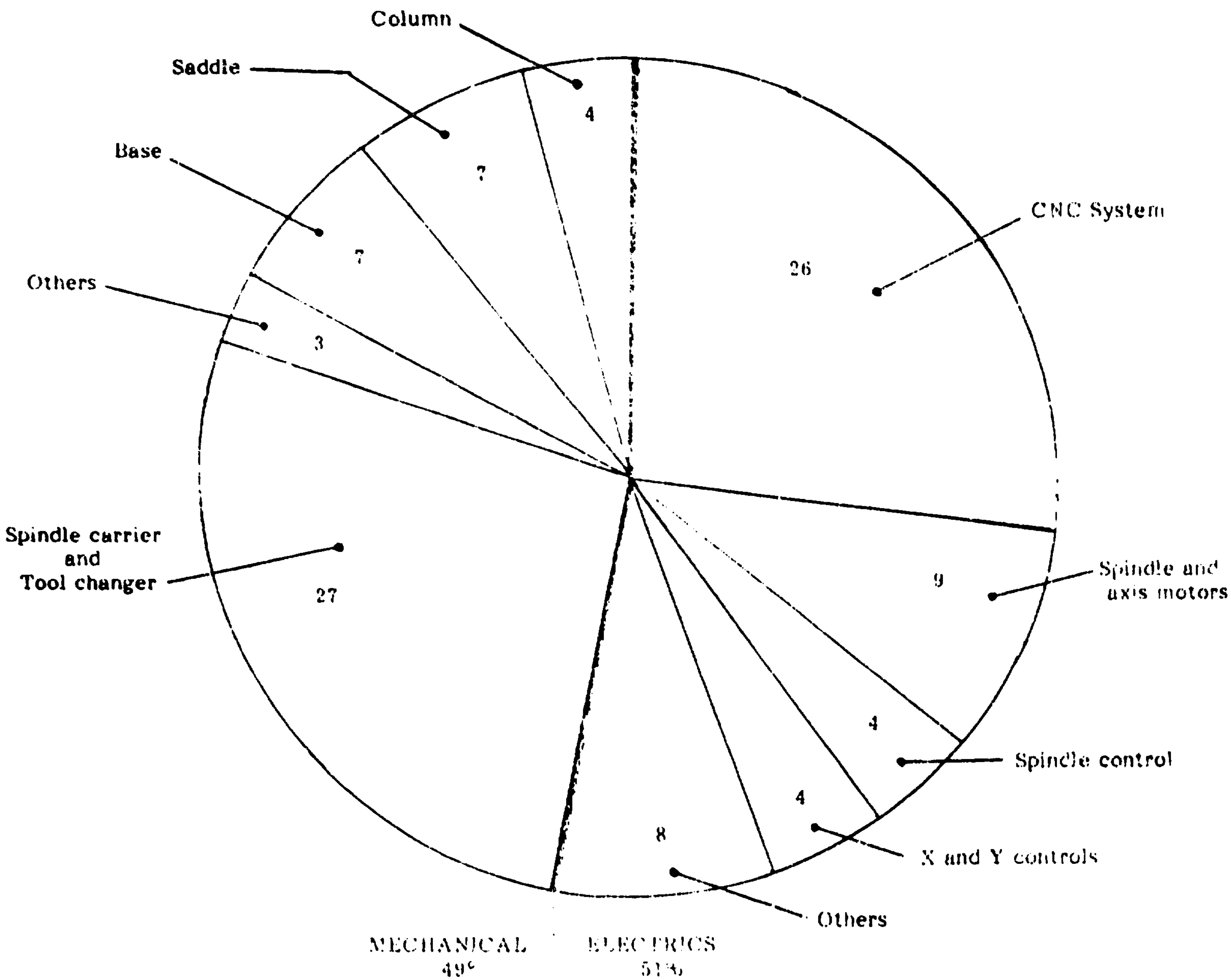
3.8.1 Feasibility study

A well documented feasibility study is required for planning the implementation of the system. The feasibility study should include, for example:

Table 2. Conventional machine versus CNC machine - basic characteristics

Features	Conventional machine tools	CNC machine tools
1. Material and labour	Intensive, predominantly: - Cast iron structures - Dependent on gear drives - Constant speed drive motor.	Specialized content consists of 50 per cent of the work cost and comprises electrics, drives, computer, usually bought from several suppliers.
2. Structure	Comprises 80 per cent of the works cost.	Cast iron structure, variable speed D.C. or A.C. drives. Little or no gearbox. Structure accounts for 50 per cent of the works cost.
3. Manufactured content	Large. All parts made in house including castings and all machining, including many gears.	Small. All component parts may be sub-contracted except for finish machining.
4. Management structure	Classical. People oriented. Works manager is totally accountable for production.	Project management structure, equipment oriented i.e. the electrical buyer carries similar responsibility as the works manager for production.

Figure 2. Breakdown of works cost - CNC machining centre



(a) Adequate engineering description of the plant to be constructed and controlled;

(b) The architecture of the production system and basic data flow diagrams;

(c) The sequence of modular implementation and timing which has been selected as practical and which lies within the scope of available resources;

(d) The availability of software to be included in identification of any areas where special software development is necessary, but remembering always that the plan must retain flexibility;

(e) Identification of human resources to firstly build the factory, then to run it.

Once the feasibility study team has confirmed the viability of the solutions in engineering terms, attention is focused upon total cost; this will be made up to capital implementation cost and the total time required for implementation.

In the case of a feasibility study where recommendations are not based on specialist implementation input, particular care should be taken in the consideration of items such as:

- Procurement time
- Equipment commissioning durations
- System integration and commissioning durations
- Costs and time required for interfacing different equipment
- Service requirements.

Normally, implementation costs, irrespective of whether specialist consultants, in-house resources, or a combination of the two are used, will be between 10 per cent and 20 per cent of capital cost, depending on the particular features and circumstances of the project. In an advanced manufacture project, however, it will be necessary to allow an additional 5 per cent to cover extensive education and training programmes.

3.8.2 Detailed planning

When the feasibility study has been successfully completed and a recommendation accepted, the concept planning of the feasibility stage changes to the detailed planning necessary to proceed. The planning process moves through functional to detail specifications, enquiry documents, vendor evaluation, contract negotiation and order placement. Problems often arise because this planning phase is frequently inadequate and the time pressure pushes project leaders into making decisions and commitments before the problems have been thought out.

It is crucial to allocate the necessary man-hours to achieve the required level of detail. Failure to do so will result in problems. It is not always possible to back-track during the later phase of the project without considerable cost. What is required is original thinking rooted in practical experience; a preparedness to work through every protocol and form in the system in detail coupled with an understanding that the on-site commissioning and system integration will be major tasks. At the detail level, the general planning phase includes the production of:

- Specifications
- Enquiry documents
- Contracts
- Acceptance procedures.

The success of the project will be directly related to how thorough, practical and accurate they are. Ambiguities and omissions in specifications are a major source of claims, cost over-runs and delays during implementation.

The definition process should normally commence with the production of a systems functional specification - a description in plain language of the functions which the equipment must perform. This will be converted to a specification defining the various elements of systems.

The functional specification, which defines how each element in the user specification will be achieved, must be examined by the project team and signed off page by page. This will concentrate the team's attention on the interfaces and details and eliminate many potential problems.

Good acceptance procedures are precise in their definitions; the production of a specific number of components to specific quality in a defined time should be supplemented by other relevant features such as reliability, noise level, accessibility and setting times. Similarly, with computing systems, not only should their functions be proved, but their ease of use, clarity of documentation and information security should be well defined. It is fundamental to include agreed acceptance procedures in the contract in order to control the duration of the final stages of implementation.

3.8.3 Implementation

When contracts have been placed, the attention of a project team will focus upon the preparation of the location, design approvals and expediting contracts.

The expediting process, in conjunction with the design approval, is the way in which contractors are managed and, if carried out effectively, can produce great benefits. The objective of good expediting is to ensure that the contractor meets the requirements of the contract. A successful technique is constructive and authoritative. It is true that there are a number of contractors and suppliers with admirable records for on-time delivery of top quality equipment, but they are, regrettably, the exception rather than the rule. Successful expediting also provides the information base which is essential to the integration of the equipment into the total system.

After installation of new plant and equipment, there are generally three stages of implementation, commissioning, acceptance and productivity audit:

(a) Commissioning

Commissioning of specific equipment can be straightforward, particularly with equipment supplied by established manufacturers using experienced installation teams. Problems can arise, however, firstly with state-of-the-art equipment where the suppliers' commissioning engineers have limited experience and, secondly, with the interfacing of different pieces of equipment with each other and with control systems. It is the areas in between that put the greatest demands on the project team and, as industry moves into areas of higher technology, including FMS and CIM, the need for skilled control and system engineers is much increased.

(b) Acceptance trials

The acceptance of hardware and software will be on a progressive, module-by-module basis, with the validation of each set of interfaces completed before proceeding to the next module.

Acceptance trials, when commissioning is complete, should be straightforward but this happens only when clearly agreed acceptance procedures are available.

(c) Productivity audit

The final phase of the project, when production is underway, is the performance audit required to confirm that the original concept has been achieved and its objectives met.

Two elements are required to manage the project through its separate phases:

- A detailed plan
- Adequate resources.

To attempt implementation without these will reduce significantly the chances of success.

For small-to-medium sized companies, starting from scratch, a period of three to six months will be required before implementation can begin. This preparatory phase will take place during the late stages of the feasibility study, in parallel with project approval. The objective is to be completely ready to commence implementation upon receipt of project approval.

Early in the feasibility work it is necessary to establish key milestone dates. The objective is not to compromise the thoroughness of the early stage, but to compel people to start thinking about the medium and long term implications. It also helps to avoid becoming obsessed with trying to achieve the impossible and highlights areas for contingency action. Typical milestones for a project are shown in figure 3.

A timing plan that is specific to the project in question must therefore be developed and each element carefully evaluated so that its duration can be determined. Features which will affect the timing plan include:

(a) The starting point in each of the disciplines, which will depend on what early development has already taken place;

(b) The logic of the sequence of modules of implementation, which will to some extent determine the overall timescale.

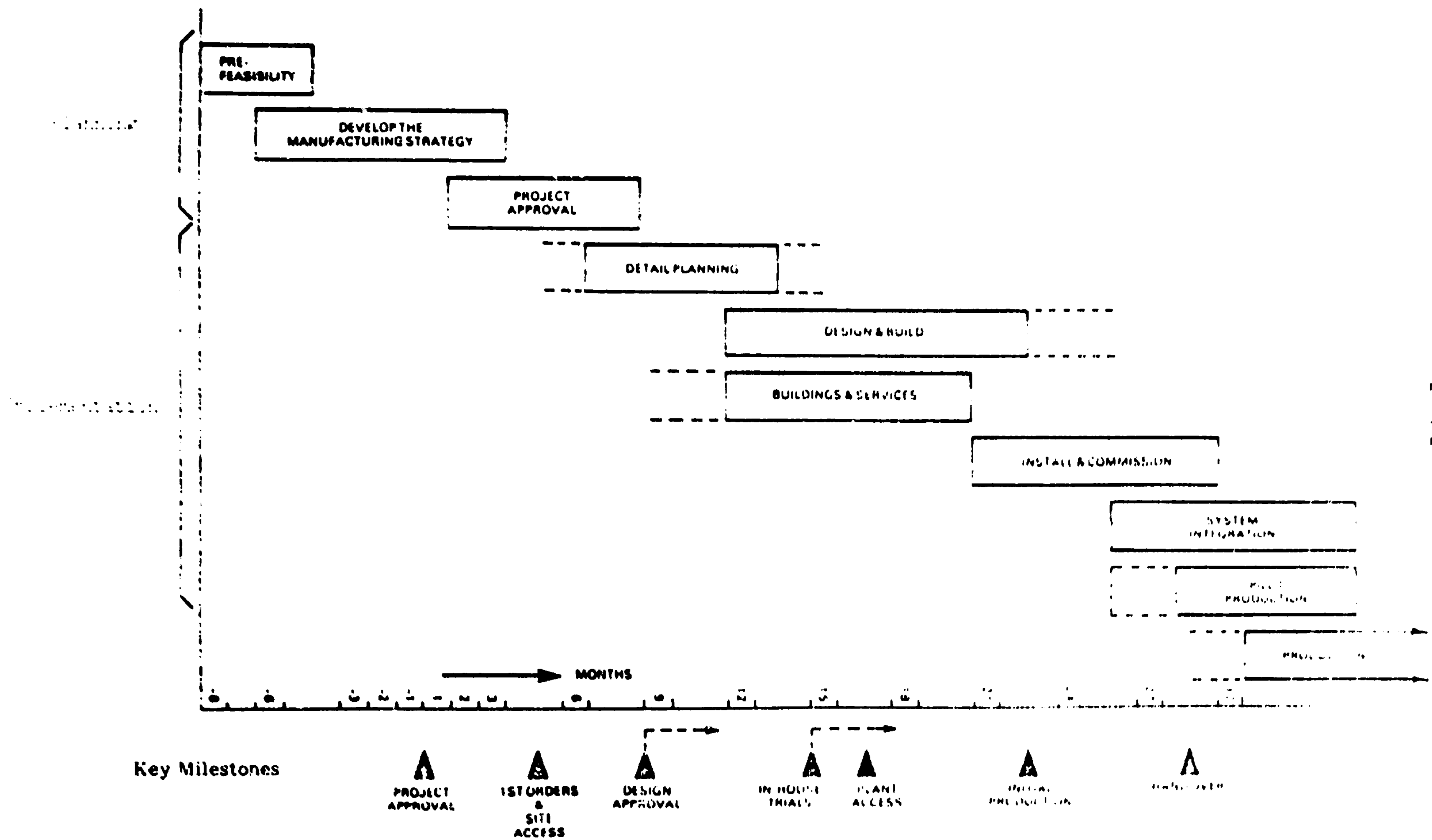
3.8.4 Investment requirements

To assess the level of funding required, detailed budgets must be compiled. Budgets will normally take the form of a hierarchy:

- Base budget
- Project cost summary
- Project cost breakdown.

At the feasibility stage most quotations and estimates are budgets; they are normally also at current prices and delivery periods. The base budget should include an amount for the anticipated financing and delivery time at

Figure [illegible]. Project planning milestone events



the likely date of purchase. This is particularly important for projects extending over more than one year. Major cost categories are listed below:

Category	Decription
1	New production equipment
2	Workflow and handling systems
3	Refurbishment and re-location of existing machines
4	Operation control and business/engineering systems
5	Support services
6	Buildings and civil constructions
7	Mechanical and electrical
8	Resource costs
9	Extraordinary items
10	Contingency

The budget should also list all items included within the overall business systems architecture:

- Computer equipment and operating software
- Business information systems software
- Computer aided engineering software
- Graphics terminals and plotters
- Shop floor terminals
- Shop data collection systems
- Tape reader/punches, or DNC links
- Manufacturing systems support.

3.8.5 Resources

Resource costs should include both human and physical resources needed to implement the project. Human resources will include:

- Project management and control
- Project engineering and development
- System engineering and development.

Physical resources will include:

- Process/equipment development costs
- Prove-out material
- Development tooling.

Irrespective of from where these resources come, the cost will be significant. It is therefore important to identify and agree the level of manning necessary to complete the task in the time required.

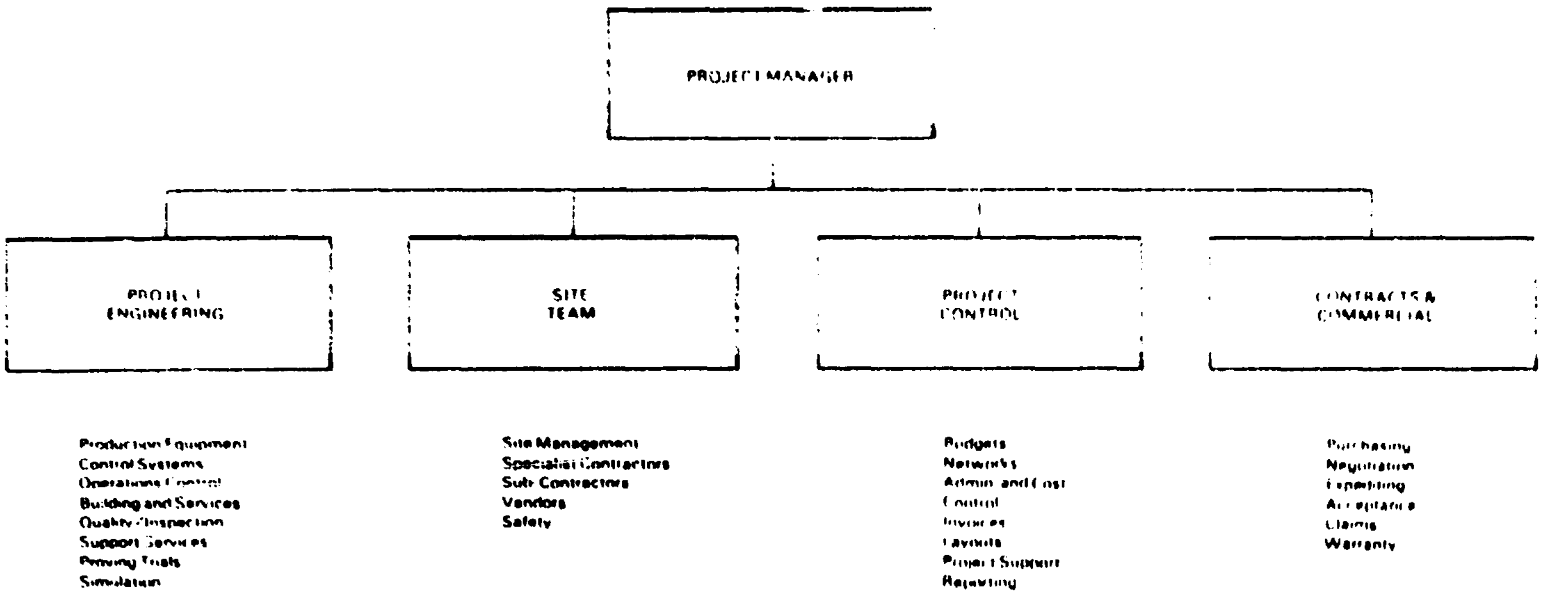
The skills required to manage projects through to a successful conclusion can be grouped as illustrated in figure 4.

The skills required are:

- Planning (engineering)
- Planning (financial)
- Civils/architectural interfacing
- Services (mechanical and electrical)
- Purchasing/commercial
- Tender evaluation
- Expediting
- Technical engineering supervision
- Engineering approval
- Installation and site management
- Commissioning
- Acceptance trials control
- Control and systems engineering
- Cost control
- Programme control
- Training.

A successful approach is for the project team to control the project fully through all its stages, with continuity of staff. Specialist assistance will be supplied when required but people possessing the skills needed should be part of the team on a full time basis.

Figure 4. Project management resources



Responsibility for specific contracts or elements of the project should be given to a project engineer who will manage that element throughout and provide continuity. He or she must have the authority and resources to do the job. The project engineer has a thorough understanding of the structure of the project and is familiar with the skills required. The project engineer will have many of the skills, but where there are limitations, he or she will be supported by specialists in the project team. The most important feature of this role is complete identification with the objectives of the project.

Practical project management experience shows that too often projects are underfunded at the early stages. This results in excessive project cost later and, when the achievement date is late, the company loses profits. These additional costs can soon negate the cost justification approved for the project at the outset.

4. TECHNOLOGICAL REQUIREMENTS FOR UPGRADING THE EXISTING MACHINE TOOL INDUSTRY IN DEVELOPING COUNTRIES

4.1 Overview

Basic concepts and structural configurations of machine tools have changed little outwardly in the last few decades, but there have been significant advances in the control of machines. With mini-computers levels of sophistication can now be achieved which were inconceivable twenty years ago, resulting in machines which can run unattended, automatically load and unload components, automatically inspect each component, automatically change tools and be capable of changing automatically from one type of component to another under remote control by means of a computerized data link.

There are several specific ways in which developing countries may:

(a) Employ such advanced machines as CNC machining centres to set new standards for quality and productivity in existing production;

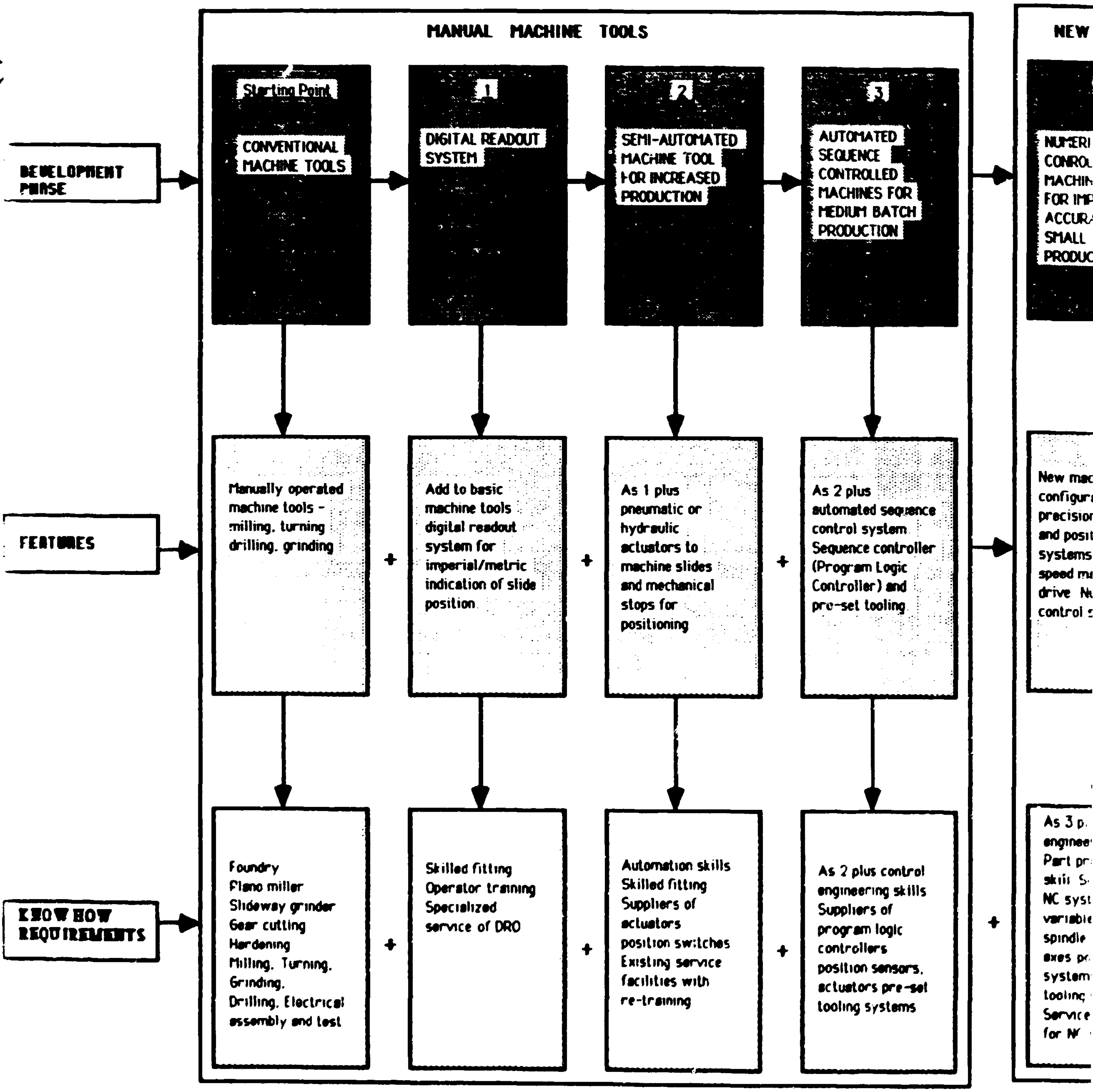
(b) Progressively update existing machine tools to utilize latest technology;

(c) Plan to manufacture machines embodying CNC systems.

As a first step, seven clearly defined stages may be identified as illustrated in chart 1. From these stages of progression the following factors which contribute to the proposed strategy include:

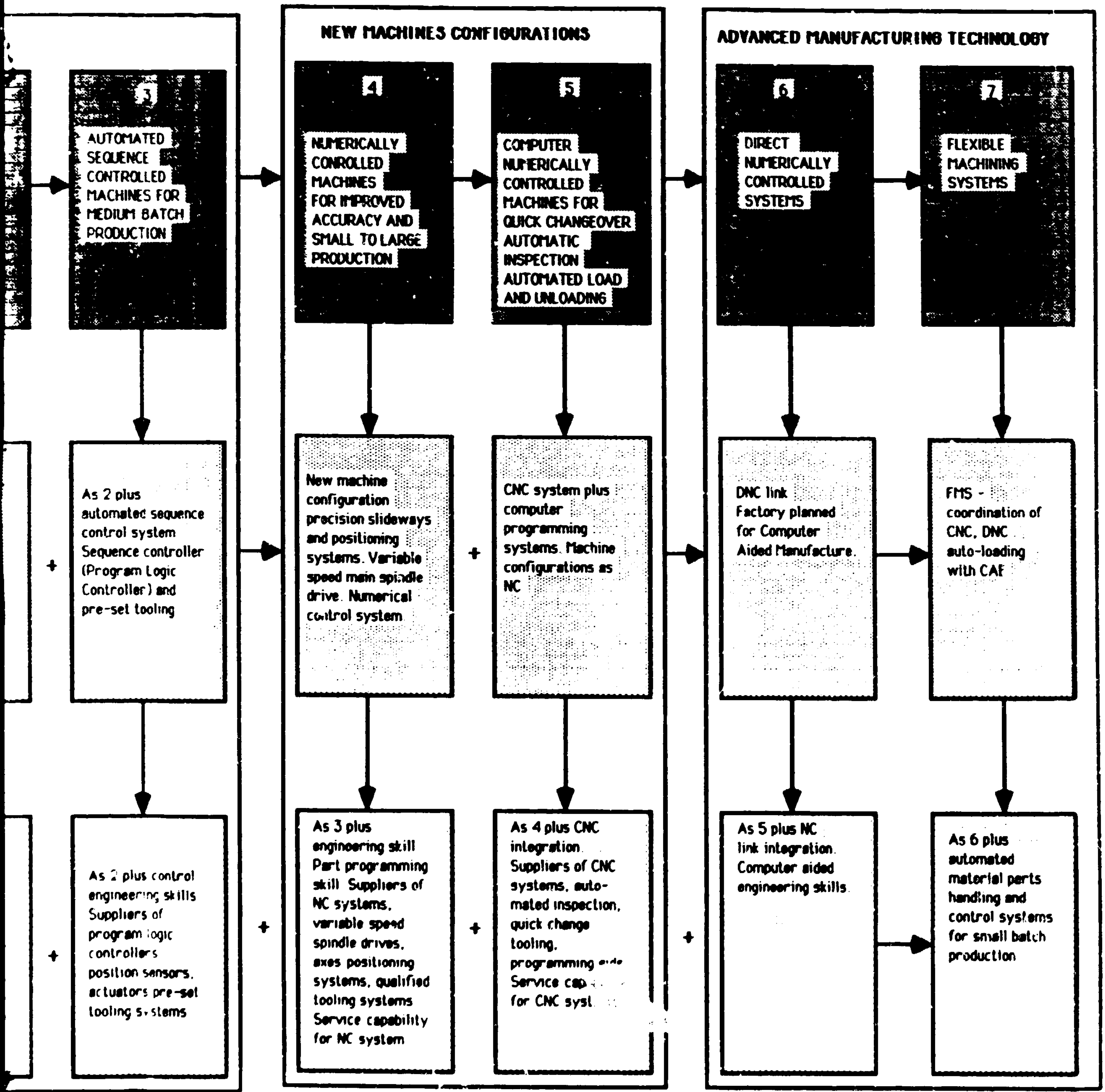
- Technology levels
- Criteria for determining the need to upgrade
- Labour consideration
- The role of CAD/CAM
- Feasibility of upgrading existing machine tools.

Chart 1. Progression from Manual Machine Tools to Flexible Machining Systems
A SEVEN POINT PLAN



SECTION 1

ble Machining Systems



SECTION 2

4.2 Technology levels

Technology levels follow a natural progression influenced by the impact of computer technology, from a predominantly mechanical engineering base in which the iron foundry is the starting point, to a control system framework, heavily dependent on computer engineering. There are a number of specialist skills comprising an advanced manfacturing system capability, from mechanical design, electrical design, instrumentation, computer interfacing, computer software, systems analysis and co-ordination. In the case of a machine tool design incorporating any form of control system it is not only necessary to know how a machine may be automated, but why the automation should be applied in a particular way. Thus management skills for multi-disciplined technological projects is the first acquisition essential to the success of the proposed venture into moving up market in the machine tool industry.

Referring to the seven point plan outlined in chart 1, a number of specific skill areas are identified:

(a) Mechanical engineering manufacture from basic metalworking casting, forging, machining, fitting and assembly to precision standards equal to or better than the machine tool under construction;

(b) Automation application engineering in pneumatics, hydraulics, electrics and tooling technology;

(c) Control engineering. Application of electronic logic control to machine tool operating techniques;

(d) N.C. engineering. Part programming. Interfacing controls with machine tools. Variable speed D.C. and A.C. drives. Closed loop positioning systems for actuation of tool slides;

(e) CNC engineering. Programme edit facilities on machine controller, automation of work handling, automated inspection, interactive (CAD) programming aids;

(f) D.N.C. engineering. Remote programming of CNC machine tool. Use of data highways to link central computer with individual machines;

(g) F.M.S. Automated cell manufacture for the manufacture of sets of parts. Computer aids for scheduling, part programming and selection, material handling.

4.3 Criteria for determining the need to upgrade

4.3.1 Manufacturing strategy

The need to upgrade is motivated by the fundamental issues of improved productivity, quality and competition.

Detailed implementation of an upgrading policy does not follow an obvious route. Factors which need to be taken into account include:

- Cost of rebuilding and converting existing machines compared with the cost of buying new.
- Elapsed time required to upgrade machines/factory.
- Availability of technical/production management skills.
- Aptitude of workforce to be trained to acquire new skills.
- Co-operation from established suppliers of machines and specialized computer control systems and manufacturing aids.

4.3.2 Project planning

The first steps in establishing a project plan may comprise:

- Manufacturing requirement in terms of size, type and accuracy of component to be handled.
- Size, present capability and growth potential of existing manufacturing units.
- An audit of all available machine tools, their physical condition and estimated life.
- The cost to upgrade proposed machines and the plan for how, what and when to complete.

Availability of suppliers of equipment in terms of hardware, software and technical support.

- Source of funding for paying the start up costs.
- Government incentives in terms of direct grants, taxation relief, loans, joint investment programmes.

4.4 Labour considerations

4.4.1 Labour programme

A three pronged approach to satisfying labour requirements is identified:

(a) Compile an inventory or skills register of likely candidates for the new venture in terms of current employment, qualifications and aptitudes, particularly among nationals who have been trained and employed overseas.

(b) Assess short term and long term needs for: trade specialists, mechanical, electronic, hydraulic, computing, semi-skilled workers, technical management and temporary imported skills e.g. consultants.

(c) Set up a government sponsored co-ordination function responsible for planning and funding training needs in collaboration with industry and established educational facilities.

4.4.2 External assistance

One of the most valuable side effects of license deals is the access to training material used for educating the agent on behalf of the principal supplier. Thus to obtain the maximum benefit from license deals there should be careful attention to the provisions for training personnel and refresher courses as required. Similar reasoning should prove beneficial when related to the purchase of specialized equipment from another country with the objective of achieving self sufficiency in technological know-how.

4.5 The role of CAD/CAM

CAD/CAM plays an important role in any scheme aimed at upgrading the existing machine tool industry as illustrated in figure 5. A number of examples are given where computer aids contribute to the success of a production operation, indeed in certain instances - programming an n.c. machine tool for example - this would not be possible without them.

4.5.1 CAD/CAM experience in industrialized countries

It is necessary to carefully plan a step-by-step introduction of CAD/CAM because experience in industrialized countries is already showing that there is much to be done before full compatibility between various elements of a computer aided production system is achieved.

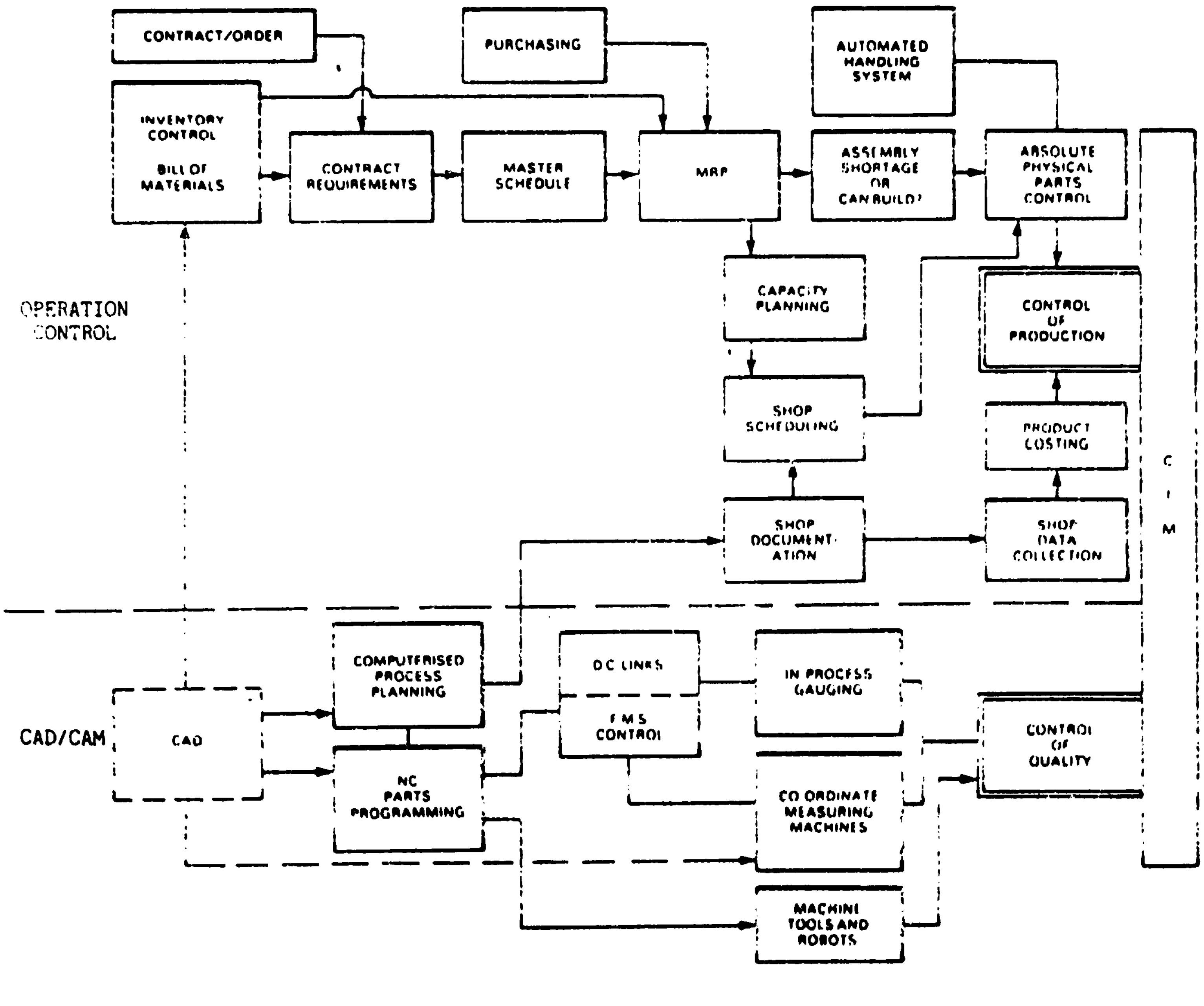
For example, in a survey conducted for the Engineering Council recently by Cranfield Institute of Technology, a quarter of the 300 companies consulted in the United Kingdom were disappointed with the returns they were getting on their CAD/CAM investments, especially in 3D design. The figures were even worse for solid modelling; a third of the users said that installations were not living up to expectations.

The requirements of the business determine how management should plan, so it is essential to establish how those requirements are changing. Being able to provide greater responsiveness to customers by reducing lead times, improving quality and offering greater flexibility, are likely to be more common requirements than cost reduction.

4.5.2 Objectives

In order to be competitive in world markets, lead times now have to be measured in minutes rather than days or weeks and batch sizes are much smaller, tending towards the number required for a single finished assembly. To control production or assembly effectively, the information systems need to respond almost immediately to any changes.

Figure [illegible]. Computer Integrated manufacturing



Conventional computer-aided production management (CAPM) systems (based on manufacturing resources planning), can only achieve this responsiveness if supported by an increasing number of computers and terminals spread around the factory floor.

To be successful it is essential that early consideration is given to the human element during planning and implementation. Human resources should be considered, particularly when contemplating fundamental changes to the working environment. It is important to question all established procedures and to think positively about the far reaching implications of change.

4.5.3 Implementation strategy

The successful implementation is dependent on taking account of three key elements:

(a) Consider all parts of an information system, not just the computer-based aspects. The successful use of computers in manufacturing requires attention to more than just a hardware or software product in one area. Consider how the function is performed at present; manual procedures that will still be needed in future; the organization structure and training needed to support them; and the skills and motivation of all the people involved in the activity (customers, users, suppliers and analysts).

(b) Identify the real objectives. For instance, in assessing requirements for CAD/CAM, consideration should be given to design for manufacture. The implication for the engineering function is that design for manufacture should be given the same importance as design for functionality. Product design and production engineering cannot be regarded as separate functions; they must be integrated. Only when these functions are brought under the same umbrella and the complex processes simplified, should technological improvement be considered.

(c) Question the need to plan manufacturing on the basis of up-to-date control information if the plans cannot be implemented in time anyway. Although planning functions (master production scheduling, capacity planning, material requirments planning) need to be carried out centrally to co-ordinate activities, the control of what happens can be distributed. Furthermore, unless control is distributed to where the action is, the necessary responsiveness to change will not be achieved without enormous investment in hardware and software.

Finally, separating planning functions from control functions and distributing the latter has four major benefits:

- Simpler modules of control
- Greater responsiveness to customer requirements
- A solution resilient to failure
- Implementation into smaller, more controllable mini-projects.

5. POSSIBILITIES OF UPGRADING THE MACHINE TOOL INDUSTRY IN DEVELOPING COUNTRIES

5.1 Manufacturing implications of CNC machining

Computer numerical control, as distinct from hard-wired numerical control, is more versatile and is cheaper than the hard-wired system for the following reasons:

(a) A standard system may be designed to drive any 2, 3, 4, or even 6-axis machine configuration, the changes being made in the software by means of an executive programme tailored to suit the machine.

(b) A computer is capable of indicating detailed information about machine performance and detecting fault conditions. (This may be called a watchdog function.) Typical examples are: spindle directions and speed; equipment and chuck control; position control of machine slides; bar feed control; tape reader input and control; safety interlocks; system status and automatic shutdown.

(c) Automatic diagnostic routines may be used to localize faults when they occur, thus minimizing down time.

(d) Computer control of the servos results in superior machine performance, particularly when contouring.

(e) A computer control system may be less prone to obsolescence, particularly when interfaced by a data highway. It is less susceptible to hardware obsolescence because the system intelligence is contained in software.

A justification for the increased cost of an n.c. machine tends to be based on a comparison of the cycle times for machining a component on an n.c. machine and on a traditional machine. Such argument, however, overlooks several important factors:

(a) For small-batch production the setting time of the machine tends to predominate; an n.c. turning lathe, for example, with versatile standard tooling, can be set up in a matter of minutes, whereas setting up a traditional turning lathe takes much longer.

(b) An n.c. machine can run for 24 hours a day and machine components repeatedly within tolerances of a few hundredths of a millimetre, thus eliminating the need for subsequent inspection.

(c) The actual productive time may be two or three times greater than that of a conventional machine of similar capacity and the new generation of CNC machines on offer today are competitively priced when this kind of comparison is made.

One of the most useful concepts in manufacturing technology in recent years is that of group technology and attendant cell manufacturing. In traditional machining processes based on conventional machines, turning operations were confined to rows of turning lathes, drilling operations to rows of drilling machines and so on, with the result that substantial batches had to be manufactured at any one time to justify the costs of scheduling and tooling. Stocks of material and work in progress therefore tended to be high. Costs of funding high inventory reduced the company's profit margins. The adoption of group technology and cell manufacturing, where components are classified into types and machines are permanently allocated to the exclusive manufacture of these types of component, has enabled work in progress to be kept to a minimum. For example, spindle diameters may be classified by means of code numbers and several turning, grinding and milling machines can be grouped in a spindle cell-manufacturing unit.

N.C. machines are a natural choice for cell-manufacturing applications; indeed without n.c. machines little advantage could be taken of group technology. How then does the introduction of computer numerical control improve the situation? The first point to make is that the introduction of an n.c. machine results in a transfer of control of a machining cycle from the planner and operator to the part programmer (frequently an ex-operator transferred to an office). Notwithstanding the assistance of computer terminals and simulators, the part programmer has a complex and difficult task to carry out.

To minimize the possibility of errors the part-programmer tends to be over-cautious and makes generous allowance for hazards such as surplus material, variations in material quality and tooling area clearances. Whereas with conventional machines the operator can optimize machine performance, conventional n.c. lathes require concise instructions to be entered on the tape which cannot be quickly changed. The important point of difference between a conventional n.c. machine and a CNC machine, therefore, is that the part programme may be modified on the machine to optimize cutting conditions. The operator, therefore, is a key figure and may excercise judgement and discretion as required. Job enrichment obtained in this way is very important and when considered together with the increasing application of group technology and cell manufacture, this will provide a powerful negotiating point for the retraining of traditional craftsmen for the operation and management of manufacturing cells.

It should be clearly understood that the use of a micro-computer in a control system enables not only the part programme to be modified on the machine but it can be edited and changed so that it becomes quite different from the original; facilities may be provided for punching a new tape from this edited version.

For a traditional n.c. machine the editing and re-punching of a tape is time-consuming and, as likely as not is done with the aid of a computer terminal which may be time shared and only accessible for specified periods of time during the course of a working day. It is therefore now more realistic to think in terms of a central data bank of part programmes which may be directly wired to the machine tool with the full knowledge that none of the part programmes will be perfect at source.

To conclude this section, therefore, the main operational differences between conventional n.c. machines and CNC machines are:

(a) Ability to reduce tape prove-out time;

(b) Facilities for optimizing machine performance by editing part-programme tapes on the machine, such corrections to be memorized in the control system computers;

(c) Scope for advanced concepts in part programming, in which the task of both designer and part programmer is simplified and thus become cheaper in terms of time and cost.

It can be concluded that CNC machines and group technology complement one another to such a degree that they become mutually dependent, because CNC machines solve the prove-out problems associated with conventional n.c. machines and thus enable quicker changeover from one component type to another and even smaller batches to be manufactured economically.

The application of CNC machines should be considered in a cell environment where part programmes may be prepared in less time and at less cost. Obviously a previously prepared library of data simplifies the task. The next logical development is to write a master computer programme for a group or sub-group of components to be manufactured in a particular cell, dealing with materials, feeds, speeds, tooling, etc. To this programme may be added key dimensional information, in the form of a macro programme by the designer, using a sub-group identification.

5.2 Feasibility of upgrading existing machine tools in developing countries

As mentioned basic configurations have remained unchanged whereas control system technology has developed very rapidly, particularly in the last ten years. Chart 1 shows seven stages of progression from mechanical conventional manually operated machine tools to computer controlled machines incorporated in a flexible machining system.

Two questions arise:

(a) How many of the existing conventional machines may be updated? and
(b) What constraints need to be overcome in technical terms?

Regrettably very few of the traditional manually operated machines of today can be converted to more than semi-automated systems for relieving the operator of the physical effort required to operate them. It is necessary to analyze the practical constraints which typify the construction of manually operated machines to understand the difficulties faced in conversion:

- Basic configuration
- Primary drive-speed selection
- Axes operation
- Accuracy
- Economics.

5.2.1 Basic configuration

In a conventional machine tool the tooling is carried on a turret which may be positioned transversely and longitudinally with respect to a rotating component in the case of a lathe and a workpiece which is moved transversely and longitudinally with respect to a milling machine/machining centre. The slides incorporate adjustments for taking up the slack in the event of wear, by tightening gib strips. Friction is a secondary consideration. In the case of a modern CNC machine, however, friction is a prime consideration because it directly affects the performance of the servo controlled slide positioning system in terms of the smallest increment of size which can be controlled. Special anti-friction slideways have been developed to minimize these effects which are not readily applied to conventional manually operated machine tools.

5.2.2 Primary drive-speed selection

Conventional machine tools tend to rely upon a constant speed A.C. electric motor, speed selection being made mechanically by means of a multi-stage gearbox. An early enhancement of this was the addition of electric or electro-hydraulic operated clutches to enable the speed to be selected by an electric function selector.

In the case of modern CNC machines the main drive is invariably a large D.C. or variable frequency A.C. motor the speed of which may be continuously controlled from the CNC system to suit the cutting conditions. Such drives are expensive. A.C. drives tend to cost more than D.C. drives - up to 50 per cent more, but offer maintenance free service because of the absence of brushes and commutator. The use of a large motor enables the gearbox to be dispensed with in many instances but the machine structure is then designed to cope with the high stresses of acceleration and deceleration made possible by such drives.

In addition, modern tooling such as tungsten carbide, boron nitride, ceramic and diamond compounds enable high surface cutting speeds to be achieved, consequently spindle speeds of up to 6,000 r.p.m. and above are not uncommon.

These speeds considerably exceed the limit of the bearings of traditional manually operated machines were 2,000 r.p.m. used to be considered adequate for use with high speed steel cutting technology.

5.2.3 Axes operation and accuracy

The classical manually operated machine employs handwheels for rotating Acme threads engaged in bronze nuts for converting the mechanical advantage offered by the leadscrew into a linear movement. Various methods have been used to automate these - electric motors directly connected for example, or their entire replacement by pneumatic or hydraulic rams, with the displacement controlled by adjustable mechanical stops. On modern CNC machine tools the most popular method for slide actuation in use today is a motorized ball screw which permits fine control to be exercised without backlash and with negligible friction. The motors may be either D.C. or A.C. driven by sophisticated electronic control. The cost of such drives is calculated per axis for D.C. drive and ballscrew up to half metre in length and proportionally more for larger lengths where stiffness would become more of a problem for say, a two metre travel.

The accuracy for a manual machine is less than a CNC machine of similar capacity and is highly dependent on the skill and feel of the operator. Whereas an operator may find difficulty in sustaining an accuracy of better than 0.05mm during an eight hour shift, a CNC machine will readily perform to an accuracy of 0.005mm.

5.2.4 Economics

In earlier chapters the high cost of control equipment was discussed in connection with the diminishing role of the machine tool mechanical structure. Referring to chart 1 it is shown how automated sequence controlled machines probably represent the limit of the extent to which conventional machine tools may be upgraded. Beyond this point an expensive CNC system and radical changes to the primary drive and axes positioning systems, which are financially disproportionate in value to the structure to which they are applied, are required.

5.3 Main factors limiting the upgrading of the machine tool industry in developing countries

5.3.1 Summary overview

Machine tools may be classified into several broad categories according to their types, functions, sizes, etc. A base differentiation according to type is between the two broad categories of metal-cutting and metal-forming machines. Machine tools may be also classified into two groups, numerically controlled (n.c.) machine tools and manually controlled machine tools. The production and consumption of n.c. machine tools is concentrated in industrialized countries because of the technical complexity of their production and because strict factory organization and programming and tooling services are pre-requisites for their use.

The output of the machine tool industry is consumed almost exclusively by the engineering industries, including the machine industry itself. The non-electrical machinery industry and the automobile industry in particular are the two most important customers. Thus the demand for machine tools depends heavily on the investment behaviour of these engineering industries which in turn depends on the domestic and export market conditions for their engineering product.

The machine tool industry has the following characteristics:

(a) It is highly skill-intensive and the manufacturing process has a high degree of complexity;

(b) Reflecting the relatively small-batch production of diverse products, small- and medium-scale operations are dominant in this industry;

(c) Most enterprises are highly specialized in the production of one type or a few types of machine tools and produce a small quantity of customized products according to orders received.

This latter feature can be expanded as follows:

First, the market for machine tools is limited to engineering industries and is small, but machine tools are diverse. Therefore, economies of scale are not possible in the production of most types of machine tools.

Second, as in the case of many other capital goods, demand for machine tools fluctuates widely following economic conditions and this requires flexibility in adjusting production in the industry.

Third, the development of skills and market awareness benefit from product specialization.

5.3.2 Drawbacks for the establishment of machine tool industry in developing countries

Machine tools are technically complex and require a large initial overhead in design and testing. An obvious disadvantage for developing countries manufacturers is that they can less easily support investment in innovation than industrialized countries. Actually many developing countries are below the critical size for innovation. They do not have the resources needed to carry out the large amounts of R + D work required, particularly in the fields of NC and electronics applications.

Close technological collaboration between machine tool producers and users in product development and innovation is indispensable to ensure that machine tools meet the technological requirements of users.

The two most essential determinants of location in the machine tool industry are the existence of sufficient demand and a comparative advantage in machine tools in the world market. A country's comparative advantage is determined by several factors such as the accumulation of technology, the availability of manpower, R + D capability, the availability of economically and technologically suitable input materials, the existence of ancillary industries, etc.

One of the problems in this industry is that highly skilled labour is essential for the successful production of machine tools. The complexity and precision of machine tools and their small batch type production limits the scope for employing unskilled labour. Thus in many developing countries, the shortage of skilled labour and qualified engineers and technicians at all levels of the production process restricts the possibility of producing machine tools, particularly those advanced machine tools which would be competitive in the international market.

The slow spread of machine tool production into the developing countries and their general comparative disadvantage are due to several structural and institutional constraints on production growth in those countries, besides the relative lack of manpower and other general technological handicaps.

Most of the machine tool producers in the developing countries have started their production with design and manufacturing techniques obtained from industrialized countries either through licensing agreements or through partnership arrangements. Many of them have continued production of the initial models without altering their designs.

Design of a new machine tool usually takes much longer than in industrialized countries and when the new product is completed the design concept is already old in the international market. The design and quality of machine tools are continuously improved in the world market in response to changes in requirements from user industries.

A research-intensive phase early in the product cycle characterizes the machine tool industry in industrialized countries that are geared to innovation. The machine tools produced in the developing countries may initially be available at a lower cost than imported machines. But, if foreign firms improve the design of their equipment more rapidly than local ones, a point will be reached at which the prices of locally produced machines will exceed that of imported machines. Unless the domestic machine tool industry is protected, users will move back to purchasing imported machines which will result in stagnant production and excess capacity in the domestic machine tool industry.

The size and the development level of the domestic market in relation to the minimum efficient scale of production is an important factor, particularly for machine tools, because penetration into international machine tool markets is very difficult and costly for newcomers and because it is important for product development to co-operate closely with the users who require new technologies and try them out when they are first produced.

In the developing countries (even in large ones), demand for many types of machine tools, particularly advanced ones, is limited because of the size of the modern sector of the engineering industries where innovativeness and the technical ability to handle advanced machines exist.

The engineering industries in the developing countries are generally much more labour-intensive than those in the industrialized countries. There is also clear evidence that the pace of mechanization and of retooling is much slower, specially due to inadequate motivation in user industries to innovate and rationalize.

Finally, limited linkage between domestic user industries and machine tool producers in the field of technological co-operation, coupled with a general shortage of skilled manpower, results in a limited capability for product design and quality improvement, of machine tools in developing countries.

5.4 Main conclusions and recommendations to promote the machine tool industry in developing countries

There are three important fundamental distinctions to be made when considering promotion of the machine tool industry in developing countries:

(a) Utilization of advanced machine tools, their operation and associated support services.

(b) Design characteristics, their suitability for their tasks in world competitive markets and needs for associated multi-disciplined technological skills in the implementation of their manufacture.

(c) Manufacturing requirements particularly for high technology CNC machine tools and the attendant requirements for international quality standards.

The design and manufacture of CNC machine tools, for example, is a formidable task embracing multi-disciplined technology linking advanced computer control with mechanical actuation, rigid structures with negligible deflection and vibration and an in-depth knowledge of metal cutting technology. On the other hand, the application of CNC machine tools in terms of utilization for any manufacturing process offers instant benefits to the user who has the aptitude to learn how to operate such machines. A sound knowledge of metal cutting technology is a pre-requisite, however, for deriving the maximum productivity from the use of CNC machining processes.

In setting out the framework for a manufacturing strategy to promote the development of a machine tool industry there will generally be four main constraints:

(a) The present levels of available resources in terms of production engineering, machine tools, quality control of materials, tooling availability and service back up.

(b) National objectives in terms of the goals to be reached in the engineering sector.

(c) An infrastructure capable of being motivated towards possible fundamental changes in education and training programmes.

(d) Funds to attain the national objectives either by direct purchase of machinery and the hire of specialist skills or the skillful negotiation of countertrade deals.

Thus quite apart from the absorption of computer technology and the attendant manifestations which this inevitably brings, in terms of hardware, software, analysts, programmers and managers, there is the fundamental need to draw up a programme co-ordinating the required objectives and events in a coherent time scale, linking the requirements of short term manufacturing plans in one sector e.g. transport with possible longer term plans in another sector e.g. agricultural machinery. The flexibility provided by modern CNC machines knows no bounds when it comes to defining product shapes and there is thus tremendous scope for developing countries to demonstrate an imaginative and innovative approach to harnessing the latest manufacturing technology at minimum cost and time scale.

There are many advantages to be obtained from the technological linkages arising from the use of CNC machine tools. These include exposure to computer aids for programming, graphics for part programme prove out and component geometry creation, advanced electronic drives for servo positioning systems and high power variable speed spindle drives, computer based systems for production control, inventory management, tooling management etc. Each of these specialist areas may be used to form the basis of training in the appropriate disciplines so as to generate a pool of technological skill which may then be harnessed to future projects aimed at self sufficiency.

To complement the development of linkages it is equally important to co-ordinate the purchases of CNC machine tools with the objective of maximising their possible application to more than one type of product. For example, a modern CNC machining centre equipped with pallet loading and tool changer may quite literally be making parts of diesel engines in the morning shift, parts for petrol engines in the afternoon and spares for old models in the nightshift. Thus it is particularly important for developing countries to be highly selective when making purchases of machine tools even though short term funding may dictate their application to the needs of a particular product. It is possible to conceive the setting up of small autonomous flexible CNC machining cells which may be quickly adapted to fulfil more than one role in order to repay their capital cost in the shortest possible space of time. This may be achieved in twelve months when the machine is running under the right conditions by properly trained personnel.

A first step towards achieving the goal of self sufficiency in advanced machining is to compile an audit of existing manufacturing plant including machining, metal forming, inspection, quality control, foundry practice and their suitability for small, medium and large products. From this audit it will then be possible to assess the most likely weaknesses in terms of machinery, procedures and people and obtain a true measure of the problems in constructing an operating plan.

The main conclusions arising from this study range from policy issues to labour training:

(a) The government is seen to be the prime mover in promoting all aspects of the industry.

(b) The machine tool industry is possibly unique (from other industries with the exception of aerospace) in that it encompasses a total range of technology from mechanical, electrical, hydraulic, control engineering, computing and tooling skills.

(c) In world marketing terms the machine tool industry is often referred to as the toughest business to be in because every new improvement in performance, quality and cost, no matter how small, must be exploited to the full in the shortest possible time to maintain a competitive position in manufacturing industries.

(d) Modern computer controlled machines now tend to be in a class of their own and bear only superficial resemblance to conventional manually operated machines.

(e) The impact of modern cutting technology has enabled high speed machining of hard materials which were inconceivable twenty years ago and which are unattainable on conventional manual machines.

(f) There is scope for converting existing machine tools to semi-automatic and automatic sequence as described in chapter 4 but little practical possibility of conversion to full CNC. The biggest area for improvement is seen to be in the adoption of digital readout systems for the benefit of all manually operated machines.

(g) Long-term future for the industry may best be secured on the basis of license deals incorporating full technological transfer, initially as agency deals, then assembly of kits of parts, followed ultimately by total self sufficiency and full manufacture. The license deals should include specialist equipment manufacture of drive systems and CNC controls.

The following recommendations emerge from this study:

(a) The most important first step to take is a marketing exercise to list all the factors which contribute to why machines and production systems have developed and will continue to develop the way they have, in addition to the more obvious details of how they are constructed, so that a meaningful market plan may be draw up.

(b) The governments are seen to be the focal point of industrial policy. It is proposed to set up a working party in the first instance representing finance, industry and education - a classic delta system of project management.

(c) The implementation of the proposed strategical plan is seen to require modern CNC machines, computer aids such as CAD/CAM and the training of personnel. As a first step it is recommended that a skills audit should be carried out of all the engineers with related experience, in particular those nationals who have been educated in foreign universities, with the objective of co-opting their assistance.

(d) A practical way to promote technological advance in the machine tool industry is seen to be the setting up of several modern CNC machines and their associated computer aided production systems to form the basis of a modular pilot scheme for training and demonstration purposes. A block shematic of such a pilot scheme is illustrated in chapter 4.

(e) It is recommended that because of the complexity of modern machine tools and their dependence on computer technology both for control and production management, a formal project management structure is set up to implement the planned improvements. This project management team should report to the government working party. Good project management is expensive but rarely as expensive as a failed project. Expenditure on project engineering must be an increasingly good investment.

SOMMAIRE

La présente étude tente d'identifier les conditions technologiques requises pour les pays en développement qui veulent s'introduire dans l'industrie des machines-outils ou qui veulent faire un pas en avant dans le domaine des machines-outils DNC et CNC. L'étude essaye aussi de proposer des moyens et méthodes pour l'établissement de centres d'usinage qui mettent à profit les plus récents développements technologiques en ce domaine.

Cette analyse se complète d'une stratégie progressive qui permette aux pays en développement de moderniser le machinisme déjà existant, de type conventionnel et manuel, pour parvenir graduellement à des systèmes de machines-outils de contrôle numérique automatisé. On passe également en revue les principaux facteurs qui limitent les possibilités de modernisation de ce machinisme dans les pays en développement.

Il résulte de cette étude une politique de développement qui puisse s'adapter aux besoins des pays en développement, quel que soit l'état actuel de leur avance technologique.

EXTRACTO

El presente estudio trata de identificar los requerimientos tecnológicos necesarios en los países en desarrollo para entrar en la producción de máquinas herramientas y/o su gradual incremento a máquinas herramientas de control númerico directo (DNC) o de control númerico computarizado (CNC), así como proponer formas y medios para el establecimiento de centros de maquinaria especializados a fin de aprovechar los últimos avances tecnológicos introducidos en las máquinas herramientas.

Este análisis se complementa con una estrategia progresiva para actualizar las máquinas herramientas convencionales existentes, las cuales son asimismo operadas manualmente en forma convencional, hacia máquinas de control númerico por computador y una aproximación a los sistemas de maquinaria flexible en países en desarrollo, incluído el análisis de los principales factores que limitan en estos países el gradual incremento tecnológico de su industria de máquinas herramientas. Los resultados del estudio sugieren el tipo de política de desarrollo a seguir, la cual puede ser adaptada a las necesidades de los países en desarrollo independiente de su nivel de avance tecnológico.

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QUESTIONNAIRE

Technological requirements for the machine tool industry in developing countries

		(please check appropriate box) yes	no
(1)	Were the data contained in the study useful?	/_/	/_/
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