SOME ASPECTS OF AN INTEGRATED MANUFACTURING SYSTEM

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Jules Farkas submitted for Ph.D.Degree 1979

SUMMARY

The concept of a fully Integrated Manufacturing System has been developed in conjunction with the basic requirements of a particular industrial company. The company, manufacturing a range of label printing presses and associated accessories has, like many other western industrialists, experienced problems, particularly of a financial nature from cheap labour countries. The realisation that manpower alone without suitable investment in technological advancement was not the answer, led to the present study to introduce computer-based working aids to all sections of the company. The project closely followed the guidelines of a specially developed "procedure technique" which simplified the breakdown of the complex problem into manageable sections. Additional to this technique, a three-dimensional system-model was conceived which brought both structure and clarity to the system development.

An in-depth study including the classification of all parts and products enabled the true manufacturing requirement to be determined. Numerically controlled machine tools were given priority in the resulting investment. Computer-aided detail drawing and operation planning based on large technological data-banks has led to reduced planning times. High technology investment in shaft-type and disc-type component production has reduced a previous requirement of 16 conventional turning machines to 3 NC turning machines. Similar work for the production of prismatic parts has seen the introduction of NC machining centres.

The philosophy developed throughout and demonstrated with the "system-model" emphasises the importance of balanced company development simultaneously approached on three fronts, namely planning, process and control. The managerial and functional problems threatened by unbalanced development and careless introduction are easily isolated and eliminated. The developed "procedure technique" and system-model are explained with particular emphasis on the machining sector in terms of its planning, process and control. Conclusions are based upon the satisfactory introduction and operation of the system in the mentioned company resulting in a 30 % increase in productivity, reduction of operators, improved flexibility of manufacture, and more realistic delivery times of finished products.

KEYWORDS:

Manufacturing
Numerical Control
CAD
Production Planning
Organisation
Machining

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DECLARATION

No part of the work described in this thesis has been submitted in support of an application for another degree or other qualition of this or any other Institution.

J. [signature]

LIST OF ILLUSTRATION

CHAPTER I

1. INTRODUCTION

The present difficult economic situation and uncertain industrial outlook for the next two decades, makes it imperative for an advanced technological engineering enterprise to secure its future in the rapidly changing and increasingly competetive world. Such a position can only be achieved through a planned and systematic improvement in productivity. The main objectives (Fig. 1) of the primary investment goods manufacturer must be: the development of marketable goods, short time-lag from design-board to sales-launch, reduced production costs, increased flexibility, and improved profitability. Consequently, the need for immediate information availability and comprehensive rationalisation concepts assume the highest priority.

Computer application and automation have now become so commonplace that they are no longer marvelled at but generally accepted in most companies. Unfortunately the full rationalisation potential is seldom achieved simply because most companies have no overall concept for their system improvement. In recent years, it has become increasingly apparent that improved industrial performance can best be achieved through comprehensive rationalisation concepts which integrate the different but related processes of the manufacturing unit. Company management must increasingly concern itself with the systematic and comprehensive application of technological and organisational optimisation.

Automated solutions in production were initially limited to large batch and mass production in the form of transfer-lines etc. however, shorter product life, demands for more specialised product ranges, shorter delivery schedules and higher profit margins make high flexibility and rational working methods vital for small and medium batch production. Many production processes are of a repetative nature and therefore can be programmed or allow a degree of automation.

Technical innovation is not however limited to machining departments, but is gradually extending into design and managerial areas.
It becomes apparent after studying these trends and facts that the general direction of future development in companies of the industrialised world has been set. Furthermore, it is evident that the full benefit of the various technical innovations will only be achieved in the framework of an integrated manufacturing system.

In modern manufacturing technology one of the central issues has become the coupling of CAD (Computer-Aided Design), CAM (Computer-Aided Manufacturing), CAP (Computer-Aided Planning). Unfortunately, in practice the important fact is often overlooked that integrated systems bring far greater long-term benefits to the company than isolated "part-solutions". The development of an integrated system is not only highly complex but also requires an extremely large investment. This could explain the relative reluctance of many companies to take this important decision.

The management of Ferd. Rüesch AG recognised at an early stage that increased productivity in the manufacturing department could best be achieved through a long-term rationalisation plan. It was in this company that the following work was developed as a contribution to the field of practical development and implementation of integrated manufacturing systems. Because integrated manufacturing systems are both cost-intensive and require a long development period, the system had to guarantee at each development stage the successful achievement of both financial and technological targets set by the company. A central issue was how to smoothly convert the existing conventional manufacturing system into an automated and integrated system. The work shows how a "procedure technique" was developed to solve this problem. Furthermore, some aspects of integration effects on organisation, machines, software, and, most important, employees are discussed and important practical results of the systems application commented upon.

CHAPTER II

2. THE INTEGRATED MANUFACTURING SYSTEM

2.1 Basic concept

According to KRIEG (1), a process orientated investigation of the workings of a company isolated the following main processes:

- Strategic and operational management processes
- Creative operational process, innovation process
- Repetative operational process, execution process.

Within these process areas (Fig. 2) the necessity to change or adapt the existing situation can arise. Strategic and operational management processes can be, as the innovative process, only to a limited degree automated, owing to their abstract character. Repetative operational processes however, being of a highly algorithmic nature, lend themselves to automation (Fig. 3). The selection of rationalisation and automation measures rests not only on company policy objectives but also on thorough analysis to isolate the areas offering maximum cost effectiveness. Various investigations (2, 3, 4, 5, 6, 7, 8) have shown that for the investment goods industry, the production department offers the greatest rationalisation potential.

The last decade has seen the production department absorb a great many technological advances in both hardware and software, from both pure research and practical innovation. These measures can be split into two main groups:

- Conventional solutions
- Automated solutions.

Conventional solutions concern mainly the various integration and standardisation measures affecting product or component range, i.e.

- Unitary workpiece numbering systems
- Group technology in planning and production
- Standardised detail drawings and worksheets
- Structured work flow organisation.
- etc.

Automated solutions in production were initially limited to large batch, and mass production in the form of transfer lines, however, the development of NC technology has increasingly encouraged the automation of small batch and even one-off jobs. Based on NC technology, highly automated production concepts have been developed ranging from single NC machines to fully automated factories. Additional to the automation of actual machining operations, the rationalisation of accompanying planning measures and the speed-up of information flow through computer application has been developed. Automation of workpiece handling through robot usage and the application of NC measuring machines for quicker and more thorough quality control are further means of attaining higher production efficiency. This technical evolution is, however, not limited to machining departments, but gradually extends into the design department. Rationalisation and automation in the design department began with computer application,from simple standardised calculations through to automatically plotted layout draughting. Investigations by MERCHAT (3, 9) show that the tendency towards automation in all areas of manufacturing will increase heavily during the next 15 years (Fig. 4).

Information flow and data processing in the various departments of the company become increasingly important. The mastering of this problem is today unthinkable without computer assistance. Computer application in the technical areas of design, work study, NC programming, etc. becomes increasingly advantageous for the following reasons:

- Almost yearly reduction in computer prices coupled with simultaneous performance increase

- Increasing availability of dialogue-capable computer systems enabling decentralised user operation
- Increasing number of otherwise qualified staff who also understand both computer applications and programming
- Increasing workforce acceptance that computers do not destroy jobs but lead to higher productivity and reduce tedious work.

It is therefore apparent that the transfer from a conventional manufacturing system to an integrated manufacturing system requires considerable pre-planning (Fig. 5). During this restructuring of the system both company policy and environmental influences must be involved to ensure that all factors affecting the economic situation of the company are considered during the planning stage. Generally, at the planning stage three main possibilities arise:

-	The company expands	(Turnover and profits increase)
-	The company consolidates its position	(Turnover and profits stable)
-	The company contracts	(Turnover and profits decrease)

Rationalisation and restructuring can be both justified and beneficial in all three company situations. For planning the system restructure, a comprehensive procedure technique is necessary. Fig. 6 shows the integrated procedure plan for the restructuring from the conventional to the automated and integrated manufacturing system. During the development of the integrated manufacturing system, the harmonised interaction between workforce, machine, and software at all process stages is of utmost importance (Fig.7) .

2.2 The present situation

Integrated systems in manufacturing comprise of hardware or software systems which automatically link related process transformation stages. Between product idea and finished product are many transformation stages both of data processing and material processing nature (Fig. 8). These transformation stages can be manually, mechanised, or automatically executed. For the physical realisation of a product from the automation viewpoint, numerical control is a necessity. For automated data processing, computer application is the obvious medium. It follows that automated and integrated production systems can only be realised through the combined application of numerically controlled plant and computerised data processing. The following section describes several integrated systems from the production, design, and planning departments.

2.2.1 Integrated systems in machining

Hardware solutions

The NC machine with "conventional" NC control can be considered a simple integrated system. Further developments based on NC technology offer scope for higher production automation and integration. The perfection of CNC (10, 11, 12, 13) greatly simplified control information processing and rationalised operation. BRINDLEY's (14) work offers a systematic and comprehensive summary of presently available NC control equipment and machines and demonstrates the development of a DNC system for NC milling.

The NC turning cell is a further example of an integrated system offering a much higher degree of automation than the NC lathe. The basic difference is found in the additional automated execution of workpiece change with robot (15, 16) and automated workpiece measurement by one of the several systems measuring either workpiece or tool. Whichever system is used, an automatic feed-back system to compensate deviation at tool point must be guaranteed. The main responsibilities of the operator remain job change, replacement of tool for wear and breakage, and general overall control of the automated functions.

Descriptions of several operational flexible machining systems for both prismatic and rotational components have been published in various countries (7, 12, 16, 17, 18, 19, 20, 21, 22) and demonstrate the next stage of integration in the production area. Here, on-line DNC computer systems handle data processing (12, 13) and material flow is automated. All these systems however offer only limited flexibility for a narrow component spectrum - much less than is required for more universal application. For the planning and control of flexible machining systems, several concepts have been developed - JUNGHANS (23), HORMANN (24), WESTKAEMPER (7) and FELTEN (16). The greatest problems in the development of hardware modules for automated component, tool, and data flow are found at the interface between hardware and software. As an example - the technical realisation of flexible automated workpiece transfer equipment was only achieved with software integration at sensor and junction control points (25).

For the above reason, research has concentrated on the control of information and material flow. Recent developments have overcome most basic problems. This is demonstrated for example by the fact that DNC flexible machining systems are already operational. Efforts to reduce control costs and simplify software development are now being made e.g. PEARL (25, 27). The ultimate objective of these developments must be the production of universal control systems, capable of controlling various highly automated machining systems.

At the PROLAMAT conference 1976, YOSHIKAWA (28) from the Tokyo University described a japanese project for an automated and partially unmanned factory. In this system the functions of worksheet preparation, machining, assembly and control were to be combined as an integrated and automated unit. Should this system become operational, the present missing links in the hardware and software chain will have been discovered which must lead to the accelerated development and application of such systems. General hardware developments are creating a structural change in small and medium batch production throughout the entire industry, from small jobbing shop to the large automated factory. Some years will be needed however before automated plant becomes generally accepted.

Based on the development available to date and cost effectiveness estimates, the long-term investment in manufacturing plant should follow the qualitative trend shown in Fig. 9 (7, 29). This development has already been realised in some companies (30, 31, 32). Apart from relatively few NC machines and machining cells, mainly conventional plant is presently in use. DNC and flexible automated systems are mainly in the test phase. From the rapidly rising production figures for NC machines it is clear that the proportion of such machines will greatly increase in the near future. Further, integrated systems based on CNC and DNC technology will find increased practical application. Production processes have become increasingly more integrated through NC machines, computer, and material transport system application. The problem of quality control however can first be integrated with the development of 3 axis measuring machines (33, 34).

Software solutions

Equally as important as hardware, software solutions to such problems as the programming of NC machining and measuring equipment are necessary to facilitate integrated production. FISCHER (35, 40) developed a concept for the computer-aided preparation of control information for NC machines, based on an integrated overall planning system of multistaged production. Several systems are briefly described in the following pages. Fig. 10 shows the state of development of several programming systems concerned with NC turning (35).

The highest degree of automated technological data processing is achieved by the systems GETURN (36) and MITURN (37). These are limited however to a narrow geometric workpiece spectrum and limited machine range. The GALLUS (6, 38, 39) system merits particular attention whilst being based on a component classification system, it enables the repeated use of standardised machining cycle macros for entire machining sequences of similar components. Most other programming systems operate with unspecific user-languages and offer therefore unspecified application. The geometric orientated systems offer some automation by simplifying tool path definition. Only EXAPT 2, a technology orientated programming system, has a higher degree of automation, although automatic tool selection and machining sequence definition are not included. Today, automated programming systems are available for all NC machines. New developments are leading to the coupling of CAD software data and NC programming data. KOERTH's (34) programming system NCMES was developed for the automated programming of NC measuring machines.

The processing sequence can be seen in Fig. 11. Divided into four phases, firstly the workpiece programme is prepared, secondly processed, thirdly the resulting control information checked and finally the actual measuring process is executed.

2.2.2 Integrated systems in manufacturing

The computer-aided design system developed for the american space programme brought interesting new possibilities of data processing to the areas of product design and product planning. With an active CRT terminal and light-pen, the designer can work in dialogue with the computer making rough layouts, calculations and various routine procedures. Peripheral equipment, such as plotters enable the graphical output of any results such as charts, drawings, etc. Since the system was first used in the sixties, several different CAD systems have been developed, which can be divided into two basic groups: Computer-Aided Designing and Computer-Aided Detailing. Additional to these main objectives, attempts have been made to add software packages coupling the preparation of production worksheets and NC control data.

SZABO (41) outlined several programming systems for preparation of operation plans in his work. BUTZ (42) developed a programme system for design layout draughting. With the programme "FUKOMP", designing using functional modules can be carried out. The programme "FERTUN" enables the automated preparation of detail drawing, parts lists and work plans. At the WZL (43) in Aachen, a further CAD system VABKON/ FREKON was developed enabling the draughting of design layouts. FREKON (44) enables the designer to combine any of the available functional modules. Selections, calculations and modifications are carried out in dialogue using the "menu-card" technique. Unlike new designs, re-designs are carried out with VABKON, where functional modules and possible combinations are limited and layout, linkage, and design have a fixed logic, enabling processing on batch processing centres. VABKON is presently operational in machine-tool spindle housing design.

The Institute of Machine Tool and Production Technology (45) of the TU in Berlin developed the programme system COMVAR and COMPAC. With COMPAC the computer-aided generation of component information is possible as well as operation plan preparation. The programme COMVAR enables the automatic production of detail drawings from standard design and component data. The programming system DETAIL (6, 38, 68) enables the automatic detail drawing and dimensioning of rotational components. (The programme system DETAIL will be further discussed in a later chapter.)

2.2.3 Methods and working aids for integrated manufacturing systems

The realisation of integrated systems demands a systematic procedure, long-term planning and high investment expenditure. Most of the above mentioned systems are relatively inflexible, making simple purchase and immediate application almost impossible. The company must carry out its own development and find optimum solutions most suitable for its own particular requirements. To enable this development it is essential to have a clear knowledge of the companies' component spectrum and the company-internal structure in the various departments. The best means of achieving clarity from a wide miscellany of components is certainly by the use of a classification system. The basis of many systematically developed, integrated and automated systems is the workpiece classification system from OPITZ (4). The main purpose of any classification system (Fig. 12) of workpiece, operation, machine, etc. is to achieve the maximum benefits of simplification and standardisation, ensure repeated used of tried and tested solutions, and enable the grouping together of similar components to reduce down-time and increase batch sizes. With a suitable classification system (that is a system meeting its exact requirements), the company has an invaluable instrument which enables objective analysis before embarking on any rationalisation measures in the machining department.

Group technology and its implications on the various factors of a company are seen in Fig. 13 after THORNLEY (46). These rationalisation measures which have been repeatedly and successfully applied in small and medium batch production (47,48,49,50,51,52) are primarily based on analysis by the above mentioned classification. The initial ideas on this method were proposed by MITROFANOW (48). The application of electronic data processing methods for analysis and evaluation of the mass of data has led to its rapidly increasing practical application.

"Group technology" or "workpiece-family-machining" can be defined as that method which aims to analyse and classify workpieces and their associated production processes so as to form logical groups and "families" which enable greater rationalisation in the field of small and medium batch production. Group technology applies some of the ideas of large batch production to achieve a degree at this rationalisation. It is however less concerned with the more obvious aspects, such as absolute minimum machining time, but more with the effects on overall economy e.g. flexibility, reduced through-put times, reduced work in progress, improved supply situation, reduced paperwork, rationalised planning, design processes, etc.

The computer must be considered the most important working aid for the realisation of an integrated manufacturing system. The ever changing terminology and description of computer equipment makes objective comparison rather difficult. Furthermore, the boundaries between process computers, scientific/technical computers and commercial computers become increasingly unclear as each manufacturer attempts with new developments to encroach on his competitors territory. With these developments, the trend towards the universal computer becomes increasingly apparent.

One of the most important requirements of the chosen computer for integrated systems is its dialogue capability. Such computers enable decentralised operation essential for the successful running of such a system. Recent development trends are leading essentially to the linking of CAD and CAM software packages. It must however be said that to date these developments are only at the development stage; only a few are in actual practical use.

2.3 Functional limits of manufacturing and definition of the integrated manufacturing systems

The meaning of the term "manufacturing" has continually changed. Earlier, manufacturing implied those activities carried out by a worker to produce a particular article. F.W. TAYLOR proposed the division of the creative work and the purely manual work, calling manufacturing the manual activities of machining and assembly (53, 54). In more recent definitions the trend is clearly towards including all activities connected with the product realisation as manufacturing activities. According to GUTENBERG (55) manufacturing implies the output of performance from the factors workforce, plant, and material, although a clear distinction between directly coupled and indirectly coupled activities is made. ELLINGER (56) defines the term as "overall economic technological and organisational measures directly linked with the processing of material". Only the latest system-technique orientated definitions (57, 58) clearly include under manufacturing all preparatory and executory activities concerned with the realisation of the product.

2.3.1 Limits of the manufacturing function

When solving complicated organisational problems, modern industrial management often applies the ideas of ULRICH (59) which are based on the basic system theory (1, 59) and cybernetics (1). Using this approach equal importance is attached to both "part process" and "whole process", to analysis as well as synthesis, to material as well as informational connection.

The workings within the company are primarily determined through the interrelationship with technology markets, sales markets and buying markets. The most important are shown in Fig. 14 (60), although how these relationships - which are outwardly the same for most companies - are converted in the internal structure varies from company to company.

To define the manufacturing activities inside the company, the effect-related black-box method is best used in the first stage, and in the second stage the structure-related method. The generalised input-output approach to company structure gives the following functionally orientated break-down (Fig. 15):

- Financing
- Manufacture
- Sales

This work concentrates wholly on the function manufacture. Applying the black-box approach to manufacturing from the technological process viewpoint, the function breakdown is as in Fig. 16 Design, Machining, and Assembly. The application of cybernetics was chosen for the analysis of the structural relationships of the manufacturing process, as multi-layered transformation processes of both material and informative nature are best approached with this technique.

FLECHTNER (61) defines cybernetics in relation to systems as "the general formal science of the structural relationship and behaviour of dynamic systems". The definition is in basic agreement with KLAUS (62) who defines cybernetics "the theory of relationships between dynamic self-regulating systems and their sub-systems". FLECHTNER extends the generalised definition of cybernetics with a special cybernetics definition which envelops the theory and design of automated data processing centres, self-teaching machines and self-reproducing machines. As an applied science, cybernetics serves other disciplines such as physics, medicine, sociology and management science in the solving of relationship based problems.

With the application of the methods and terminology of cybernetics, an analytic investigation and solution of the problem can be attempted. KRIEG (1) sees the definition as follows: "Cybernetics is the formal inter-disciplinary science of structures and information transformation of any purposeful dynamic system".

From the cybernetics approach it is apparent that the technological transformation process - design, machining and assembly - is accompanied by planning and control processes. Fig. 17 shows the different types of relationship between design, machining and assembly. From the process approach, each transformation step will be examined and the necessary input and resulting output defined. At each transformation stage input and output data must be stored and regulated. Planning provides the target data, such as schedules, capacity, costs, etc. which after each transformation step must be compared with the actually achieved results. Control requirements of the-from transformation stage to transformation stage-achieved results are determined dependent on respective transformation importance. From the above approach, manufacturing can be defined as follows: "Manufacturing encompasses the processes - including planning and control process - required for product realisation from product idea to finished product".

Fig. 18 shows manufacture initially as a static system whilst only with the addition of the workforce and material does it become a dynamic system. The dynamic production system is shown in Fig. 19. From this approach, the following definition results: "A dynamic manufacturing system includes all processes, workforce and materials, necessary for product realisation from product idea to finished product". This broad definition of manufacturing inside the company serves as the basis for developing the definition of the integrated manufacturing system.

2.3.2 Definition of the integrated manufacturing system (IMS)

The relationships of the IMS are shown in Fig. 20. By integration (63) (fusion into an entity) is meant the connection of systems and sub-systems. By system (1, 59) is meant the organised whole, the elements of which exist in, or can be placed in, a specific relationship. With the comprehensive definition (compare 2.3.1) manufacturing ranges from idea to finished product. With this extension of the function manufacturing, the basis for an integrated manufacturing system, in short "IMS", is found. As seen in Fig. 20, an IMS includes as its main functions: planning, process and control. These functions are arranged as an automatic control circuit in which attained results are continuously analysed and necessary corrections and new targets are at least partially automatically inputed.

PLANNING (the target-setting system) can be defined as the overall steering of all plannable activities - capacity, schedules, costs, etc. - which occur between product idea and finished product.

PROCESS (the realisation system) can be defined as the entire actual technological transformation, both creative and material, necessary for the realisation from product idea to finished product.

CONTROL (the controlling system) can be defined as the entire spectrum of quantitative and qualitative technological and managerial factors, necessary for the controlling and documentation of the process.

This comprehensive definition of what a manufacturing system actually entails should assist the development of the IMS by setting clear aims. The main economic objective of systems integration is the increase in system productivity. Actual aids to be used depends on whether process-system, information-system or management-system integration is sought. In the case of manufacture, the integration of systems to achieve a high degree of automation of the functions - planning, process and control - is sought. The degree of automation (7) of the manufacturing system can be defined as the quotient of those programmed, automatically executed operations, measured in quantifyable amounts e.g. times, costs and quality.

<u>An integrated manufacturing system (IMS) embraces all logically connected functions of planning, process, and control sub-systems, promotes their automation and optimises interrelationship with plant and workforce to achieve improved productivity, higher quality, reduced costs, and a better working environment.</u>

On the basis of this definition the development of the integrated functioning system will be shown and presently operational system components documented. It is first necessary however to describe briefly the company in which this "IMS" was developed.

CHAPTER III

3. THE COMPANY FERD. RUESCH AG

3.1 Development

The company was founded in 1922 when the present owner's father purchased a weighing scale factory with about 40 employees. The present owner, Mr. Ferdinand Rüesch, has managed the firm since 1953. Up to the second world war, weighing scales were the primary product although label printing presses were built before 1930. The production changed in the 1940ies after export success with the printing presses. Weighing scale production became increasingly less important and was finally ceased in 1971.

Company growth led to the founding of the subsidiary companies FERMAG AG and GALLWAG AG in 1961 and 1962. FERMAG AG concentrated mainly on prototypes and spare parts manufacture. GALLWAG AG concentrated on design and manufacture of specialised printing press tooling.

The parent company first became a Ltd. company in 1974. In recent years the company has rapidly expanded, presently employing approx. 250 people, and can be categorised as a small/medium sized business. The rapid expansion unfortunately led to the wide spread distribution of workshops and offices at several different locations across the town. This decentralisation on eight locations made coordination and management more difficult.

3.2 Production programme and market situation

The production programme includes a wide range of label printing presses of different size and complexity, enabling a wide variety of labels, punch cards and allied products such as tickets, stickers, and tags to be produced. Presently a yearly output of approx. 100 machines is exported to 30 countries in 5 continents. The export business is unusually important, presently accounting for 98 % of turnover.

Appendix I shows some of the company's products. Current models are grouped according to web material transport system:

- Rotary printing presses
- Semi-rotary printing presses
- Varo printing presses.

The presses are designed for modular combination enabling specific requirements to be met. A label printing press can be generally compared with a transfer line. All operations, such as die-cutting, punching, printing, perforation, stamping, slitting, etc. are performed in-line. Dependent on label type however, different operations are necessary and high machine flexibility required. A high machine quality is also demanded. Label presses with the trade name GALLUS occupy a leading position on the world market, renowned for their performance, flexibility and quality.

An internal sales organisation assisted by agencies abroad copes with sales. Until 1974 there was little competition because world demand for label presses outstripped supply. This led to long delivery dates even though measures to increase capacity had already been introduced in 1970. The economic recession of 1974 and increasingly strengthened Swiss Franc was equivalent to price reductions of competetive products which confronted the company with new problems. The recession also affected the printers (the company's customers) who demanded even greater flexibility, new printing processes, even shorter delivery dates, still lower prices, etc. The changing situation soon became apparent and the management instigated the following structural measures:

- The development of new models
- The rationalisation and modernisation of plant
- The overhauling of the management system
- The centralising of the dispersed branches.

Further information about the company and its problems seen from the IMS viewpoint is given in the next chapter. A systematic method, the procedure technique is used for developments of both products and systems in the company.

3.3 System development using the procedure technique

For several years the design department has successfully developed many new products with the SULZER (8, 63, 64) method of the procedure technique. The system technique (additional to the procedure technique) and also from SULZER (8, 63, 65) is also operational. Experience suggested that either of these techniques would prove beneficial in the development of the IMS. Both were examined to determine which would be most suitable.

3.3.1 Procedure technique in product development

The application of procedure technique in product development is shown in Fig. 21. It consists of firstly a procedure plan which maps out the logical phases of product development, and secondly a catalogue of methods and working aids which can or should be used in the various phases. The most important characteristic of this technique is the decision required after each phase as to whether the achieved results are acceptable - in which case the next phase is taken - or unacceptable - in which case one or more phases must be repeated until acceptable results are obtained. In the phase "selection of project" important and systematic inputs related to the project are determined. In the phase "feasability study" the realisation possibilities are estimated and specifications defined.

3.3.2 System technique in system development

System technique can be defined as the systematic structuring of both established and new techniques and aids to assist in solving highly complex problems and help in the conception and realisation of new systems. With system technique a complicated problem can be broken down into logical component parts, each of which can then be examined without losing the overall context. The structure of the system technique, which gives the logical phases of system development, is shown in Fig. 22.

In preliminary study of the system, fundamental research isolates the main areas of rationalisation and defines the main problems. With newly developed systems, a system model is advisable to ensure a sound start. This phase is extremely valuable and can shorten development and implementation times, increase a system's useful life span and help bridge the gap between theory and practice.

In the system build-up phase, the concept and its aids are developed and tested. System build-up can be compared with the design phase of a product development in which solutions to satisfy given specifications must be found.

In the system instruction, three levels of information must be distinguished:

- General orientation
- Management introduction
- Specialist training.

The first level aims at general orientation of all employees who are in any way affected by the system. The second level informs management of the basic objectives of the system especially application possibilities, so as to enable a smooth system introduction. The third level concentrates on the system handling and system implementation. With implementation begins the system maintenance phase which involves user advice, information and system improvement.

3.3.3 Synthesis of the product development and system development procedure techniques

The comparison of both techniques demonstrates that neither technique is alone ideally suitable for the development of an IMS, whilst the system development procedure technique lends itself to the solving of complex system theoretical problems, the product development procedure technique, with its activity orientated nature is more suitable for the practical application.

By the development of an IMS however, both these factors are of extreme importance which suggests a synthesis of both procedure techniques as being advantageous. Fig. 23 schematically shows this synthesis named the "GALLUS procedure technique" which is briefly described below.

3.3.4 Procedure technique GALLUS

Application of the procedure technique GALLUS is not narrowly limited but suitable for the solving of various tasks and problems which may arise in the company. Obviously its application is only meaningful, when the solution is not immediately apparent, that is, only by complex problem solving. The procedure technique GALLUS consists of two component parts, that is the procedure plan and the accompanying methods and aids.

Procedure plan GALLUS

The procedure plan GALLUS shown in Fig. 24 consists of seven consecutive phases embracing the most important basic decisions.

Procedure phase 1 : Selection of project

In the phase selection of project critical trends, situations, bottlenecks etc. in company and environment must be analysed, defined and documented in a general project formulation. With the more complex problems this phase is normally carried out by the highest level of management. Generally this phase can also be interpreted as company policy planning whilst current relevant information from inside and outside the business must be collected, sifted and processed. This phase can also be applied to shorter term planning, as many similarities and relationships exist despite the narrower limitations. The outputs of this first procedure phase form the preliminary project specifications, setting quantitative and qualitative aims and where necessary limitations on the sought after solution.

Procedure phase 2 : Feasability study

The purpose of the feasability study is the determination of optimum specifications which can be used as a sound basis for the problem solution. Analysis results are necessary to determine measurable limiting values, although certain demands can simply be defined especially with a project of a highly innovative nature. The selected specifications are laid down in a specification sheet. To a great extent, the quality of the resulting solution depends on the quality and accuracy of specification sheet data. Several of the factors to be considered during the compiling of the specification sheet are mentioned below. Specifications must be neutrally described so as to avoid influencing the solution at this early stage.

Two categories of specification can be defined: Static specifications and dynamic specifications. The static specifications result mainly from the analysis of available structures and data and are generally of a quantitative interpretable nature,for example costing, deadlines, qualities, amounts, limits, etc. Dynamic specifications are obtained from more abstract sources - company policy, environmental influences, system characteristics, etc. and are of a more qualitative nature.

The division into static and dynamic specifications proved to be necessary as practical experience has shown that whilst structural data remains basically constant over a long period of time, policy, technology and environmental influences are constantly changing. System development being of a long-term nature must therefore attach great importance to these dynamic specifications.

Procedure phase 2 defines the specifications and arranges them into three groups: absolute specifications, minimum specifications and optional specifications. This specification sheet must be checked and approved by those responsible before being released for further processing.

Procedure phase 3 : Conception of the solution

In the phase " conception of the solution " an optimum solution concept, based on the phase 2, specification sheet must be established. In this phase, great emphasis must be laid on abstract thinking in terms of systems and functions. A further characteristic feature of this phase is the determination of different model solutions using the solution matrix method. An evaluation technique enables the most suitable of the alternative model solutions to be selected. By system development application, this phase must also define realisation time schedules, realisation stages, and priorities. The output of procedure phase 3 is a preliminary solution concept which must be approved or repeated before moving on to procedure phase 4.

Procedure phase 4 : Development of the solution

In the phase "development of the solution" the relatively sketchy solution of phase 3 becomes more solid. Alternative solutions can be compared, and again using evaluation techniques, the best design solution selected. The output of procedure phase 4 is a definite but not yet detailed design solution. Again, the result must be approved or the stage be repeated.

Procedure phase 5 : Detailing of the solution

The phase "detailing of the solution" entails working-out and perfecting the solution concerning function, performance, schedules, etc. until the final approved solution, accompanied by all necessary documentation and introduction plans is finalised. The output of procedure phase 5 is a usuable solution although once again an approval is necessary.

Procedure phase 6 : Implementation of the solution

In this phase, the solution becomes operational. The workforce must be trained and assisted. All problems and mistakes which emerge must be immediately confronted. The output of procedure phase 6 is the feed-back of achieved results and discovered weaknesses.

Procedure phase 7 : Maintenance of the solution

Application of the solution will obviously lead to the need for improvement and new developments. Increased usage will create higher demands on the solution. According to necessity, back-tracking through one or more phases may be needed to ensure the required development. Occasionally it may even be necessary to start from scratch with phase 1 again. The outputs of procedure phase 7 are specifications for the further developments or information for the next "selection of project".

This work demonstrates how, using the procedure technique GALLUS, an IMS was developed and how some sub-systems were implemented.

CHAPTER IV

4. DEVELOPMENT OF AN INTEGRATED MANUFACTURING SYSTEM IN THE COMPANY FERD. RUESCH AG

The previous chapter showed the importance of rationalisation in the various manufacturing areas. The company Ferd. Rüesch AG and its specially developed procedure technique were explained. Several examples of working integrated systems were considered. This chapter demonstrates how the integrated manufacturing system (IMS) was developed using the procedure technique GALLUS. To demonstrate the wider application possibilities of the procedure technique, the description will be of a company neutral nature as far as this is possible.

4.1 Selection of the project

As previously mentioned, companies must constantly strive to improve their productivity performance in order to ensure their survival in increasingly competetive world markets (Fig. 25). Necessary improvement measures do not just happen by chance, but result from systematic company policy making which concerns itself with the analysis and prognosis of the company's relationship with its environment. Based on management decisions resulting from the interpretation of this information, the formulation of investment aims, system development aims, and marketing aims can be made.

The "selection of the project" requires a situation analysis of the company and its environment from which the critical areas for improvement can be determined. Fig. 26 schematically illustrates these relationships.

4.1.1 Environment analysis and prognosis

The following section attempts to analyse (and where possible predict) the relevant environmental factors (66), affecting manufacturing companies in the industrial world, particularly those aspects concerning productivity which are of direct interest to the investigation.

Labour costs

The development of labour costs in the industrialised world is mainly influenced by the following trends:

- Reduction of the work potential per employee
  through shorter working week, longer holiday, higher training requirements, etc.

- Increased wages bill
  through inflation linked rises and real terms rises (partly financed by productivity deals)

- Rising social benefits
  through improved social security and insurance schemes.

These trends result in an increase in unit labour cost which is almost inevitably higher than inflation increases.

Employment market

Developments in the labour market situation vary considerably especially relating to trends in labour potential. In countries, such as W. Germany and Switzerland, birth rate stagnation and the repatriation of foreign workers to their native countries has led a stabilisation of the labour market. Other countries (the majority) are experiencing varying degrees of unemployment. Even in times of stable economic growth, structural changes and new technologies led to redundancies.

Despite this increased labour availability, the fact remains that steadily increasing demands on new employees (skills and specialised knowledge) leave many companies unable to recruit sufficient suitably qualified personnel, without incurring considerable retraining and further education costs. It follow that new employees, whether as replacements or for newly created jobs, incur increasingly greater training expenses.

Environmental protection

The increasing awareness and concern about environmental pollution in the last few years has had considerable effect on manufacturing companies. Regulations relating to pollution control limits have, to varying degrees, hindered the economic optimisation of many manufacturing processes:

- The financial burden of the installation and operating of environment protection plant and equipment. (Water-, air- treatment chemical waste disposal, etc.)

- The limitations of maximum plant utilisation caused by limits on noise emission, restrictions on operation, etc.

Summing up, improvements in pollution control bring the company additional costs per performance unit.

Raw materials and energy

The future trend of costs related to materials and energy can, undoubtedly, be said to be rising. Suppliers labour costs, and all other costs will, in the long-term, invariably increase. Occasional price fluctuations and price crashes are mostly of a temporary nature. Increasing scarcity of raw materials which are either impossible or difficult to substitute, will lead to price escalation directly proportional to demand (e.g. mineral oil).

The necessity of continuing rationalisation

One of the basic axioms of free market trading is that the customer of goods or services can choose between all available competing offers. Normally the contract or order is received by the supplier offering best value. Consequently, the company must constantly strive to remain competetive in its market segment. This means, offer sellable products at acceptable prices. For a company highly dependent on export trade, this burden is not lightened by the increasingly hostile world of international competition and import restrictions. Still more problems arise if the company is based in a hard currency country where repeated currency revaluations must either be absorbed or passed on as price increases.

The points made in chapter 4.1.1 can be summed up as follows: The company must constantly improve its productivity performance by at least that amount required to cover increased manufacturing costs which must be absorbed to remain competetive. This in turn means that the company must increasingly employ electronic and technological aids to achieve these rationalisation effects without incurring additional labour costs. This statement may be initially interpreted as being socially/politically unacceptable. Closer analysis of the matter reveals however that particularly during times of high unemployment, the company must remain solvent and profitable in order to enable:

- the guaranteeing of existing jobs
- the payment of unemployment and other social security benefits
- the payment of taxes
- the generation of further employment in sub-contracting and services
- etc.

4.1.2 Generalised company analysis and prognosis

Generalised company analysis

The life-cycle analysis of the existing product range revealed that several products had already reached the market saturation phase and some the decline phase. This situation is shown in Fig. 27. From this analysis the realisation that the development of new products would have to be intensified became clear.

The analysis of plant capacity and loading revealed for example in the machining sector, a relatively large capacity shortage (Fig. 28). The proportion of work being sub-contracted was too high leading to relatively long delivery delays and inflexibility (Fig. 28). The geographic decentralisation of the company resulting from building unavailability during early expansion is shown in Fig. 29. The physical separation proved disadvantageous to both material and information flow. Furthermore, coordinated and objective management of the company as a whole proved both expensive and difficult.

General company prognosis

The positive evaluation of both the medium and long-term market situation led to a product development programme of both completely new machines and improved units. The future product development programme (Fig. 30) shows that each product group should cover approximately an equal proportion of the total turnover. This decision had the following concequences on the manufacturing sector:

- A much wider spectrum and larger volume of different components would pass through both machining and assembly areas
- Product development and updating would be spread over a wider area
- Spares and service problems would be increased.

This change in the manufacturing programme entailed changes in the manufacturing structure. Fig. 31 shows several areas in which the existing situation differed widely from the required situation. To increase capacity, plant investment was necessary. The increase in capacity and complexity placed increased demands on the workforce. Rationalisation measures from the industrial management viewpoint were also found to be necessary.

The management divided the company development into three phases. In the first development phase, existing production bottlenecks were to be eliminated. This phase could however only be realised with high investment outlay and was designated the "first investment phase". The second phase, the "consolidating phase" featured the usage of these investments. In the third phase, all the scattered branches were to be centralised on one location. As this objective also involved a high investment outlay, phase three was designated the "second investment phase".

4.1.3 Summary of the main factors affecting development of the manufacturing departments

Consideration of the influences and demands of both environment and company lead inevitably to the realisation that improvement in productivity performance was of prime importance to the manufacturing sector. The main criteria for this improvement could be summed up as follows:

- Accelerating changes in market structure require a quicker succession of new products and the willingness to solve specific customer problems. This means that higher flexibility must be achieved.

- New products developed in shorter time spans quickly increase the component spectrum and accompanying paper work. This leads to structural problems which must be solved with modern methods and working aids.

- The demand for shorter delivery schedules requires shorter throughput times for order processing. This makes rationalised plant and information flow necessary.

- A wider product spectrum leads to a relative reduction in batch size which causes problems in handling a wide range of different components and information. This leads to an increase in system complexity.

- Developments in the market environment, particularly in the employment, financing, buying, and selling fields compel the increased rationalisation and automation of product function and operation.

- Acceptance of the fact that the employee is both the most expensive and the most flexible of the system's components means that great attention must be paid to the humanising of the working environment.

With the analytic investigation of this complicated problem, it became increasingly clear that the solving of the different problems could not be undertaken in isolation from each other. Measures taken in the design department would have far-reaching effects in the machining and assembly departments and vice versa. Improvement in plant flexibility would bring only limited success if the planning system remained rigid or customer demands could not be realised due to inflexible order processing. These few examples serve to demonstrate the necessity of solving the various problems with an integrated solution.

For these reasons the company management decided on the systematic optimisation of the manufacturing departments based on the realisation of the integrated manufacturing system.

4.1.4 Formulation of the general brief

The general brief formulation outlined the actual project and contained certain aims, specifications, and non-vital additional wishes.

General brief

An integrated system is to be developed which encompasses all manufacturing areas and ensures process rationalisation. The solution must satisfy the following requirements:

- improve productivity
- increase flexibility
- raise profitability
- reduce costs
- conform to government legislation
- be compatible with overall company policy
- enable the integration of other solutions
- improve employee motivation
- raise product quality
- minimise paperwork and bureaucracy
- minimise introduction expense.

- The system development must follow in such stages justified by technical progress and company finances

- The system development must apply the tried and tested GALLUS procedure technique

- The system development should be realised with existing company employees and, for specialised know-how, external advisors.

- Existing proved and tested sub-systems are to be integrated where applicable

- Monthly progress reports based on critical path analysis techniques must be submitted to the management.

Based on this brief, the next phase of the procedure technique "feasability study" dealt with the definition of specifications for the IMS.

4.2 Feasability study IMS

Relevant system specifications can be deducted from analysis of the various functions in the manufacturing area. Fig. 32 shows which specific areas require analysis which should also include the following aspects: Flow charts and logic diagrams (the "how"), actual activities (the "what"), working aids (the "with what"). In the following section actual analysis results from the manufacturing area are documented.

4.2.1 Results of the design sector analysis

In the drawing offices, data concerning staff activities was collected employing the method of voluntary personal work-measurement. Over a period of weeks each staff member was allotted the extra task of recording the time expended on various activities. The collected data was then computer processed and the figures evaluated. Fig. 33 shows the resulting structure. Indirect design activities accounted for 56 % of the working week whereas direct design activities only 44 %. Of the direct design activities, detailing (with 25 %) proved most time consuming (67).

The analysis of pure design activities (Fig. 34) showed that redesigns and modified designs were most time consuming. The frequency and distribution of drawing type and drawing format are seen in Fig. 35 and may be used at a later stage (for example to help select the size and type of drawing aids required).

The analysis of the problem orientated design process (Fig. 36) clarified the extent of work of algorithmic and heuristic nature. The extent of working aids application in the drawing office (Fig. 37) exposed weaknesses in the information system. In Fig. 38 an extract of the functional breakdown of a label printing press is shown. The purpose of a functional break-down is the isolation of solutions to specific functional requirements which can then be reapplied during later design work.

The method of isolating functional modules and functional elements is shown in Fig. 39. It should be noted that not only geometric information of the solution, but also the application, dimensioning logic and parameters must be determined. From the frequency distribution diagram of design solutions for the functional element "shaft bearing" (Fig. 40), those most justifying standardisation can be determined. These standardised solutions together with their design logic and parameters also serve as a basis for computer aided design data. Whereas the functional breakdown of the product is mainly of interest to the designer, the product structure breakdown is important to the entire manufacturing system, for example parts-lists organisation for the assembly department, or spare-parts service. Fig. 41 shows an extract of the product structure breakdown of a label printing press. With the analysis of the product structure breakdown came the realisation that the existing identification systems and assembly-drawing system were unsuitable for the rational identification of assembly or spares groupings.

Design planning operated on a conventional basis, that is, the chief designer estimated the development requirements of a particular unit or machine delegated the necessary staff and determined time limits. No exact figures for time required for detail drawings or designs were available. The control of both work and deadlines also operated on a conventional basis. In the new system an improvement in the planning and design functions must be achieved.

From the analysis and the aims of the design and development departments, the following specification guidelines for the system development could be determined:

- A reduction of at least 30 % in time spent on indirect design activities

- Improvement in the information availability from drawings, parts-lists and standards

- Systematic structuring of drawings and parts-lists systems
- The reduction of draughting time for the detailing of rotational and prismatic components
- Increased standardisation of detail drawings
- Standardisation of functional modules and functional elements
- Reduction of draughting time of layout drawings
- Reduction of time spent with routine calculations
- Improvement in planning functions
- Improvement in control functions.

These qualitative and quantitative specifications condensed from analysis of the design department served as inputs for the phase "conception". They must however first be compared and harmonised with the specifications from the machining and assembly departments.

4.2.2 Results of the machining sector analysis

A thorough and comprehensive appraisal of the machining sector cannot be made without an analysis of the component spectrum. The description and collection of component data enables the isolation of important information concerning machinability, production methods, machining times, etc. To enable this component spectrum analysis, a classification system (63) was implemented. The components were described with both a workpiece code and a machining code, the resulting data computer processed, and correlated according to various company specific criteria. This procedure is shown in Fig. 42. Primarily, the results concentrated on two structures, namely the workpiece structure and the machining structure (Fig. 43).

The workpiece structure

The workpiece structure analysis concerned itself mainly with the geometric aspects of the component, its size and form being important basic data for work planning, machine tool selection, tooling and fixture requirements etc. The resulting workpiece structure is shown in Fig. 44. At this generalised level of breakdown, three distinct workpiece groups were apparent, namely

- rotational components - 46 %
- prismatic components - 42 %
- sheet-metal components - 12 %

Sheet-metal components (actually a sub-grouping of the prismatic components) were, because of their fundamentally different machining technology, classed as a separate group. To ascertain usable information however, a finer breakdown of the workpiece data was necessary (in this work demonstrated with the example of the rotational components - the same logic also applies however to the other groups). The reproduction of all results of the component structure analysis is impossible within the framework of this study. The most useful purpose of this procedure was the achievement of clarity enabling relationships between different levels of component geometry and size to be isolated and identified. The results are mainly of a product neutral nature, as in the workshop, workpieces from all products are mixed.

Rotational components were further divided into two sub-groups: shaft-type and disc-type (see Fig. 45). Fig. 46 shows the further breakdown of the grouping "shaft-type components" and the resulting frequency profile. Two main areas were clearly identified - firstly the group of relatively simple, small workpieces, and secondly the group of larger more complex workpieces. Similarly, Fig. 47 shows the breakdown of disc-type components and the clearly visible concentrations. The rotational component, e.g. a shaft, has at this stage only been considered as a whole. More detailed examination however reveals that a further breakdown into primary and secondary elements was possible. Through this minute examination, further information concerning both component similarities and distinguishing features was made available. Fig. 48 shows the frequency distribution of primary elements in the investigated sample of shaft-type components. Fig. 49 shows the same for secondary elements.

In addition to the knowledge of the total spectrum of component structure, the product related component structure was of great importance to the manufacturing system. Fig. 50 shows the component structure of a particular product (the label printing press T 180). This component structure was expressed in the primary and secondary elements of the classification code after SULZER (63).

So far, only criteria of component geometry have been considered. A further analysis approach was as already mentioned the machining method and the required machining time per operation. Similarly to the division of the workpieces into rotational, prismatic and sheet-metal components, machining methods could be divided into machining classes e.g. rotational machining, flat machining, bore machining, etc.

The resulting machining structure is shown in Fig. 51 where the comparative profiles of machining class and respective machining times are overlaid. This perspective effectively demonstrated the dominant position of rotational, flat and boring operations in the overall machining profile. As in the case of rotational components, "rotational machining" will be used to demonstrate the further breakdown of the machining classes.

The structural breakdown of the machining class "rotational machining" into its respective machining methods is shown in Fig. 52. Again machining times were also compared showing that the machining method of "turning without screw cutting" proved predominant. Following the breakdown further, Fig. 53 shows the sub-groupings of the machining method "turning without screw cutting" together with corresponding time profile. Again, the predominant groupings could be identified, in this case, horizontal turning between centres and horizontal chuck turning. These results were further broken down in the size matrix which enables the size distribution of the machining groups to be seen (Fig. 54). Vital information relevant for plant-loading and plant-investment is also shown.

Several further analysis were carried out, the aim being to provide for example an overall profile of raw materials and finished workpiece dimensions, or required quality, tolerances, and surface finish. Knowledge of such factors played an important role in improving the existing situation. The size structure of shaft-type and disc-type workpieces is shown in Fig. 55. Fig. 56 shows the blank-form and blank-size of the same component group. The quality structure of the analysed component group is seen in Fig. 57 which further demonstrates the high quality demands of this particular product range. Fig. 58 and 59 show respectively the material group structure and the weight group structure of the shaft-type and disc-type components.

Similarly to the component structure, the machining structure of, for example the product type T 180 has been analysed (Fig. 60). All other component groups were also analysed in a similar way resulting in an overall picture of the entire company component spectrum. This basic information was an absolute necessity if an objective analysis of the manufacturing situation was to be achieved. On this foundation a sound programme of investment and improvement could be built which could spare the company the unpleasant surprises, often resulting from the implementation of unsuitable plant, stemming from subjective decisions or inaccurate situation assessment.

In the analysis of the machining sector, the component spectrum analysis and implemented plant analysis are of equal importance. In the described case, the entire plant operated with conventional methods. From 1970 onwards, an investment programme for the implementation of NC machines was drawn-up. A more detailed examination of these machine tools is unnecessary as plant modernisation has already been mentioned as one of the primary policy aims of the company.

Worksheet preparation was entirely manual without computer application. Generally, working aids even of a manual nature were only occasionally used, especially in production scheduling and control. Worksheets were mainly of a simplified operations-list type and capacity planning only possible with approximations. The entire production planning and control rested in fact to a large extent on the experience of the employees.

Quality control in the machining sector was the responsibility of the quality control department. Basically all workpieces were channeled through the department and checked although gradually statistically based sampling control was being introduced. NC measuring machines were not implemented.

Because the success or failure of the company is highly dependent on the achievement of the required quality, in the IMS the guarantee of quality at each stage of the process assumes major importance. From the analysis and policy aims which have been shown, the following demands on the system development were determined:

- Reduction of job throughput time in the machining sector $\geq$ 35 %
- Increase in the productivity of rotational machining $\geq$ 30 %
- Increase in the productivity of flat machining $\geq$ 30 %
- Increase in the productivity of bore machining $\geq$ 30 %
- Reduction in general manual operations $\geq$ 50 %
- Improvement in compatibility of plant to component spectrum
    - rotational workpieces
    - prismatic workpieces
    - sheet-metal workpieces
- Plant layout better suited to component classes (group technology)
- Improvement in tooling systems
- Improvement in jig and fixture design
- Increase in machining quality
- Linkage of information flow with drawing office and assembly dept.
- Improvement in worksheet preparation
- Improvement in capacity planning

- Improvement in control
- Improvement in job-loading and scheduling
- Improvement in machining data collection
- Standardisation of similar and identical machining processes
- Reduction in plant breakdown delays
- Increase inautomation and modernisation where technically meaningful and economocially justified
- No increase in personnel.

The above listed qualitative and quantitative requirements formed the input for the next phase of the system development, namely "solution conception". They must, however, first be complemented with the requirements of the "design" and "assembly" department.

4.2.3 Results of the assembly sector analysis

The products,assembled in small batches were highly intensive in manual activities. The fitters were in general highly qualified craftsmen who assembled and "de-bugged" units and machines in many cases with relatively seldom reference to assembly instruction manuals etc. These critical remarks only emphasise the extreme shortage of ideas concerning the analysis of small batch assembly. Further, it was apparent that especially with small batch manufacture the assembly shop was invariably burdened with the extra job of correcting all faults and failures of the preceeding departments.

In the framework of the study, it seemed purposeful to pragmatically select suitable areas of analysis. The following points were examined:

- The logical assembly procedure for sub-units, units, and machines
- The preparation and availability of components for the various stages of assembly
- The design and contents of assembly documentation (drawings and parts-lists)

- The method and necessity of checks and controls during assembly
- The examination of suitable working aids for the various assembly stages
- The qualification and training necessary for fitters at the different assembly stages
- The evaluation of assembly performance avoiding "piece rate" methods.

The assembly sector consisted of two separate departments. The unit assembly department was responsible for the assembly and testing of units on a batch basis. The final assembly department assembled, tested and installed complete machines on a modular basis to customer order. The units from the first assembly department were used. Each department was divided into sections, each specialising on a particular machine type. Fig. 61 gives an idea of the assembly shop layout and the product complexity.

The assembly planning was to a large extent the responsibility of the various section leaders relying extensively on their experience. The assembly instructions were only infrequently listed in logical order and contained practically no functional evaluation data. Parts preparation and availability presented a large problem if, as was often the case, a few components were missing at assembly start. The realisation of improvements within the framework of the IMS were also for assembly of the utmost importance. Resulting from the analysis and policy aims of the assembly sector, the following specifications for the system development were determined:

- Reduction in the scraping, filing and bedding-in of parts $\geq$ 50 %
- Reduction in assembly throughput time $\geq$ 35 %
- Improvement in assembly planning
- Linkage of information flow with drawing office and machining dept.
- Improvement in data collection in assembly
- Improvement in quality in assembly

- Application of modern information systems
- Application of modern working aids.

The above listed qualitative and quantitative requirements formed the input for the next phase of the system development. They must first be complemented with the requirements of the design and machining sectors.

4.2.4 Summary of the relevant demands on the IMS

The requirements determined in the analysed sectors - design, machining and assembly - formed a part of the input for the phase "concept for the IMS" (as previously defined in the procedure technique). A further part of the input resulted from aspects of company policy planning (Fig. 62). Through the combination of demands resulting from both company policy and departmental analysis it was ensured that all influencing factors would be considered when the IMS concept was formulated.

At this stage of the system development, the qualitative and departmentally overlapping requirements dominated. As the solution crystallised, the predominant requirements became increasingly of a quantitative nature. Fig. 63 schematically illustrates the relationship between the degree of system development and the corresponding nature of the requirements. At all stages of development however, all requirements retain their validity and must not be overlooked. In this work, the requirements determined in section 4.1.4 "formulation of the general brief" for example increased flexibility, or improved productivity, remain of greatest importance. This fact is emphasised in Fig. 64 which shows how the relevant requirements were used at each stage of development to evaluate the different solution possibilities. Shown in Fig. 65 are the relevant "requirements-catalogue" for the development of the IMS as applied to this work. Based on this sound foundation resulting from company development policy and situation reports from the departments design, machining and assembly, the next procedure stage "concept determination" could be approached.

4.3 Conception of the solution IMS

In section 2.3.2 the integrated manufacturing system was defined. It was determined that the IMS entails the integration of information and material processing, the application of modern working aids and methods whilst bearing the factor "working environment" in mind. The primary function of the IMS is demonstrated with the schematic "black-box" method in Fig. 66. Stemming from this primary function of the system, the respective functional sub-systems could be isolated and defined. The relevant sub-systems of the IMS are shown in Fig. 67. This diagram demonstrates the extreme complexity of the project. The connections or interfaces between the various sub-systems presented the greatest problem when searching for solutions. To facilitate a better understanding of the total problem IMS, and to enable a clear arrangement of functions and sub-systems, the next stage will describe the development of an abstract IMS model. This model aids clarification of the overall solution and enables the easier solving of sub-system problems and linkages.

4.3.1 Development of the IMS model

From the relationship illustrated in Fig. 67 between the various sub-systems, the sub-system "machining" is taken as a "model-building-block". The relationship between the other system components - design and assembly - can be resolved in a similar way.

Seen as a geometric shape, the model-building block "machining" (Fig. 68) gives a rectangle. The arrows symbolise the information and material flow both to and from the adjacent sub-systems. It is immediately clear that an intensive, one could even say, an inseparable relationship exists between this building-block and the adjacent blocks. Initially, the block "machining" will be considered in a two-dimensional, solution-neutral form, totally independent of possible solutions (e.g. conventional or NC machined). By adding the factor solution to this two-dimensional model-block it can be extented into a three-dimensional model-block (Fig. 69).

Through the conversion of the model-block into a three-dimensional volume with the interfaces a + b and the relationships m1 to m^2 the basis for the development of a model for the entire IMS system is established. The surfaces a + b represent the interfaces to the adjacent development stages of the system. (It is assumed that the overall system IMS will be developed and realised in stages.) These model-blocks can also be designated "solution-quadrants" in the framework of the stage by stage development of the entire IMS. With this interpretation, the volume of each solution-quadrant represents the sum of all part-solutions involved in achieving the functional performance of its respective sub-system. (Under the "sum of all solutions" all hardware-, software-, organisational- and personnel-related solutions should be understood.)

This model-based interpretation of the system and its sub-systems can be applied in several different ways to simplify the understanding of various aspects of the problem. Before the next stage of the IMS model development can be carried out, a "system-heirachy" must be developed which enables a logical and clear arrangement of the model-blocks. This heirachy is shown below:

Overall system:	The "overall system" encompasses the complete IMS solution and its planning and control processes (Fig. 70)
System:	A "system" encompasses the planning,process and control of a particular function e.g. "machining" (Fig. 71)
Sub-system:	A "sub-system" encompasses a logical part function of a "system" e.g. "control of machining" (Fig. 72)
Sub-system element:	A "sub-system element" encompasses a solution to logical part function e.g. "NC measuring machine".

Before appraisal of the aspects of integration of systems and sub-systems in the framework of the IMS can start, it must first be decided on which criteria the integration is to be evaluated. The definition states "fusion into an entity" (69). The integration of systems can be judged from the viewpoint of information flow or material flow. According to the stage of development reached and type of solution being considered, data-, organisational-, or technological-integration can take priority.

By the integration of systems, sub-systems etc. it is important that efficiency-loss is kept to a minimum. Efficiency-loss is best avoided when the system solutions to be integrated are made as compatible as possible as demonstrated in case A of Fig. 73 . When the system solutions are to a large degree incompatible as shown in case B of Fig. 73 a large "integration-gap" occurs which greatly effects system efficiency. It is clear that some efficiency-loss must occur at the interface between system components, however the greater the system compatibility, the less this loss will be. With the development of integrated systems, regardless of complexity, the compatibility of the selected solutions is of the utmost importance.

A further important factor is the "balance" of the solutions. It would be possible to so develop a part-system of the IMS that its advanced level of sophistication and technology differed so much from the other part-systems that tension and friction would occur in the company. This case is demonstrated with the model in Fig. 74. The cube with side length 1 containing the three identical cubes - planning, process and control - symbolises with the respective identical vectors - the theoretically ideal degree of "balance" between system solutions. In the second example, the unequal quadrants with differing vectors demonstrate a state of extreme unbalance between the system solutions. It should therefore be the aim of every extensive integrated system development to achieve an overall harmonic relationship between all the system solutions. Based on the above described model-block approach, the model for the overall system IMS was developed. The "process" composed of the sub-systems design, machining and assembly should be considered firstly as this builds the core of all activities. Planning and control only play a supporting role, considered alone they have no meaningful purpose. Assuming that at a point in time "X", the sub-systems have reached a solution development level "A", they can, stage by stage be further developed or optimised. Fig. 75 shows a coordinate system in which the X-axis represents the different process sub-systems - design, machining and assembly. The Y-axis represents the different development stages A, A+1 to A+n. The Z-axis represents the total degree of automation of the solution. It can be basically assumed that in optimising the process, the continual striving for increased automation of the various algorithmic activities will be made.

Assuming that by a degree of automation of zero all activities are executed manually, it follows that utopian full and total automation has a degree of automation of one. This level will almost certainly not be achieved in the forseeable future when applied to integrated systems. Certain single activities can however operate fully automatically. The sum of all activities in a system or sub-system of the IMS will have a degree of automation less than one. It can however be said with certainty that the solutions of the IMS will vary between zero and one concerning degree of automation.

The decision as to how many development stages should be chosen depends on the technical feasability, on the policy decisions, on financial possibilities and lastly from expected benefit. The schematic representation of the process development model shown in Fig. 75 can similarly be applied to both planning and control. It should be explained that each process element logically requires adequate planning and control elements as integrated parts of the system. By these linkages the criteria of "balance", "harmony" and "compatibility" as well as the avoidance of integration gaps must be carefully considered. The Fig. 76, 77 and 78 show a graphical interpretation of the ideas of the IMS model and demonstrate the stage by stage development technique at both system and sub-system levels. The increasing degree of automation, and the interdependance of solutions for planning, process and control are both clearly shown.

Summing-up all these ideas into a single overall picture, the system model IMS shown in Fig. 79 results which portrays the overall system IMS as a three-dimensional system model. Of the three axis, the X-axis represents the different sub-systems, the Y-axis the respective development stages, and the Z-axis the achieved degree of automation. A system, for example the machining system, is shown as the shaded vertical column combining the sub-systems planning of machining, machining, and machining control. This overall system model can also be considered as a control circuit having defined inputs, defined outputs, whilst being internally self-regulating. This model complies to the definition in section 2.3.2 showing the full extent of the system. The entire performance producing sector of the company from the product idea to finished product, involving the three main functions - planning, process and control - are included. These three main functions apply to the process functions - design, machining and assembly. The model both documents the complexity of the IMS and brings clarity to the problem, allowing the structuring of solutions and their interrelationships.

The development of an integrated system, especially a wide-reaching system, such as the IMS, requires a system philosophy. This philosophy must act as a guideline throughout the entire development, becoming particularly necessary when different system components are being developed simultaneously by different project teams. Successful coordination is of extreme importance in such a case and can be considerably simplified when based on both good planning and a sound system philosophy. The following section demonstrates the development of the IMS solution concept employing these ideas.

4.3.2 Conception of the IMS system

With such a complex problem as the IMS, the procedure technique step "conception of the solution" was executed in a modified and simplified manner, otherwise a "solution matrix" too large to be comprehensible would result. The solution matrix extended from the simple conventional solution to solutions with higher degrees of automation. The "solution matrix" was structured as shown in Fig. 80, the number of solutions being limited to the four possibilities shown. Quantitative definitions of different degrees of automation were meaningless at such an early stage of the procedure technique. The qualitative interpretation of the degree of automation must be seen from the viewpoint of the whole system and not as an isolated part. The stages of automation could be interpreted as follows:

- Zero automation
  The existing situation at project start. The conventional solution

- A low degree of automation
  for example the application of NC machines in the machining shop

- A medium degree of automation
  for example the application of DNC machines in the machining shop

- A high degree of automation
  for example the application of flexible machining systems.

After specifying the different levels of automation, the individual solutions of the system components can be conceived. In the framework of this third procedure technique stage, only the concept possibilities for the process parts - design, machining, and assembly - were determined. (The core of the problem being the process.) It should be mentioned that the solution possibilities shown in the solution matrix are not intended to be universally valid but applied specifically to the requirements of this particular case. The sought after solutions embraced the problems information and material flow, working methods and workforce application.

4.3.2.1 Conception of solutions for the "process" parts

It must again be repeated that solutions at this stage had only a generalised nature. The solutions became progressively more detailed in the procedure stages shown in Fig. 24, namely "design of solution" and "detailing of solution". It is normal when using the "procedure technique" to neutralise the considered problem in the form of a "black-box" abstraction having only inputs and outputs. This freeing of the problem from any existing solutions promotes innovative and wide-based approach to search for new ideas.

Conception of the solution for "design"

Considering the function "design" as a "black-box" abstraction, the relationship shown in Fig. 81 resulted. The overall function of the design could thus be defined as "the development of design solutions for predetermined problems". In fulfilling this function, many different steps must be taken. The main operative functions inside the overall function design could be broken down as shown in Fig. 82.

Stemming from these design functions, the respective "function solutions" could be determined and entered into the solution matrix shown in Fig. 83. The different part-solutions gave, when linked vertically, solution concepts for the overall function "design". In the horizontal, the part-solutions show from left to right, an increasing degree of automation. For the function "design" this meant that starting from the existing situation a stage by stage automation was possible, determined entirely from the actual company requirements (see section 4.2.4). Obviously, a jump from the conventional solution of solution possibility 1 directly to solution possibility 4 would be both impractical and impossible. The main purpose of this work is to demonstrate a logical, step by step approach to the gradual development of the performance producing sector of the company. The solution possibilities shown in the solution matrix can be summed-up as follows:

Following on from the conventional solution possibility 1 which represented the existing situation in the company, solution possibility 2 would see the introduction of the computer to the design department. It must be seen as a working aid and not as a substitute for designers or detail-draughtsmen, its primary purpose being improving information handling, giving staff quicker access to standards, formula, drawings, etc. In this phase, the computer orientated systemising of information and information flow would take place. Solution possibility 3 dealt primarily with computer application in the areas of layout and detail drawing preparation. The computer would assume the information storage function and execute the tedious activities such as lining, lettering and dimensioning. Put in other words - the computer would graphically depict the designers solutions and produce detail drawings. In solution possibility 4 the entire process part "design" would be from beginning to end "computer-aided". The designer would form a so called "person-machine-system" together with the computer. All relevant design data for the following process-parts of "machining" and "assembly" would be stored in the computer being available "on-line".

At this stage no mention will be made of the necessary hardware systems and software packages. These will be dealt with in the next procedure stage, namely "design of the solution IMS".

Referring back to the system model shown in section 4.3.1, the actual solution concept for the process-part "design" can be seen in Fig. 84, the stage by stage development being clearly shown. The Z-axis (indicating the degree of automation) equally represents the degree of computer application in the design process. The combined solutions to the process-part "design" are termed "Computer-Aided-Design" (CAD).

Conception of the solution for "machining"

Considering the function "machining" as a "black-box" abstraction, the relationship shown in Fig. 85 resulted. The overall function of "machining" could thus be defined as "the conversion of raw-materials into the state specified on detail drawings stemming from the preceeding process-part "design". The functional breakdown of the machining department was not as straight forward as was the case of "design". The machining process could be broken down into material flow, information flow, or machining method. A breakdown to the level of worksheet analysis would have been too detailed for this stage of the procedure. Another factor was that by the breakdown of the machining process at this stage, only the technological aspects were of interest, as machining planning and machining control were examined at a later procedure stage. For these reasons, the functional breakdown of the machining process shown in Fig. 86 appeared suitable, whilst at this "generalised" level, work flow and machining technology could be combined without resorting to the detailed operation level. Stemming from these machining functions, the respective solution possibilites (with the previously mentioned limitations) could be determined and entered into the solution matrix (Fig. 87).

The respective characteristics of the solution possibilites could be summed-up as follows:

The solution possibility 1 showed the existing situation. In solution possibility 2 the application of NC technology stood central in the development. Obviously, all associated factors (especially NC programming) would also be dealt with in this solution. Through the application of computers and NC machine tools, the efficiency of data-processing in the machining process could be greatly increased. The solution possibility 3 chiefly involved the application of DNC and computer-aided NC programming. Further, machine loading and unloading would be realised with robot application. In solution possibility 4, information flow and material flow would be automated. Through the build-up of workpiece group orientated flexible machining systems, manual activities could be largely eliminated. Here, as in the design process, a "person-machine-system" results in which workpieces of the required quantity and quality would be produced.

Similarly to the design process, the combined solutions to the process-part "machining" are termed "Computer-Aided-Manufacturing" (CAM). The actual solution concept for the process-part machining can be seen in Fig. 88.

Conception of the solution "assembly"

Similarly to "design" and "machining", the function "assembly" was also considered as a "black-box" abstraction (Fig. 89). In the framework of the process-part "assembly", components i.e. workpieces, bought-in parts, fixings, etc. constitute the input. As was the case with the two previous process-parts, the assembly process was executed in several stages until finally the fully functioning unit or machine was finished. It was therefore seen as advantageous to functionally breakdown the assembly process in the same manner as by the two preceeding process-parts. For the described case, a product neutral standard logic for the assembly procedure was possible. The process breakdown is shown in Fig. 90. Stemming from these assembly functions, the respective solution possibilities could be determined and entered into the solution matrix shown in Fig. 91.

The respective characteristics of the solution possibilities could be summed-up as follows:

The solution possibility 1 showed the existing situation. With solution possibility 2, assembly information for fitters would be largely "computer-aided". Stored data would include assembly instructions, product break-down structures, etc. In dialogue mode, fitters could obtain all relevant assembly data needed for the respective assembly stages. In addition to computer-aided information flow, solution possibility 3 envisaged the application of freely programmable assembly robots for certain assembly functions. Further, all other assembly aids would be so systemised to enable a more rational and productive assembly. In solution possibility 4 information flow and material flow would be automated. The flexible assembly systems would allow a product structure orientated assembly, again resulting in the "person-machine-system" which would produce the required quantity and quality of units and machines.

The actual solution concept for the process-part "assembly" can be seen in Fig. 92. Similarly to the preceeding process-parts, with the application of computer techniques, the combined solutions are termed "Computer-Aided-Assembly" (CAA).

4.3.2.2 Summary of the solution concepts for the whole process

In the previous section, the respective solution concepts for the process-parts "design", "machining" and "assembly", all incorporated a common characteristic, namely the continuously increasing degree of computer application. In addition to the computer, modern technologies, such as NC control, robots, transport systems, etc. were employed. In Fig. 93 all process-parts are combined to give the entire "process". The process-part solutions CAD, CAM and CAA provide a sound basis for all future developments to rationalise and optimise the performance producing sectors of the company.

For the considered case, solution possibility 2 was selected as the first development target (although it was simultaneously decided to progress to the next stage as soon as the first target was realised). Consequently, from the total solution spectrum, shown in Fig. 93, the shaded system components indicate the extent of the selected development. A smooth transfer from stage A to A+1 and from A+1 to A+2 required special consideration of the model developed in section 4.3.1, particularly concerning the integration criteria.

As already mentioned, "planning" and "control" must be adapted to meet the particular requirements of the process solution (the three sub-systems then combining to form the control circuit). A similarly detailed concept study for "planning" and "control" lies outside the framework of this work, however in order to demonstrate the full extent of the idea, these two sub-systems are briefly described.

4.3.2.3 Conception of the solution for "planning"

Considering the overall function "planning" as a "black-box" abstraction, the relationship shown in Fig. 94 resulted. The central purpose of the function "planning" is the logical structuring and procedural organisation of the workings of the process. The results are defined in plans (69). Based on these plans sizes, capacities, deadlines and quantities etc. are determined and the resulting objectives set. "Planning" seen from the viewpoint of the process can be broken down into the structure shown in Fig. 95. From these functions, solution possibilities can be determined and entered into the solution matrix (Fig. 96) in the manner shown for the process.

The solution possibilities entered into this solution matrix refer only to the more important planning functions and are therefore relatively incomplete and abstract. They show however the intended effect of an increasing degree of automation. It can be clearly seen from the solution possibility 4 "high degree of automation" featuring the dominant application of dialogue-capable computer systems, that a great similarity exists between the planning functions of design, machining, and assembly. It is clear that in each case the required hardware would be basically similar, and software at least structurally similar.

Fig. 97 shows the abstract solution concept for the planning system based on the solution matrix and its solution possibilities. With the application of computers, this planning function can be designated "Computer-Aided Planning" (CAP). The three planning sub-systems being CAPD (Computer-Aided Planning of Design), CAPM (Computer-Aided Planning of Machining) and CAPA (Computer-Aided Planning of Assembly).

4.3.2.4 Conception of the solution for "control"

As with "planning", the overall function "control" as a "black-box" abstraction results in the relationship shown in Fig. 98. The central purpose of the function "control" is the comparison of the performance results achieved during the execution of process operations with the preset specifications and plans from the function "planning". The factors requiring control include schedules, quantities, times, costs and qualities, etc. The functional breakdown of "control" shown in Fig. 99 corresponds logically with the functional breakdown of "planning". In the solution matrix (Fig. 100) generalised solution possibilities for the function "process-control" are shown.

Similarly to the function "planning", "control" is also required in all parts of the "process" - design, machining, and assembly. Control functions include in addition to data collection and processing, the checking of technological solutions. For example, in design all drawings must be controlled to ensure that standards, machining and assembly restrictions etc. are observed. Many of these control routines can be integrated into CAD software programmes. In machining and assembly, relevant measuring and test machines must be installed with programmable control systems, thereby enabling an automated control function.

Fig. 101 shows the abstract solution concept for the control system. Again with this system, the computer occupies a central position permitting the use of the term "Computer-Aided-Control" (CAC). The three control sub-systems being CACD (Computer-Aided Control of Design), CACM (Computer-Aided Control of Machining), CACA (Computer-Aided Control of Assembly).

4.3.3 Solution concept for the IMS

The solution concept IMS for the described case is composed of the part-solution for the planning CAP, the solutions for the process parts CAD, CAM, CAA and the part-solution for the control CAC. This integrated manufacturing system operates in the manner demonstrated in the cybernetic model of the control circuit shown in Fig. 102. Market information is first processed into product requirements which are then converted using the procedure technique into definite specification sheets. Based on these technical and economic product specifications (which form the input data for the IMS), the procedure control mechanism of the IMS is started. The conversion of product specification into finished product requires the activation of all three IMS process sub-systems following in their logical sequence.

Firstly, the design system of the IMS converts this input data into drawings and parts-lists, that is into an input form which the machining system of the IMS can interpret to carry out its function, that is the conversion of materials into the state specified by the design system. Finally, these components are combined in the assembly system according to the given specification, the output being the finished product.

From the total spectrum of solution possibilities shown in Fig. 102, the solution concept selected in the considered case was the shaded second stage of the integrated manufacturing system (bearing in mind the degree of automation). This second stage of the IMS has already been termed as "of low degree of automation" and must be developed from the "conventional solution" stage 1. It must be so developed to allow a smooth transfer to the later stage of development stage 3 "of medium degree of automation". In this stage 2, computer-aided solutions are applied to problems in the process-parts design, machining, and assembly. It is certainly one of the most important phases in the restructuring,as the new working aids and methods can bring great clarity to the daily workings of the company. This can only be achieved through concerted teamwork which is so important that company organisation should be adapted to the system. All levels of company management and employees in all affected departments must be trained and prepared for the changes caused by the application of systems such as CAD, CAM, etc. The selected solution concept for the considered case embraces the important stage 2 of the full IMS as shown in Fig. 102. The IMS is divided into three main systems, namely the design system, the machining system and assembly system. Each of these systems is composed of the three main functions - planning, process and control.

The design system is schematically represented in Fig. 103 and corresponds to the solution possibility 2 of the solution matrix shown in Fig. 83. It consists basically of Computer-Aided Planning of Design (CAPD), Computer-Aided Design (CAD) and Computer-Aided Control of Design (CACD).

The machining system is schematically represented in Fig. 104 and corresponds to the solution possibility 2 of the solution matrix shown in Fig. 87. It consists basically of Computer-Aided Planning of Machining (CAPM), Computer-Aided Machining (CAM and Computer-Aided Control of Machining (CACM).

The assembly system is schematically represented in Fig. 105 and corresponds to the solution possibility 2 of the solution matrix shown in Fig. 91. It consists basically of Computer-Aided Planning of Assembly (CAPA), Computer-Aided Assembly (CAA) and Computer-Aided Control of Assembly (CACA).

Each of these systems of the IMS is in itself a fully functioning control circuit system producing an output which is required by the following system. To enable a clearer and more detailed understanding of the solution concept, an attempt to set-down the main IMS solution components in a schematic functional diagram has been made. At this conceptional phase of the procedure technique, it is too early to be concerned with such details as, which computer should be used, or how the different programmes should be structured. It is however important that the function of the systems together with all main procedure steps and necessary input and output relationships are clearly established. Furthermore, the determination of where and how the different required aids and methods will be applied, together with how the organisation should function, also belong to the stage of conception.

Referring back to the model of the IMS developed in section 4.3.1, it will be remembered that the solution quadrant was interpreted as a three-dimensional model-block (see Fig. 69). The input and output relationships between the different systems of the IMS and the linking of information and material flow were shown to be the main integration criteria. The higher the degree of system automation becomes, the greater must be the integration of systems and sub-systems. Considering the selected solution concept for the IMS with its "low degree of automation" (which will later be extended to a higher degree of automation), it becomes immediately apparent what great importance this "integration" assumes. Without going into detailed description of individual solutions, the importance of integration can be illustrated with the examples of the solution possibility CAD - detail drawing production - and the solution possibility CAM - NC machining - and their respective interdependance. Assuming that a solution concept for the integrated manufacturing system has been developed, it will already be guaranteed at this early stage of the concept, that the information flow from the design department to NC programming is such that all relevant data from design can be directly applied for programming without further manual modification. This is an example of information flow (data) integration between computer-aided detail drawing preparation and computer-aided NC workpiece programme preparation.

The hardware configuration used in the design department for the computer-aided detail drawing preparation must be compatible with that used in the machining department for the computer-aided preparation of NC workpiece programmes. Further, the work flow organisation must be adapted to meet these changed realities. All other hardware-, software- and organisational integration measures must be approached in a similar way, always bearing in mind the overall solution concept for the IMS. These aspects of integration will be dealt with in greater detail in the later procedure stage "Design of the solution IMS".

Fig. 106 shows the functional structure of the selected solution concept for the IMS. The functional structures of the different systems, such as design system, machining system and assembly system are clearly demonstrated. It can be seen for which tasks the computer would be applied and the approximate extent of the necessary hardware configurations. Further, the main programme packets could be identified.

In the design system the computer employed would be primarily engaged in the automatic preparation of detail drawings. The computer configuration consisting of a central processor, interactive CRT, plotter for up to A0 format drawings, disc memory, line printer, and punch tape reader and perforator. With this configuration, the following tasks must be performed:

- CAD detail drawing production for rotational components and prismatic components of simple to medium complexity (excluding housings, etc.). The software packet must be so developed that drawing dimensioning would be executed fully automatically by the computer. Organisational data must also be mainly automatically processed. The system must have "dialogue capability" and all inputs and outputs be compatible with the working practices of the drawing office staff. All draughting standards and machining standards must also be fully integrated in the software.

- Wide-ranging technical calculations - statics, dynamics, etc. must be possible in dialogue mode.

- Raw material selection for the detailed components in dialogue mode.

- Workpiece classification (using the classification code of the company) must be automatically determined for all detailed components.

- The statistical analysis of stored classification data to aid the repeat usage of existing components and to determine workpiece groupings (workpiece "families").

- Provide the designer - in dialogue mode - with information concerning standard components, bought-in components, existing design solutions, patents and technical literature etc. Information must be available by inputing functional code, or keyword, or identification code.

- All relevant data stored from the detail drawing production must be further processed for later use in NC programming and workflow sheet preparation.

- The application of a drawings and parts-lists system which meets the demands of the machining and assembly departments. For planning and control operations, all data prepared with the computer should be output according to system specification. All remaining planning and control work should be continued manually. All manually produced drawings must be dealt with in the same way as the CAD produced drawings however certain operations must continue to be executed as previously in the conventional solution. It is important to note that with the step by step introduction of the new system, existing well-established and familiar methods and procedures must be retained until the replacement systems are fully operational. The actual design process phases "conception" and "design" continue on a mainly manual basis, only calculation being carried out with computer application.

Within the framework of the machining system, the application of NC machines occupies a position equally as important as computer application. For NC programming, a computer system must be applied which serves either as a terminal for programme transmission to and from a time-shared large computer centre, or is capable of self-processing with a universal NC programming language. The computer configuration should consist of central processor, line printer, punch tape reader and perforator, card reader, disc memory and interactive CRT. The computer must be capable of "multi-programming" and dialogue mode operation. It should assume the following tasks:

- NC programme production for machining operations of rotational, prismatic and sheet-metal components using the data from the CAD systems. (CAD-CAM linkage).

- Administration of existing programmes.
- Administration of tooling-, material- and macro-data banks.
- NC programming data collection, processing and analysis.
- NC machining production data collection, processing, and analysis.
- Stores-control for production tooling, drills, tips, etc. (Movement, statistics, etc.)
- Workplan production in dialogue mode employing data available from CAD system.
- Capacity and loading planning, schedualing, for normal production (excluding express jobs, one-offs, etc.).
- Preparatory work for the later introduction of the solution possibility 3 of the solution matrix Fig. 87 namely full DNC operation.

Considering the entire workpiece spectrum of the company, it is immediately clear that not all workpieces - rotational, prismatic and sheet-metal - can be produced on NC machines. The analysis results in section 4.2.2 clearly show however that a large percentage can be NC machined. In the following procedure technique phases "solution design" and "solution detailing", the application of NC machines will be dealt with in greater detail. Similarly, the functions - planning of machining and machining control - will be examined in the next procedure stage.

In the development stage 2, the assembly system barely changes from that in the conventional solution. The primary objective being to improve assembly information, starting from the design process where much of the information relevant to assembly originates. Typical assembly information includes:

- Product breakdown structure
- Sub-assembly and assembly drawings
- Assembly and setting instruction manuals
- Inspection and test sheets
- etc.

It is important that this information be prepared in the form most suitable for the assembly department. Technical data such as drawings, parts-lists etc. could be micro-filmed and stored in such a way to enable the fitter immediate access to information at his place of work. Assembly instructions could be obtained in dialogue mode from digital terminals for both sub-assemblies and units. This would enable the fitter to benefit directly from the modern working aid - the computer - and allow him greater independance and self-reliance in the execution of his work.

The described concept for an IMS requires a fully compatible "computer heirachy". Both hardware and software must be capable of step by step expansion to cope with the increasing integration whilst avoiding - as far as possible - any integration gap. Fig. 107 again shows the IMS model this time demonstrating the application of computer hardware. A central computer primarily assigned the task of data administration and processing serves the IMS as an overall management aid. Linked to this central processor are three computers for the functions - planning, process and control - (Fig. 108). Coupled to these three computers are all system related hardware elements such as NC machines CAD plotters, data input and output terminals etc. (Fig. 109). System software must be of modular concept, so designed that extension blocks can be constantly added without modification to the existing software. The step by step extension of fully compatible IMS hardware and software can best be realised when a comprehensive concept for the entire system has been previously determined. In this manner much time and money can be saved during the development and application of an IMS.

From this description of the solution concept IMS, the great changes required in all IMS systems compared to the "conventional solution" are apparent. The involved employees and the company organisation are most affected having to absorb the greatest amount of change. The effects of change on working patterns is dealt with in a later section. To round off the procedure stage "conception of the solution IMS", the organisation of the manufacturing sector will be illustrated.

Section 2.3.2 defined the integrated manufacturing system and showed its relationship to other areas of the company. Based on this structure and considering the technical solution of the IMS, it becomes clear that unlike the classical organisation forms a change occurs. Three separate "control circuit systems" are created which, through the application of computer technology are also inseparably coupled together. From this interpretation follows the organisation form shown in Fig. 110. In industry, it is often assumed that the application of rationalisation aids automatically lead to increased productivity and greater efficiency. The full exploitation of rationalisation measures is however only then possible when the related organisation is also integrated in the solution. Both the management organisation and the work flow organisation must be adapted to the changed situation in design, machining and assembly. Through computer application, various separate tasks become combined into single operations. The linkage of the different departments through common data-banks makes intensified interdepartmental cooperation essential. The expectations of employees concerning job, training, and promotion is also considerably affected, for example the fact that detail drawings are produced with CAD profoundly affects the detail draughtsman's perception of his purpose or function. All these factors must be seriously considered in the organisational structuring to enable a smooth transition from development phase to development phase.

It cannot be emphasised enough that organisation is one of the most critical factors of the system, unfortunately where most mistakes are made. Considering the aspects of organisation for integrated systems, it becomes apparent just what advantages the overall concept of the IMS offer. The organisational structure needs to be made only once and can then be improved step by step and expanded with the growth of the IMS. Through this technique, the company can save both time and, more long-term, money. The employees can be gradually retrained or introduced to new methods and the management of the IMS can grow with the system. The organisation diagram in Fig. 110 shows the relevant organisational positions. The responsibilities on the respective employees in these positions are thereby perfectly clear. The controlling manager of the manufacturing sector, responsible for both the daily operations and the development of the system IMS, must be both a highly qualified engineer and an industrial manager with a good knowledge of computer applications. The managers of the different departments are primarily specialists in their particular field although management capabilities and computer knowledge are also necessary. It could be asked, where in this organisation are those who in most organisational forms are found in management advisory departments etc., all the "specialists" such as systems-analysists, organisers, management specialists, programmers, etc. The answer is, they are organisationally integrated into those departments where the day-to-day workings of the company take place. They work together with the practical staff directly where the problems occur and must be confronted and not isolated in "back-rooms" creating theoretical systems which are often totally irrelevant to the problems of day-to-day reality. The responsibility for the development of the IMS rests with the directly affected departmental managers. Each develops the section of the system relevant to that particular section. Problems affecting several or all systems or departments are solved in temporarily created project teams.

With this organisational concept, the manufacturing sector develops a self-motivating dynamic development and assumes a responsibility which to a large extent guarantees the successful running and permanent adaptation of the system to the changing realities. The enrichment of the day-to-day work, the extension of responsibility and the working in teams all echo the increasing demands from employees for greater involvment which this organisation form even institutionalises. The innovative character of this organisation concept lies in the institutionalisation of employee participation which is logically effected by the functional character of the IMS.

The procedure technique phase "conception of the solution IMS" is finalised with the completion of solutions for hardware, software and organisation. In the next phase "design of the solution IMS" only the machining system will be covered and not the entire IMS. It should however be stated that both the design system and the assembly system must also be developed as demonstrated in the next section to obtain a detailed overall picture of the IMS. During the development phase of the design system, the company worked in cooperation with a technical university. This project was divided into stages, the first being the application of CAD for detail drawing production. The main development stages of the design system are shown in Fig. 111. The respective interfaces between "design" and "machining" will be dealt with from the viewpoint of the machining system in the following section. The development of the two systems "design" and "machining" were carried out simultaneously although with partially staggered phases. The assembly system development will not be dealt with in great detail until the preceeding systems "design" and "machining" have been to a large extent realised.

It is of great importance during the next procedure phase that not only the machining system (which will be further used as an example) but also the design system and the assembly system are all compatible to the overall solution. It must be possible in all phases of the system development to have a clear view of the situation and be capable of unmistakably identifying for "what" and "why" any development is being made. One reason for this is the rapid advance in technology, which could lead to the mistake of making repeated "fresh starts", a mistake which should be avoided by all means. Should such measures prove necessary, only the affected solution modules of the IMS should be replaced with new modules and not the entire system.

Considering that the realisation of an IMS requires a time-span of approx. 10 years, it must be accepted that technological change and computer advances will occur. This must be allowed for in the planning of the system development. Companies which have already begun with the realisation of some modules of the manufacturing system have decided wisely since IMS systems will never be on the market both "made to measure" and "off the shelf" in one parcel. Based on this knowledge and the acceptance of the step by step development, a company should start with that part of the IMS which offers it the greatest rationalisation possibilities. Certainly hardware and possibly also software should be bought-in. In this case, during the first phase of development of the IMS, the main efforts were concentrated on machining, in the second phase on design and thirdly on assembly. For this reason, within the framework of this work the machining system development will be demonstrated further.

4.4 Development of the solution for the IMS machining system

In the preceeding section, the concept for the machining system was briefly described. The machining system is, as already mentioned, a system of the IMS consisting of the sub-systems - planning of machining (CAPM), machining (CAM) and control of machining (CACM) (Fig. 112). In the framework of the procedure phase "development of the solution" for the machining system, solutions were developed for the hardware, software, and organisational aspects of the sub-systems, all based on the guidelines set in the solution concept.

The machining system must conform to the technical requirements of the workpieces which form the output from the design process. The machining processes, size of the machines, general work flow, raw material form, workpiece tolerance etc. are all determined by the design system. The machining system must therefore be constantly adapted to the latest state of the constantly changing workpiece spectrum. Simultaneously, the design system must constantly attempt to produce workpieces suitable for the available plant.

The workpiece spectrum analysis (already shown in section 4.2.2) formed the basis for the selected rationalisation measures. The machining system solution most suitable for the company must be developed in the same manner as shown in section 4.3.2. Clearly, the other system components, namely the design system and the assembly system must, as the above mentioned machining system, be based on the previously defined solution concept. These two sub-systems are not followed further in the framework of this thesis, except where they exert a dominating influence on the machining system.

4.4.1 Development of the solution for the machining process

Firstly, the process itself that is "machining" will be developed followed by the complementary functions "planning of machining" and "control of

machining" which must adapt to the requirements of the process.
In the framework of the concept for the machining system, the function "workpiece machining" was broken down into the following sub-functions:

- Workpiece raw-material preparation
- Workpiece machining execution
- Workpiece transportation
- Workpiece storage.

For these sub-functions, solution possibilities were established of varying degrees of automation. For the machining system, the solution possibility 2 was chosen (see solution matrix Fig. 88 and the functional description in Fig. 106). From this selection it is clear that the considered workpiece spectrum proved to be suitable for machining with NC plant. From the analysis of both the different workpiece classes - rotational, prismatic and sheet-metal - and the respective machining processes - turning, milling, drilling, etc. - the areas mostly requiring increased productivity were apparent (see section 4.2.2). The solution to be developed for the machining system must meet these requirements.

A further stage in this development involves breaking-down the workpiece spectrum according to batch size and the selecting of the most suitable machining methods for each group. Such a breakdown, especially the classification of batch size is only valid on a company specific basis. The grouping into "one-off", small-, medium- and large batch sizes requires a flexible interpretation of limits. The machining methods and respective workpiece groupings shown in Fig. 113 should initially be seen as having a primarily classifying character.

"One-offs" are mostly involved with the machining of prototypes and spares, usually work with tight schedules, important deadlines and frequently unsatisfactory documentation. Further, the organisation concerning the machining of these parts also demands considerable improvisation often requiring special treatment . The machining of such workpieces mostly involves conventional, universal plant, where possible in small shops. The small batches are primarily machined using a combination of both conventional and NC equipment. Medium and large batch production can be grouped together as both employ almost exclusively NC machines. From this approximated breakdown result the three main machining classes as shown in Fig. 114.

It was decided during the formulation of the overall manufacturing policy that surface and heat treatment as well as gear cutting would continue under reliable and experienced sub-contractors. It can be seen in the analysis of section 4.2.2 that sheet-metal workpieces constitute only 12 % of the total workpiece spectrum. Based upon this knowledge, that sheet-metal workpieces form a relatively unimportant part of the total workpiece spectrum, it was decided to leave this development until a later stage. This decision meant that only prismatic and rotational workpieces were to be considered in the initial development. A further selection was made by concentrating primarily on the medium and large batch production, thus covering the main machining requirements.

The primary metal removing machining operations required in the considered case are shown in Fig. 115 together with an approximate grouping of relevant machining methods. Clearly indicated is the dominant role of NC machines for the most frequent machining operations. This fact not only meets the specifications set in section 4.2.2 but also confirms their validity: - An increase of $\geq$ 30 % in the productivity of rotational, flat, and bore machining without workforce expansion. This can only be met through the application of higher performance plant - the reason for already specifying NC machines during the concept phase. The application of NC plant in the machining sector represents the core of the whole rationalisation effort and for this reason NC technology forms the basis of the machining system of the IMS.

Dividing the primary components of NC technology into hardware and software groups, the main aim of the development phase becomes clearer, namely the realisation of suitable, compatible, company orientated solutions for each of these factors (Fig. 116). The technical and economic performance requirements of the NC machine together with the selection of suitable programming techniques depends primarily on the workpiece spectrum. As a first step in approaching this problem, possible alternative solutions for the main factors namely the NC machine, the control system, the jig and tool system, the programming system etc. were considered. From the workpiece spectrum analysis as shown in section 4.2.2 with the example for rotational components, the primary dimensional data for the selection of machine size, and the workpiece complexity data for programming system selection could be taken.

When selecting machine tools, machines for rotational and prismatic workpieces were sought independently as influencing factors vary considerably. By the selection of the programming system however, both workpiece groups could be considered together - the aim being as universal a solution as possible.

Within the framework of the company machining policy, several important decisions were previously agreed with the company management which on the one hand limited "freedom" during the development phase, on the other hand however kept the solution possibilities within reasonable bounds. Several of these basic decisions are listed below:

- The purchase of NC machining centres, NC lathes and auxiliary equipment would in each case involve a single supplier.
  This meant that the search for possible suppliers could be concentrated on those producing a range of machines covering the total workpiece spectrum. The preferred solution was one supplier for NC machines for prismatic components, and one supplier for NC machines for rotational components. The advantages of this clear division included:
  - all negotiations were carried out with the same partner
  - less conflict occurred concerning responsibility

- simpler service
- standardised equipment operation logic (easier workforce training).

- The resulting system encouraged efficient operation from the start.

- The projects "NC machining of prismatic workpieces" and "NC machining of rotational workpieces" were to be developed in close cooperation with the plant suppliers.

- The numerical - control systems for all machines were to be of the same manufacture, the obvious advantages being - service, fault-finding, spares, operating, and programming.

- The development of the overall system "NC machining" and its breakdown into logical stages were to be acceptable to the company finances, and the workforce capabilities.

- For the operation of the system, existing staff were to be employed, where possible necessary transfers being made early in the development phase to enable sufficient training in NC technology.

- The NC machining was to follow in two daily eight-hour shifts to fully utilise the plant investment.

- Whilst insufficient space was available in the existing machine shop, it was decided to build a completely separate new building for NC machining.

- All environmental considerations must be accounted for, the following specifications being set:

  - noise level $\leq$ 75 dBA
  - recycling where possible
  - central coolant system for all machines
  - vapour and gas extraction centralised
  - optimum safety measures
  - etc.

4.4.1.1 Hardware development for the machining of rotational workpieces

As a basis for the development of hardware for machining rotational workpieces, the relevant specifications were taken from the specification sheet shown in section 4.2.2. An extract from this specification sheet is shown in Fig. 117 and also includes the main specifications for the final development phase. These specifications include, in addition to the application of NC machines, automated blank preparation, automated handling, and automated measurement control during the actual process. Grinding operations were to be largely untouched until a later stage in the development. This resulted in a clearly defined problem concerning rotational machining and the preceeding operations for the total rotational workpiece spectrum of the company. The results of the workpiece spectrum analysis, detailed in section 4.2.2, forms the foundation for all measures and solutions developed in this phase of the work. The development of the solution followed the procedure technique described in section 3.3.3.1.

Through the "black-box" representation shown in Fig. 118, the activity assumed an abstracted nature. With the functional breakdown shown in Fig. 119, those part-functions requiring solution possibilities were determined. In the solution matrix shown in Fig. 120, generalised solution possibilities which came into question for the considered case are shown. These solution alternatives were evaluated in cooperation with the chosen supplier.

From the solution possibilities shown in Fig. 120 the following were selected:

- NC universal lathes with disc and universal turrets, with and without bar-feed option
- Conventional numerical control of the same type and manufacturer
- Conventional clamping systems chuck, between centres, and between centre dog-drive system

- Standardised tooling system
- Robotic loading and unloading coupled to transport system
- Automated diameter measurement inside machining area.

The various selected solutions were further developed all details being finalised with the cooperation of the chosen suppliers (16, 70). To determine the number of machines required for each machining process, that is for both the turning and the preceeding operations, it was necessary to make several capacity calculations. In the workpiece spectrum analysis, the capacity requirements for conventional turning distinguished between disc-type and shaft-type workpieces. Consequently, the capacity requirements for NC turning were calculated separately despite the fact that universal machines, capable of turning both classes of workpieces, were selected for the system. The machining time reduction factors to be considered with the transfer from conventional to NC machining were obtained from calculations made for a typical sample of both workpiece classes. In the figs.121 to 124 the different machining times for disc-type and shaft-type, conventional and NC machined workpieces are compared. The figs.122 and 124 show the results for the machining of the total workpiece spectrum. Based on the requirements given in the specification sheet, the tabulated data accounts for only 80 % of the original conventional capacity.

Less obvious reasons for the large reduction from conventional to NC rotational machining times include for example that many disc-type workpieces could be produced direct from bar, or by shaft-type workpieces between centres dog-drive clamping reduced multiple operations. Included in the floor to floor times for NC rotational machining are automatic loading and unloading, automatic measuring, and tool-tip correction times.

The calculated capacity requirements for turning must from experience be increased by the 30 % to allow for breakdown, maintenance and standing time. (This percentage is verified by actual analysis figures obtained from automated production data collection systems.) This results in a total yearly NC rotational machining capacity requirement of 9215 hours. Because a capacity increase of 28 % was planned for the next few years, the system required a capacity of 11'800 hours. Given an average production time of 3300 hours per year with two shift working, this resulted in a requirement of 3.6 NC lathes. This meant that the NC rotational workpiece machining system, when fully developed, required 4 NC lathes with overlapping machining capability.

From the workpiece spectrum analysis, the largest workpieces could be machined on standard equipment from the supplier. The analysis further showed however, that over 75 % of the total could be produced on the next smaller model. In this first development phase, four machines with two-shift working would mean over-capacity. Two machines would be insufficient. It was therefore decided to install three machines of the same size, and basically same configuration thereby overlapping and allowing for any machine breakdown.

For the external turning of disc-type and shaft-type workpieces, a tool turret with eight tool positions was selected. For the internal machining of chucked workpieces, both disc-type and bar-feed, an universal 4-post turret enabling the mounting of six to eight tools was selected. This number proved insufficient, especially for bar-feed components, however the design and application of special tool holders raised the maximum possible tools to sixteen.

According to the specification sheet, a total of 72 % of the conventionally machined workpieces were to be automatically handled. This required handling equipment capable of gripping both disc-type and shaft-type workpieces. Whilst both groups required different movement cycles, the equipment had to be freely programmable and have quickly interchangeable programmes. An industrial robot appeared to be most suitable. Based on a maximum workpiece weight of 20 kg for automated handling and with double gripper arm, a maximum work load of 40 kg was possible. The maximum grip diameter for disc-type workpieces was 400 mm, for shaft-type workpieces 130 mm. The maximum workpiece length for automatic handling(600 mm)covered a large proportion of the workpiece spectrum, especially high-batched workpieces. A further reason for this limit was the avoidance of unnecessary over-dimensioning of the related automated transport system pallets. The large proportion of workpieces which could, at least in the first operation, be machined direct from bar, justified the installation of bar-feed equipment on at least two of the machines. To improve the efficiency of this equipment, the stub-end of a used bar was to be automatically recognised and removed, a new bar automatically loaded from the hopper. A special counter control enabled different workpieces to be produced from the same bar in automated sequence without relying on the operator control. Parted-off workpieces were to be collected by the industrial robot and deposited outside the machine.

The specification sheet required that workpiece measurement be carried out inside the working area of the NC lathe. The large number of possible sizes occurring even on one workpiece required an extremely flexible measuring system which, because of the adverse working conditions inside the machine, swarf and coolant, etc. required to be either extremely robust or fully protected.

The friction wheel measuring system was selected for several reasons. Firstly, extensive practical experience had been obtained with this system. Secondly, the friction-wheel system proved extremely flexible - with one wheel the entire diameter range could be measured. Further, exact positioning of the wheel during measuring was unnecessary as, by circumferencial measurement, this has no noticeable effect on accuracy. The problem of internal measurement was solved with the combination of large (normal) and small friction wheels which enabled the introduction of the small wheel into the bore. The rigid coupling of both wheels enabled the usage of the same measurement data processing equipment. The entire measuring head was mounted on the transverse slide of the machine, and had two independent positions - the protected "rest position" and the exposed "measuring position". The mounting of the measuring head on the transverse slide guaranteed that the working area of the machine would not be additionally limited by the measuring equipment.

A further part of the NC rotational machining system was the automated blank preparation. Fig. 125 shows the proposed fully completed solution for the NC rotational machining system. It is important even at an early stage in the realisation that all part-solutions be compatible with the overall solution. Related to this problem and equally important are workpiece flow and information flow. It is however most probable that particularly in these last three areas great changes will take place before actual realisation. A further part of the proposed system was DNC. First steps were possible with the computer-aided storage and editing of NC programmes. This saved the time-consuming job of maintaining and modifying a large library of NC tapes. The danger of absolete tapes being used was also largely avoided.

With this brief look over the whole NC rotational machining system, the problems of blank preparation, workpiece measurement and handling, information flow and machine application have been thought-out. The final development phase could only be achieved gradually which led to the definition of the following development stages:

Stage 1 : Introduction of a first universal lathe equipped with many features of the NC rotational machining system, for example

- automated bar-feed
- integrated measuring
- industrial robot application.

From this complex machine, important practical experience could be made. This machine is shown in Fig. 126.

Stage 2 : Introduction of further machines of the same specification and first attempts with simple workpiece transport linkage.

Stage 3 : Application of the DNC system - automated information flow and full operation of automated workpiece flow. This represents the final development stage of the NC rotational machining system (Fig. 125).

With this structuring, the procedure phase development for the hardware of the "machining of rotational workpieces" was completed. Final detailing follows in the later procedure phase "Detailing of the solution".

4.4.1.2 Hardware development for the machining of prismatic workpieces

The prismatic workpieces could be divided into three basic groups based on their relative complexity. These groups and their frequency distribution per dimensional sub-grouping are shown in Fig. 127. From this workpiece spectrum it is clear that different types of machine are required to cover the whole range. The specifications of the machines should basically conform to the complexity of the respective workpiece group, typical evaluation criteria being for example the number of machining elements, and the quality requirements of the workpiece. This evaluation enabled easier determination of such machine factors as, horizontal or vertical spindle, number of machining axis, number of tools etc. Considering the frequent occurance of alternate milling and boring operations, there resulted a strong argument for the selection of NC machining centres as opposed to pure NC millers or borers. The same procedure as used for rotational workpieces also applied for prismatic workpieces, that is the establishment of a specification sheet followed by the development of an acceptable solution. Again the application of NC machines, in this case machining centres, assumed prime importance. For the development phase of the prismatic workpiece system, a relatively short description suffices as a great deal is practically identical to that described in the preceeding section. An extract from the specification sheet for prismatic workpiece hardware is shown in Fig. 128.

Through the "black-box" representation (Fig. 129) the process assumed an abstracted nature. With the functional breakdown shown in Fig. 130 those part-functions requiring solution possibilities were determined.

The solution matrix shown in Fig. 131 lists those solution possibilities relevant to the considered case. The following solutions were selected:

- Two identical vertical-spindle NC machining centres with automatic 18-position tool-change
  Working limits (mm) X-axis 800 Y-axis 450 Z-axis 400

- Two identical horizontal-spindle NC machining centres with automatic 40-position tool-change
  Working limits (mm) X-axis 1500 Y-axis 830 Z-axis 400

- Two identical vertical-spindle NC machining centres with automatic 9-position tool-change
  Working limits (mm) X-axis 500 Y-axis 340 Z-axis 220

- NC control system from the same manufacture as that of the NC lathes.

- Standardised tooling system with tool setting away from the machine.

- Entirely modular jig and fixture building system.

For the NC machining of prismatic workpieces, six NC machining centres were found necessary. The selection was based on the results of the workpiece spectrum analysis. The target level of automation to be achieved with the machining of prismatic workpieces, was deliberately set lower than that for rotational workpieces. The main reasons included the considerably more complex handling, clamping, and measuring of the workpieces, and the unavailability of suitable technologically and economically feasible hardware for the relatively small batches involved. Further, the required high degree of flexibility could not be guaranteed.

Further automation of the prismatic machining system is planned for a later development phase. The actual layout of the NC machining centres is shown in Fig. 132. These machines have been gradually introduced over a period of eight years.

4.4.1.3 Software development for the NC programming of rotational and prismatic workpieces

The importance of carefully planned software development for NC workpiece programming cannot be overemphasised. The first integration measures between the design system and the machining system involved software, that is information flow. In the IMS concept (see section 4.3.3) one of the main areas designated for improvement during the first development phase was the integration of information flow, both within and between the various sub-systems, especially the design and machining systems. To achieve this goal, it is necessary during the development phase to seek those solutions which promoted CAD/CAM integration. During the first phase it was important that both systems could also operate independently, thereby avoiding disruption to the daily workings of the company. The actual integration could then be introduced step by step, department by department, without constant organisational shake-ups. This software development involved firstly the selection of a suitable NC workpiece programming system and secondly the wider aspects of CAD/CAM software integration.

Concentrating on the NC workpiece programming, the first considerations involved the workpiece spectrum to be machined and the complexity and features of the respective NC machines. Both the workpiece spectrum and the hardware solutions have already been described in the preceeding sections. The decision whether to employ manual or automated programming methods could be made to a large extent from a review of these primary factors, as shown in Fig. 133. The basic aims of the IMS concept dictate an automated, that is, computer-aided programming method. An extract from the specification sheet for NC software is shown in Fig. 134. From these specifications the need for a universal programming system covering the entire workpiece spectrum was apparent. Furthermore, a high degree of automation was required. It is not intended within the framework of this work to evaluate the different programming methods but to demonstrate the importance of long-term wider evaluation during the selection of a suitable system. Before the actual criteria are discussed, the development of the programming system selected for the considered case will be shown. Fig. 135 shows the function "workpiece programming" as a "black-box" abstraction.

From the functional breakdown shown in Fig. 136 it is clear that the subfunction "determination of machining sequence" is actually a part of the system "planning of machining". The preparation of "machining sequence plans" remains a frequently discussed topic both in the theory and practice of manufacturing. Normally the job is the responsibility of the planning department and from there according to requirements, delegated to the NC programmers. In the detail-development of the CAD/CAM solution, this problem will be examined closer. At this stage it is important to recognise the close relationship between NC programming and planning of machining, particularly sequence planning.

Considering the pure programming activities, manual and automated programming methods can generally be compared. The different automated programming systems can be implemented on small, medium, or large computer systems depending on their complexity and structure. The solution matrix in Fig. 137 differentiates only generally between the methods without going into great detail, the reason being that for the considered company the need for automated programming was already defined in the specification sheet.

From the whole range of universal programming systems, the EXAPT system (71) offered the greatest long-term advantages and was consequently selected. The main reasons for this selection were the following:

- Universal system applicable for turning, boring, milling, nibbling, etc. (EXAPT 1, EXAPT 1.1, EXAPT 2, EXAPT 3, etc.)

- The automated processing of technological data necessitated and encouraged the systematic application of tooling and cutting data.

- The highly developed and refined system guaranteed rational NC programming.

- The application of EXAPT necessitated the uniform preparation of all programming documentation and working aids.

- The required flexibility in the NC machining department was to a large extent guaranteed.

- The inevitable increase in wider, computer-orientated thinking of employees in the machining sector formed a sound basis for further automation at later development stages.

- The autonomous working of the programming system guaranteed with EXAPT.
- The later integration with CAD was possible.

In addition to the above reasons, several beneficial secondary effects result, for example, only a single universal programming system had to be introduced, meaning that personnel training, and organisation were simplified and not excessively expensive.

The realisation of the EXAPT programming system (72,73) was split into four phases:

- Realisation phase 1 :

  In the framework of this phase, the necessary data-banks for the EXAPT system were built-up. The NC programmers were trained in EXAPT programming methods but only after the vital basic training in purely manual methods. The machine specific postprocessors required for converting EXAPT data to machine data were developed and tested. During this phase, all EXAPT workpiece programmes were relayed via terminal for processing on a large computer centre.

- Realisation phase 2 :

  The primary aim of the second phase was the rationalisation of the actual NC workpiece programming. Software developments included the application of "macro" programming techniques. The introduction of a process-computer enabled the computer-aided preparation of EXAPT programmes, although as in phase 1, the actual programme processing still required the large computer-centre. The macro programming system which was internally developed, specifically based on the workpiece analysis (sections 4.2.1 and 4.2.2) is examined closer in the following procedure stage "detail development of the solution". A further development in this phase was the training of the NC programmers in computer operation.

- Realisation phase 3 :

  In this phase the linkage with the CAD system was the primary development aim. As already mentioned, the development of the machining system and design system were carried out almost simultaneously. In this phase the software coupling of computer-aided detail drawing and computer-aided NC workpiece programming was realised. The detail drawing data generated in the design department can be automatically processed into EXAPT usable data, so prepared that the NC programmers, working in dialogue with the computer and using detail drawing, work-sequencing chart, detailed operation plan and pre-printed checklist, can quickly add the missing data. Primarily the programmer adds important information stemming from his skill and experience of exactly how the machining sequence must follow. The repetative routine work is spared. A further aim of this phase was the realisation of a comprehensive NC programme administration system. Basically all NC workpiece programme data was to be stored in the computer and, with multiple addressing possibilities, rapid access achieved. Some of the requirements of this administration system are listed below:

- Simple and rapid input and output of the programmes
- Correction and modification in dialogue mode
- Integrated administration of CAD data, EXAPT programmes, macro-data, and EXAPT data-banks
- Control of new programming jobs, both organisational and schedualing.

With the realisation of phase 3 the problem of rationally producing 1000 new workpiece programmes per year was solved. The main aspects of the third realisation phase are shown in Fig. 138.

- Realisation phase 4 :

The fourth phase entails primarily the development of software for the planned fully developed CAD/CAM system, especially from the viewpoint of NC machining. The main features of this development stage can be briefly described as follows:

- Full CAD/CAM integration
- Comprehensive development of the CAM administration system
- Integration of CAPM /CAM/CACM (NC planning of machining, NC machining, NC machining control)
- Implementation of the full EXAPT system on the company-owned computer.

With these developments, the main requirements for the integrated manufacturing system IMS can be satisfied. The system components realised to date are discussed in the next phase "detailing of the solution". The existance of an overall concept and the stage by stage realisation of the overall system enables the company to develop gradually at a pace compatible with its financial and physical growth limits.

4.4.2 Development of the solution for "planning of machining"

The trends for the development phase of the planning function were set to a large extent in the concept phase (section 4.3.2.2). Particularly in this area, large amounts of data must be processed, a fact which clearly calls for computer-aided systems. At this stage it is not intended to show the development of a complete production planning and control systems but to concentrate on those functions of production planning which particularly affect NC machining.

The "planning of machining" must primarily be adapted to the hardware and software requirements and possibilities of the process "machining". The function "planning of machining" must therefore incorporate as well as loading and capacity planning and schedualing, the workflow sheet and NC programme preparation.

A specification sheet was produced for "planning of machining" similarly to the previously mentioned functions (Fig. 139). The specifications clearly demonstrate that the planning of machining system required a high degree of flexibility to cope with the problems of day to day running in the machining department. Furthermore, emphasis must be placed on group-technology techniques and planningfor similar parts. The function "planning of machining" shown as a "black-box" abstraction in Fig. 140, is broken down into sub-functions requiring solutions in Fig. 141.

The solution possibilities for the function "planning of machining" are shown in the solution matrix in Fig. 142. The following "planning of machining" system for NC machining was developed:

- CAD data from the computer-aided detail drawing data-bank must be processed into a form usable for computer-aided workflow sheet preparation.

- Data-banks must contain all constant data concerning the main operations of planning of machining - times, routing, machines, substitute machines, etc.

- Constant data must be complemented with variable data added in dialogue mode - scheduals, batch sizes, priorities, etc.

- The combined data (constant and variable) can be added to the actual production data-bank which must be constantly updated with actual data - finished work, machine breakdowns, extra shifts, etc.

- Simulations of loading, capacities and scheduals variations must be made until an acceptable solution is found. This then forms the machining plan until the next update.

- The planning must allow for urgent jobs to be squeezed in without great administrative effort or disruption.

- Availability of material, tooling, NC programmes, jigs, measuring instruments, must also be coordinated in the planning.

- The system must give immediate situation reporting on order progress.

Fig. 143 shows the general functional structure of the NC planning of machining software. As shown with the development of the previous solutions the importance of integration between the different sub-systems of the IMS also applies here. Similarly to the actual process , "process planning" can also be developed stage by stage. A more detailed description of the planning of machining is given in the next procedure stage "detailing of the solution".

4.4.3 Development of the solution for the "control of machining"

The final part of the machining system "control of machining" requires the same treatment as the previous parts that is the development of a solution suitable for the specific needs of the company. Again the solution concept of section 4.3.2.2 forms the basis for this development. "Control of machining" can be divided into two main sub-functions; firstly the control of the quality of technological data resulting from the process (target/result comparison) and secondly the control of the planning data, for example quantity, cost and scheduals etc., again with target/result comparison. The importance of an efficient and flexible solution to this double function "control of machining" is obvious. In the framework of the IMS, "control of machining" can be seen as guarantor of the qualitative and economic performance. "Control of machining" therefore requires data from all machining related sources.

The extreme importance of the function "control of machining" necessitates extreme care by the formulation of specifications. The output data from control greatly influences the management decisions which in turn influence the performance of the process "machining". An extract from the specification sheet for "control of machining" is shown in Fig. 144. In the specification sheet, the emphasis is placed on assuring quality and increasing the economic performance. The function "control of machining" as a "black-box" abstraction is shown in Fig. 145. The breakdown into sub-functions is shown in Fig. 146.

The solution possibilities are shown in the solution matrix of Fig. 147. The solution selected can be described as follows:

- Quality control initially relied on basically conventional methods and equipment. Later, the application of three-dimensional NC measuring machines was planned. The development of "in-process" measurement as used in NC rotational machining will be followed and applied where possible. The organisation enabled NC machine operators to systematically self-control their work during the machining operation.

- A further central issue was the NC-specific data collection and processing, primarily the control of programming data and machine usage data.

- The collection and evaluation of actual production data formed the last important component of the solution. This sub-function was however closely related to the preceeding function "planning of machining".

Fig. 148 shows the development for the CACM system (Computer-Aided Control of Machining). On the three axis NC measuring machine both prismatic and rotational workpieces can be inspected. The quality control of both external and internal diameters of workpieces produced on the NC rotational machining cell (Fig. 126) takes place during the actual machining process.

4.4.4 Development of the solution for the machining process

The most relevant solutions to the functions planning of machining, machining, and control of machining are described in the preceeding sections. The predominant factor throughout the whole development was NC technology which is gradually replacing conventional machining. Obviously, conventional plant will remain, even long-term, a part, although an increasingly less important part of the whole machining system. For this reason, the solutions for the machining system are to a great extent biased towards the particular requirements of NC machining.

In the phase development of the solution IMS, extensive computer application justified the terminology CAPM (Computer-Aided Planning of Machining), CAM (Computer-Aided Machining) and CACM (Computer-Aided Control of Machining). The integration of the machining system components CAPM, CAM and CACM as a part of the overall IMS was a central issue. Further, the necessity of clearly identifying the different interfaces between the sub-systems to enable step by step or partial development was shown.

The developed solutions for the machining system can be divided into the following three groups:

- The machining system hardware
- The machining system software
- The machining system organisation.

The development of the machining system hardware concentrated on the two main workpiece groups - rotational and prismatic. The main features of the hardware solution are listed below:

- Separate workshops for the two machining groups with NC machining centres for the prismatic workpieces, NC lathes and NC rotational machining cells for rotational workpieces.

- All NC machines employing control systems of the same manufacture. The control systems being extendable to DNC operation in the next development phase.

- All NC machining centres for prismatic workpieces employing a single interchangeable tooling system and a single modular jig and fixture system.

- All NC machines for rotational workpieces employing a single interchangeable tooling system and a single interchangeable clamping system.

- All tooling, jigs and fixtures for all NC machines pre-set and pre-built before machine set-up.

- All applied tooling standardised and catalogued to EXAPT system specifications.

- In winter, warm air from NC machine motors, hydraulics etc. is collected, filtered and recycled for the dual purposes of heating the workshops and eliminating snow and ice build-up on surrounding access roads.

Individual hardware solutions are explained in detail in the phase "Detailing of the solution IMS".

In summarising the developed software solutions, the main features can be listed as follows:

- A single universal automated programming system for all NC machines (EXAPT).
- All technological data stored in computer data-banks, tooling data, cutting speeds and feeds, machine data, clamping systems data etc.
- Computerised NC programme administration and NC workpiece programming.
- Computerised NC data evaluation of machining usage, programming efficiency, etc.

Individual software solutions are explained in detail in the phase "Detailing of the solution IMS".

To enable the consequent and efficient working of the above mentioned machining system, an organisation was needed which fully corresponded to the specific system requirements. With this organisation, the system management, system operation and application of working aids must be guaranteed (Fig. 149). The management organisation stems from the "organisation concept IMS" (Fig. 110). The machining system was divided into three sub-systems - planning of machining, machining, and control of machining. Machining was further sub-divided into conventional machining and NC machining. The organisational division of NC and conventional machining proved necessary for the following reasons:

- The two departments are on two separate locations.
- The NC machining department works on a two-shift basis, the conventional department on a single shift basis.

- The hardware employed in NC machining is totally different from that in the conventional department.
- NC technology requires a special organisation suitable for its specific needs.
- The workforce employed in the NC department requires a different working attitute to that in the conventional department.

The operations organisation within the machining system was adapted to suit the logical job and workpiece flow. When considering methods and working aids, computer application received high priority.

It was shown within the framework of the system concept for the IMS that the individual systems -the design system, the machining system, and the assembly system - are closely interrelated. From the discussed machining system with its already dominant and increasing trend towards NC technology the design system is greatly influenced. The hardware and software solutions selected for the machining system placed certain demands on the design system which required consideration during its development. From the machining system (Fig. 150) the following demands on the design system resulted:

- The working limits of the available NC machines must be considered when dimensioning components.
- The possibilities and limitations of NC control must be considered during product development and component detailing.
- The application of available tooling from the standardised tooling catalogue must be considered during product development and component detailing.
- Components must be detailed bearing in mind the possibilities of the modular jig and fixture system.

- Component tolerances should not be closer than the repeatable accuracy of the NC machines.

- Component materials should be selected to enable optimum machining performance.

- Component dimensioning should conform to the requirements of NC technology (programming techniques).

- Software and hardware linking CAD and EXAPT-NC programming must be compatible.

To ensure that the influencing factors of the machining system were actually implemented in the design system, relevant working aids in the form of catalogues, specifications, handbooks, programmes, etc. were made available to the design department (Fig. 151). The development of an efficient integrated CAD/CAM system cannot be realised without a healthy and continuing dialogue between the design and machining departments.
In the next section some of the main aspects of the machining system will be examined in closer detail.

4.5 Detailing of the solution for the machining system

According to the procedure technique (Fig. 24) the phase "detailing of the solution" is concerned with the finalisation of the solutions for hardware, software and organisation. The logical follow-up to the phase "development of the NC machining system" is the "detailing of the NC machining system". This system, schematically shown in Fig. 152, and consisting of the sub-systems - planning of NC machining, NC machining, and control of NC machining - has been fully realised and implemented in the considered company. Only some of the more important aspects will however be examined in detail as a full review of all solutions and details exceeds the bounds of this study. The interface between the machining system CAM and the adjoining system CAD receives particular attention as the integration of the processes CAD and CAM constitutes the foundation of a comprehensive IMS. Based upon on these systems it is possible, as described in the concept phase, to build-up stage by stage an overall IMS.

4.5.1 The CAD system and its input for the CAM system

The machining system and design system were developed to a large extent simultaneously. The first development stage of the CAD to be realised was the sub-system for computer-aided detail drawing of rotational workpieces (8, 38, 39, 67, 68, 74). From this CAD detail drawing system result the inputs required for the NC programming - a sub-system of the CAM system. The CAD system for rotational workpieces described below allowed the initial integration between CAD and CAM systems to be realised.

The input data required for computer-aided detail drawing can be taken from the design layout drawing and entered into the form sheet 1 (Fig. 153). From the back of this form sheet the designer can see the coding syntax of the permitted geometric forms, technological elements, etc. (Fig. 154) and describe the actual workpiece. The input language is relatively simple and corresponds to the designers interpretation of the workpiece structure.

Fig. 155 shows the input data required by the CAD system to both detail and dimension the workpiece. In the upper section the input elements are unsorted, in the lower section primary and secondary elements sorted and combined by the computer as required. The sorting criteria is by line numbering. It has proved practical to number primary elements with rounded "hundred" numbers and the related secondary elements with "tens". Modifications and corrections can be easily made to the input data at this stage. The second form sheet (Fig. 156) contains organisational and general data and, for geared workpieces, gearing data. In the section general remarks, additional information can be transferred to the drawing. For example, should the word "harden" occur, this data is processed and the results automatically integrated in the data-bank for the following EXAPT workpiece description. Grinding allowances are set at those positions where the tolerances dictate grinding.

In dialogue mode with the computer, information concerning for example material selection, weight, price and availability can be obtained. This workpiece data is checked for formal logic faults to ensure that the data can be further processed (Fig. 157). Changes and corrections can be easily made. Before actual processing, the data must be converted by the computer from the designer orientated form into a processor useable matrix. It is hoped that the search for repeat use workpieces could take place at this stage, however this point is still to be examined. The actual drawing production has several phases. Firstly, the scale must be worked out, based on drawing size, workpiece size and workpiece complexity (and allowing for dimensioning, cross-sections of keyways, gearing data, tables, etc.). Earlier versions of the CAD programme reserved a fixed proportion of the available space for dimensioning. This proved unacceptable as either the space was insufficient in the case complex workpieces, or by simple workpieces resulted in badly used space. The present version ensures optimum paper utilisation. After the scale is established, the actual geometry is automatically drawn, including where necessary cross-sections, etc. Dimensioning also takes place fully automatically as does the drawing of gearing data tables, tolerance tables, etc. The workpiece classification code, a 10 digit number, is automatically produced from the resulting data-bank. Finally the drawing number, name, date and general information are added also by the computer. Fig. 158 shows a typical detail drawing produced with the above mentioned CAD system.

When the detail drawing is completed, the draughtsman's job is completed, however the data generated to produce the drawing is automatically stored for further processing into the EXAPT workpiece programme. With this linkage the drawing assumes a new function. It is no longer the sole carrier of technical information describing the workpiece but instead a graphical representation of the workpiece data stored in the CAD system. The CAD detail drawing system operates on a small computer system linked to a plotter for drawings up to DIN A0 format. The hardware configuration can be seen in Fig. 159. This computer configuration forms a part of the computer heirachy shown in Fig. 109. The output from the CAD system consists of the detail drawing and corresponding workpiece data block which can be computer-processed for the NC workpiece programming.

4.5.2 NC workpiece programming as a sub-system of the CAM system

The programming of an NC workpiece follows a set procedure in which the workpiece data-block, stemming from the CAD system, can be fully integrated. Fig. 160 shows the computer configuration used in the NC department. This configuration forms a part of the computer heirachy shown in Fig. 109. The general procedure used for the CAD/CAM linkage is shown in Fig. 161. The NC programmer uses the workpiece data-block from the CAD system as a basis for, in this case an EXAPT 2 workpiece programme. The dialogue mode procedure of the NC workpiece programming system is shown in Fig. 162. The CAD workpiece data is firstly processed into an EXAPT usable form. Non-rotational data such as keyways, or non-generated elements such as circlip grooves are eliminated from the data-bank (being irrelevant for the turning operation). Using the macro-programming system the workpiece falls into one of three workpiece classes:

- as a bar-feed workpiece
- as a disc-type workpiece (chucked clamping)
- as a shaft-type workpiece (between centres clamping)

The extensive use of sub-programming (macro) techniques greatly simplifies the work of the NC programmer. In one extreme case - a bar-feed workpiece, except for one programme line specifying a standard tooling combination - the entire EXAPT 2 workpiece programme was automatically produced by the CAD/CAM system. On average, about 80 % of the previously manually prepared data is now generated by the CAD/CAM system. Attempts to automate the remaining 20 % - the technological parameter definitions have so far met with only limited success. The main problem being that more exceptions than rules seem to occur.

The classical structure of the EXAPT workpiece programme consists of four parts:

- General information
- Blank contour description
- Workpiece contour description
- Technological and executive parameters

These parts remain unaffected by the coupling to the CAD system. The fusion of CAD system and the CAM macro-programming techniques means that missing workpiece data can simply be added in dialogue mode. The completed EXAPT workpiece programme (Fig. 163a) is stored in the computer for input in the EXAPT 2 processor and postprocessor. Typical drawing examples for shaft-type and disc-type workpieces are shown in Figs.163b and 163c. The result is the NC machine control tape data which is also stored in the computer.

As previously mentioned, the programming of NC workpieces is supported by macro-programming techniques. Fig. 164 demonstrates the degree of standardisation and rationalisation which these techniques have brought to the EXAPT 2 programming process. In the first part, "general information" reoccurring data and standard procedures were automated. In the second and third parts the geometric contour descriptions of the workpiece were standardised and simplified. With the linkage of the CAD/CAM systems, this is now fully automated. In the fourth part technological information was standardised, for example data for form elements such as circlip grooves were packed into sub-programmes including geometry, dimensions, tooling, speeds, feeds, etc. A CALL command and two or three simple variables substitutes the large amounts of routine programming work previously needed. Executive parameters were to a limited extent also standardised and automated although as previously mentioned, scope for improvement remains.

Fig. 165 and Fig. 166 demonstrate the application of macro-techniques to rotational workpieces. Three groups of rotational workpiece are defined: chucked (mostly disc-type), between centres (mostly shaft-type), and bar-feed (both types of workpiece suitable for bar-feed production). For reoccurring logical algorithmic data-blocks, sub-programmes were developed. After thorough testing these "macros" have brought a large reduction to programming times and a great reduction in programming mistakes. The macro-system shown in Fig. 166 includes the following types of sub-programme:

- for the setting of start parameters
- for geometric patterns (circlip groove, V-groove, etc.)
- for standard tooling combinations
- for standard clamping configurations
- for machining sequences (screw-cutting, parting-off)
- etc.

Additionally to this macro-system, a workpiece family programming system was developed for groups of similar workpieces. Both systems are designed to allow maximum flexibility and easy up-dating and extension. The integrated CAD/CAM system based predominantly on NC technology has been described with a typical shaft as example. This CAD/CAM system is extremely flexible and can be modified and extended to meet changing requirements. The CAD/CAM system is fully operational for both rotational and prismatic workpiece classes. To support this system, a data-bank has been developed which, similarly to the CAD system, stores and administers the relevant data. The previously mentioned computer heirachy and some of the described software are used.

Fig. 167 shows the CAM/NC programming system and the programme administration system (75). The main features of the CAM system can be summarised as follows:

- CAD data is automatically entered into the CAM system (addressed with workpiece part number).

- The dialogue mode preparation of NC programming assignments belongs to the function Planning of NC Machining (CAPM).

- The EXAPT workpiece programmes are produced in dialogue mode with automatic integration of the macro-system.

- The EXAPT workpiece programmes are converted to machine control tapes with the application of the EXAPT processors and postprocessors.

- Graphical output of the machining sequences are possible to check for mistakes or collisions. Tape corrections with the EDITOR programme are possible in dialogue mode.

- Test-runs of new programmes take place on the machines. Resulting data is fed back and stored in the computer.

- Workshop documentation necessary for NC machining e.g. control, tape, programme listing, tooling list, etc. is directly output from the computer. This guarantees central data administration and storage.

- With the stored data, analysis to aid management, programming, standardisation, etc. are carried out. This part of the programme belongs to the function Control of NC Machining (CACM).

4.5.3 Planning (CAPM) and control (CACM) of NC machining

The planning of NC machining can be divided into two basic functions, firstly planning of the NC programming process and secondly the loading and schedualing of the actual machining process. The control of NC machining can be divided into three basic functions:

- The quality control of NC machining
- The control of NC plant utilisation
- and the retrieval of NC machining data.

From this range of planning and control sub-systems, the scope of this work permits only typical examples to be given.

4.5.3.1 The planning of NC programming as a sub-system of the CAPM

The planning of the NC workpiece programming process in terms of programming capacity and programming schedualing is coordinated by the higher level Computer-Aided Planning System (CAP). This CAP system, in determining which workpieces are to be machined at which time, consequently gives the start signal for the NC programming of new unprogrammed workpieces or for programme modifications. A general idea of the workpiece programming planning system presently operating in computer dialogue, is shown in Fig. 168.

A detail drawing print of the workpiece to be programmed is passed from the machining planning department (CAPM) to the NC programming department. Here, in dialogue with the computer, a programming job-sheet is produced including the following information:

- General job data such as part number, description, job number, date, name, etc.
- The programming deadline
- The name of the assigned programmer (NC technician)
- The machine type (also determines programming language EXAPT 1, EXAPT 2, etc.)
- An estimate of required programming time
- etc.

The job-sheet has provision for reply-data required from the programmer including:

- the actual required programming time
- the testing time required
- the setting time
- the machining times
- etc.

After completing the programming assignment, the programmer (the NC technician) enters the reply data in the job-sheet for feeding into the CAM system. The NC technician must also produce the complete operations-sheet for the workpiece including non-NC operations. In this way, NC programming and operation sheet preparation are integrated into one job. One of the reasons for this decision was the previously discussed intention of producing operation sheets in dialogue mode direct from the CAM system.

4.5.3.2 NC data retrieval as a sub-system of the control of NC machining (CACM)

From the NC machining system, data relating to plant utilisation, programming activities etc. must be collected for evaluation. Fig. 169 shows the NC data retrieval system for the two mentioned areas. Plant utilisation data is recorded with a time measurement system employing for each NC machine and shift a separate recorder disc. The machine operator registers the beginning and reason of any stoppage over a push-button linkage from the machine control panel to the recorder stations located in the NC office (Fig. 170). The following stoppage reasons can be recorded:

- Machine repair
- Tool breakage or tool fault
- Machine maintenance
- No job or operator available
- Machine setting time.

By machine restart after a stoppage, the recorder automatically reverts to recording production time. The automation of this data retrieval system is already planned as forseen in the IMS development.

From the above mentioned data, and that returned with the programming job-sheet (see 4.5.3.1) several different computer analysis and evaluations are made primarily to control the overall productivity of the NC machining system. Fig. 171 shows some of the evaluation criteria applied for this purpose, although basically three main criteria predominate, namely quality, quantity and cost. From the quality viewpoint the effect of NC machining on the entire production is of importance, by the quantity and cost the unit programming rate, the unit production rate and the unit cost rate are of interest. A continuous comparison of target results and actual results provides data for system optimisation measures. Some of these measures are reviewed in the section "Discussion of results".

4.5.4 The NC machines and working aids as a sub-system of machining (CAM)

The NC hardware was dealt with in some depth in the phase "development of the system" however as this work concerns the optimum utilisation of these high performance NC machines and associated working aids, they will be illustrated at least in picture form. The performance capabilities of such machines have revolutionised manufacturing making many existing ideas absolete. The high investment costs have led to increased computer application in the machining department to achieve improved capital returns.

Fig. 172 shows the NC lathes presently in operation. One of these lathes has already been developed into an NC rotational machining cell (16, 76) featuring robotic loading and unloading, in-process measuring, automatic bar-feed system, etc.

Fig. 173 shows the NC machining centres. Both machine groups operate in permanent two-shift working. A good tool-setting and tool preparation system is essential for the smooth and efficient running of the machining system. Fig. 174 shows the tool-setting department where preset tooling, job-card, control tape, programme data, etc. are prepared on mobile trolleys ready for transport to the machines. The fully modular jig and fixture building system is shown in Fig. 175.

4.5.5 NC organisation

Throughout the concept and development phases of the IMS, the extreme importance of organisation in automated systems has been emphasised. As seen from the given examples of hardware and software, the organisation of NC machining presents a complicated problem. It must conform to the specific requirements of the particular situation paying particular attention to the workforce. The following requirements were defined for the NC organisation:

- Operation of the machines on a daily two-shift basis
- Degree of plant utilisation $\geq$ 90 %
- Integration of operations-sheet preparation in the NC programming process
- Application of modern working aids, particularly computer techniques
- Gradual increase in NC plant capacity whilst maintaining the same basic organisation
- Gradual improvement in general programming efficiency
- The integration of CAD and CAM systems.

Based on the NC organisation concept (Fig. 149) it was determined that all NC-related processes were to be the responsibility of the NC workforce. Particular attention was paid to improving the working environment - ideas of job rotation, job enrichment and job enlargement - were all implemented (76). From the process breakdown chart (Fig. 176) two distinct processes can be differentiated. Firstly, the machining of new workpieces when the NC programming must be included in the process, and secondly the repeat machining of workpieces when the machining programme exists. Based on this division, an organisational structure has been developed which, relating primarily to the process, works in the manner of a control circuit system. (Fig. 177)

The NC programmer or "NC technician" assumes a function of primary importance in the organisation. The NC technician has dual responsibility, firstly NC workpiece programming and secondly supervision of the actual NC machining. This flexibility is achieved with the operation of a job rotation cycle. The normal day time hours (7.00 to 12.00, and 13.00 to 17.00) are worked when programming. When supervising,the early shift from 4.30 to 14.00,is worked, the late shift starts at 13.30 until 22.30. The cycle covers a 4-week-period giving the NC technician 2 weeks of programming whilst working normal hours, 1 week supervising the early shift and 1 week the late shift. This combination of planning-, process- and control-responsibilities results in high job satisfaction. The NC technician is responsible for a workpiece from the programming assignment to the release of the machined and inspected first batch. Further responsibilities include jig and fixture designs, tooling, test runs, general workshop supervision and quality control. The time spent in the workshop ensures that invaluble practical experience is gained and guards against a loss of skills. This results in optimised NC workpiece programmes.

The NC technicians are assisted by teams of "NC craftsmen" and "NC operators" in permanent shift working. The NC craftsmen, primarily machine setters, also work on tool-setting, jig and fixture building and can, because of a basic training in programming, make minor control tape modifications, etc. The NC operators are responsible for machine loading, workpiece quality, tooling, control and stripping and cleaning down. They are also trained in some aspects of machine setting. This overlapping of responsibility and capability both reduces "who does what" conflicts caused by over-specialisation and guarantees the smooth and efficient running of the system, even by the inevitable absence of otherwise key workers. The NC programming offices were deliberately positioned centrally between the NC workshops to be directly linked to the actual process (Fig. 178). From this office, the NC technicians can overlook both workshops and are immediately available if required when problems or stoppages occur. Furthermore, the NC craftsmen and NC operators have direct access to all programmers guaranteeing optimum information exchange. For the two-shift operation, 6 NC technicians, 6 NC craftsmen and 14 NC operators are required. Where possible, two machines are worked by one NC operator.

This brief profile of the NC workforce should help to explain the high productivity and problem-free introduction of automation measures which has been achieved. Obviously the whole NC workforce regularly attends internal training courses to which great importance is attached. The daily contact with computer systems and NC machines of varying complexity has led to a natural and harmonic acceptance of automation. With this organisation form, the problems of "person-machine-systems" have been reduced and to a large extent eliminated.

4.6 Implementation of the solution IMS

The previous sections described some aspects of an IMS built-up with the application of the procedure technique. The successful realisation of a part or the whole of such a system depends to a great extent on the implementation phase. The reaction of the workforce will be either positive or negative depending to a great extent upon the successful conclusion of this phase. Negative workforce reaction and prejudgements ruin the success prospects of even the best system improvements. Responsibility for successful system implementation starts at the highest management level. The positive involvement of senior management can greatly influence the positive acceptance at lower levels. System implementation must be systematically planned, just as all previous procedure phases. To this planning belongs frequent management orientation concerning the state of system development. Departmental heads and specialists must also be fully informed on new developments.

With a system as extensive as the IMS, it is advisable to inform the entire workforce of the importance which the management attaches to the development. They should be informed of the necessity of the changes and the beneficial advantages for all involved. Films or lectures explaining some of the new technologies also have positive effects. Such extensive orientation measures can greatly improve workforce morale resulting in a positively motivated approach to the developments and changes. It is important during this orientation that recognition is given to that work which remains, at least temporarily, outside the new system. Neglect of such areas leads not to motivation but to frustration and interdepartmental friction. All employees must feel that their work is appreciated and that rationalisation measures are primarily seen as aids to greater efficiency and easier coping with daily problems.

In addition to orientation and constant motivation, the affected workforce requires training. This training requires both a concept and a fixed time schedule. Fig. 179 shows the training concept, divided into 4 areas, for the workforce of the NC machining department.

- NC programming
- NC job preparation
- NC operation and control
- NC machine maintenance.

In the area of NC programming, the NC technicians are comprehensively trained in all related activities. In the first stage they learn the manual programming of all operational NC machines, both NC lathes and NC machining centres. In the second stage they learn automated programming (EXAPT 1.1 and EXAPT 2). Additional to the programming activities, instruction is given in computer operation. Further subjects include specialised NC machining technology, tooling systems, jig and fixture systems. The NC technicians are also trained in machine maintenance and fault finding so that any minor breakdowns occurring during their shift supervision can be quickly repaired. Finally they are instructed in system organisation and leadership. All employee groups - NC technicians, NC craftsmen and NC operators - are instructed in machine operation, quality control and job preparation. The training of the workforce involves a combination of internal and external courses. A better qualified workforce leads to higher productivity and greater efficiency. Self-confidence is boosted and motivation high. The initial training of an NC technician takes on average approx. 900 hours. The regular training courses covering the entire NC workforce involves 100 hours per employee per year.

4.7 System maintenance

The phase "system maintenance" represents the final stage of the procedure technique which has been used throughout the entire IMS development. In this last phase, the results of the realised system are collected and analysed. Necessary system corrections and improvements in the areas of hardware, software and organisation are developed and integrated into the overall solution IMS. For example, from the NC data-retrieval system (Fig. 169) important data concerning programming efficiency and machine utilisation can be evaluated. The following section describes typical quantitative and qualitative results of system maintenance.

4.7.1 NC workpiece programming

After a short manual introductory phase, NC workpiece programming was carried out entirely with the EXAPT programming system. Development costs of the software - postprocessors, tooling data, cutting data, macro-system etc. - were relatively high. The total investment required for the automated programming system (including salaries of development staff) stands at approx. 750'000 SF (£ 215'000). The system has however reduced the unit programming expenditure by approx. 55 % per workpiece compared to the initial manual programming methods.

This reduction in programming time and cost has enabled the introduction of further NC machines to be made in rapid succession. One of the basic investment principles has been to first order a further NC machine when the existing machines were fully operational in two-shift working. It has thus been possible to introduce 9 NC machines (6 NC machining centres and 3 NC lathes), all operating in full two-shift working, in the time span of 8 years.

The CAD/CAM linkage has been operational for the last 2 years bringing further rationalisation. Compared to the initial manual programming, a 75 % saving has been achieved. The result is that NC workpiece programming no longer presents either a cost or time delay problem in the process execution. Programmes can be rapidly and cheaply produced. This compares with the situation found in many companies where NC programming is considered a time and money consuming delay factor - frequently used as an argument against investment in NC technology.

To date, a total of 4180 workpiece programmes have been produced, 2400 for the NC machining centres and 1780 for the NC lathes (Fig. 180). The administration and maintenance of this large number of programmes and the increasing production rate of new programme (presently 700 per year) caused large problems in terms of system maintenance. These problems have to a large extent been solved with the development and recent implementation of the CAM administration programme. The NC technician has many responsibilities other than NC workpiece programming (section 4.5.5). In the case of first-time machining, the full process from programming assignment to finished workpiece remains the responsibility of the NC technician. The distribution of activities demonstrating the dynamic and interesting work of the NC technician is shown in Fig. 181.

4.7.2 NC machine utilisation

Since the initial implementation of NC machines great importance has been attached to the minimisation of machine idle time. This "lost-time" is influenced by several factors including the loading situation, the organisation, the NC programming, and the reliability of the machines. It is therefore a matter of prime importance to eliminate as many of the technical and organisation factors contributory as possible. To reduce technical stoppages, a maintenance team has been systematically built-up. The NC technician is initially responsible for the isolation and (where possible) the repair of machine faults. The preventative maintenance of the NC machines and associated equipment follows a detailed maintenance plan. For the annual servicing and inspection of the NC plant condition, service personnel from the machine manufacturer are assisted by members of the NC workforce. This teamwork is also considered valuable maintenance training for the NC workforce.

In establishing the degree of utilisation of the NC machines, the following data is evaluated:

- Planned loading time T_B, based on the two-shift operation of the NC machines.
- Utilisation time T_N. The time actually used on production.
- Test-run time T_T. The time required for testing new or modified NC workpiece programmes.
- Maintenance time T_{IS}. The time required for servicing or repairing the machine.
- Idle time T_{RU}. The time lost not through machine defect but through organisational inadequacies, for example programme fault, lack of operator, absence of material, etc.

The NC machines were initially divided into 3 groups:

- Group 1 comprising of 2 identical vertical-spindle NC machining centres (Fig. 173a)
- Group 2 comprising of 2 identical horizontal-spindle NC machining centres (Fig. 173b)
- Group 3 comprising of 3 software compatible NC lathes (Fig. 172).

The results for machining group 1 are shown in Fig. 182. With an average 93 % utilisation, these machines have become the most productive in the company with an extremely low breakdown rate. This reliability simplifies the organisation, operation and planning of the machines. Equally positive are the financial results. Fig. 183 shows the investment return figures for this machine group. The validity of the results is obviously to be seen from the company viewpoint however, the trend is clearly positive. The absolute figures for 1977/78 reflect the high productivity of this machine group. The utilisation time of 10'000 hours per year for 2 machines is a satisfactory result. The high utilisation rate of these machines enabled the break-even point (BEP) to be reached after only 18 months. Further, an 18 % capital return per year could be achieved.

The condensed results of the machine group 2 are shown in Figs. 184 and 185. It should be noted that these figures refer to one machine only - the second machine became operational in March 1979. The first machine suffered considerable technical problems during the early months. The control/machine interface, the automatic tool changer and overheating caused greatest trouble. The problems were gradually eliminated resulting in the average of 81 % utilisation for machine group 2. On these horizontal spindle machines, most of the large, primary workpieces are produced (housings, side frames, etc.). This meant that for several years machine determined the delivery cycle of the products. The recent implementation of the second control-tape compatible machine means that this bottleneck situation has been resolved. One of the main aims for the near future remains the improvement in utilisation of machine group 2 to approx. 90 %.

The Figs. 186 and 187 show the results for machine group 3 - the NC lathes. The first machine, the NC rotational machining cell with robotic loader, automatic bar-feed and integrated measuring system was introduced in 1976. Two further machines, similar but without robot and measuring system, were introduced in 1977 and 1978 respectively. It follows that the presently available data for this machine group is of limited use. The first interpretable figures will be those of the year 1979. It can already be said however that the machine utilisation can be greatly improved when technical and organisational stoppages are reduced. Some measures including better maintenance, improved programming (less collisions) and more thorough training for operators, have already been implemented. The overall effect of NC machining on workpiece quality has been positive. The incidence of re-machining and assembly shop scraping, filing, etc. has been greatly reduced. In the unit assembly department, 4 fitters have been transferred to final assembly despite a 20 % increase in assembly volume. The two-shift working has proved generally problem free from the start. After 8 years successful operation, the results can be said to be satisfactory. From the procedure technique phase of "system maintenance" the following conclusions have been reached:

- The installed NC machining capacity is insufficient to fully satisfy the ever shorter delivery requirements demanded by the market. Further NC machines must be installed in the near future.
- The utilisation of the NC machines particularly the NC lathes must be improved, primarily through a reduction of technical breakdowns.
- The last phases of the CAM programme software must be completed to further minimise the administrative work needed for the NC programmes.
- The integration of CAD and CAM must be extended to prismatic workpieces to achieve a balanced technological development level over the whole programming system.
- The organisation must be further refined and the constant training of the NC workforce continued.

With this brief review of the phase "system maintenance", the development of the IMS and the implementation of a part of the IMS have been described. The framework of this study permitted only some aspects of the IMS to be dealt with. Further, many specifications and solutions have a heavy company specific bias, therefore the work should be seen from this viewpoint, and not regarded as a universal solution for all cases.

CHAPTER V

5. DISCUSSION

From the beginning, the project IMS has been positively encouraged by both the company owner and senior management. Without this support and active assistance the idea of developing the comprehensive IMS as a guideline for long-term company development would not have been possible. Since 1971 however, progress has been made towards a comprehensive IMS concept. Each year has seen a marked advance towards the realisation of the complete IMS. This rationalisation of the process in the areas of design, machining, and to an extent in assembly, has strengthened the market position of the company. The overall IMS project investment including hardware, software, organisation, and salaries, has required a yearly average of 1.5 million sFr (£ 430'000). In this time the effective turnover volume has increased by approx. 35 % enabling the company's position as market leader to be further consolidated.

5.1 Procedure technique

The selected procedure technique (section 3.3.4) has proved to be an ideal tool for developing such a complex system as the IMS. A systematic, step by step approach must be taken which leads to better results. A vital factor was certainly the comprehensive and detailed analysis of all involved departments to objectively determine the relevant system requirements. A major advantage of the procedure technique is - "the characteristic proportional decrease in problem area with increasing degree of solution detail". This funnel effect helps to prevent confusion and clarifies the logical interrelationship of the whole system. The procedure technique can be successfully applied to all types of system development.

5.2 The IMS model

The development of the IMS model enabled the important and complex overall system relationships to be portrayed in an abstract yet clearly understandable manner. The definition of the IMS (section 2.3.2) clarified the main aspects of the overall system. These include the planning, process, and control of all activities concerned with the development, machining and assembly of the product. With the IMS model, all function solutions can be easily identified and positioned in the overall system. All related interfaces can be immediately identified. The model helps to isolate and clarify the problems which inevitably occur in system development.

The three dimensional character of the IMS model (Fig. 79) clearly emphasises the different development phases and helps to guarantee that important intermediate development stages are not overlooked. Balanced and phased system development minimising the creation of integration gaps has assumed considerable importance throughout.

5.3 Conception and development of the IMS

With the basic concept of an "IMS of low degree of automation", the company had the framework of a comprehensive 10 year rationalisation programme for the manufacturing process. The division of the IMS into the design, machining and assembly systems has proved very practicable. The central character of computer application in all system areas has enabled far-reaching changes to be made.

The design system consisting of the sub-systems - design planning (CAPD), design (CAD) and design control (CACD) has, in varying degrees already been realised. The computer-aided detailing drawing of rotational and prismatic workpieces is fully operational. The CAD/CAM link for rotational workpieces is fully operational.

The machining system development consisting of the sub-systems - planning of machining (CAPM), machining (CAM) and control of machining (CACM) - has centered primarily on the expanding application of NC technology. Again, varying degrees of progress have been made. Fully operational is the automated NC workpiece programming with CAD linkage. All machines operate in full two-shift working. Extensively developed is the (CAPM) sub-system involving machine loading and schedualing and the planning of NC programming. The (CACM) sub-system is presently manually operated, however development has already begun.

The assembly system consisting of assembly planning (CAPA), assembly (CAA), and assembly control (CACA), remains to date practically untouched. The aims and some solution ideas already exist but development will first take place when the recently begun factory centralisation project is completed in 1982. The centralisation of all sections of the company will obviously have a great beneficial effect on the present disjointed assembly system.

5.4 Integration CAD/CAM

The system components CAD and CAM have both been implemented and feature a high degree of automation, especially concerning information processing. The sweeping changes caused in both the design department and machining department proved problematic in the implementation phase. The elimination of the manual draughting of detail drawings and introduction of unusual new methods caused considerable uncertainty and anxiety amongst drawing office staff. Many felt that their jobs were threatened. Others insisted that they could still draw faster than the plotter. With daily use however, most doubts were gradually lost and the knowledge that the detail drawing could be produced on the CAD system became both accepted and welcome.

The workforce in the machining department also experienced early problems with the new "computer drawings" as some dimensioning and layout changes had been made compared to conventional detail drawings, however, the direct link from computer-aided detail drawing to automated NC workpiece programming brought many advantages to the manufacturing of new designs. The time required from detail drawing production to machined workpiece could be greatly reduced. In several test cases, the total time required was reduced to a mere 3 hours including detail drawing production, NC workpiece programming, and machining. Obviously few assignments are carried out in 3 hours but the fact that the installed CAD/CAM system is capable of such performance is proof of its value to the company. With the successful implementation of the CAD/CAM solution, two of the primary aims of the company - the increase in flexibility and a marked reduction in costs - have been fulfilled, at least for an important part of the process.

5.5 NC machining

The implementation of the NC machines has solved the difficult problem of serious bottleneck situations in the machining department. The system has been so optimised that, compared to the previous situation, a greatly reduced inventary of modules and units need to be stored. Customer orders can to a large extent be assembled from workpieces directly from the machining department. This aspect has led to considerable financial savings and freed capital. The selected NC machines, both NC machining centres and NC lathes, have been well proved in two-shift working. The selection of control equipment from a single manufacturer has proved a great advantage as the NC workforce can be easily and confidently switched to any of the machines. The servicing problem has also been greatly simplified.

For the machining of rotational workpieces, it is planned to install small NC lathes (max. workpiece diameter 200 mm, max. length 500 mm) alongside the existing machines to cover the entire rotational workpiece spectrum. The implementation of the NC rotational machining cell has brought several problems. The actual NC lathe functioned ideally from the very beginning, however the automated bar-feed system, robotic loader, and diameter measuring system proved generally unreliable with frequent faults and breakdowns. The robotic loader worked well, however with disc-type workpieces. Robot setting time for change-over from disc-type to shaft-type component proved time consuming and the application spectrum limited. The specified performance for the robotic loader was only partially realised and considerable optimisation will be required in this area. The integrated diameter measuring system with friction wheels for internal and external diameters has to date proved extremely disappointing. Measurement during the process has proved possible in only a few cases with this system. The idea of measuring during the process certainly has considerable future, however much development work is necessary before a practically useable system is realised. An increase in the automation of the machining department including the application of NC machines, robotic devices, transport systems and in-process measuring equipment can only be achieved when the technical reliability of the required hardware can be guaranteed.

5.6 Organisation

The economic success of an IMS depends not only on good software and good hardware as these factors can first be fully utilised but also when an adequate and efficient organisation is present. The development of an organisation, based on the control circuit model, has guaranteed the success of the IMS. In the NC department, the creation of three employee groups - NC technicians, NC craftsmen and NC operators, and their combination as a team - has brought many advantages. One particular aspect should be emphasised. The realisation of a part of the IMS based on modern technology (computers, NC, etc.) and a modern organisation concept has meant that many capable employees otherwise lost to the machining department (in planning, work preparation, jig and tool building, etc.) have been won back. The work in the machining department has again become attractive for both trained employees and young apprentices.

CHAPTER VI

FUTURE WORK

The large number of remaining unsolved problems leaves plenty of freedom in selecting future work. This study was concerned primarily with the development of the overall system IMS and only some of the systems and sub-systems have been developed to date. The following areas offer wide scope for further study:

1. The development of a CAA system (Computer-Aided Assembly) and its integration with the related process functions CAD (Computer-Aided Design) and CAM (Computer-Aided Manufacturing).

2. The development of a CAC system (Computer-Aided Control) which integrates all aspects of quality, quantity, cost, and schedual control for all process functions CAD, CAM, and CAA.

3. The full integration of CAP and CAC in the sense of a self-regulating on-line control circuit system which continuously processes input and output affecting the overall IMS.

4. The study of the effects of the integrated manufacturing system (IMS) on the workforce, particularly the effects of extensive application of computers and automated plant.

5. The study of the effects of the unconventional workforce utilisation (e.g. NC technician) on the industrial training of both the workforce and future apprentices.

6. Future work is required on the NC rotational machining cell to improve the efficiency of both robotic loader and integrated measuring system.

CHAPTER VII

CONCLUSIONS

1. The fact that the company posesses a long-term programme for the development a realisation of an IMS means that rationalisation can be carried out in a planned coherent manner in all areas of the company.

2. With the realisation of CAD and CAM the market position of the company could be further consolidated.

3. Productivity, especially in the machining department, could be greatly increased without an increase in workforce.

4. The flexibility of the company was increased with the idea of the IMS.

5. The company could respond more quickly to market changes.

6. The development time required for new products could be greatly reduced.

7. The delivery times for ordered machines could be reduced from the previously 10 months to 5 months. Turnover was increased by 25 % without workforce increase.

8. Successful implementation of an IMS or a part thereof requires not only comprehensive planning and coordination but the careful informing of all involved employees.

9. The development of a practice orientated IMS cannot be commenced without a thorough analysis of the different activities, products, capacity, organisation, etc. of all sections of the company.

10. The analysis, necessary at different levels with different degrees of detail, should involve as many of the affected employees as possible.

11. By the implementation of the IMS, all details of the solution should be consequently thought-out to ensure that minimum efficiency-loss results.

12. For the realisation of the IMS, too few sufficiently qualified employees were available. These had to be trained to fulfill the system requirements.

13. The changeover from the old system to the IMS proved both difficult and exhausting.

14. The introduction of the CAD detail drawing system in the design department had positive effects on the working methods of this department.

15. The realisation of NC technology on a wide basis has brought the company great benefits in view of both machining capacity and financial situation.

16. The division of NC machining and conventional machining proved ideal for the successful introduction of the completely new ideas of NC technology.

17. The automatic NC workpiece programming system proved extremely advantageous to the optimum execution of the machining process.

18. The integrated CAD/CAM linkage has resulted in a large rationalisation of the information flow between design and machining.

19. The organisation of the NC department including modern working ideas such as job enrichment, job enlargement and job rotation has proved successful during several years of practical application.

20. With the implementation of NC machining, throughput times in the machining department have been reduced by approx. 50 %.

21. Through the application of the IMS, the company could launch 4 new products within 4 years. Previously 10 years were required for the same number.

22. NC machining has led to a large reduction in scraping, filing and re-machining in the detail assembly department.

23. The integrated measuring system of the NC rotational machining cell failed to meet specified requirements. Problems remain in guaranteeing reliable cleaning of the measured surface (swarf and coolant).

24. The robotic loader of the NC rotational machining cell has proved useful in certain cases, particularly disc-type workpieces. Problems remain in,by accurate "second clamping", slow operation and time consuming setting.

25. The missing IMS system components for example CAP and CAC continue to cause difficulties in the daily running of the system.

26. The degree of utilisation of the NC lathes has not yet attained the specified level.

27. The installed NC lathes do not cover the entire rotational workpiece spectrum. Small NC lathes must be additionally installed.

28. A reliable and regular maintenance organisation is of great importance to the NC department. Faults and breakdowns result in capacity and financial losses.

29. The realised parts of the IMS have proved beneficial to all processes within the manufacturing sector of the company.

30. Both management and workforce were presented with a difficult and unusual challenge which resulted in the dynamic motivation of the entire company.

31. The IMS has helped to guarantee the long-term existence of the company, as the developments meant that all functions within the company had to be examined and re-thought. The result is the continuous modernisation, rationalisation and optimisation of the company.

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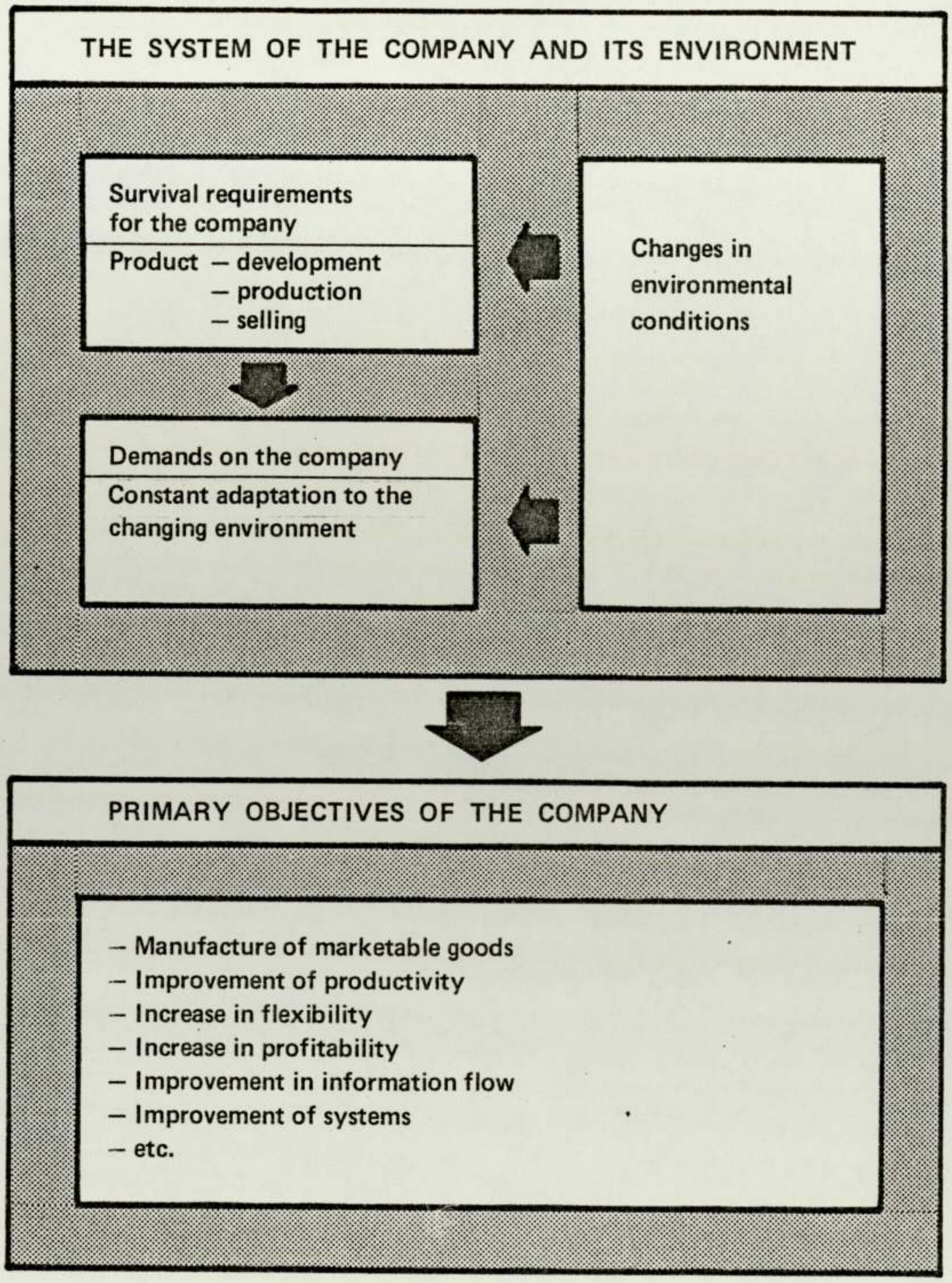


FIG. 1 RELATIONSHIP BETWEEN THE COMPANY AND ITS ENVIRONMENT

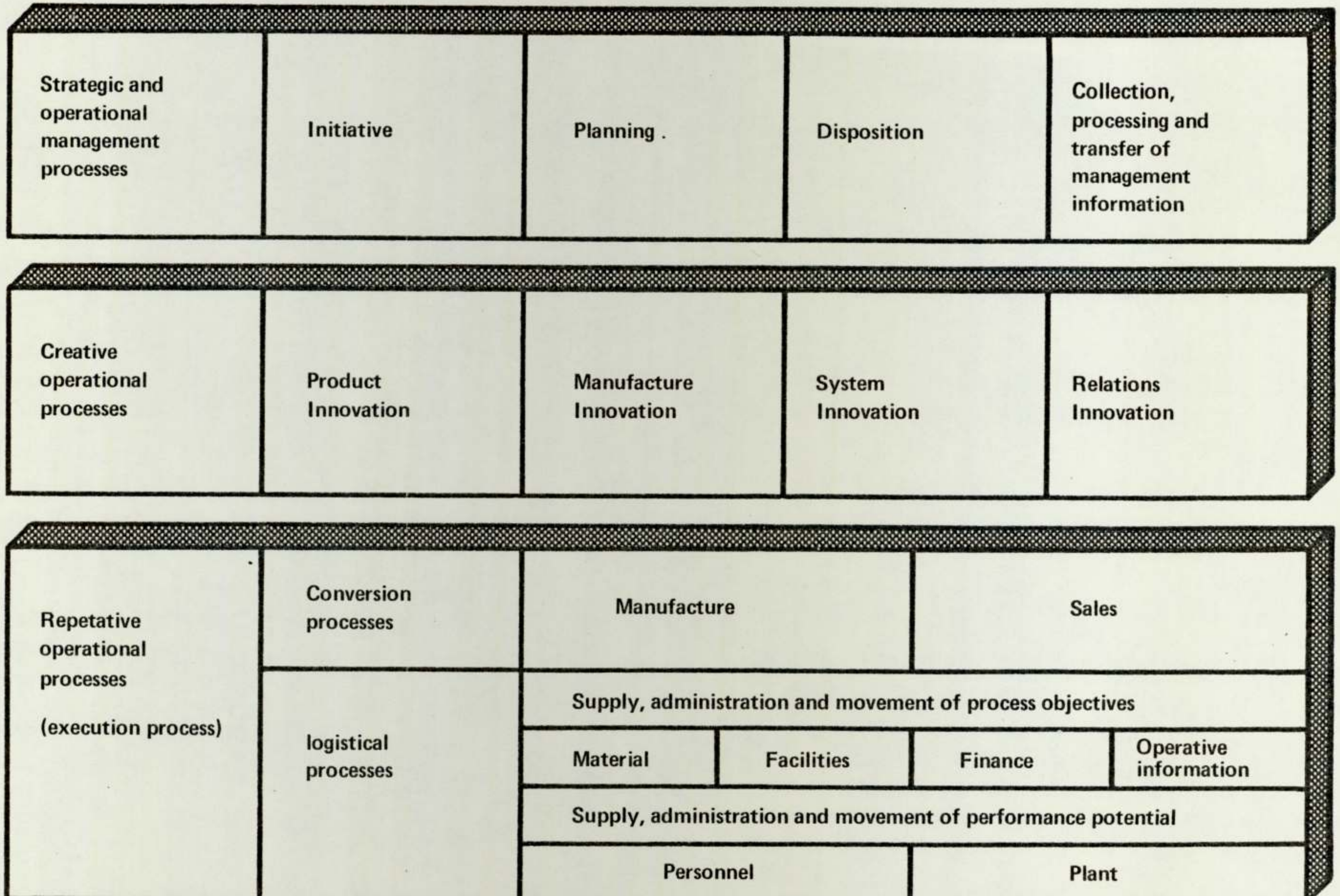


FIG. 2 THE MAIN PROCESSES IN A COMPANY (AFTER KRIEG, REF. 1)

FIG. 2

FIG. 3

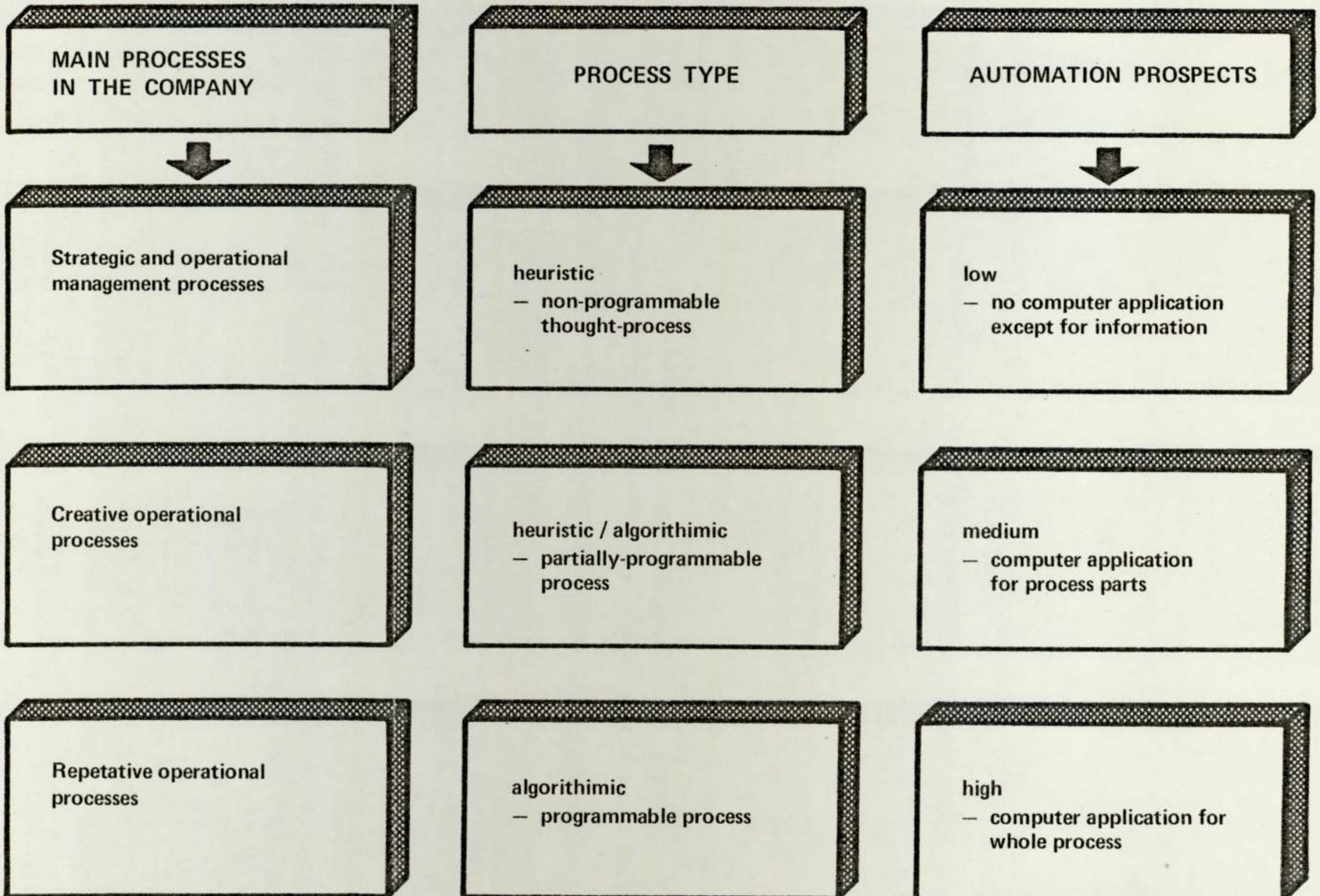


FIG. 3 QUALITATIVE COMPARISON OF THE MAIN PROCESS AUTOMATION PROSPECTS

	AUTOMATION IN MANUFACTURING		
	DESIGN AND DETAILING	WORK SHEET PREPARATION	MACHINING AND ASSEMBLY
1980	Industrial application of CAD systems for simple machine parts (e.g. shafts)	Industrial application of computer-aided work sheet preparation for component families	Widespread application of DNC systems
1985	Industrial production data-processing, drawings, parts lists, work sheets, NC programmes	Application of computer aided work sheet preparation in 80% of all cases in 50% of all companies	Complete on-line optimisation of plant with process computers
1990	Graphic data processing for 75% of all machine tool designs	Integrated work-sheet planning, coupled with CAD and CAM	Over 50% of all plant NC All NC machines coupled to process computers. Automated quality control, on-line coupled between machine tool and measuring machine

FIG. 4 DEVELOPMENT TRENDS IN MANUFACTURING AUTOMATION (AFTER ETZENBACH, REF. 3,9)

FIG. 4

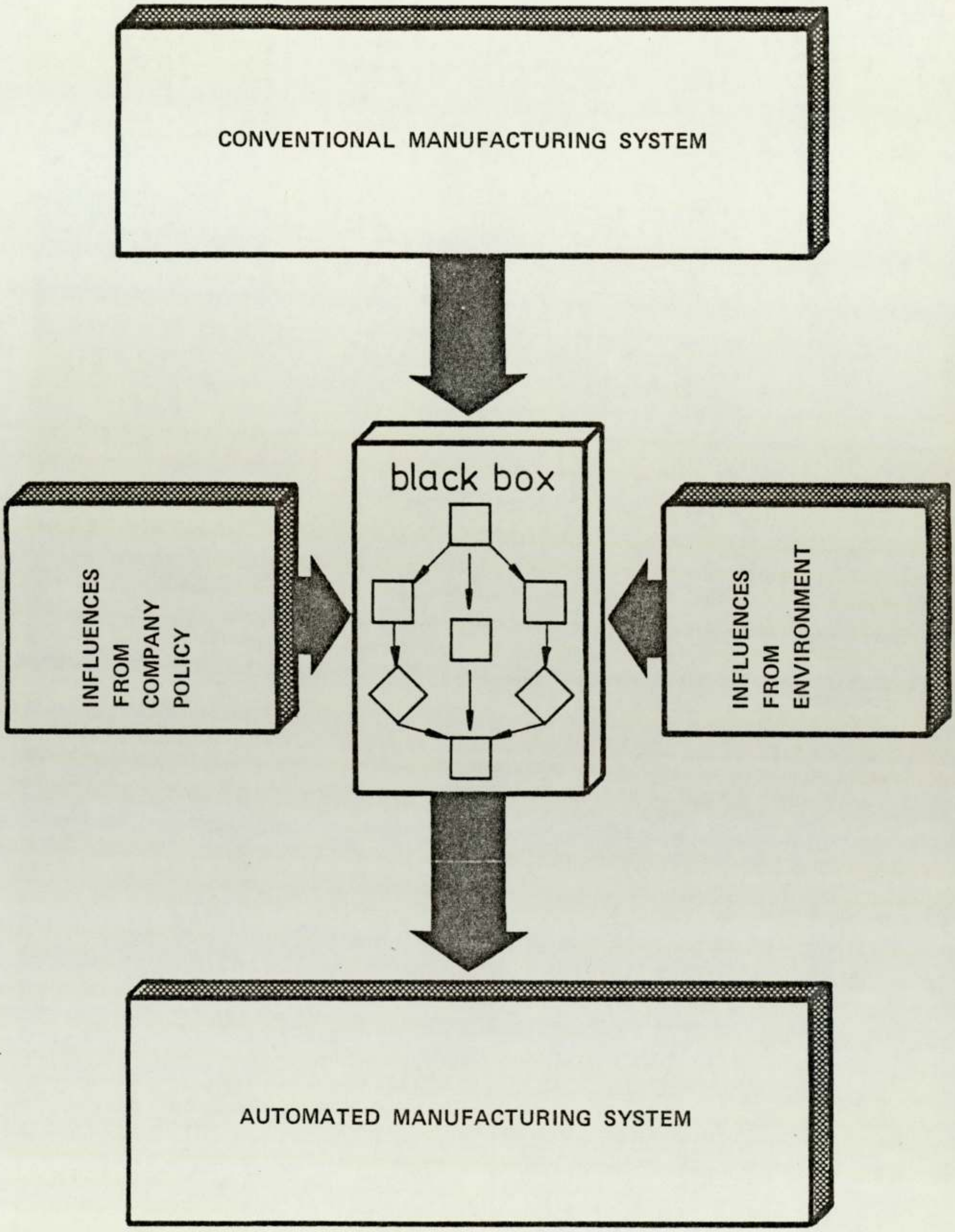


FIG. 5 REDESIGN OF THE MANUFACTURING SYSTEM

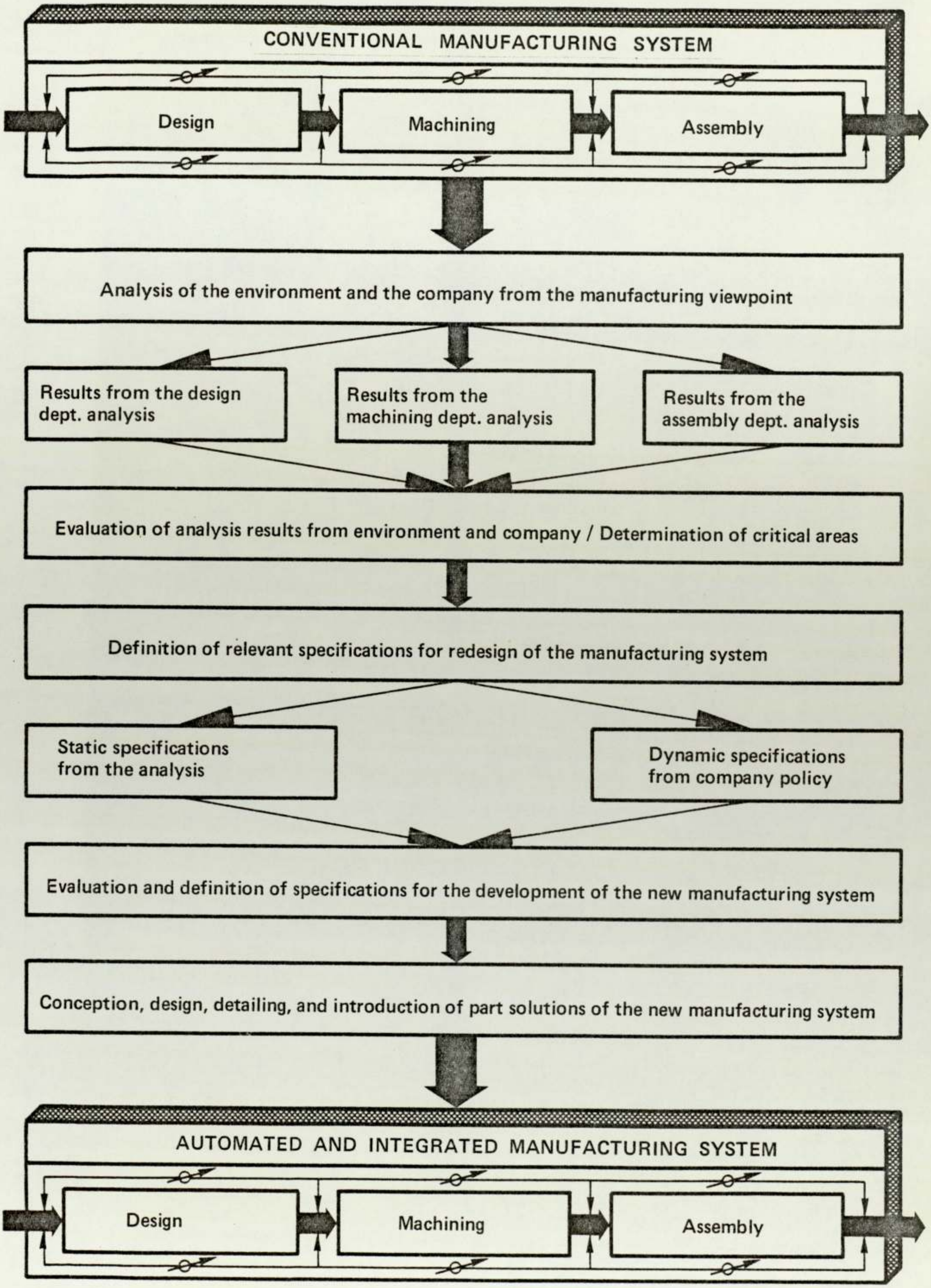


FIG. 6 PROCEEDURE PLAN FOR THE DESIGN OF THE MANUFACTURING SYSTEM

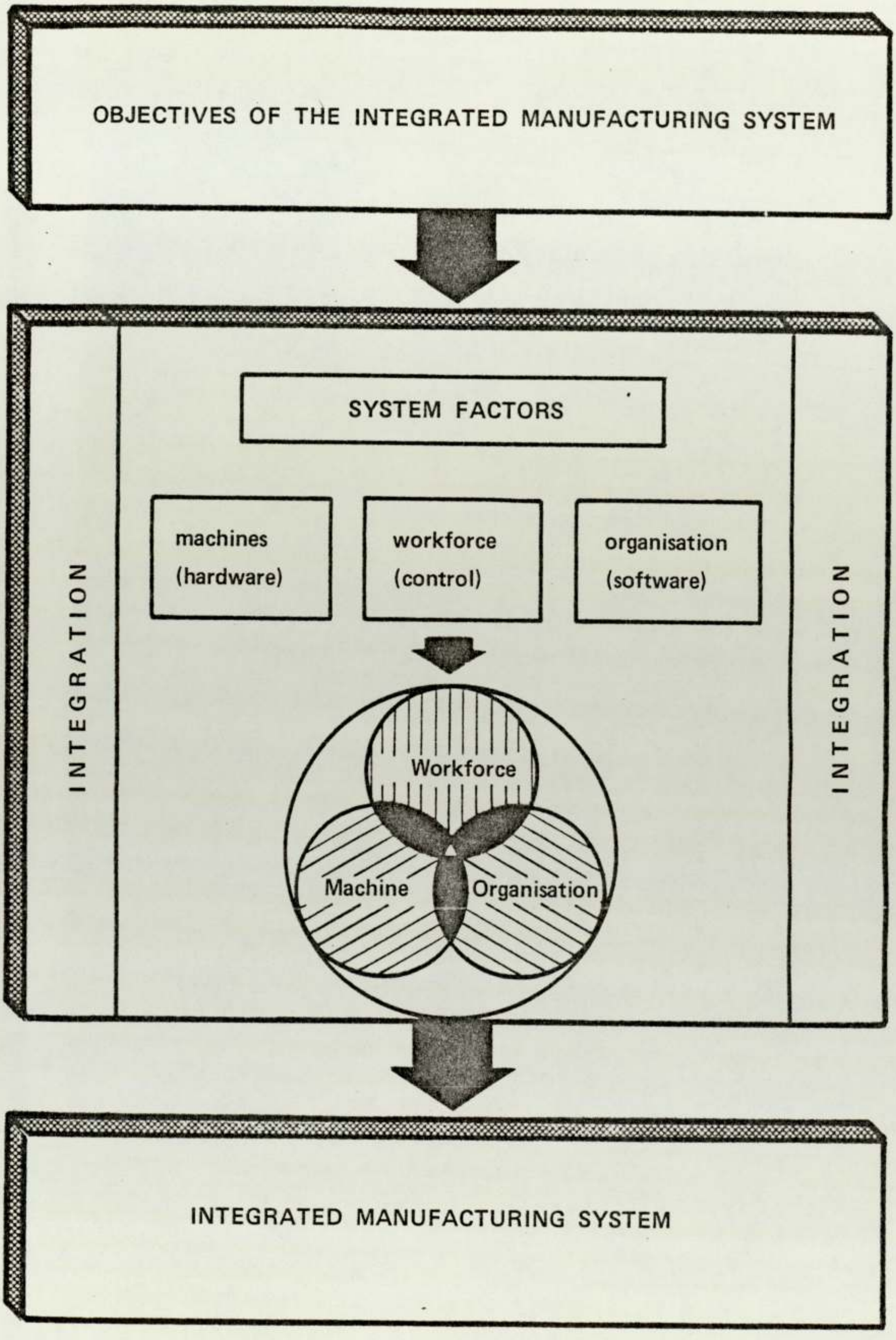


FIG. 7 INTEGRATION OF THE SYSTEM FACTORS WORKFORCE, MACHINE, AND ORGANISATION

General process steps \ Criteria	Information processing	Material processing	Primary execution mode: manually	mecha-nised	auto-mated
Conception	●		■		
Design	●		■		
Detailing	●		■		○
Machining planning	●		○		■
NC workpiece programming	●				▲
Material preparation		●	■	○	○
Machining control	●		○	○	■
Machining	◑	◑		▲	○
Quality control	◑	◑	○	■	○
Component storage	◑	◑	■	○	○
Sub-assembly planning	●		○		■
Material preparation		●	■	○	○
Sub-assembly control	●		○		■
Sub-assembly		●	■	○	○
Quality control	◑	◑	○	■	○
Sub-assembly storage	◑	◑	■	○	○
Final assembly planning	●		○		■
Material preparation		●	■	○	○
Final-assembly	◑	◑	○	■	○
Final-assembly control	●		○		■
Quality control	◑	◑	○	■	○

● definite
◑ mixed
○ partial
■ primarly
▲ completely

FIG. 8 GENERAL PROCESS-STEPS FROM PRODUCT IDEA TO FINISHED PRODUCT

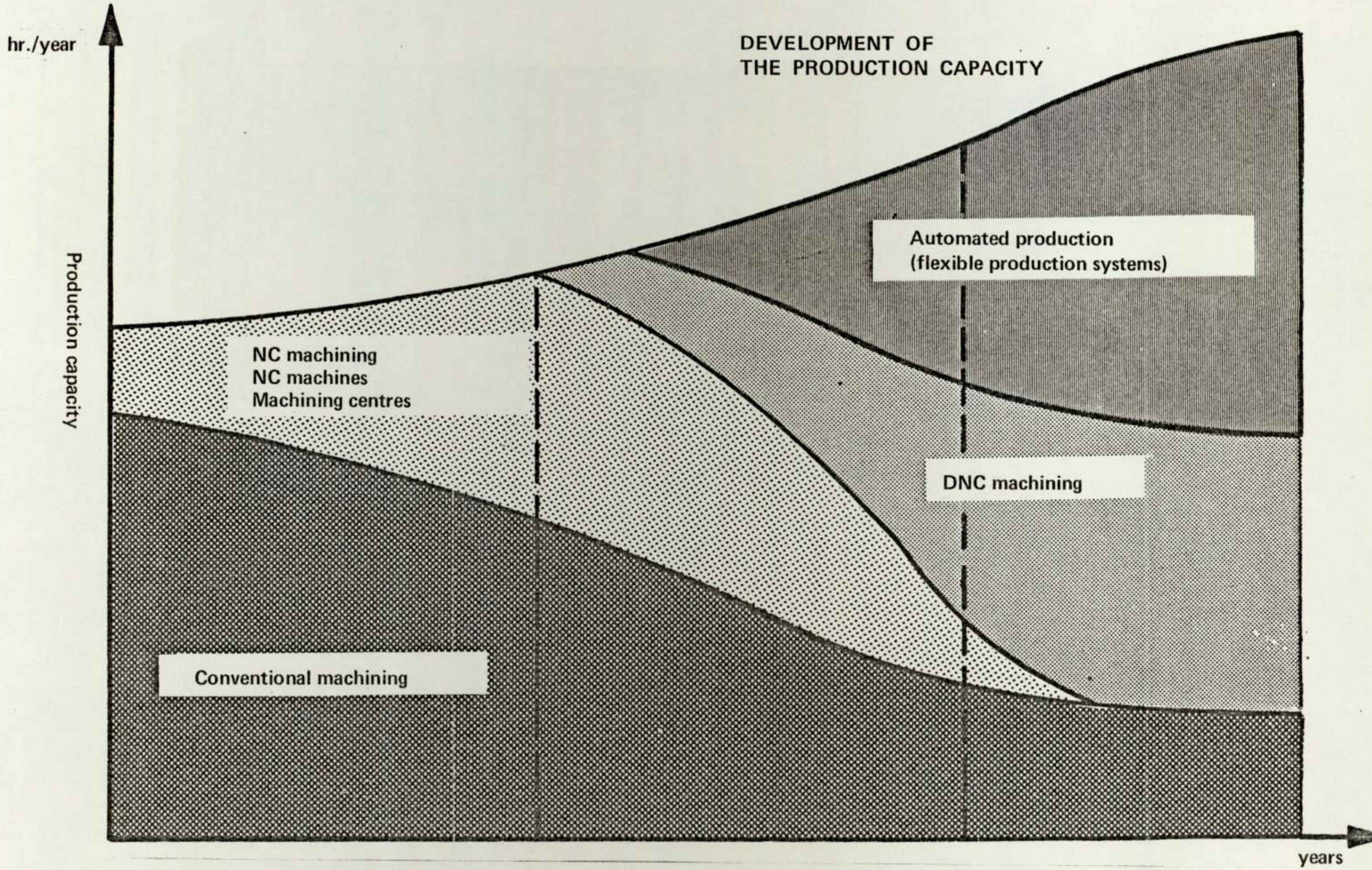


FIG. 9

FIG. 9 MACHINE TOOL DEVELOPMENT TRENDS FROM THE AUTOMATION VIEWPOINT
(AFTER WESTKAEMPFER, REF. 7)

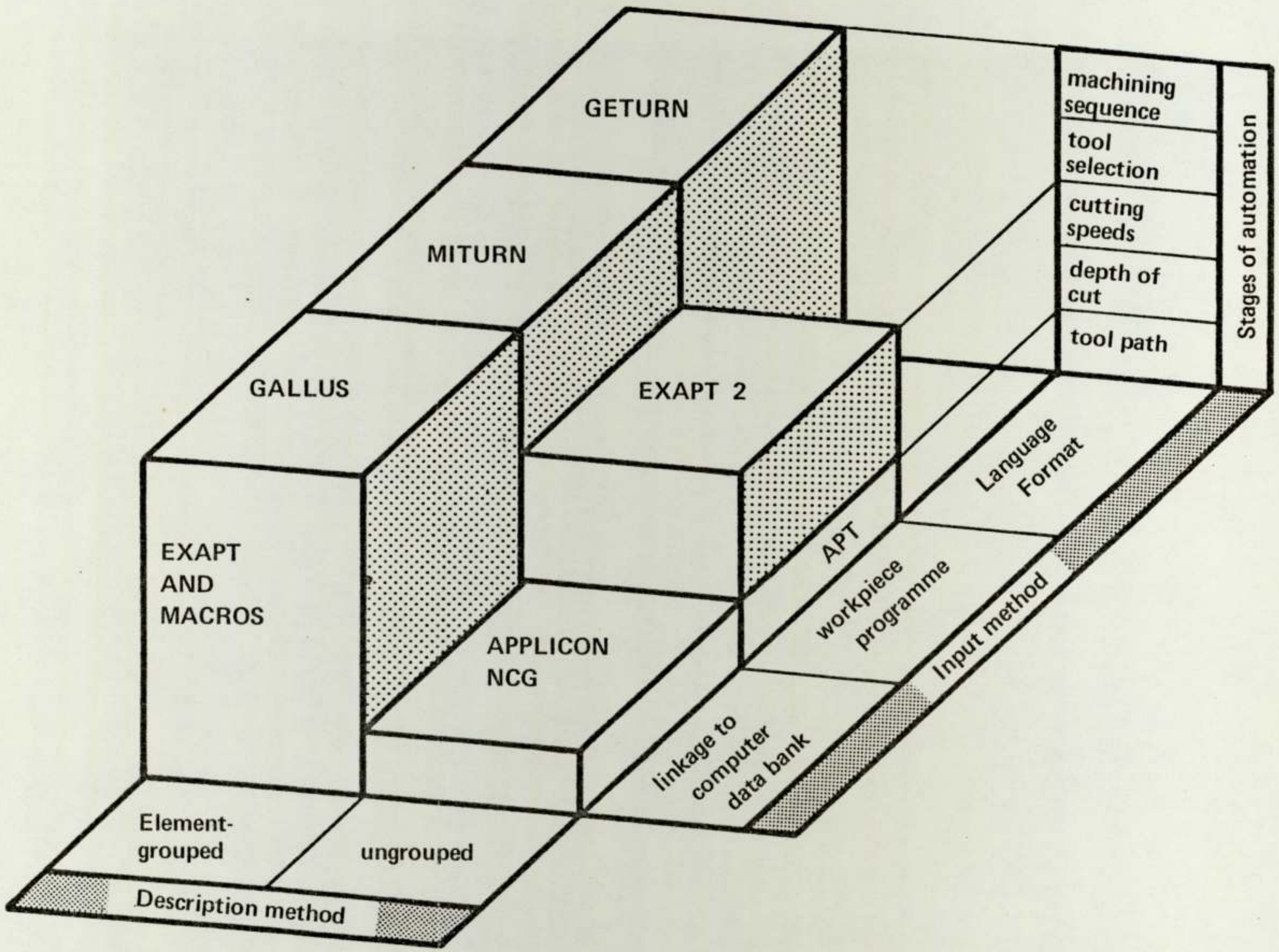


FIG. 10 DEVELOPMENT STAGE OF SOME PROGRAMMING SYSTEMS FOR ROTATIONAL MACHINING (AFTER FISCHER, REF. 34)

FIG. 10

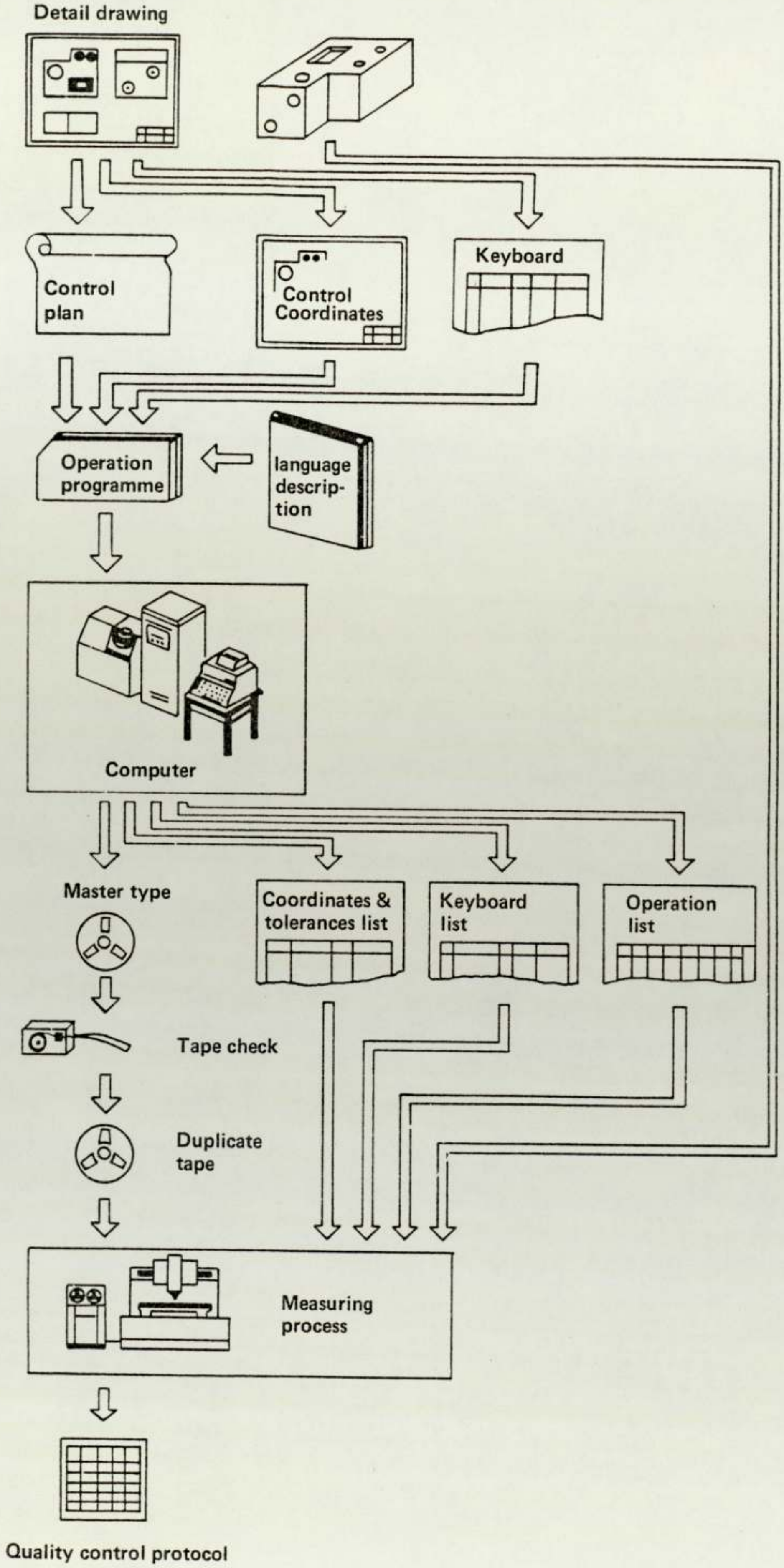


FIG. 11 AUTOMATED PROGRAMMING OF THE MEASURING PROCESS WITH NCMS (AFTER KOERTH, REF. 34)

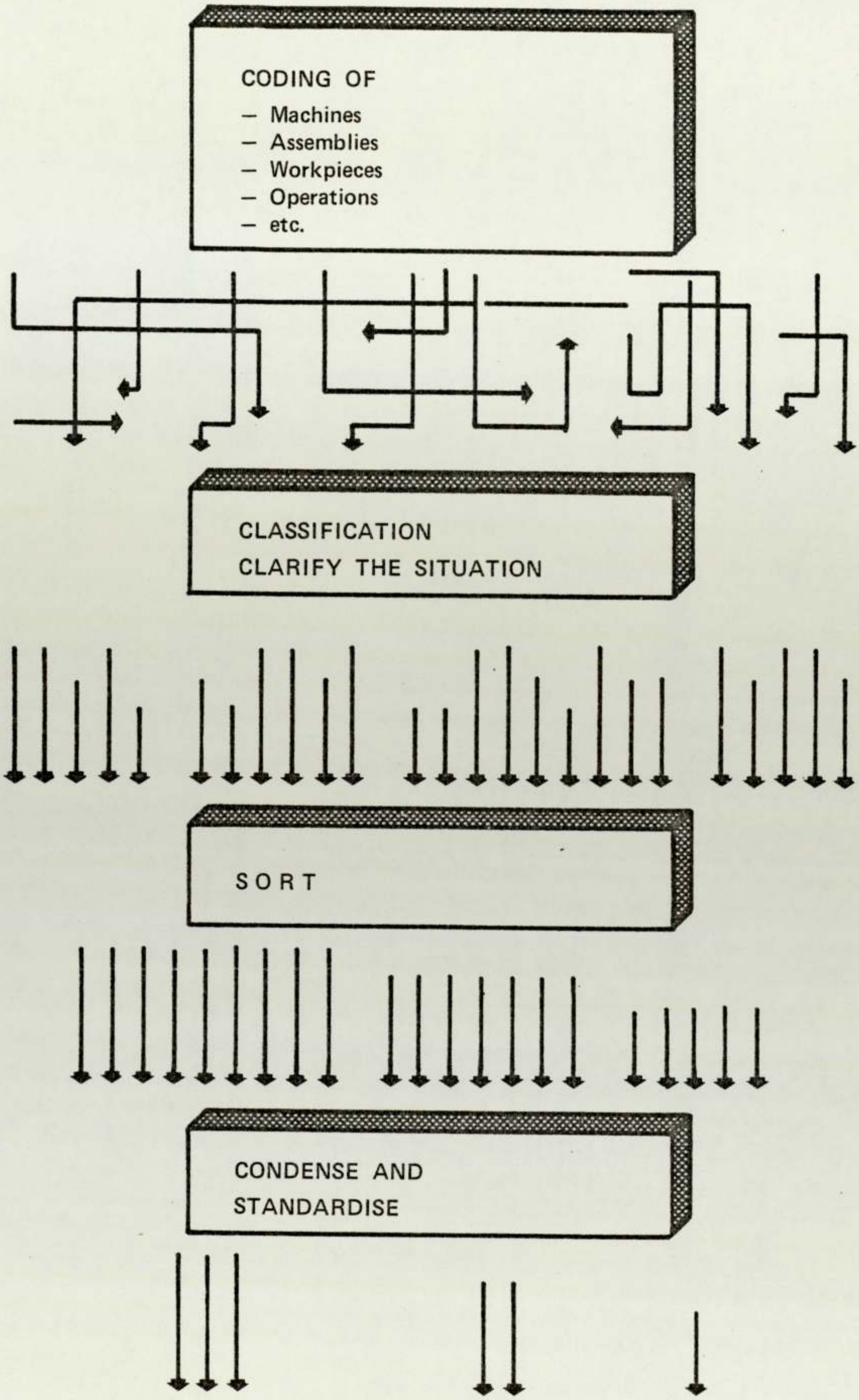


FIG. 12 THE AIMS OF CLASSIFICATION

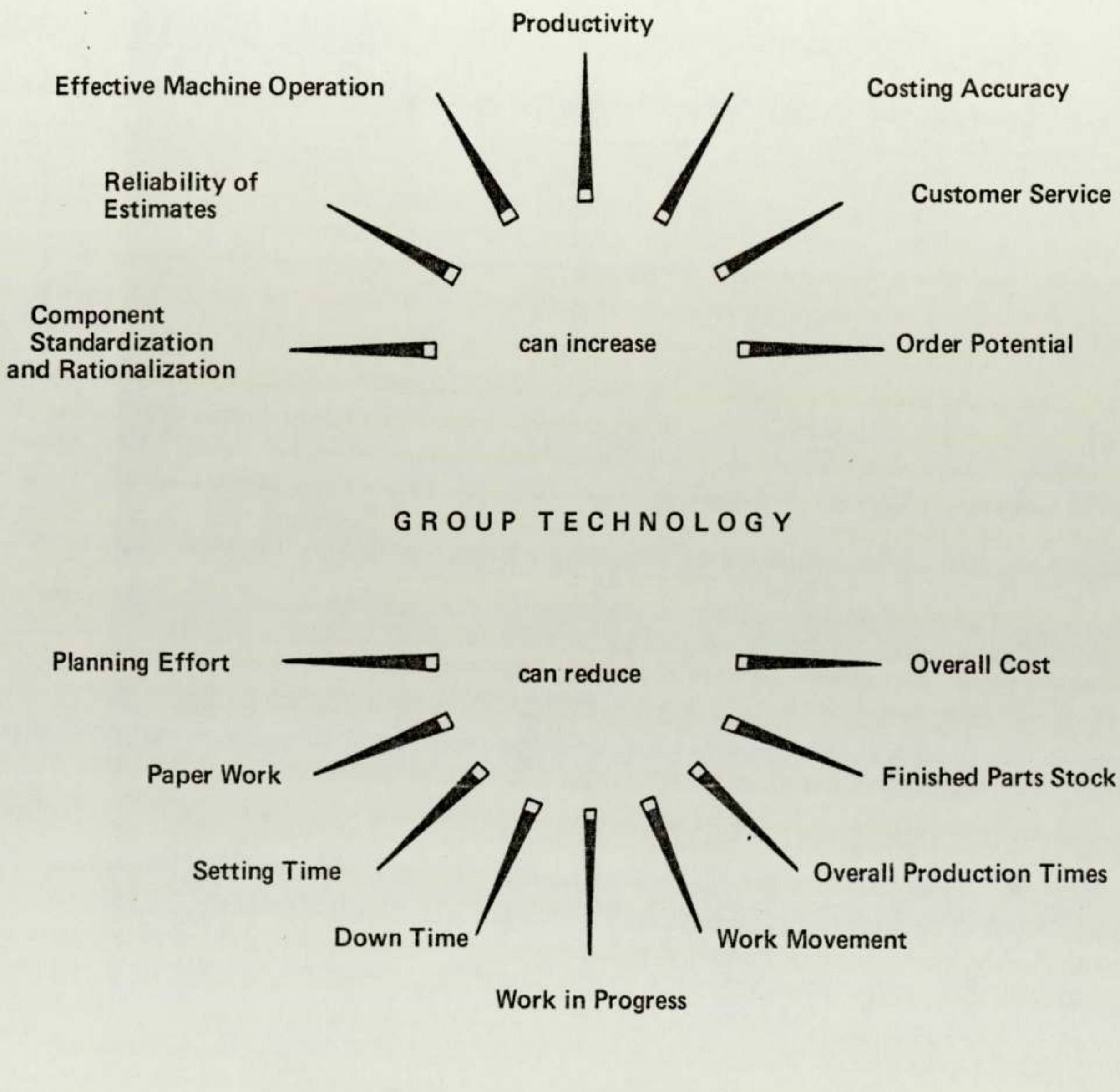


FIG. 13 GENERAL BENEFITS OF GROUP TECHNOLOGY
(AFTER THORNLEY, REF. 52)

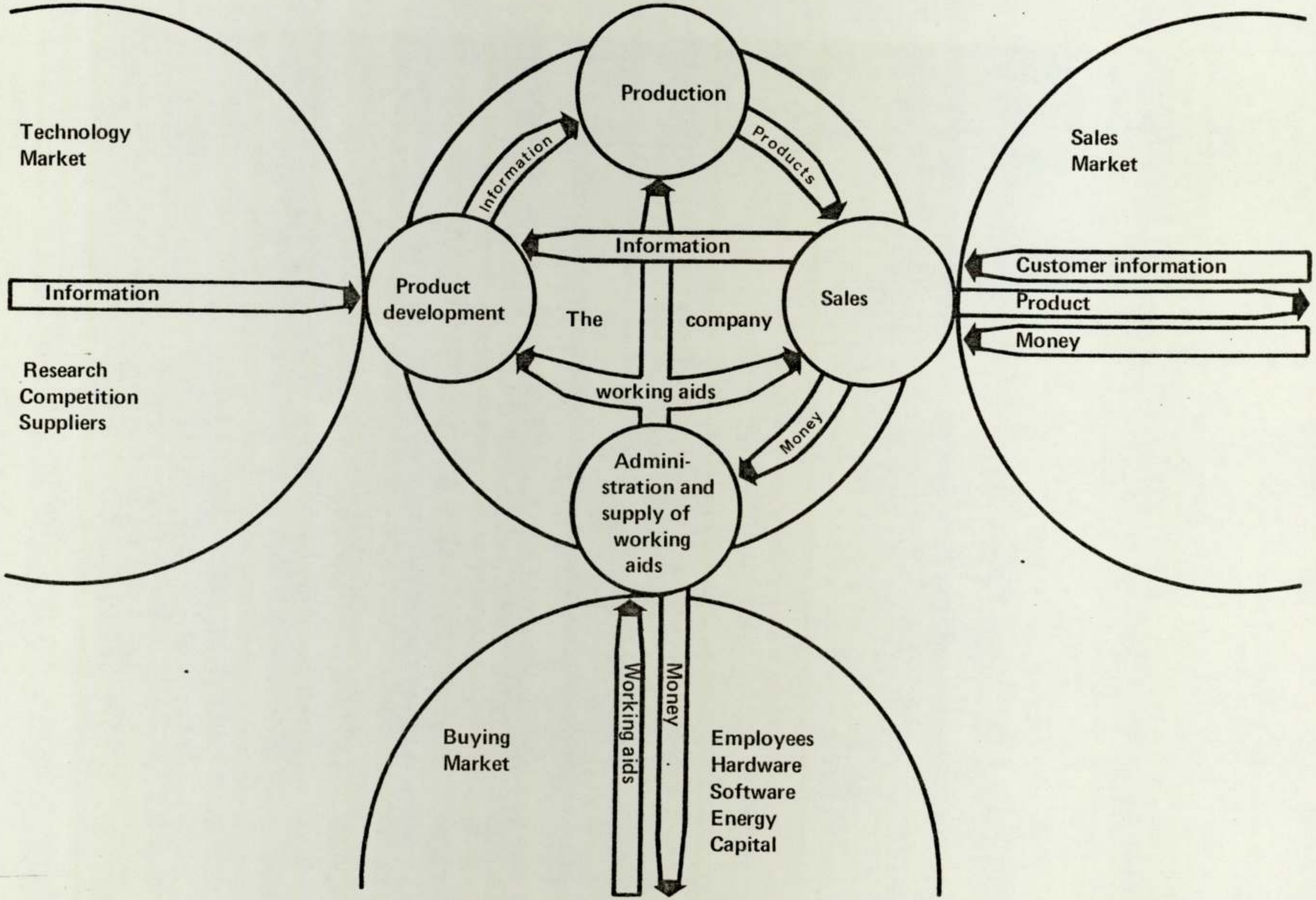


FIG. 14 RELATIONSHIP BETWEEN COMPANY AND MARKET (AFTER STUDER, REF. 66)

FIG. 14

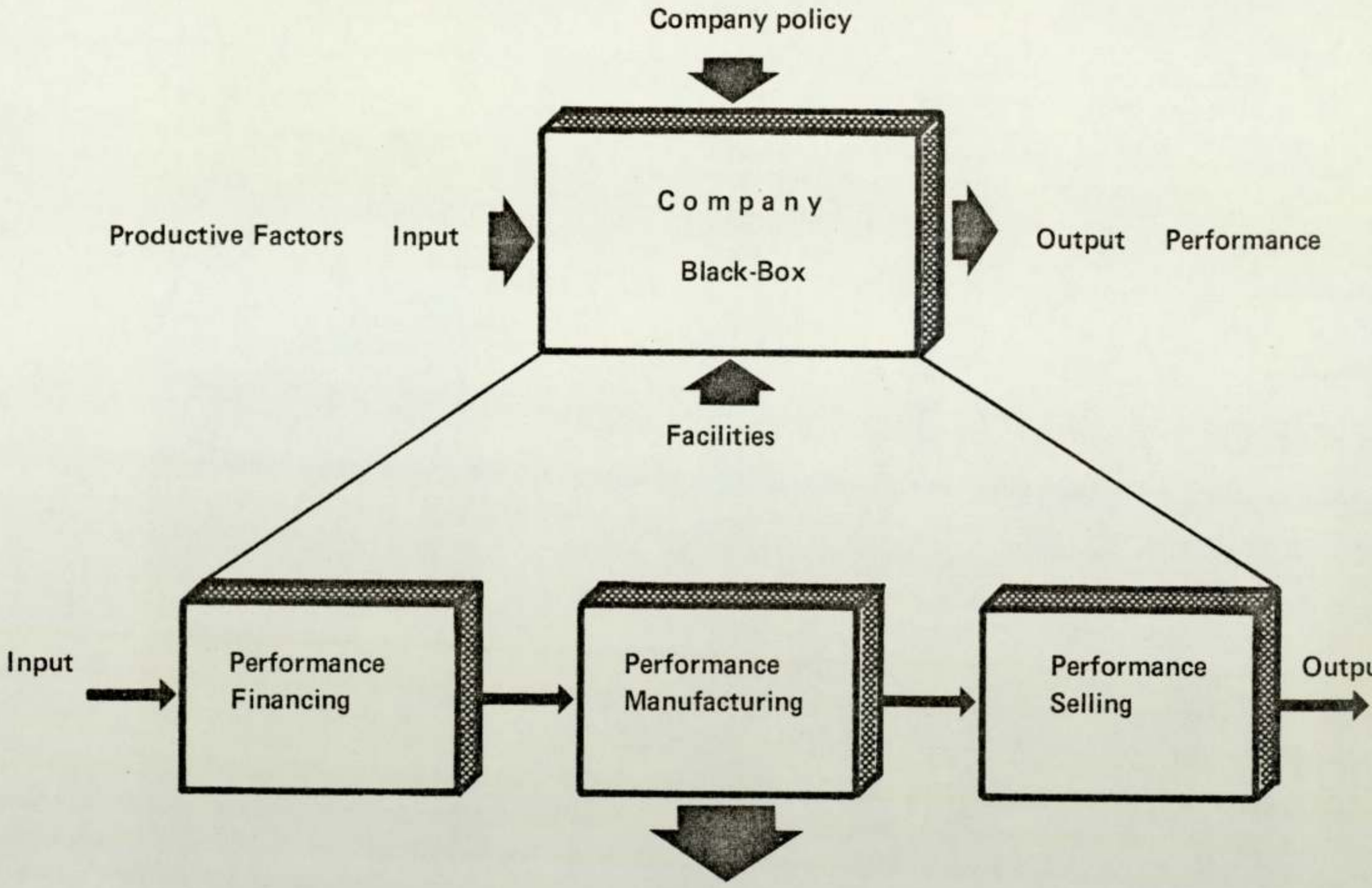


FIG. 15 THE COMPANY FROM AN ABSTRACT INPUT/OUTPUT VIEWPOINT

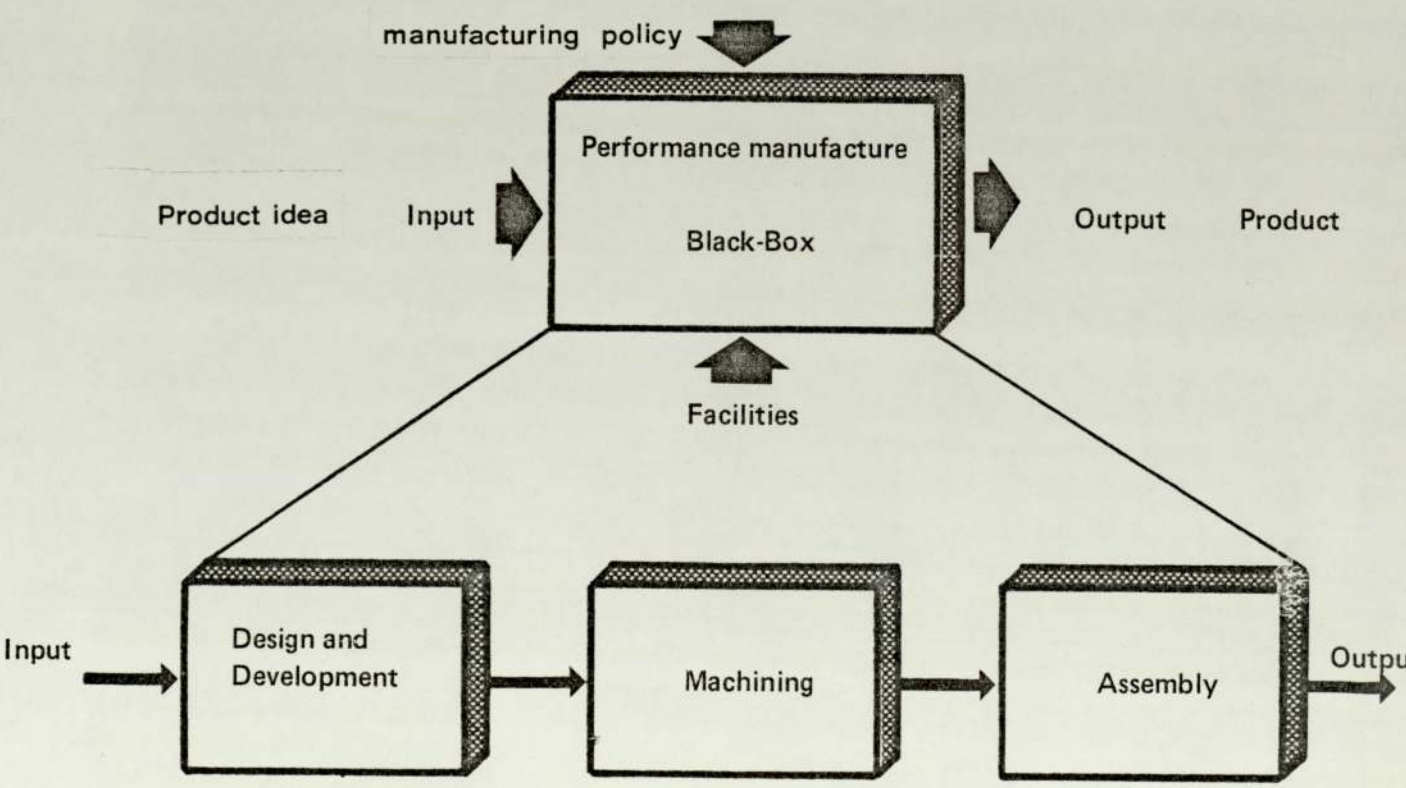


FIG. 16 PROCESS ORIENTATED BREAKDOWN OF THE FUNCTION PERFORMANCE MANUFACTURE

FIG. 15/16

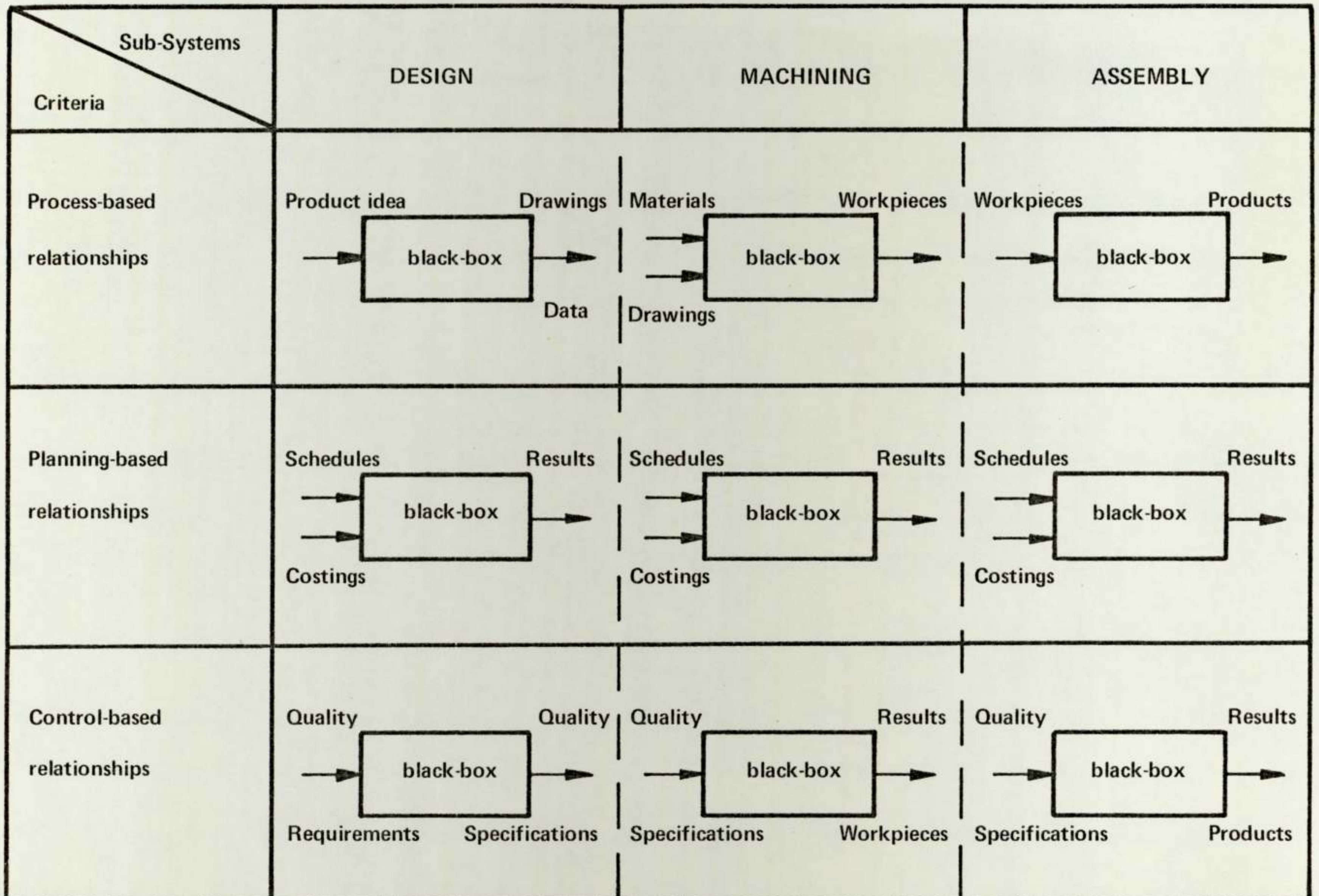


FIG. 17 INTER-RELATIONSHIP BETWEEN THE MANUFACTURING SUB-SYSTEMS

FIG. 17

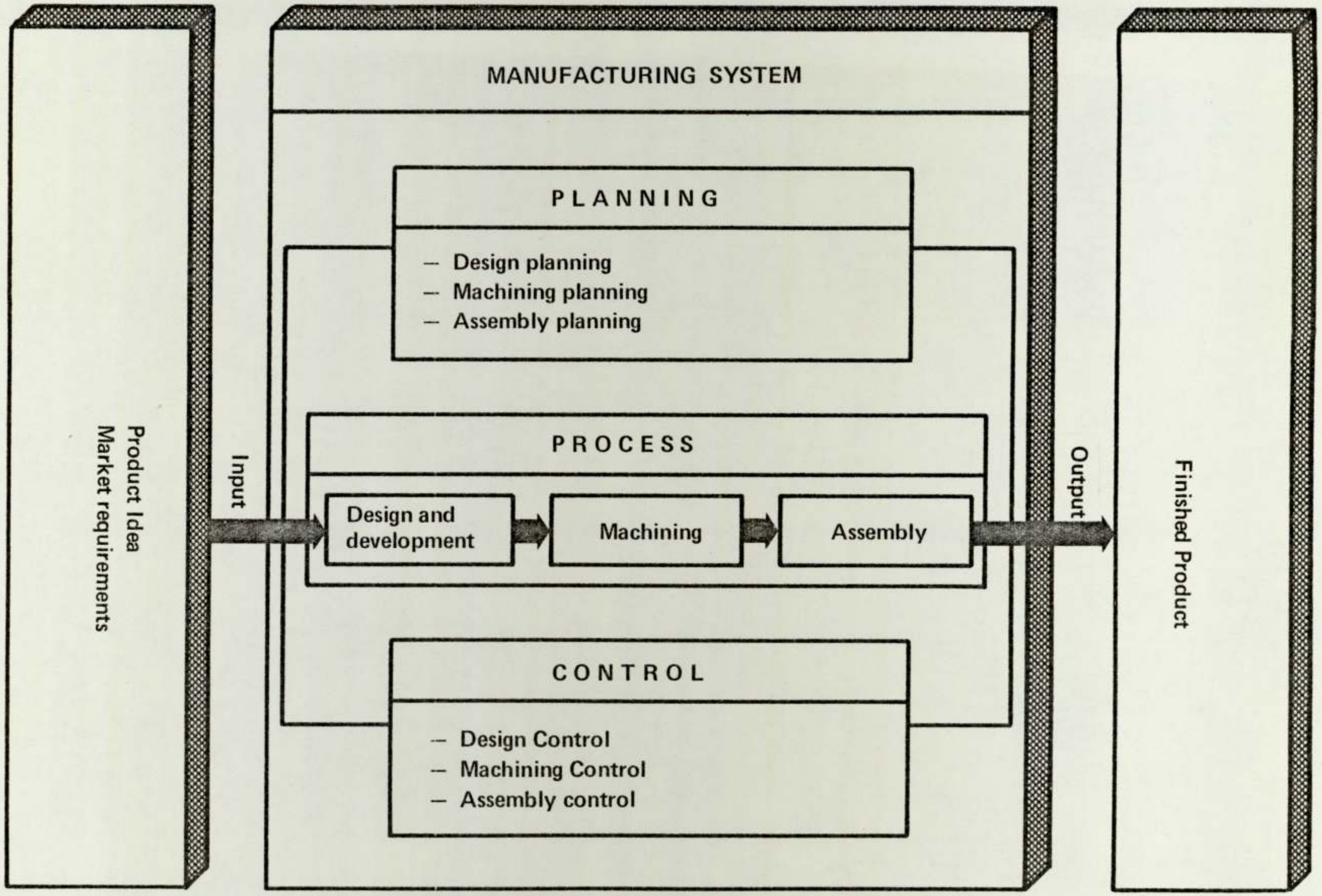


FIG. 18 MANUFACTURE (STATIC ASPECTS)

FIG. 18

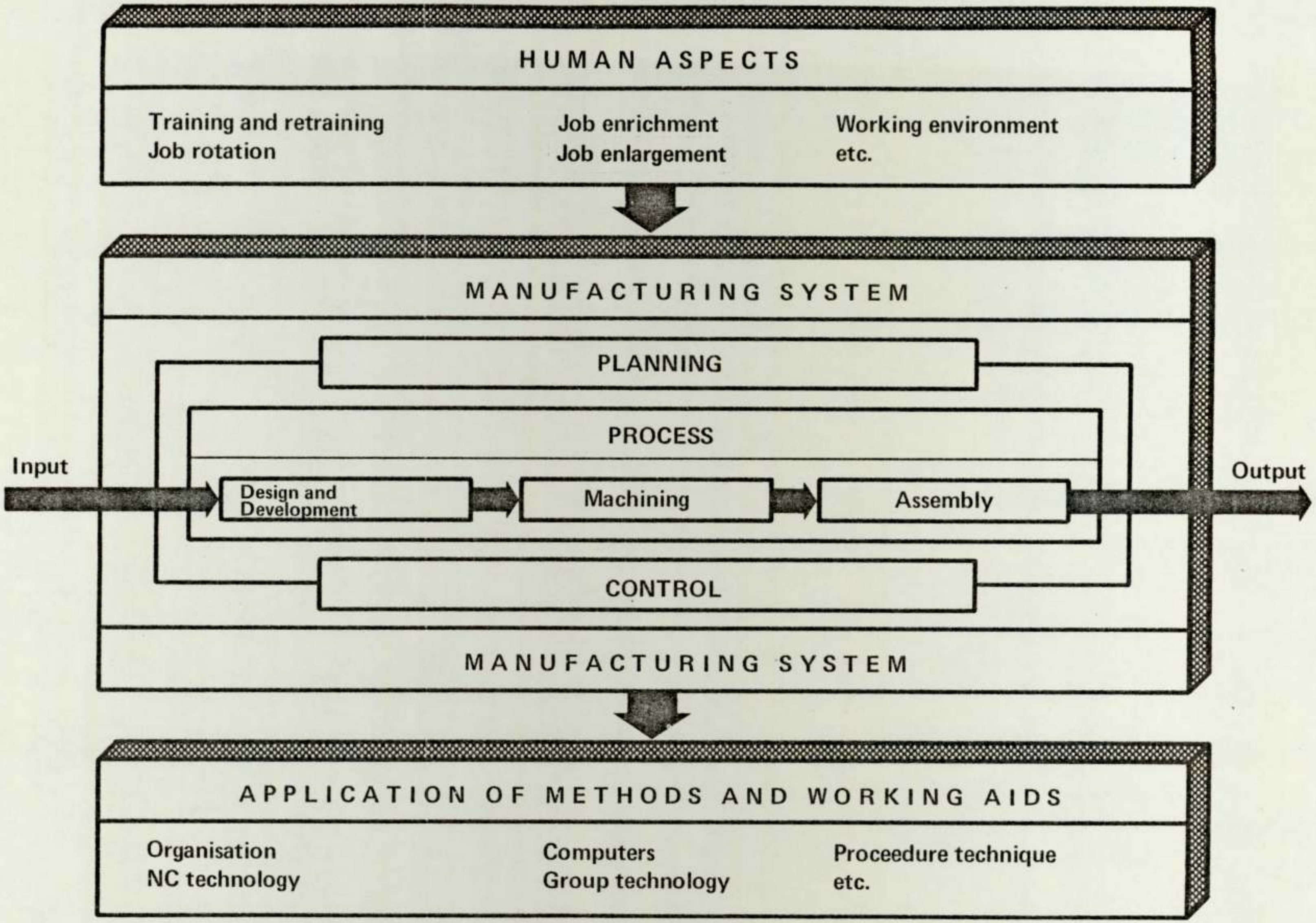


FIG. 19 MANUFACTURE (DYNAMIC ASPECTS)

FIG. 19

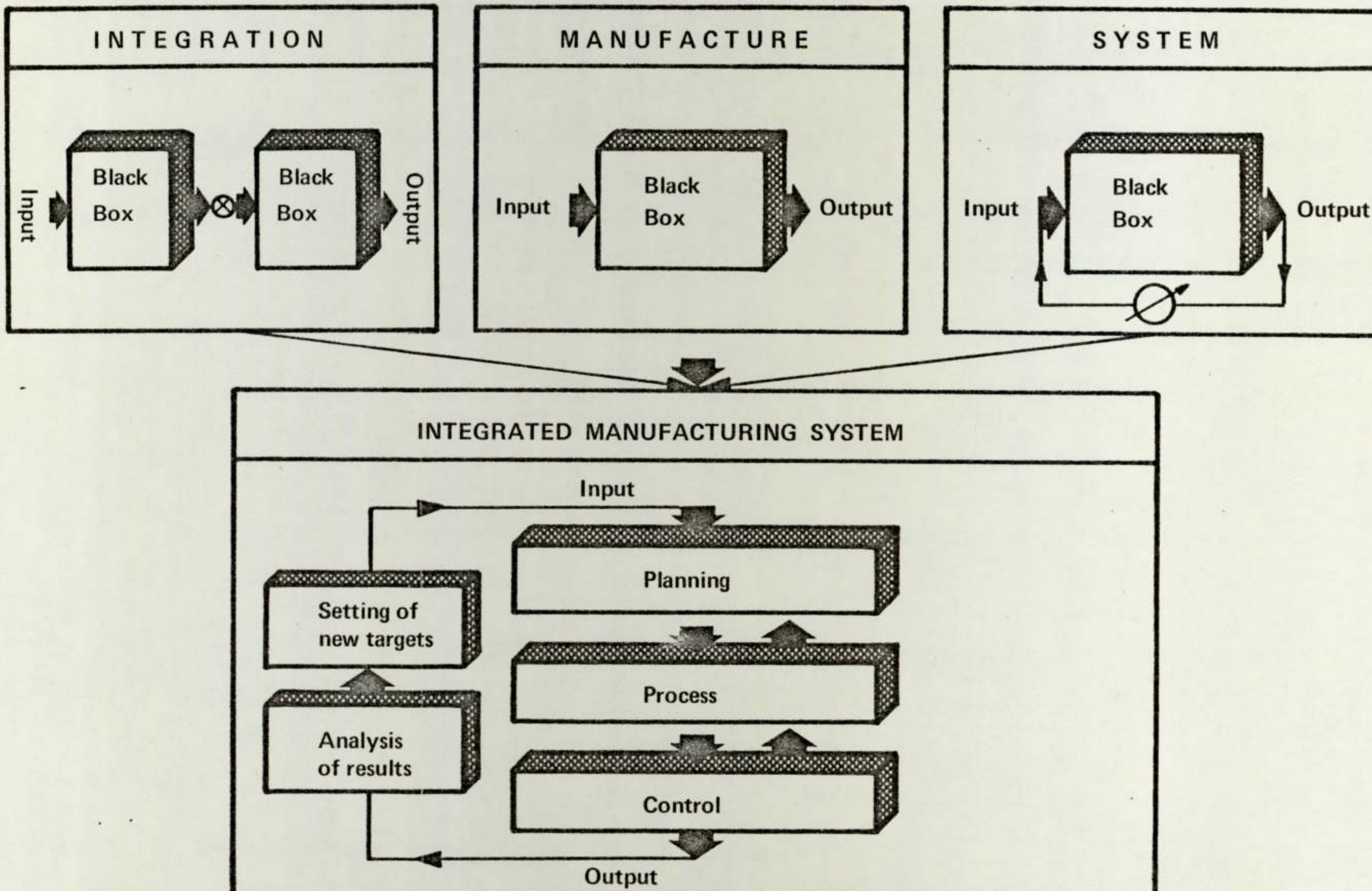


FIG. 20 SCHEMATIC MODEL OF INTEGRATED MANUFACTURING SYSTEM

FIG. 20

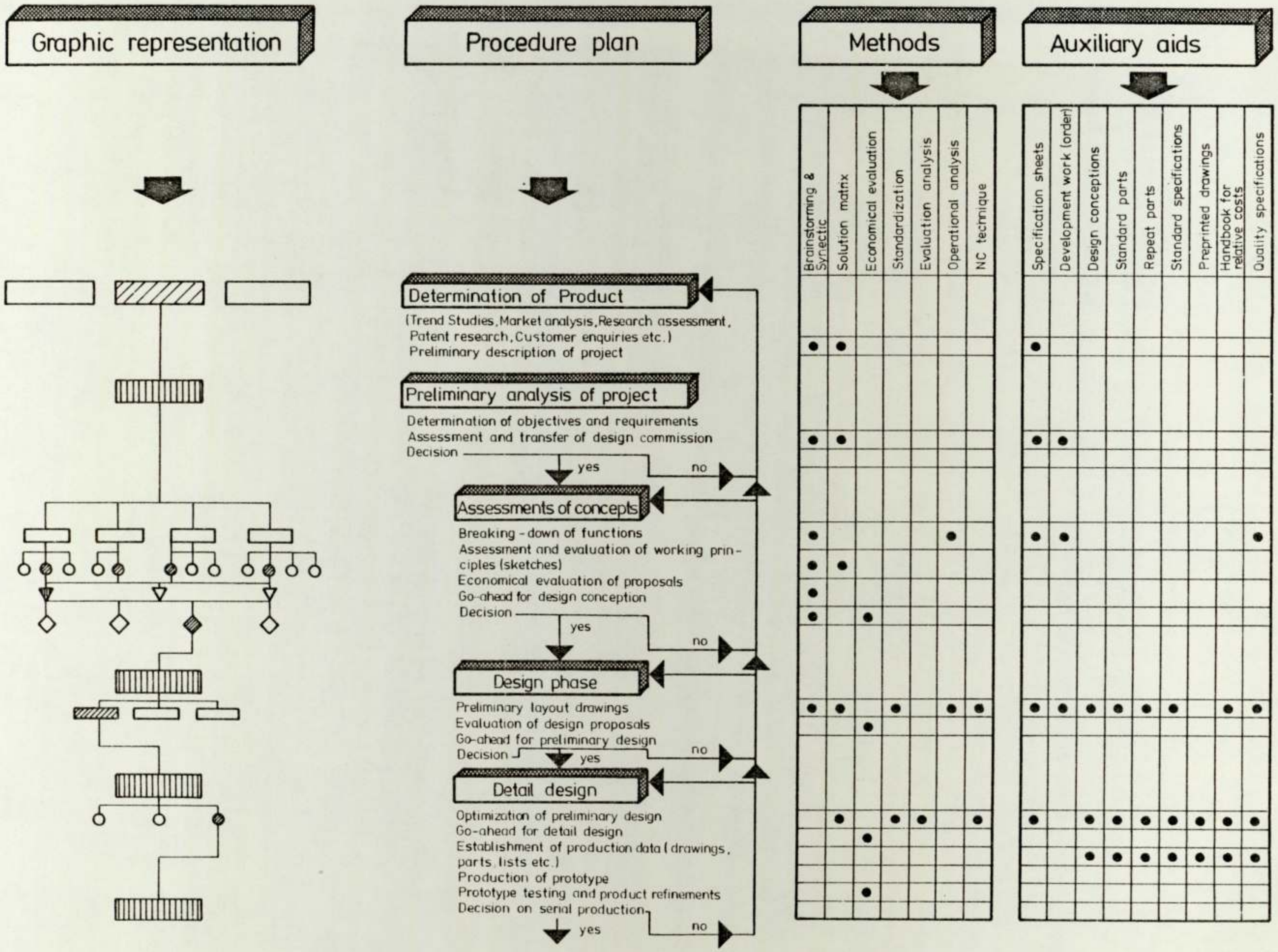


FIG. 21 PROCEDURE TECHNIQUE

FIG. 21

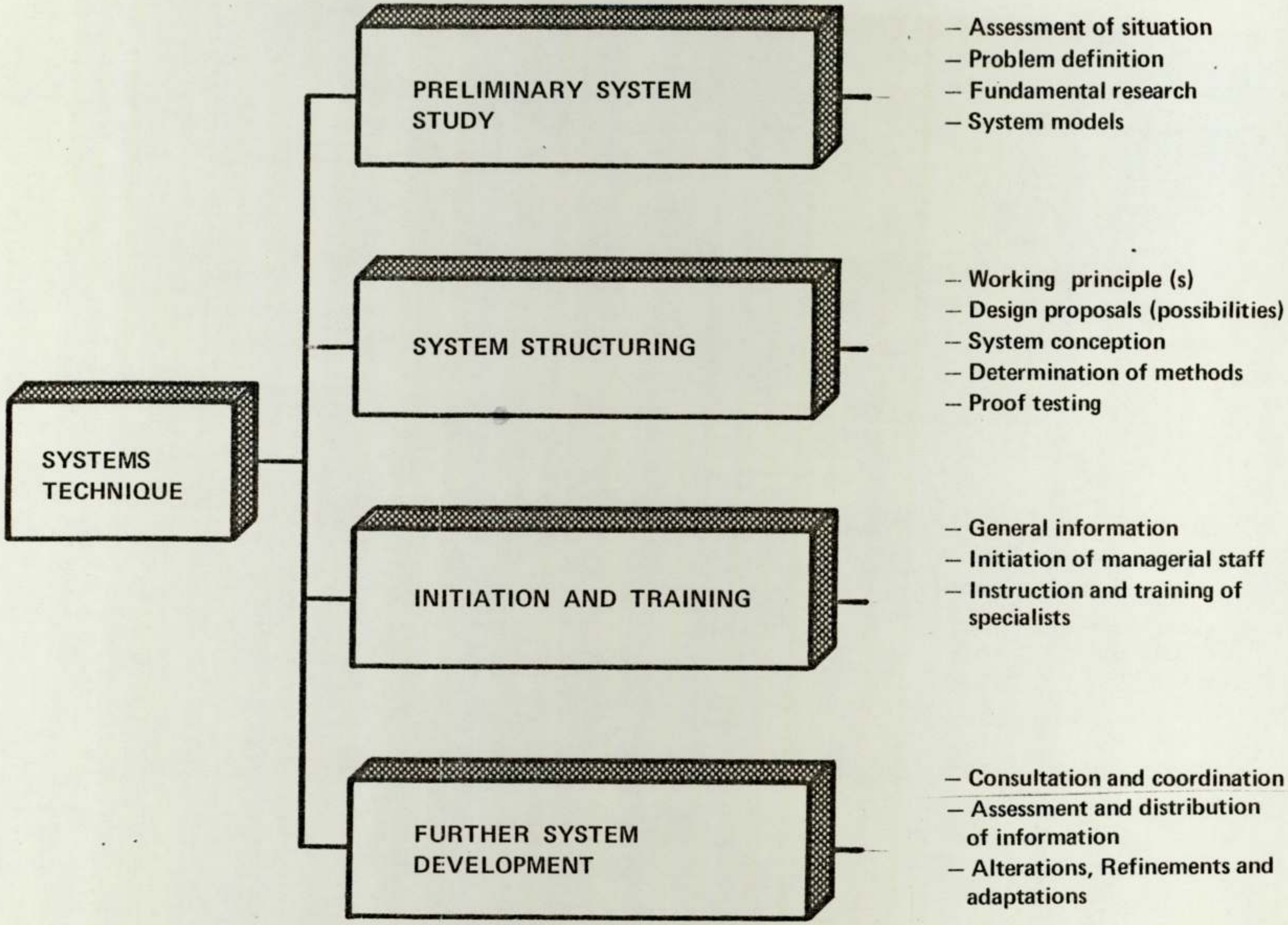


FIG. 22 PROCEEDURE OF SYSTEMS TECHNIQUE

FIG. 22

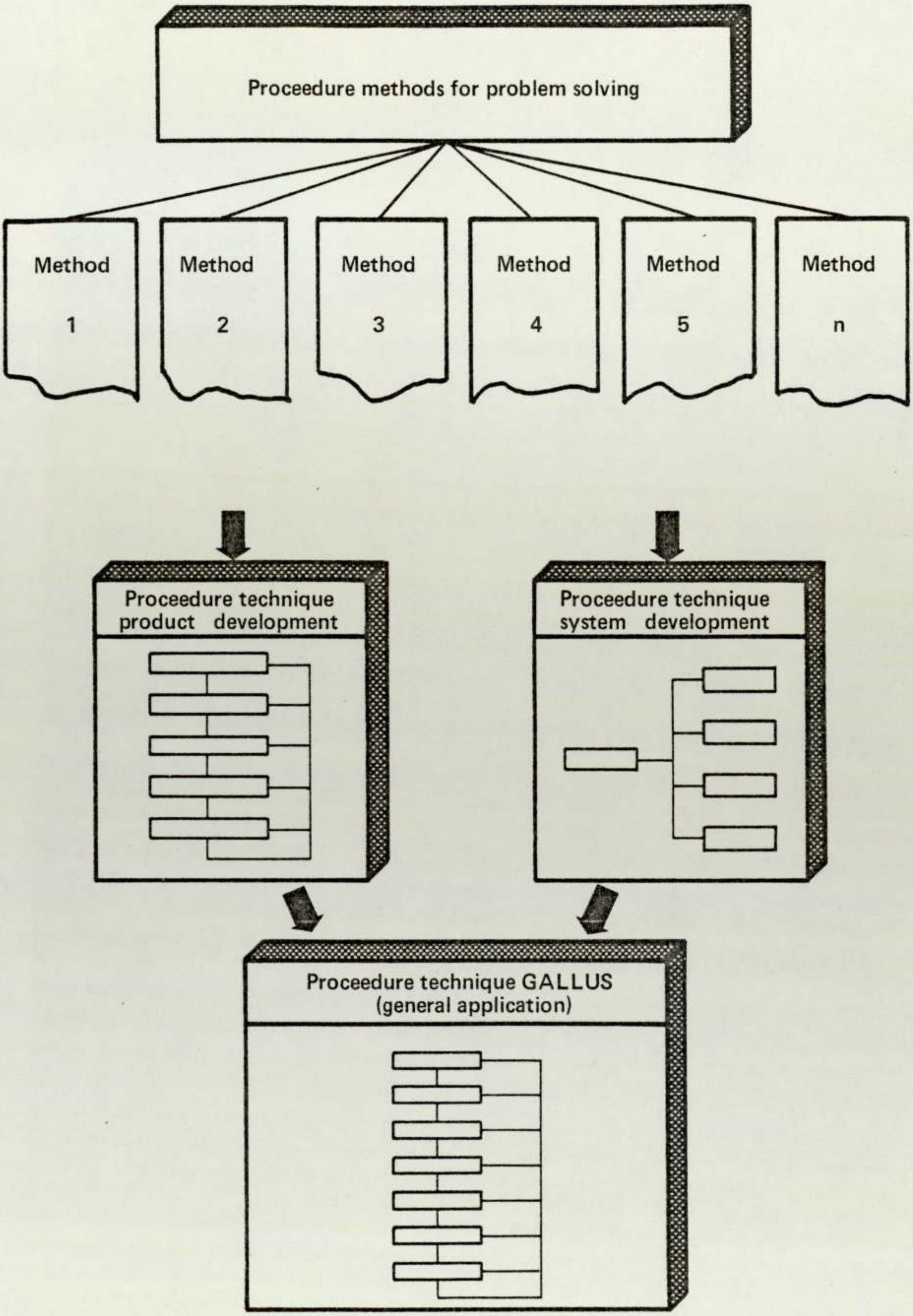


FIG. 23 SYNTHESIS OF THE PROCEEDURE TECHNIQUES

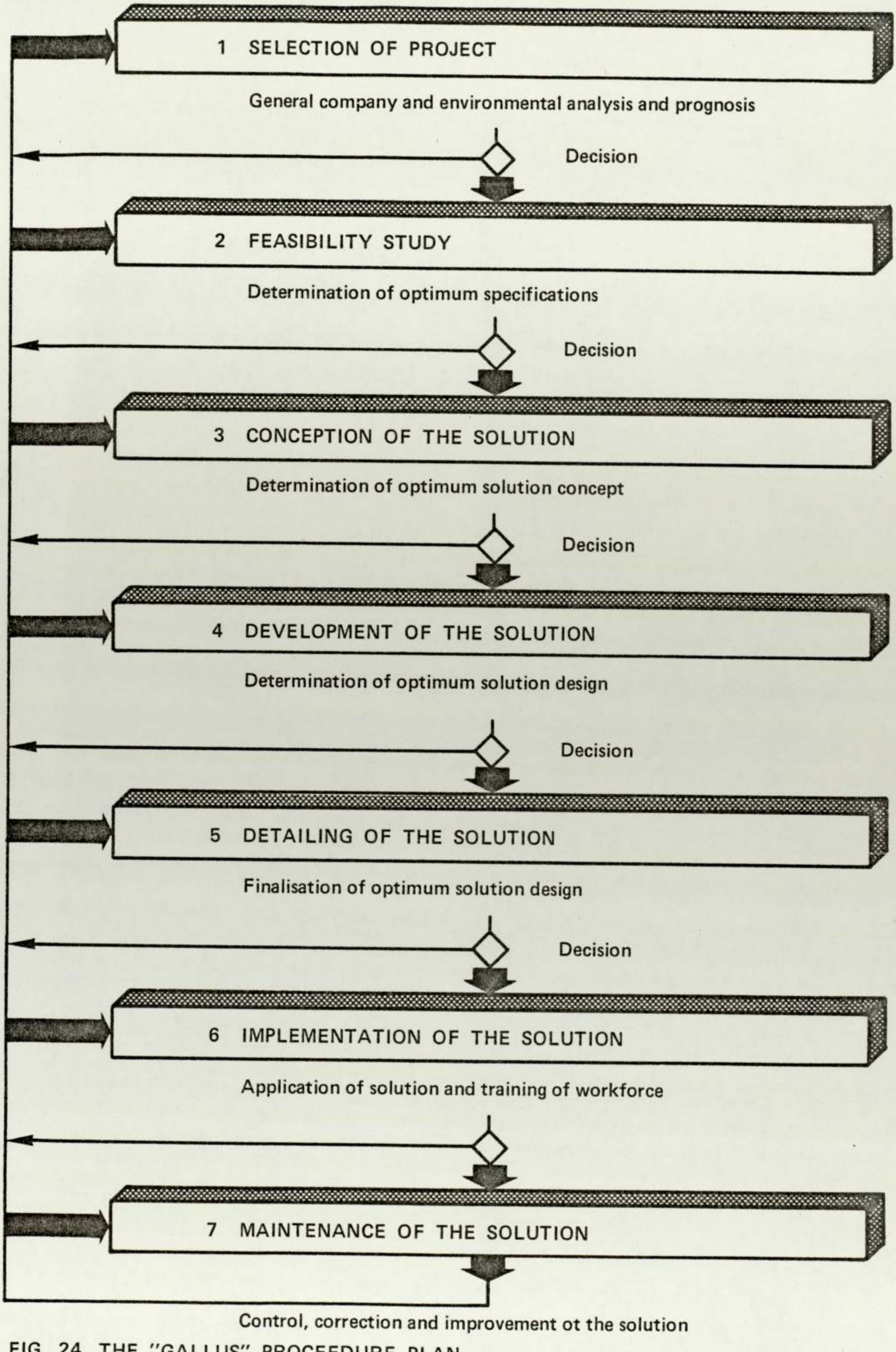


FIG. 24 THE "GALLUS" PROCEEDURE PLAN

FIG. 24

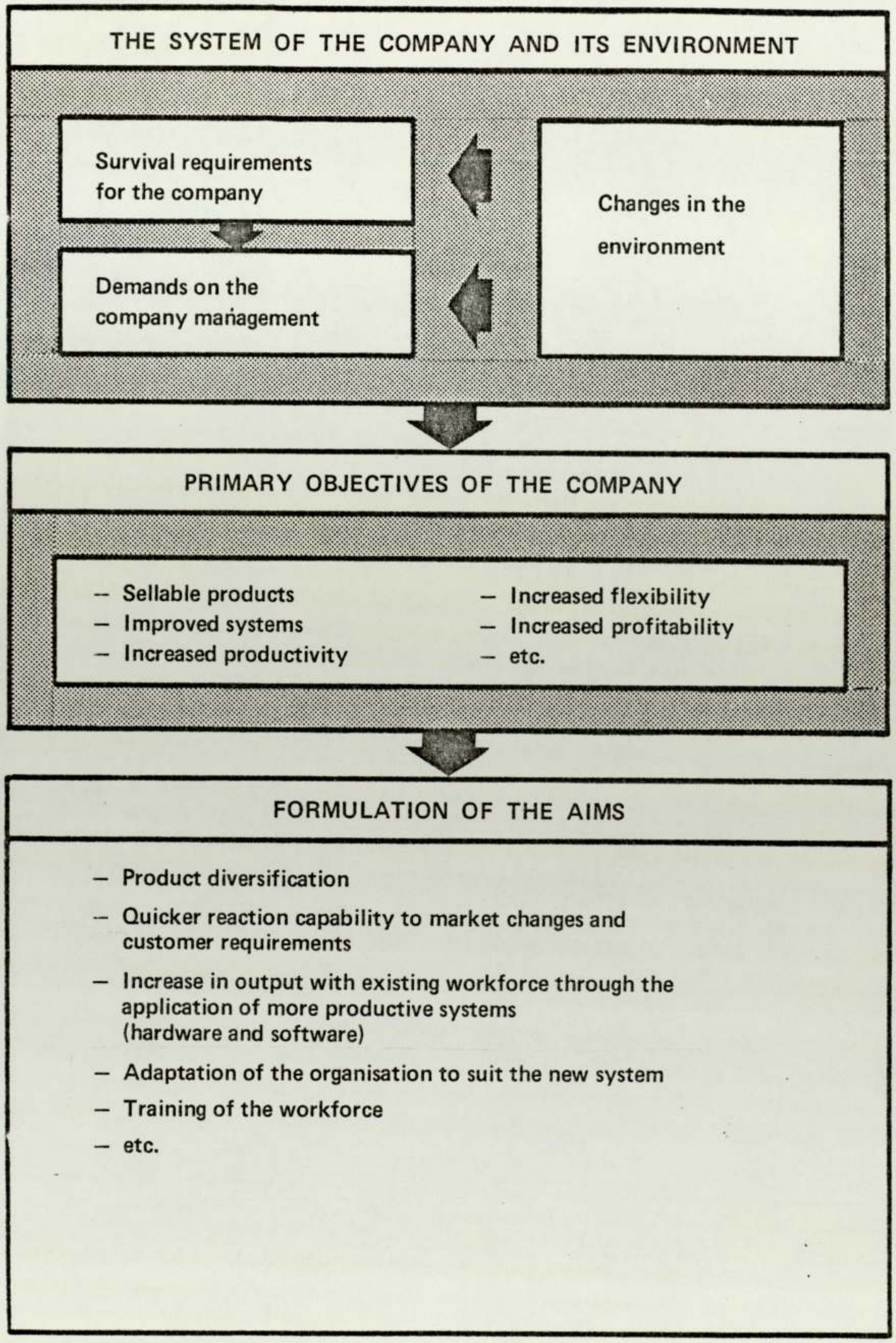


FIG. 25 PRIMARY OBJECTIVES OF THE COMPANY

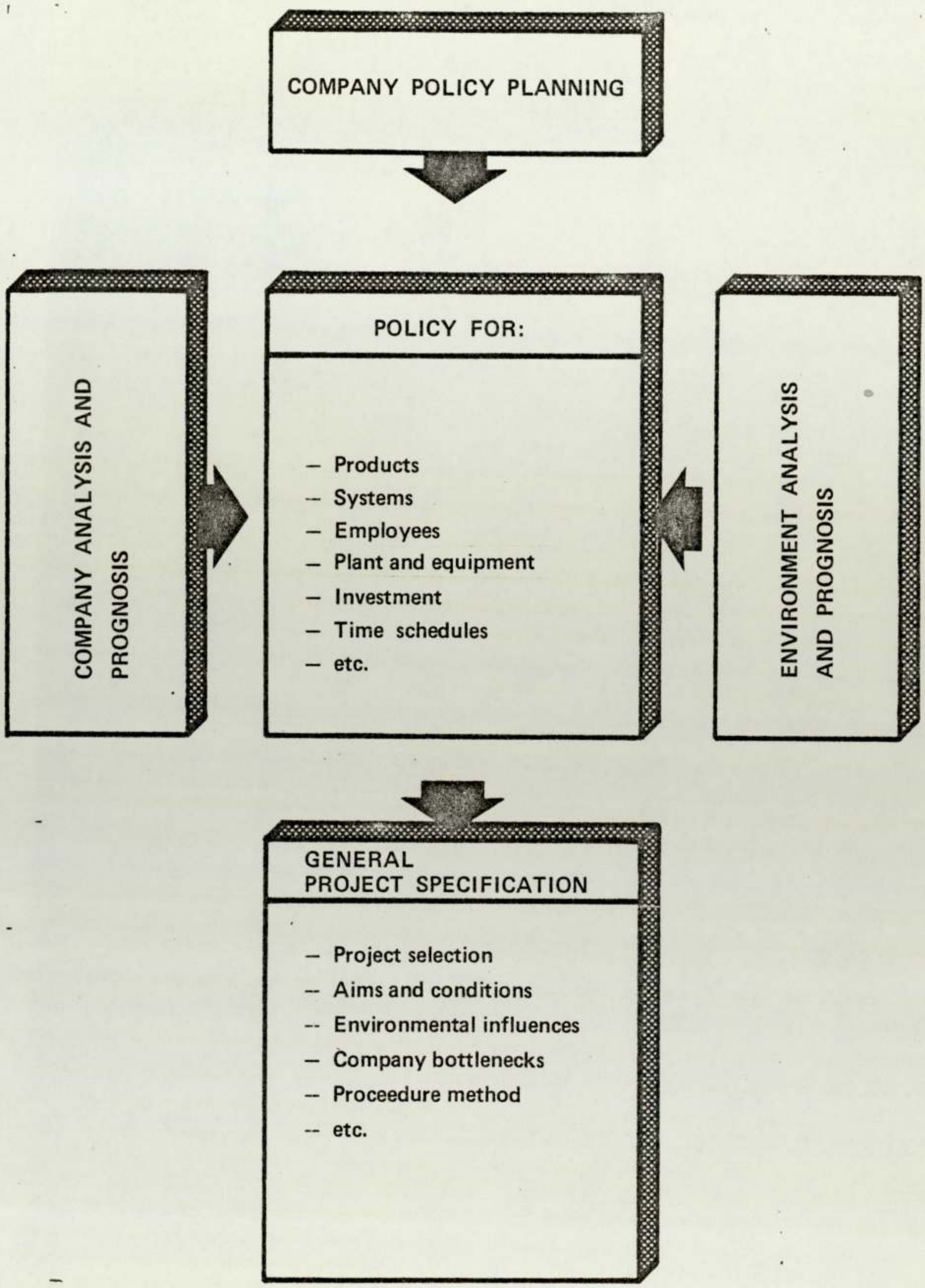


FIG. 26 DETERMINATION OF THE GENERAL PROJECT SPECIFICATIONS

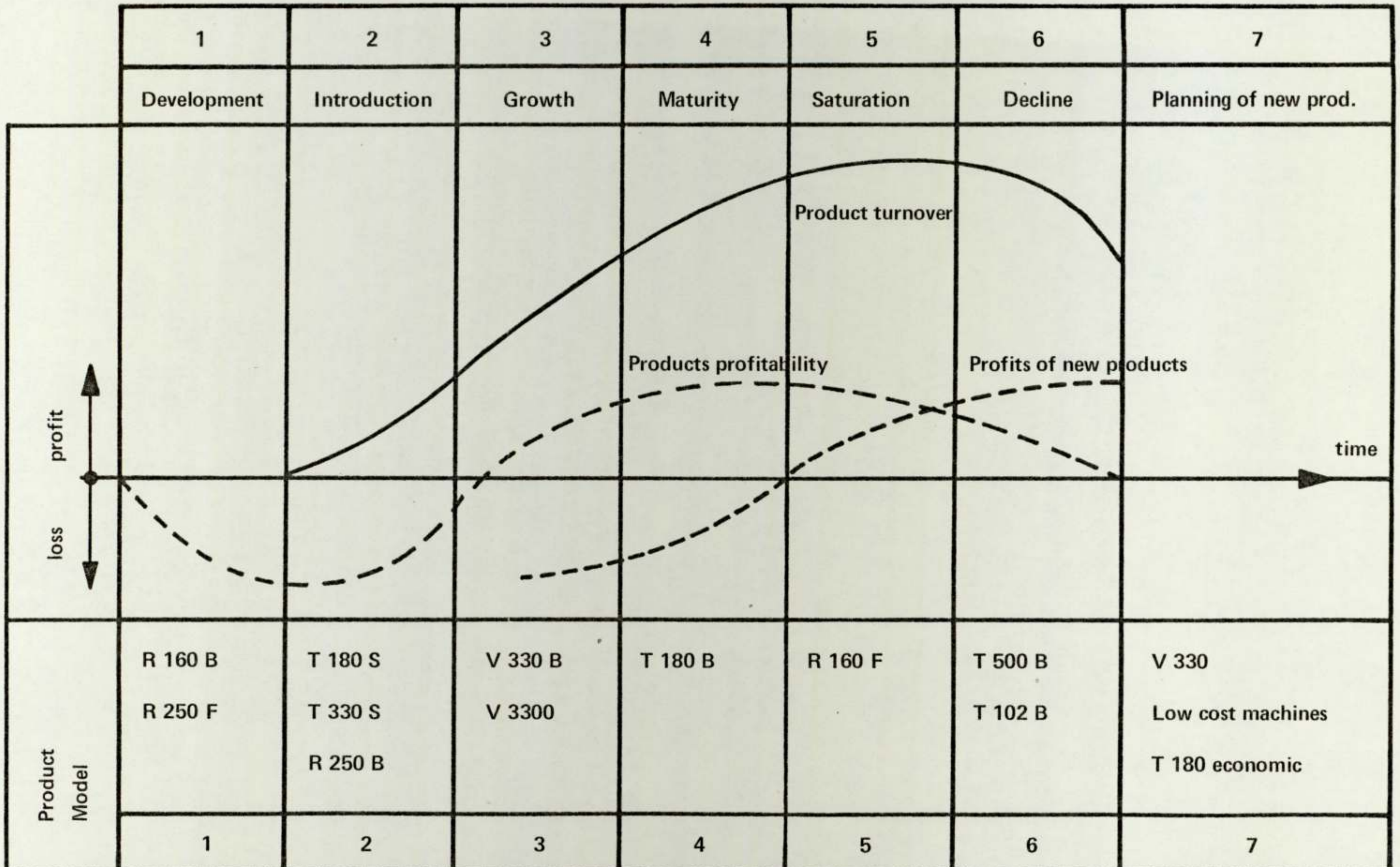


FIG. 27

FIG. 27 LIFE CYCLE OF THE PRODUCT

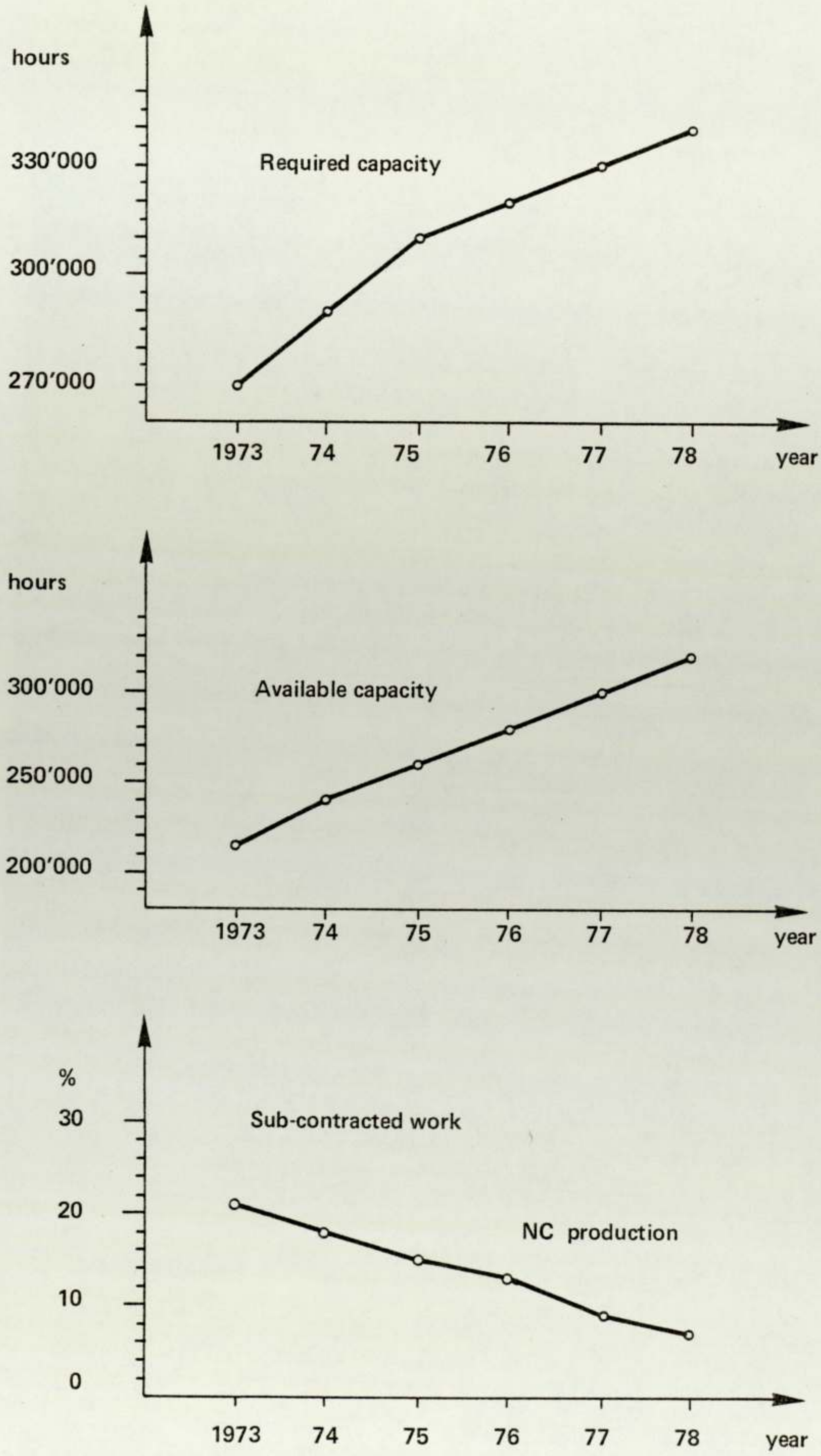


FIG. 28 MACHINING CAPACITY SITUATION

FIG. 28

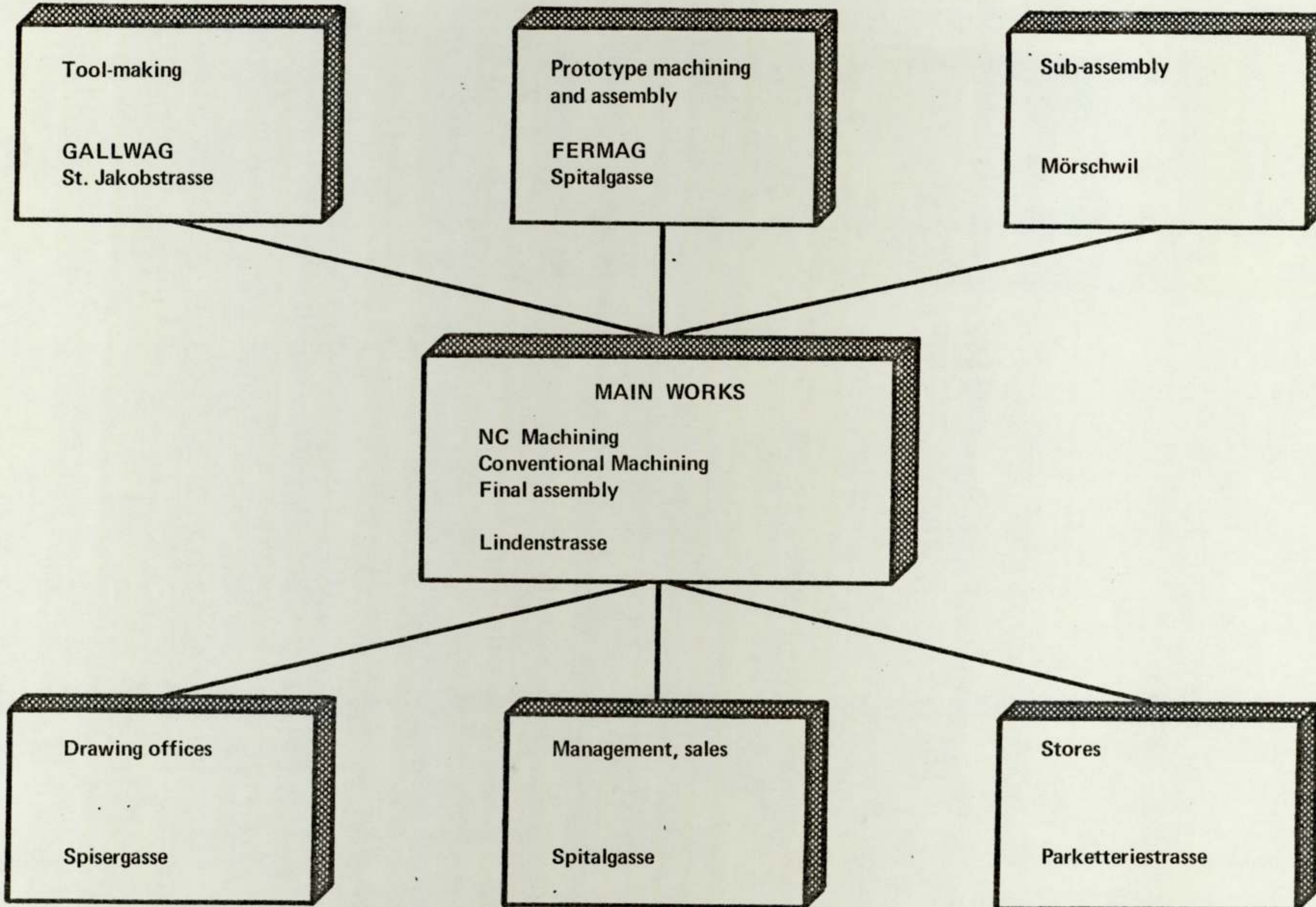


FIG. 29 GEOGRAPHICALLY SEPARATED COMPANY LOCATIONS

FIG. 29

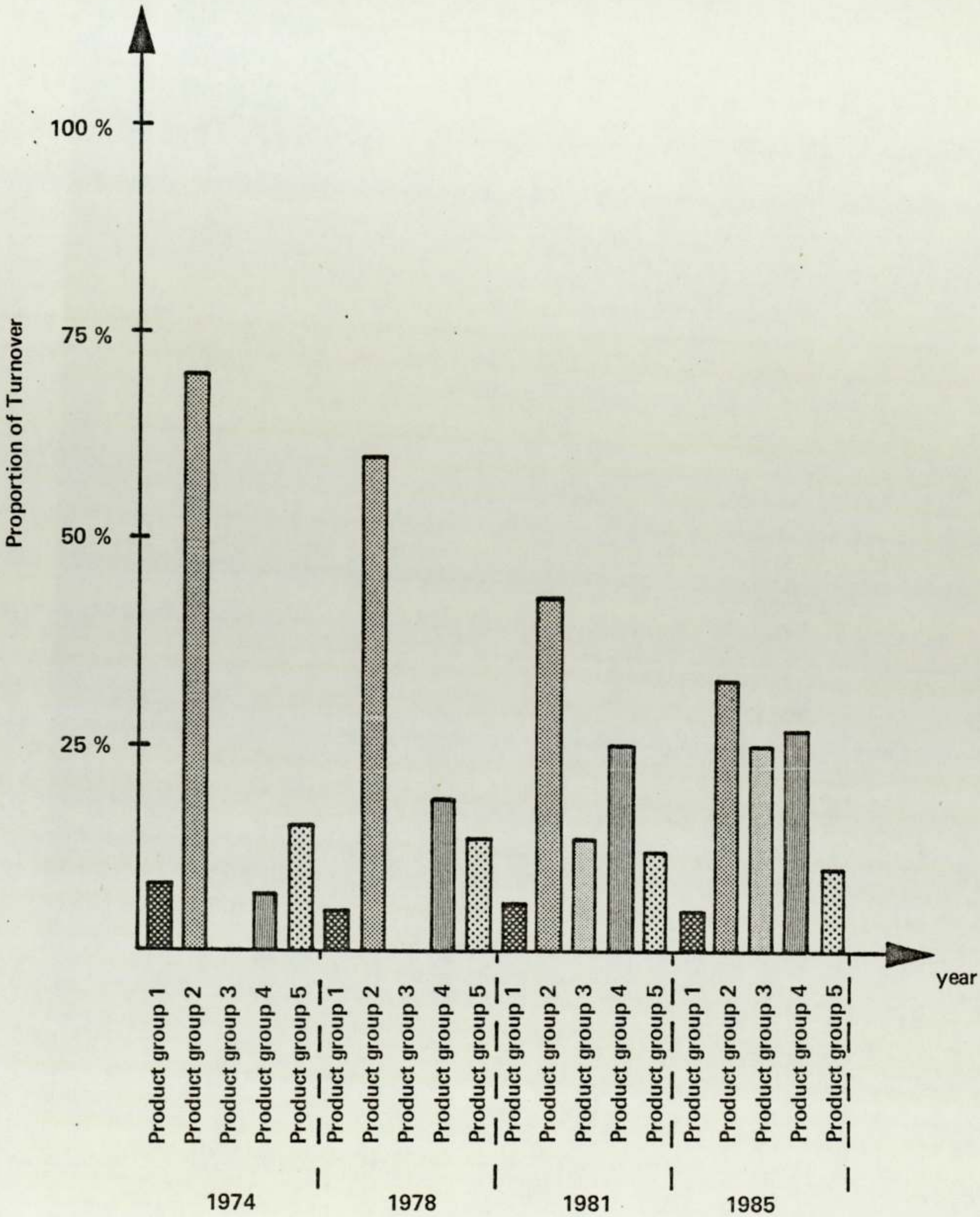


FIG. 30 FUTURE MANUFACTURING PROGRAMME

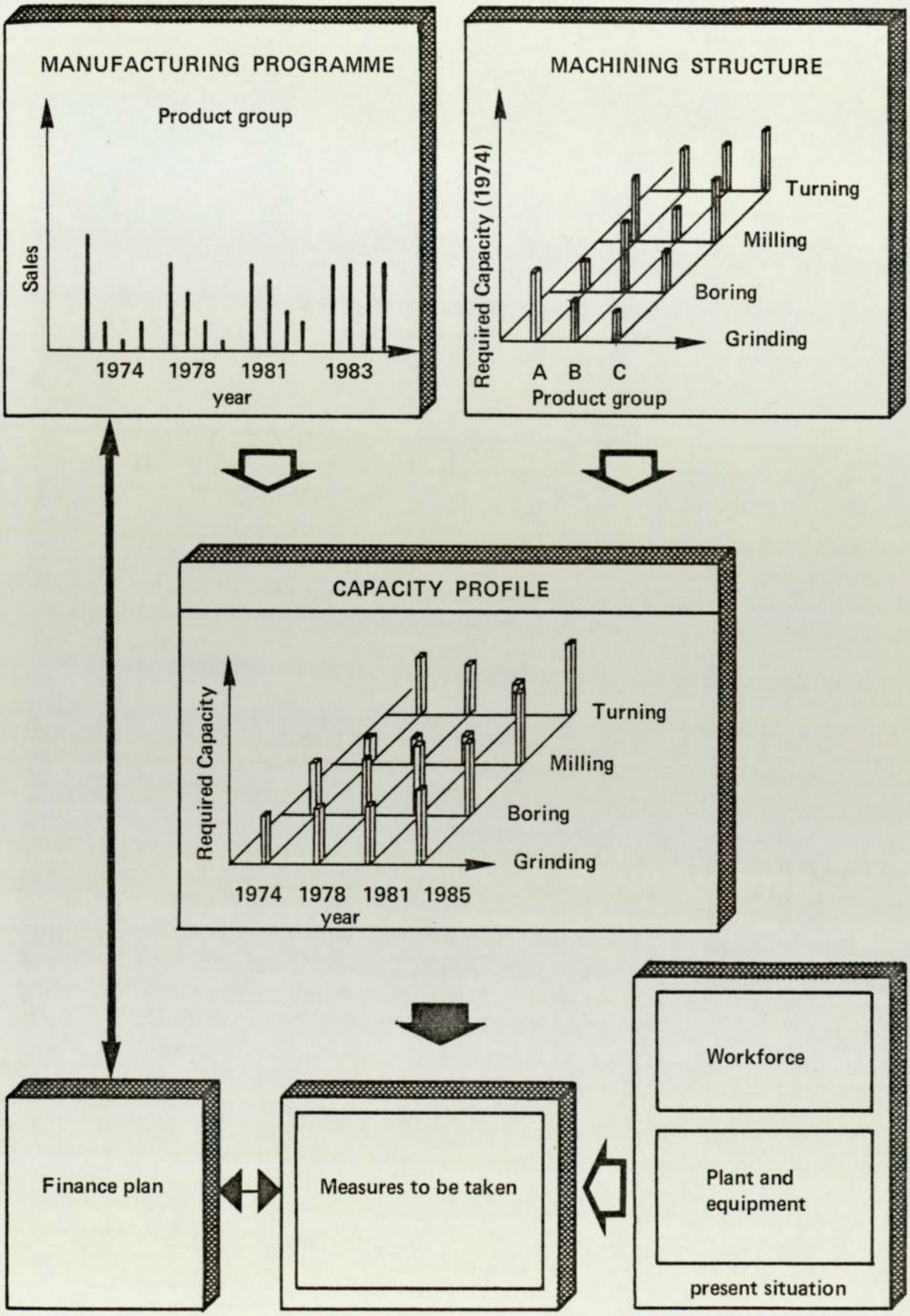


FIG. 31 CONSEQUENCES OF CHANGE IN THE MANUFACTURING PROGRAMME (SOURCE WZL AACHEN)

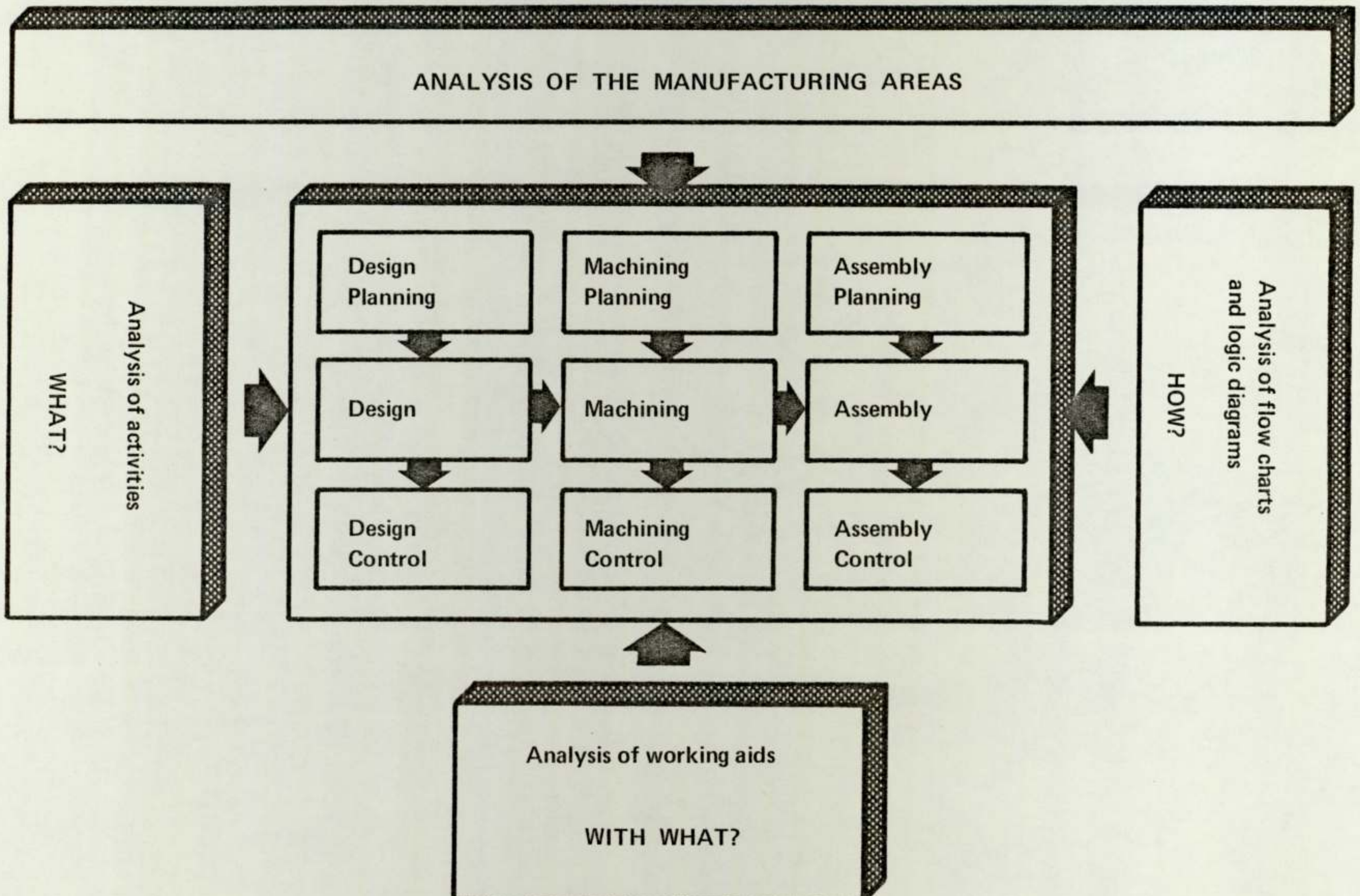


FIG. 32

FIG. 32 ANALYSIS OF THE MANUFACTURING AREAS

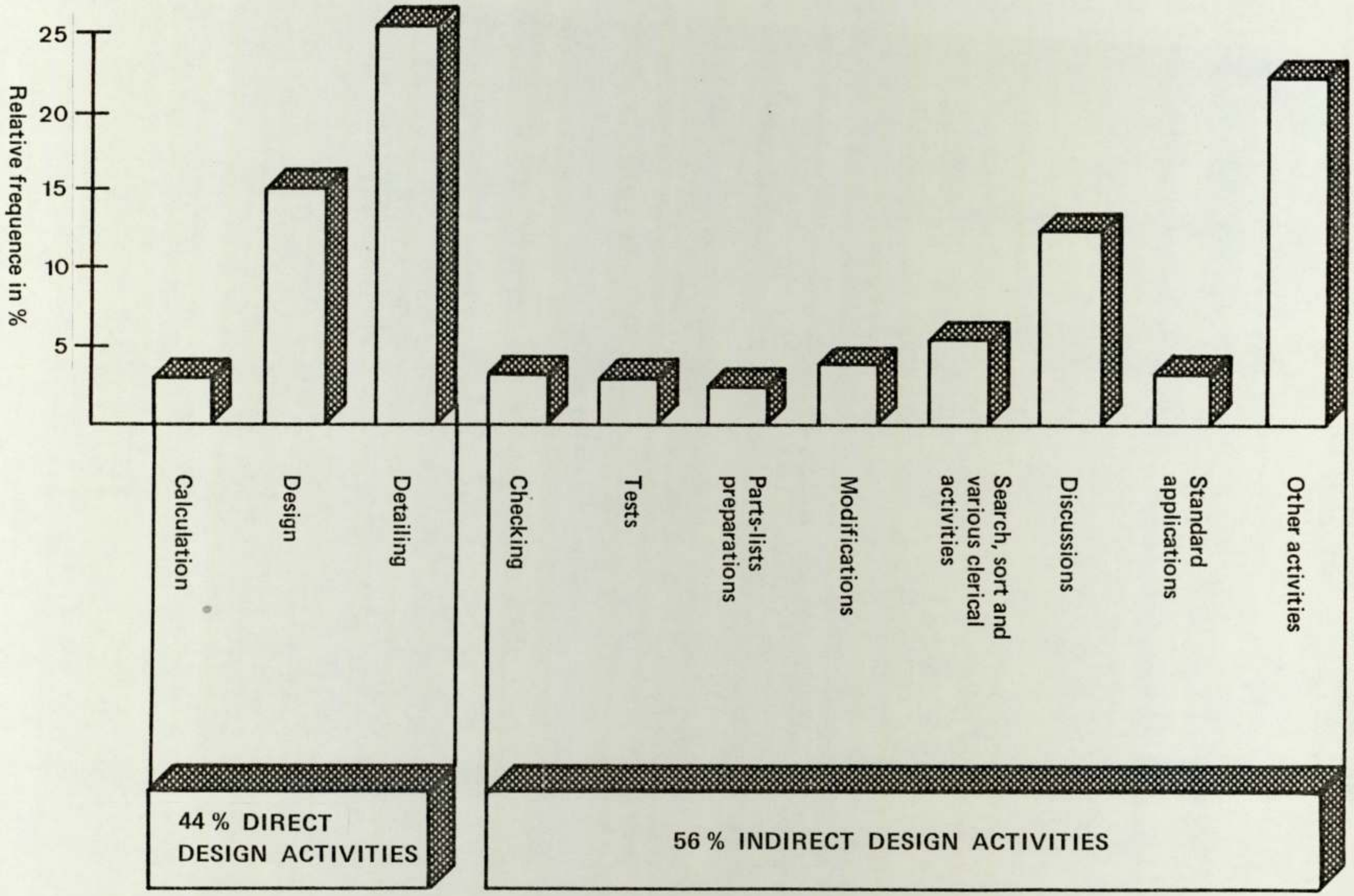


FIG. 33 FREQUENCY DISTRIBUTION OF DESIGN ACTIVITIES

FIG. 33

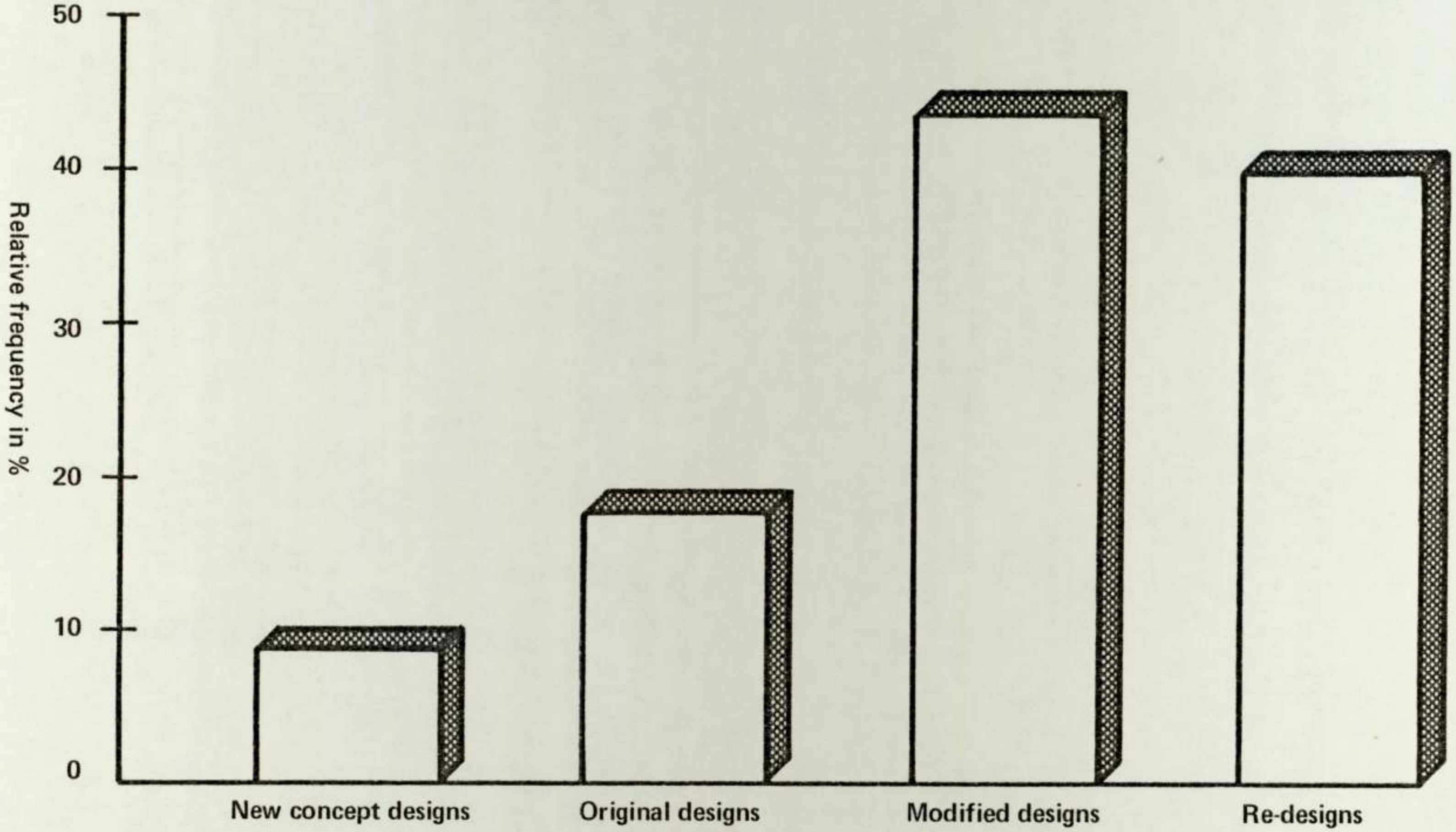
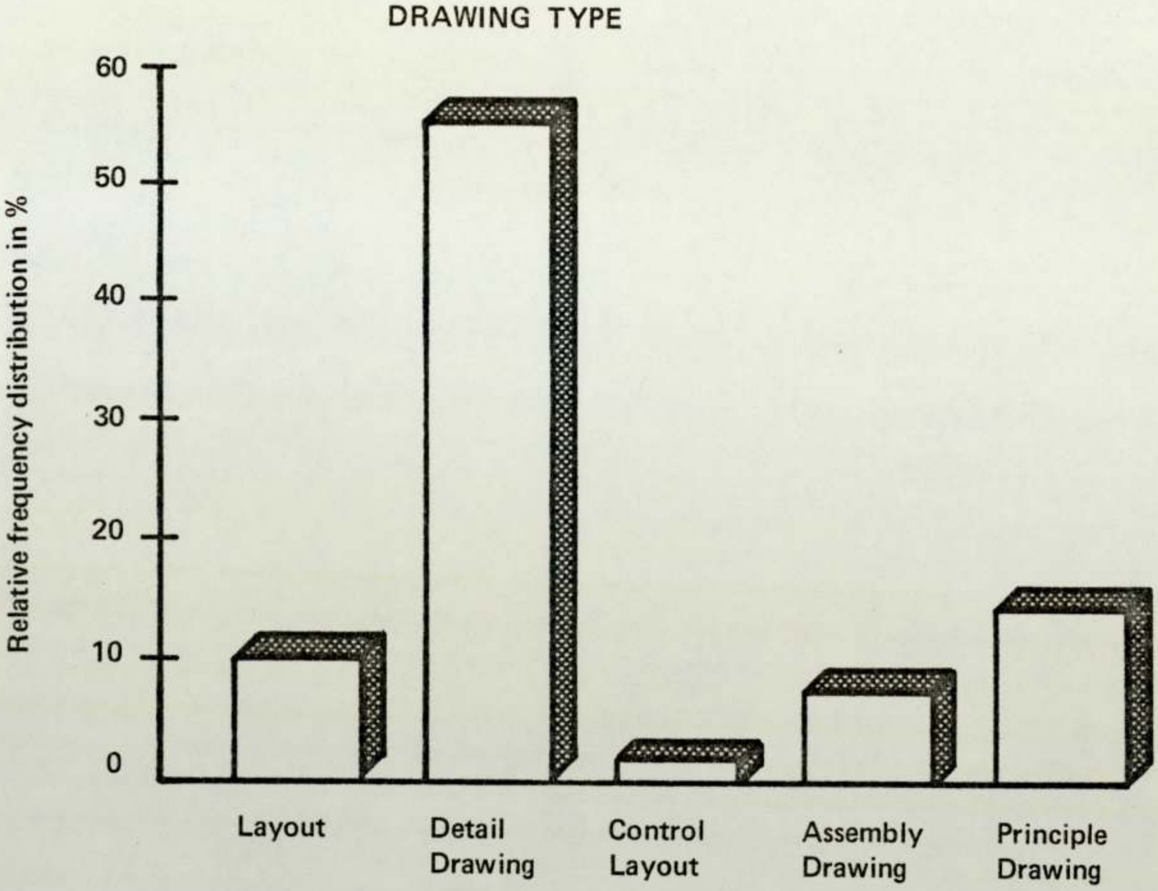


FIG. 34 RELATIVE FREQUENCY OF DESIGN TYPES

FIG. 34



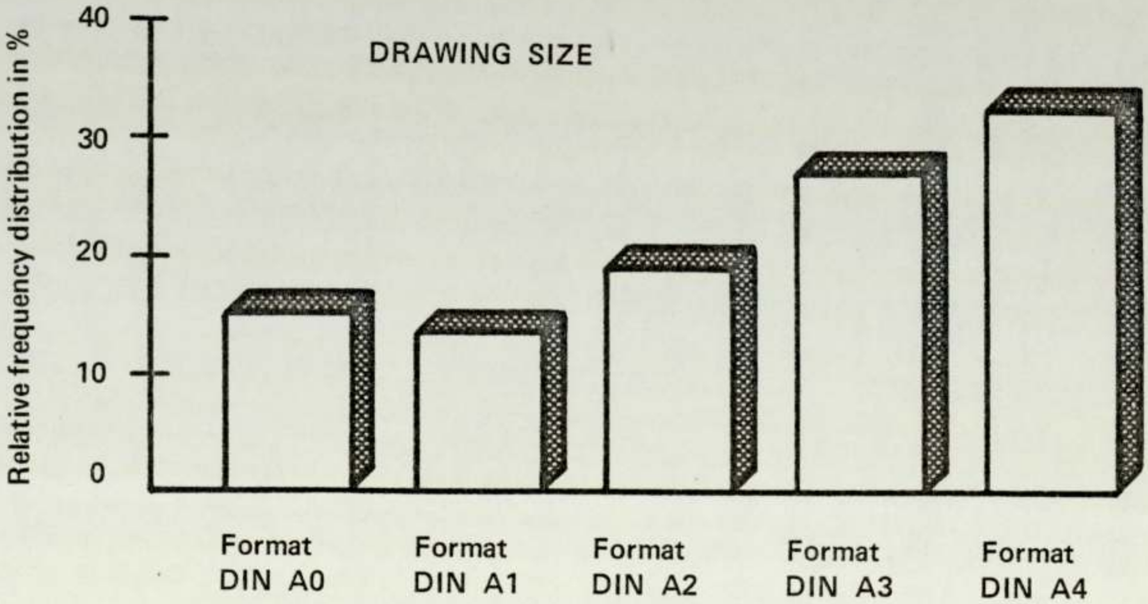


FIG. 35 RELATIVE FREQUENCY OF DRAWING TYPE AND SIZE

Grounds for product development

- Competition
- Value analysis
- Customer problems
- fault statistics
- technical progress
- etc.

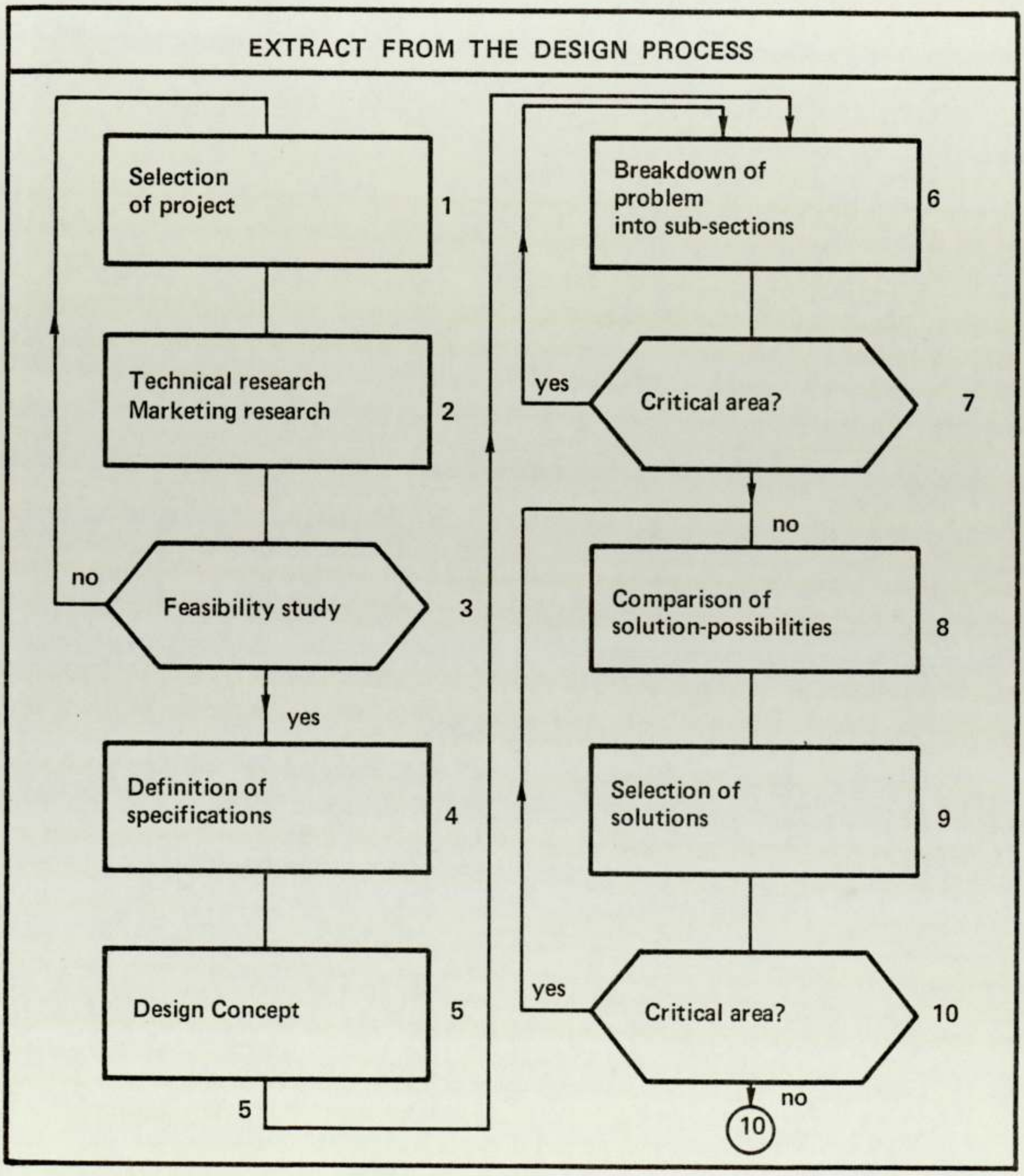
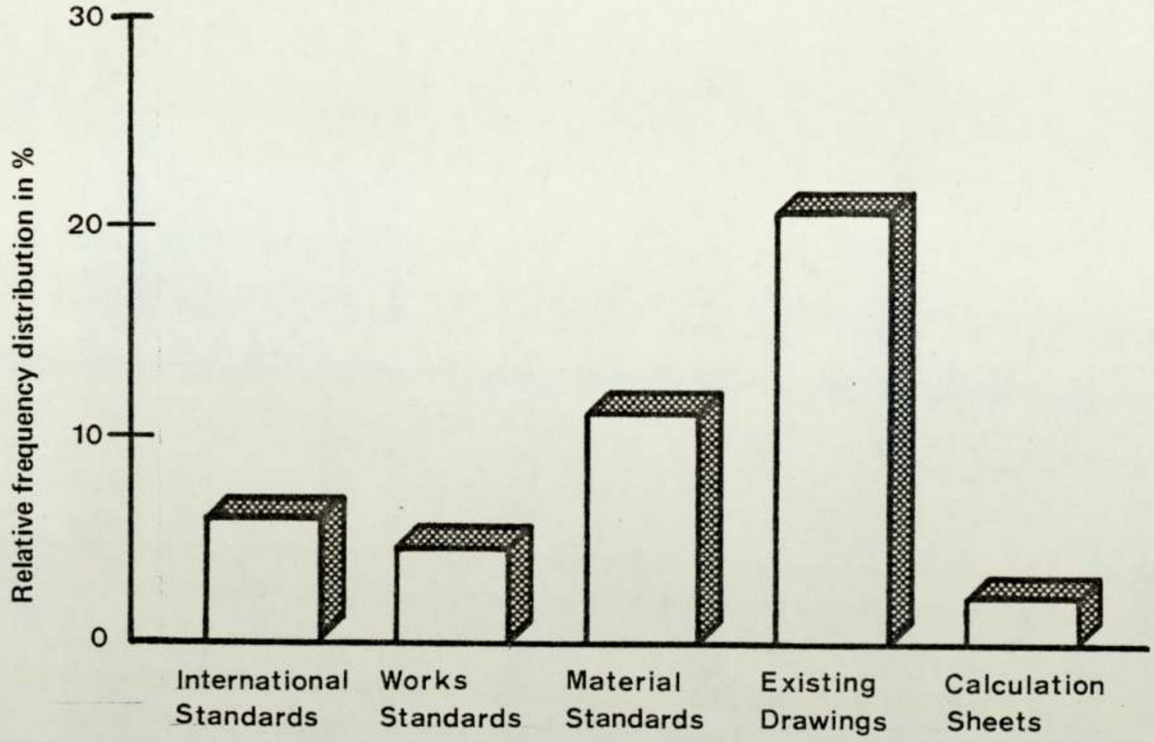


FIG. 36 PROBLEM ORIENTATED DESIGN PROCESS



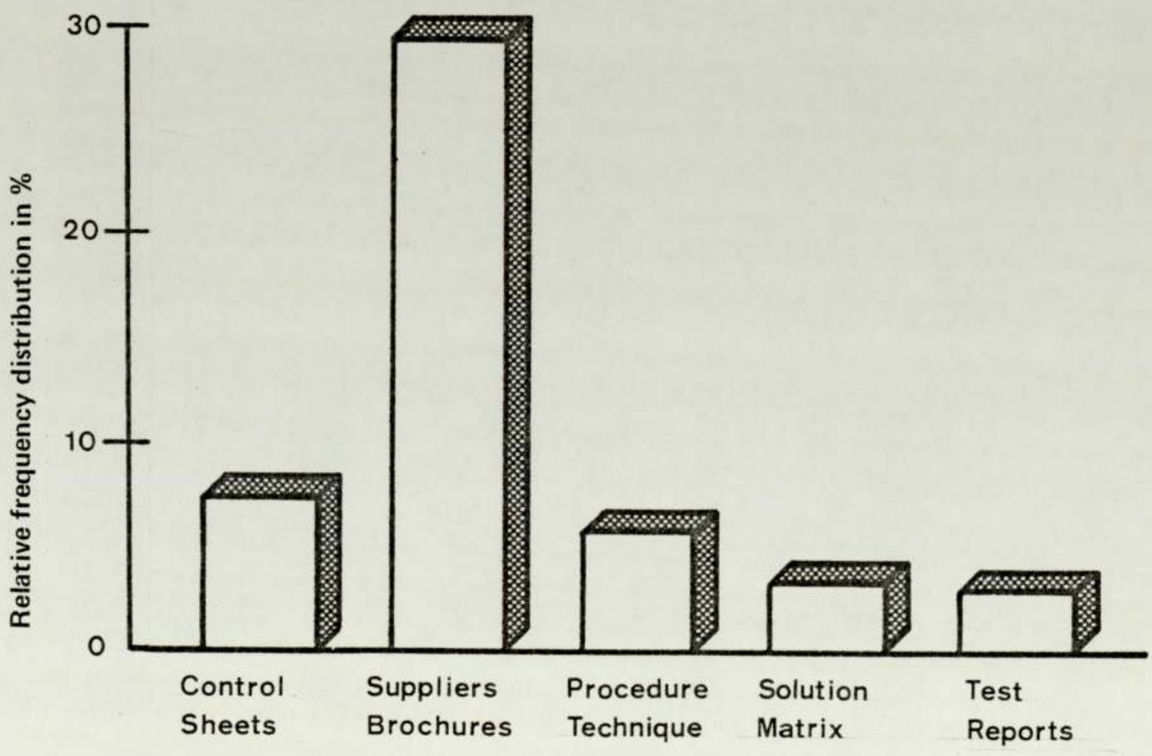


FIG. 37 FREQUENCY DISTRIBUTION OF WORKING AIDS IN THE DRAWING OFFICE

FIG. 38

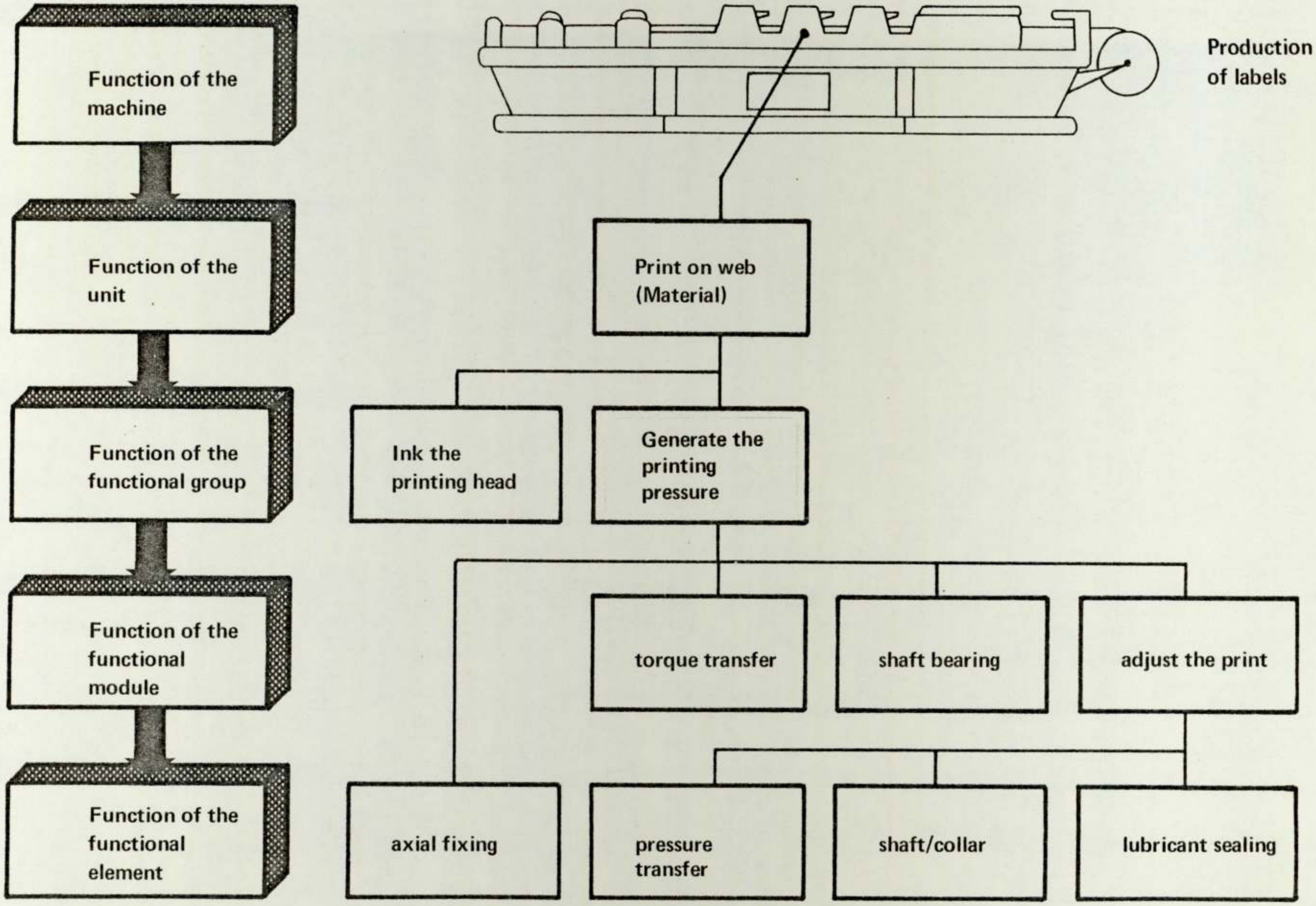
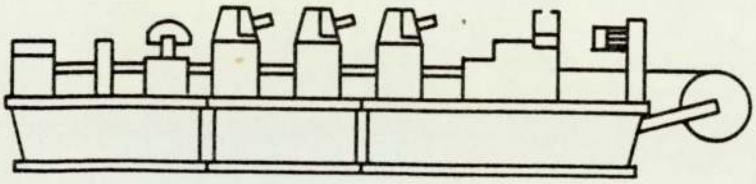
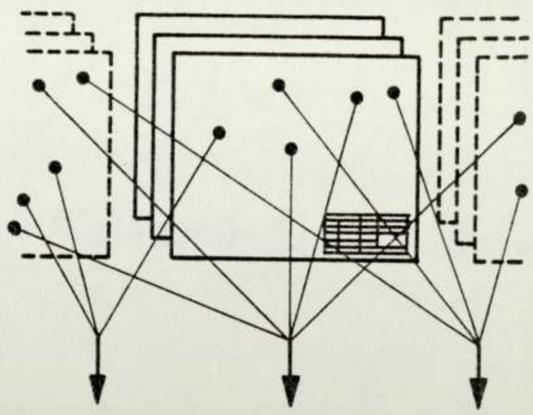


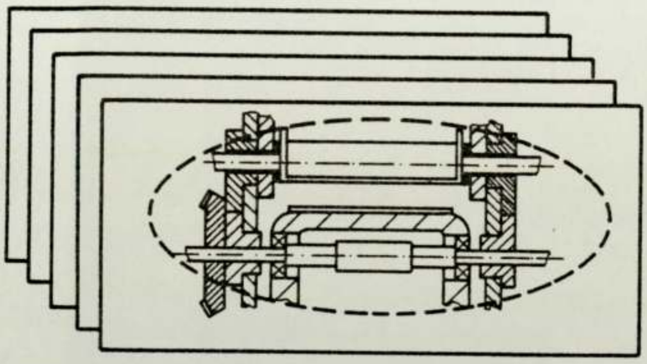
FIG. 38 FUNCTIONAL BREAKDOWN OF A LABEL PRINTING PRESS



Function of the machine
(Label Production)

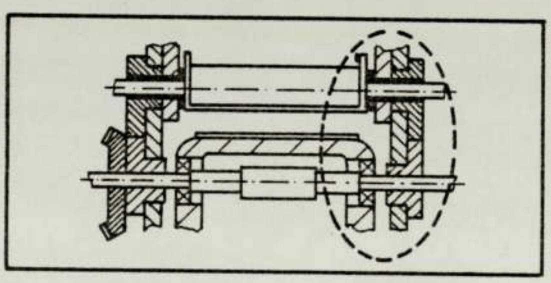


Assembly drawings of the
different units
analysed to functional
element level

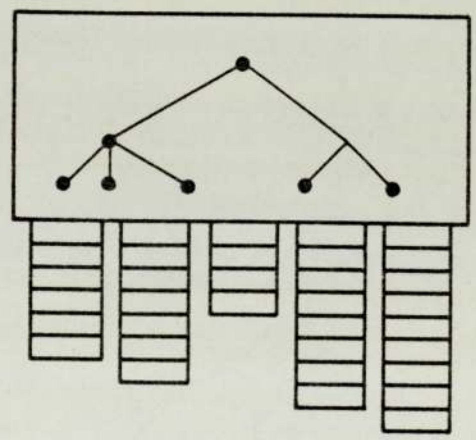


Function of the unit (Print on the web)

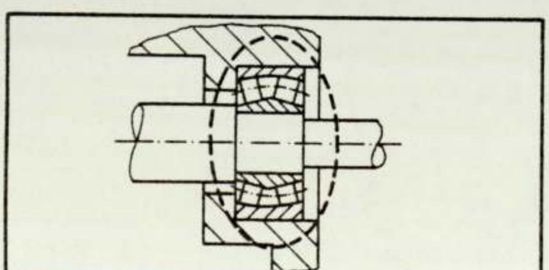
Function of the functional group
(Transfer of printing pressure)



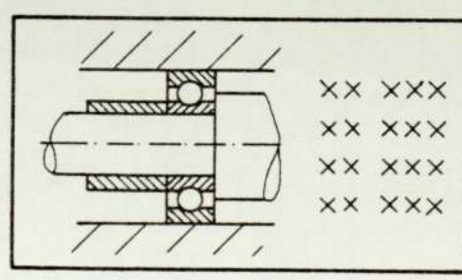
Function of the functional module
(Change of movement direction)



Functional breakdown
with card groupings



Functional element (Shaft bearing)



Typical element card
– Geometry
– Reference data

FIG. 39 PROCEEDURE TO DETERMINE FUNCTIONAL MODULES
AND FUNCTIONAL ELEMENTS

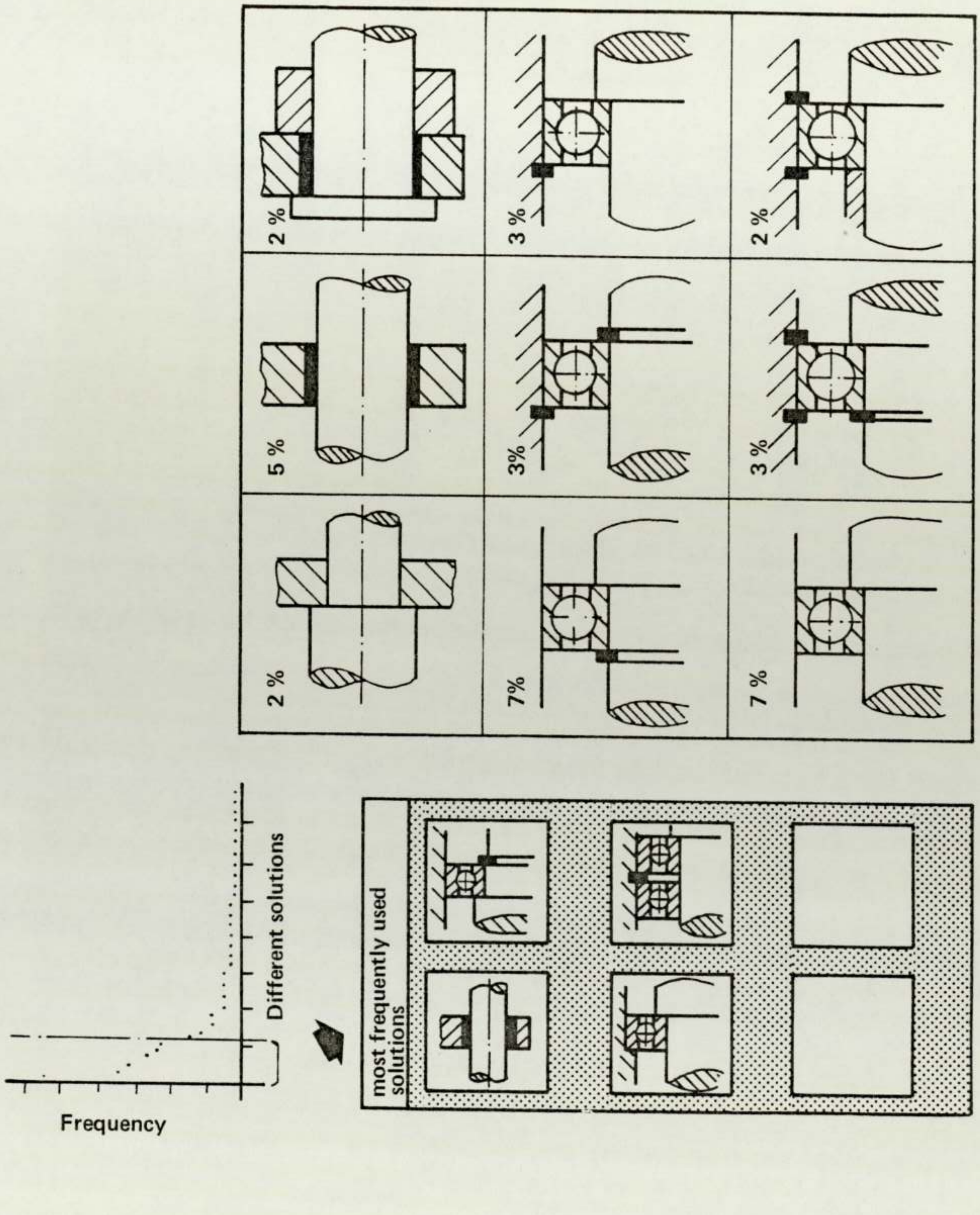


FIG. 40 FREQUENCY DISTRIBUTION OF DESIGN SOLUTION FOR THE FUNCTIONAL ELEMENT "SHAFT BEARING"

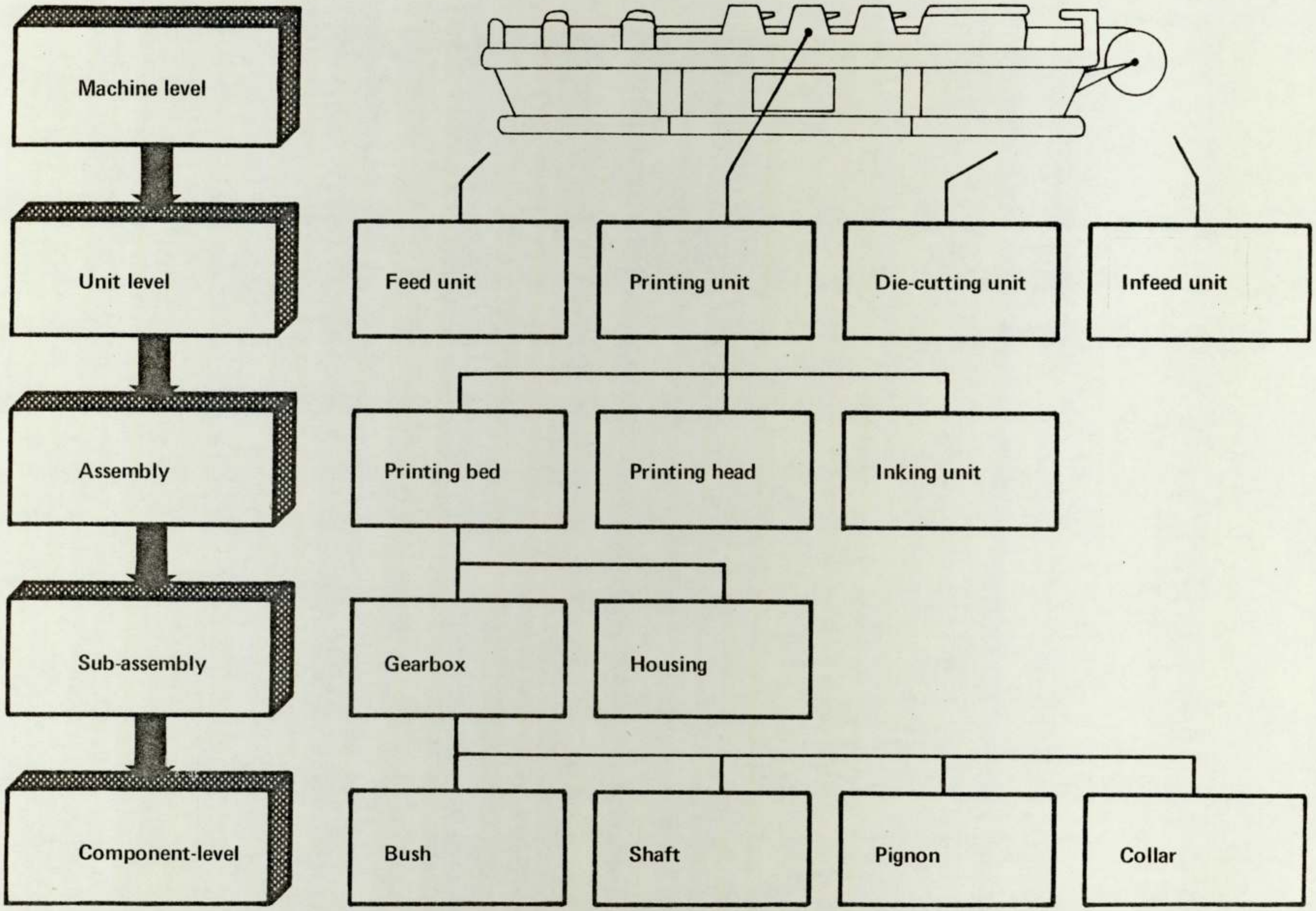


FIG. 41

FIG. 41 PRODUCT STRUCTURE BREAKDOWN OF A LABEL PRINTING PRESS

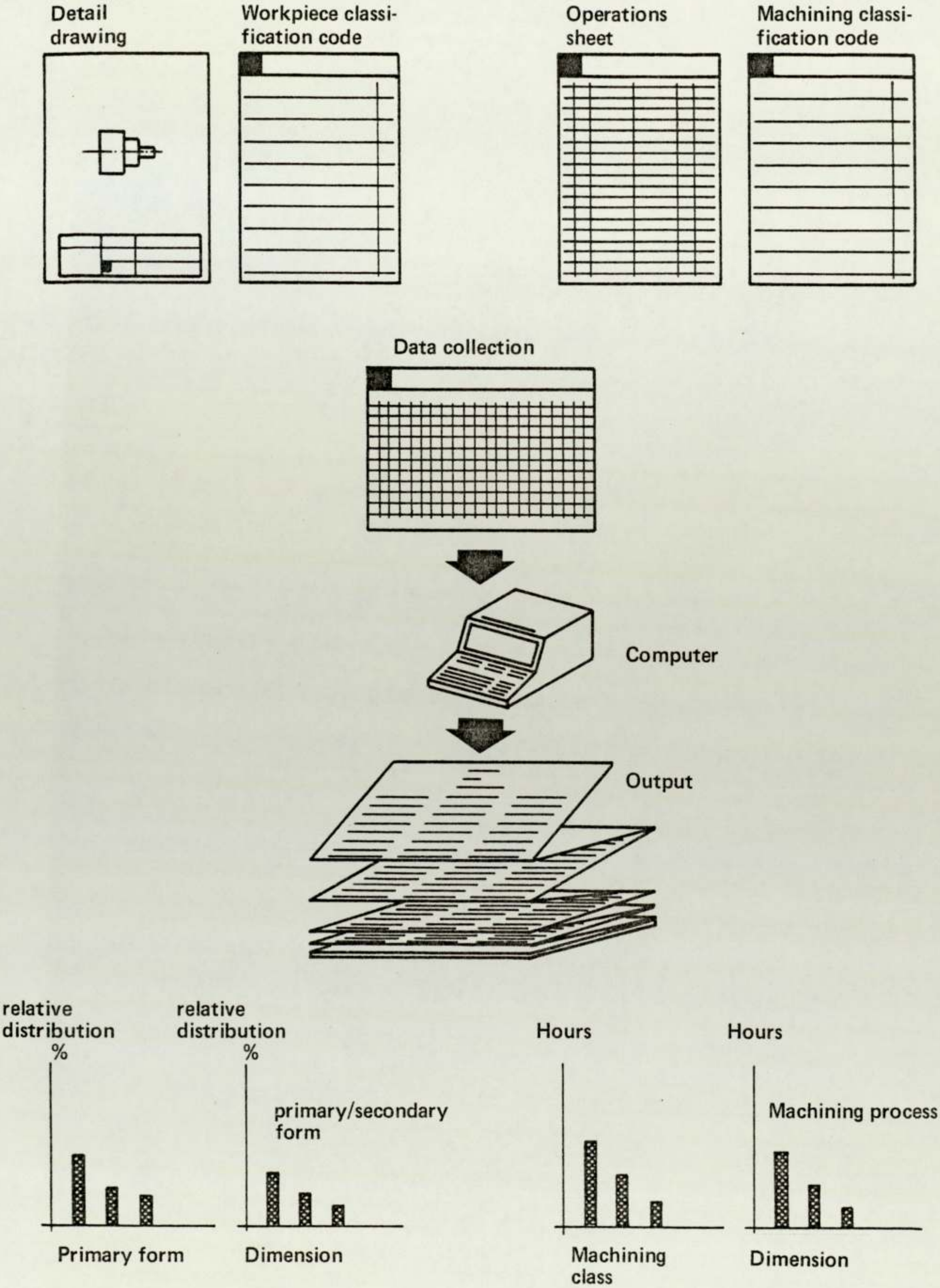


FIG. 42 PROCEEDURE TO DETERMINE THE MACHINING REQUIREMENTS

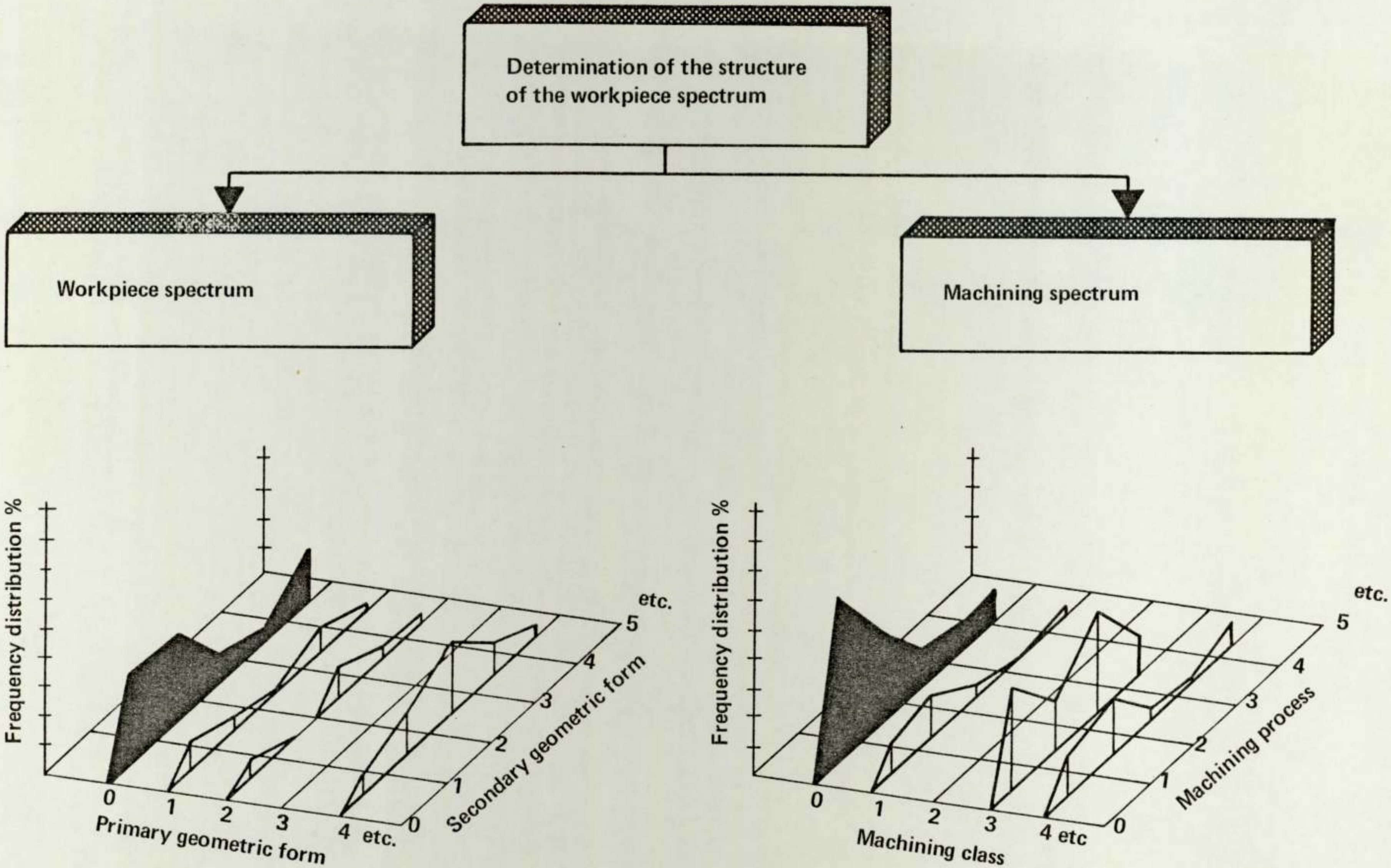


FIG. 43 WORKPIECE AND MACHINING STRUCTURES

FIG. 43

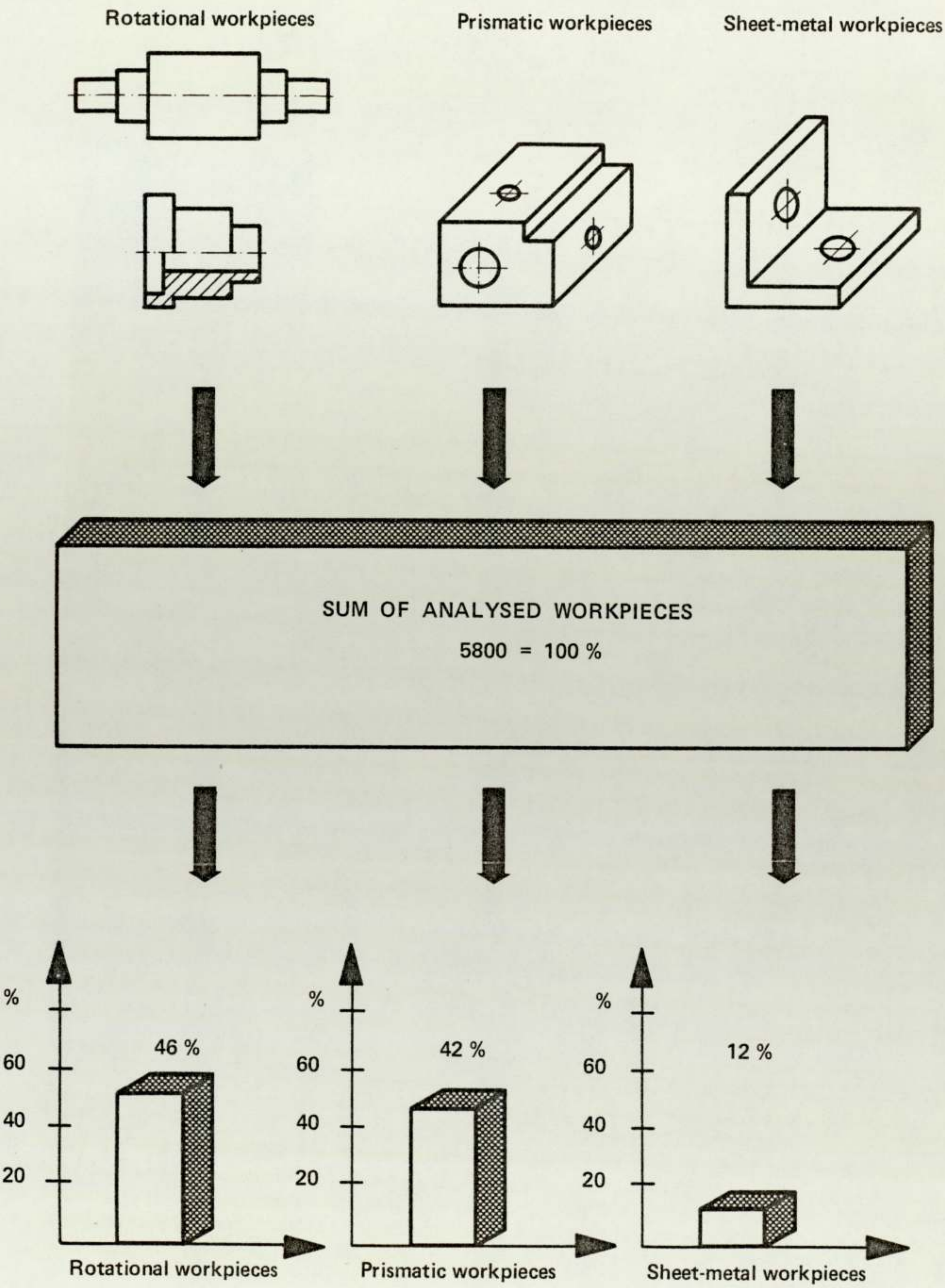
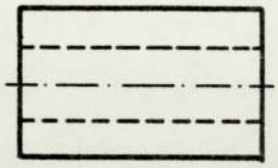
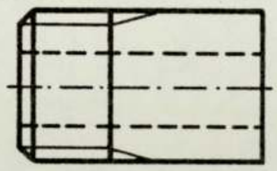
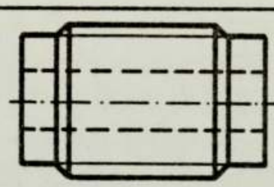
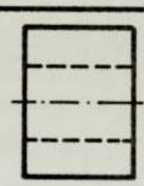
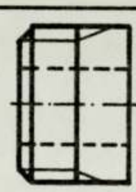
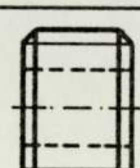


FIG. 44 WORKPIECE STRUCTURE AT THE BASIC LEVEL

	Pos. 1: Primary geometric form		Distribution	
	Code	Description	absolute	relative
Shaft-type L > D	0		625	84 %
	1		90	12 %
	2		30	4 %
Disc-type L ≤ D	3		528	99 %
	4		5	1 %
	5		–	–

Sum of analysed workpieces: 1'277

comprising of 744 spindle-type 100 %
533 disc-type 100 %

FIG. 45 ROTATIONAL WORKPIECE STRUCTURE

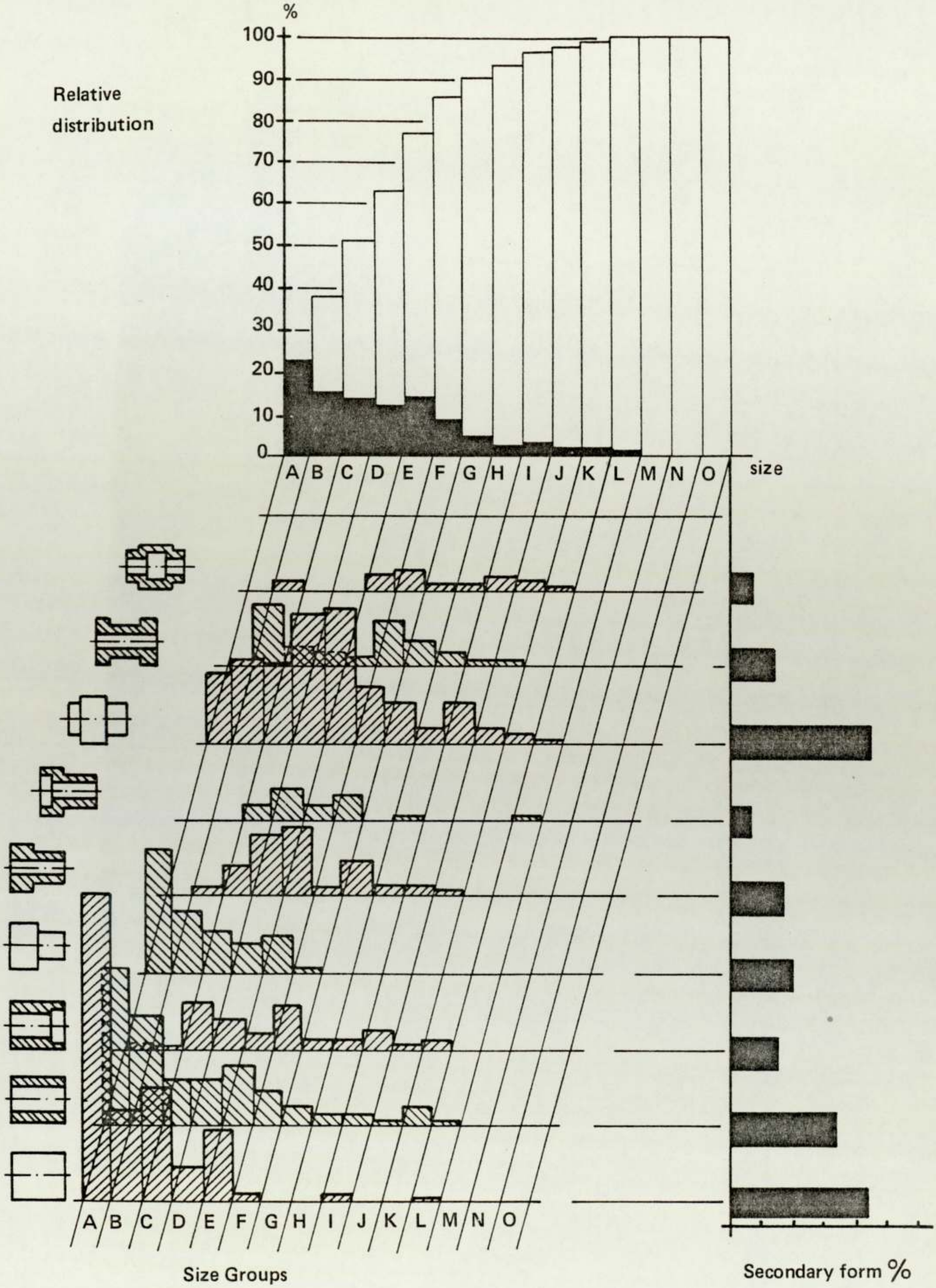


FIG. 46 WORKPIECE PROFILE OF THE SHAFT-TYPE PARTS

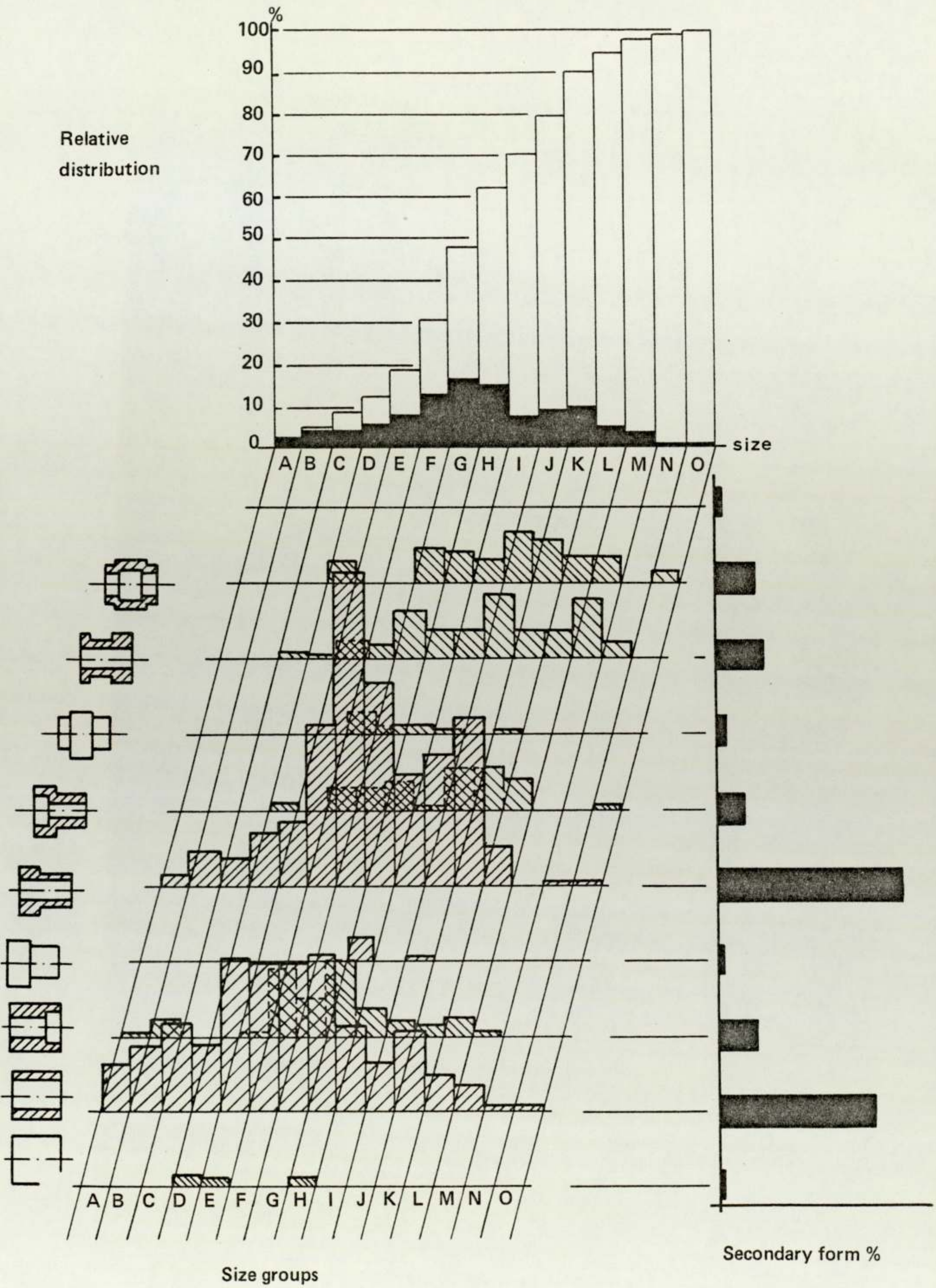


FIG. 47 WORKPIECE PROFILE OF THE DISC-TYPE PARTS

FIG. 47

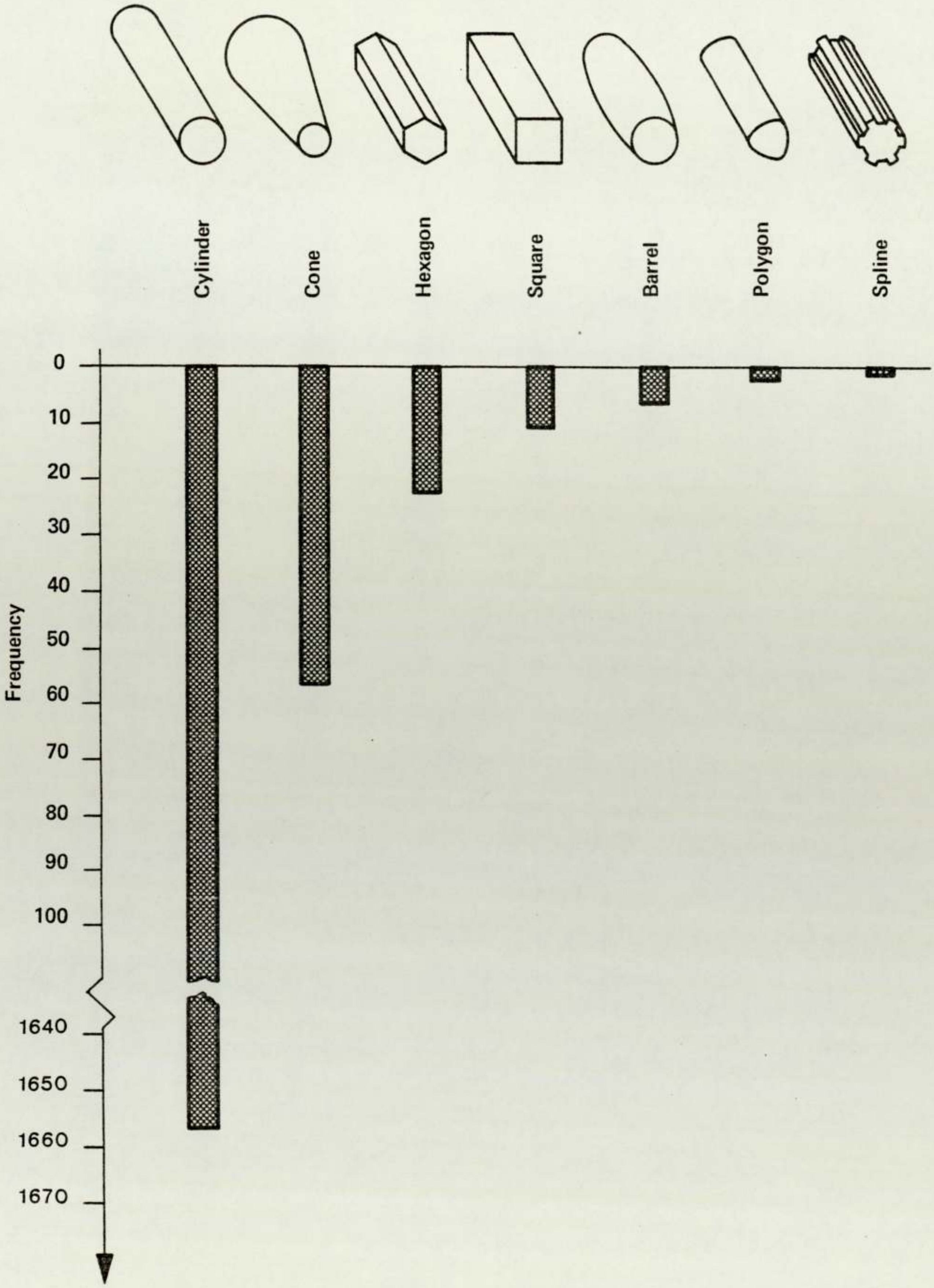


FIG. 48 FREQUENCY DISTRIBUTION OF THE PRIMARY ELEMENTS

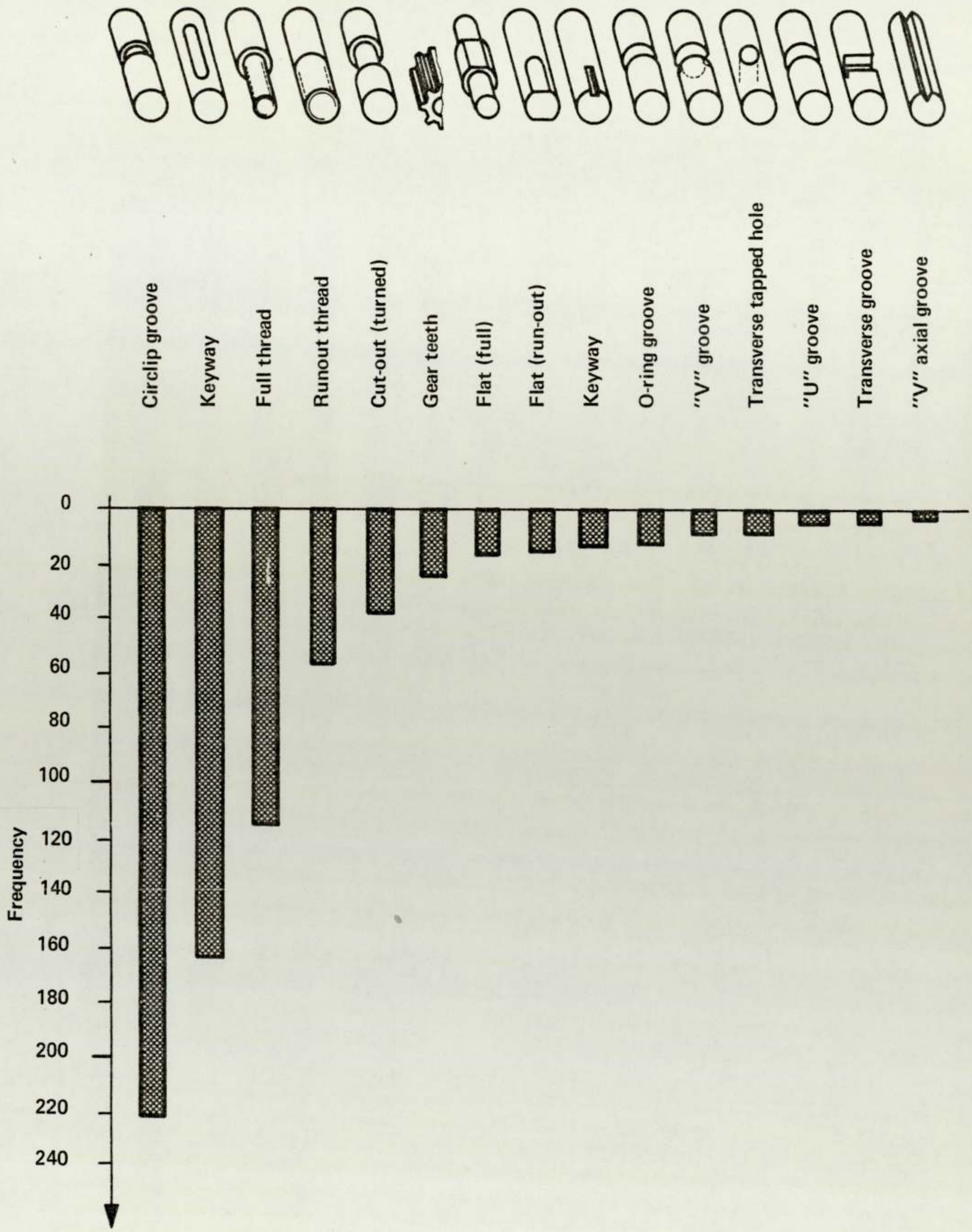


FIG. 49 FREQUENCY DISTRIBUTION OF THE SECONDARY GEOMETRIC ELEMENTS

FIG. 50 WORKPIECE STRUCTURE OF THE PRODUCT T 180

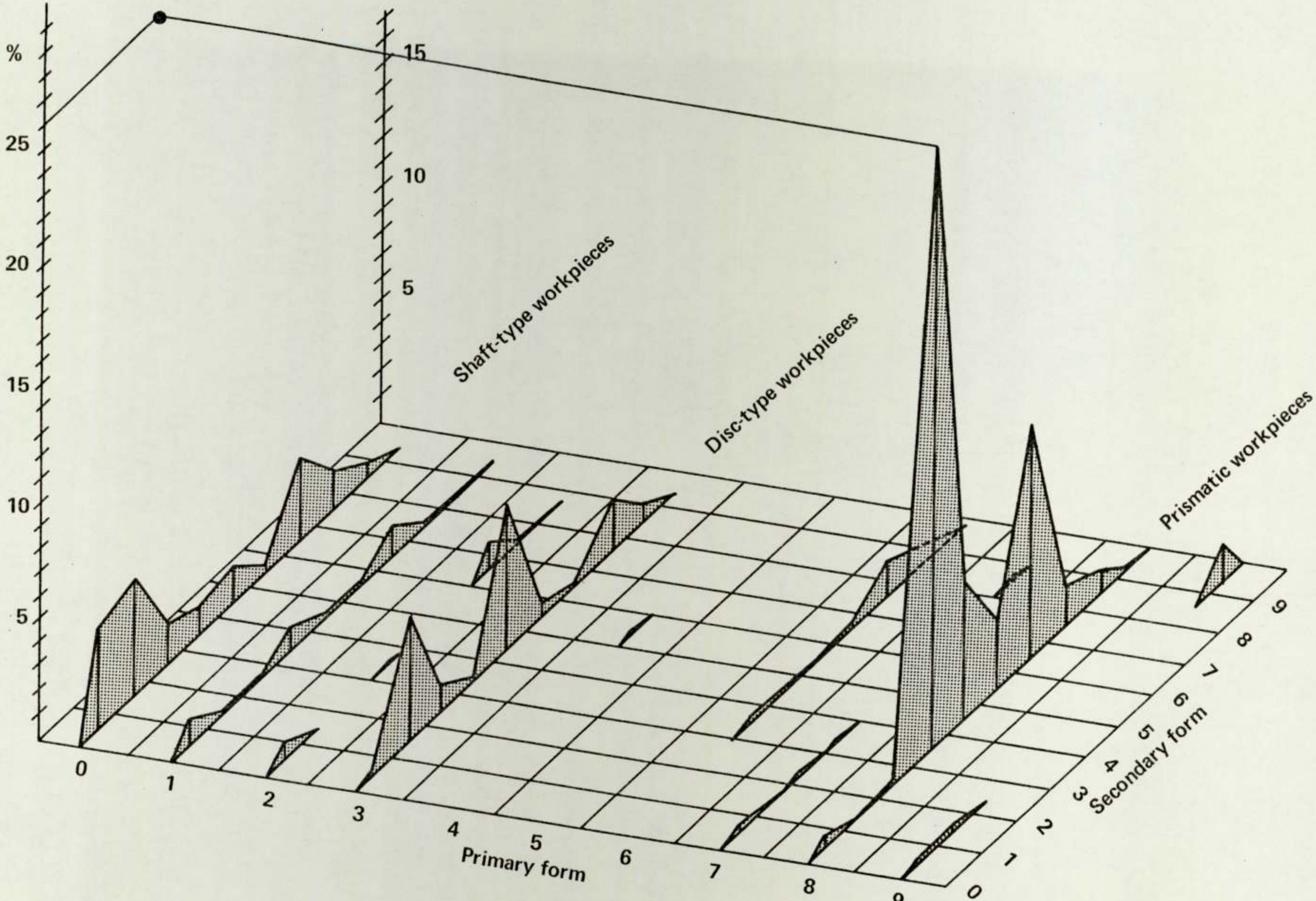


FIG. 50

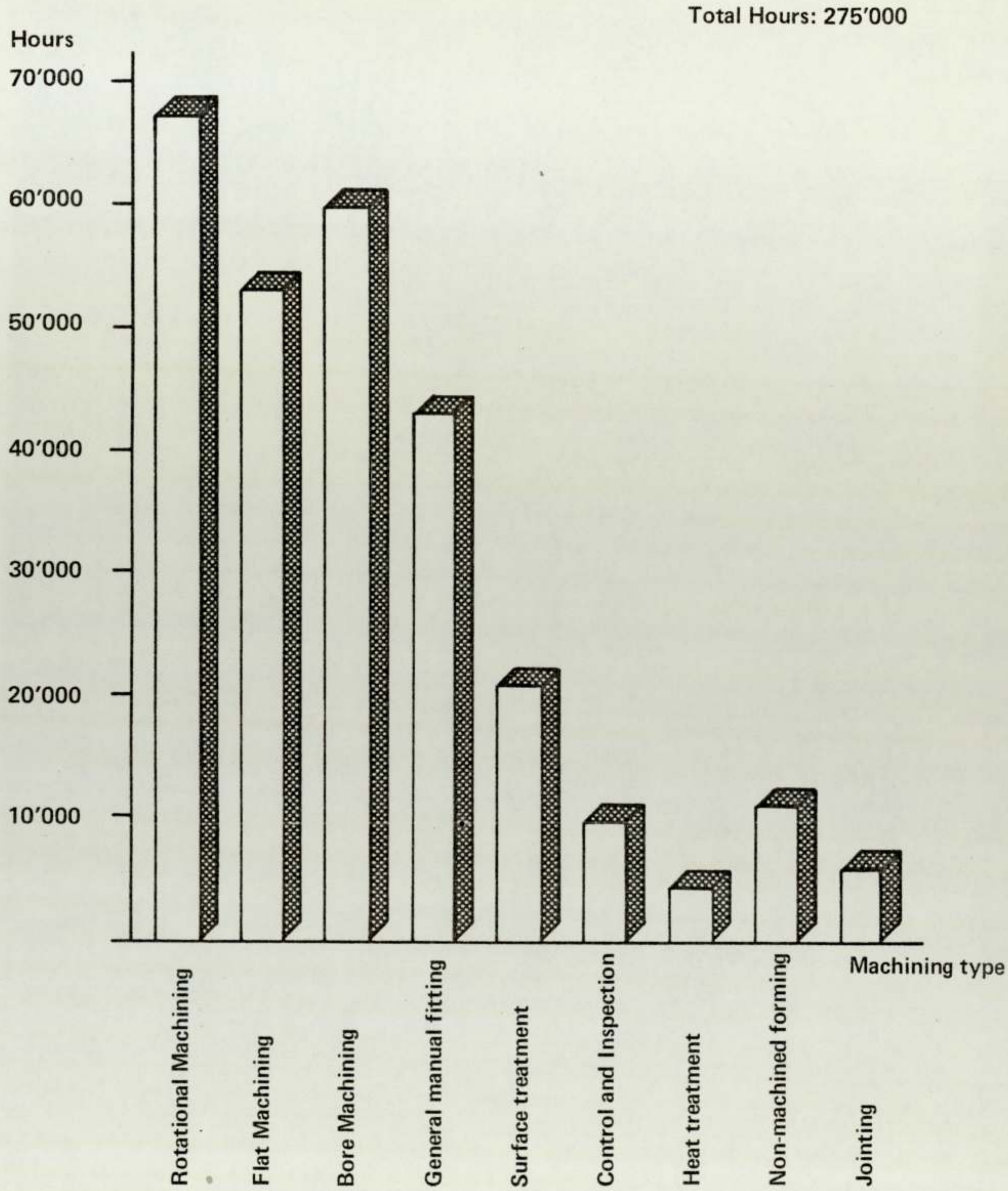


FIG. 51 MACHINING STRUCTURE AT THE GENERALISED LEVEL

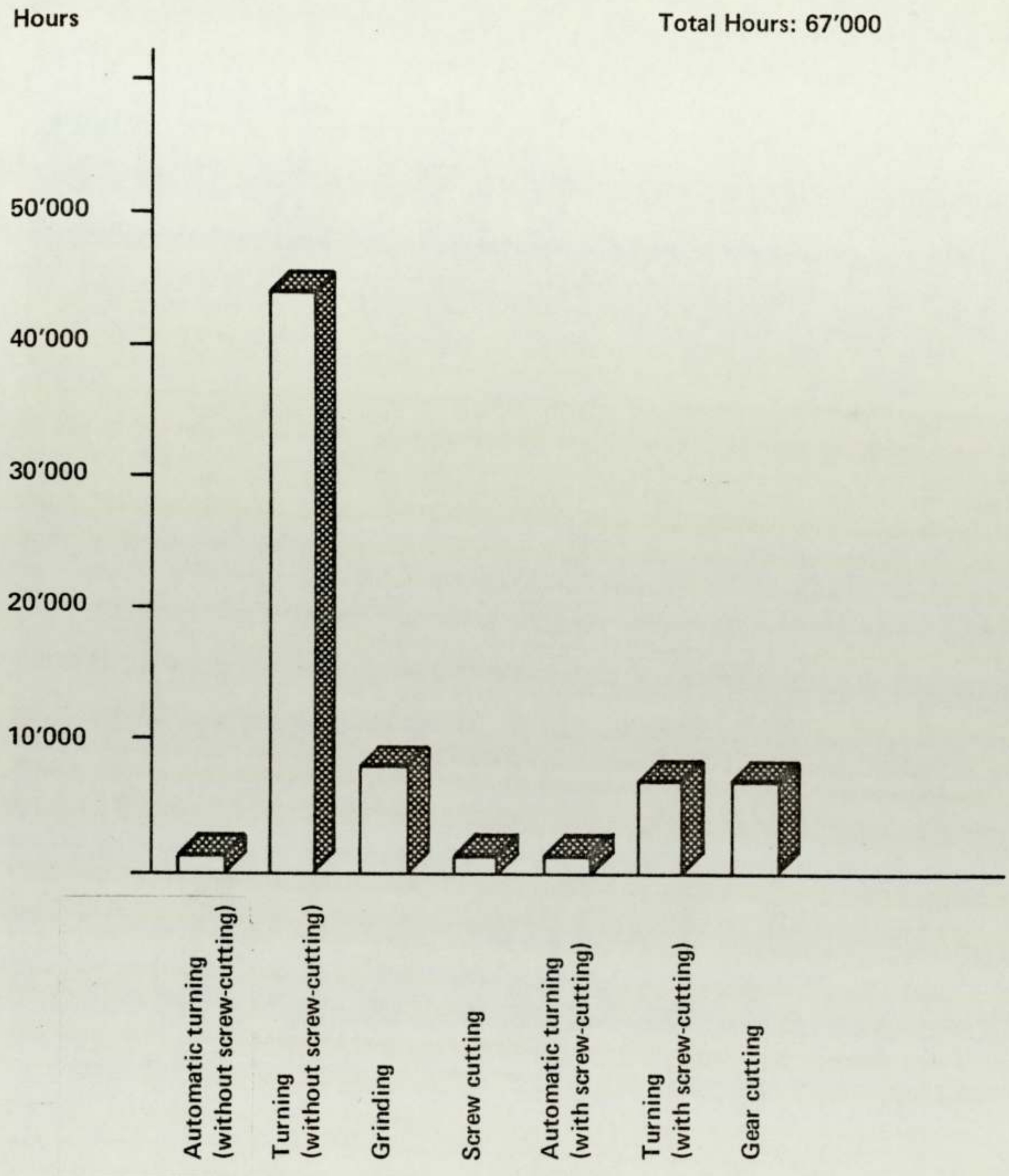


FIG. 52 ROTATIONAL MACHINING STRUCTURE

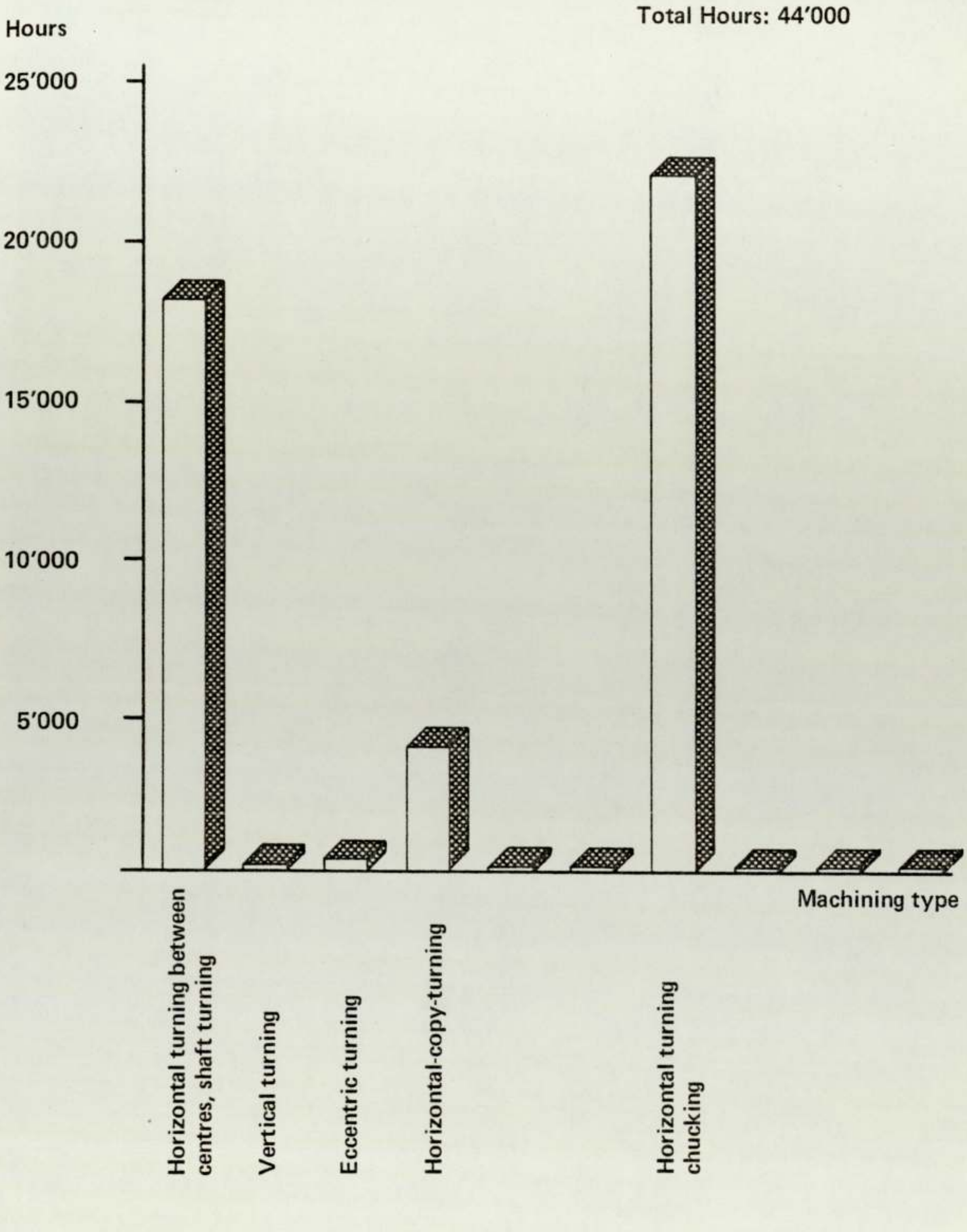
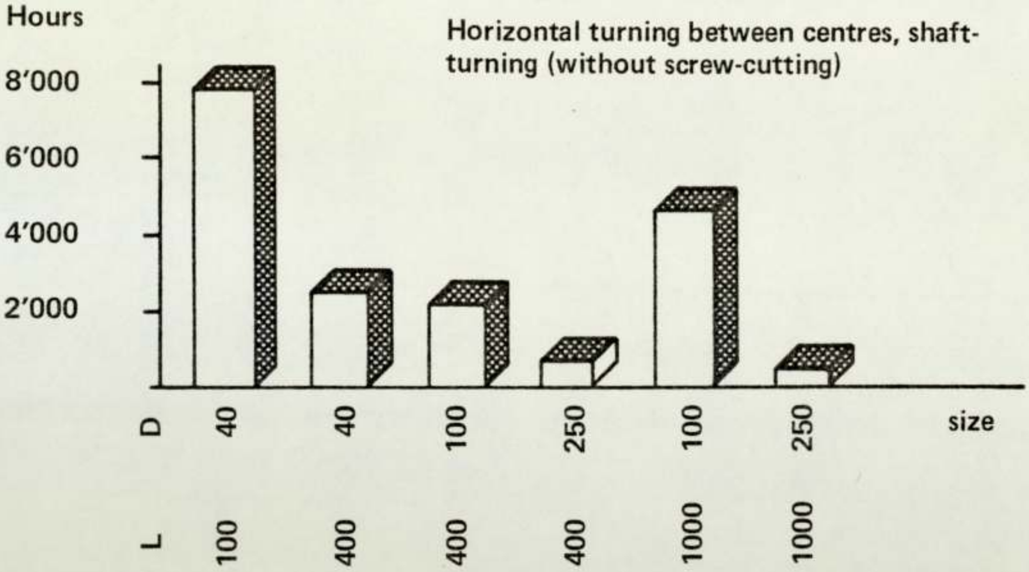


FIG. 53 MACHINING PROFILE "TURNING WITHOUT SCREW-CUTTING"



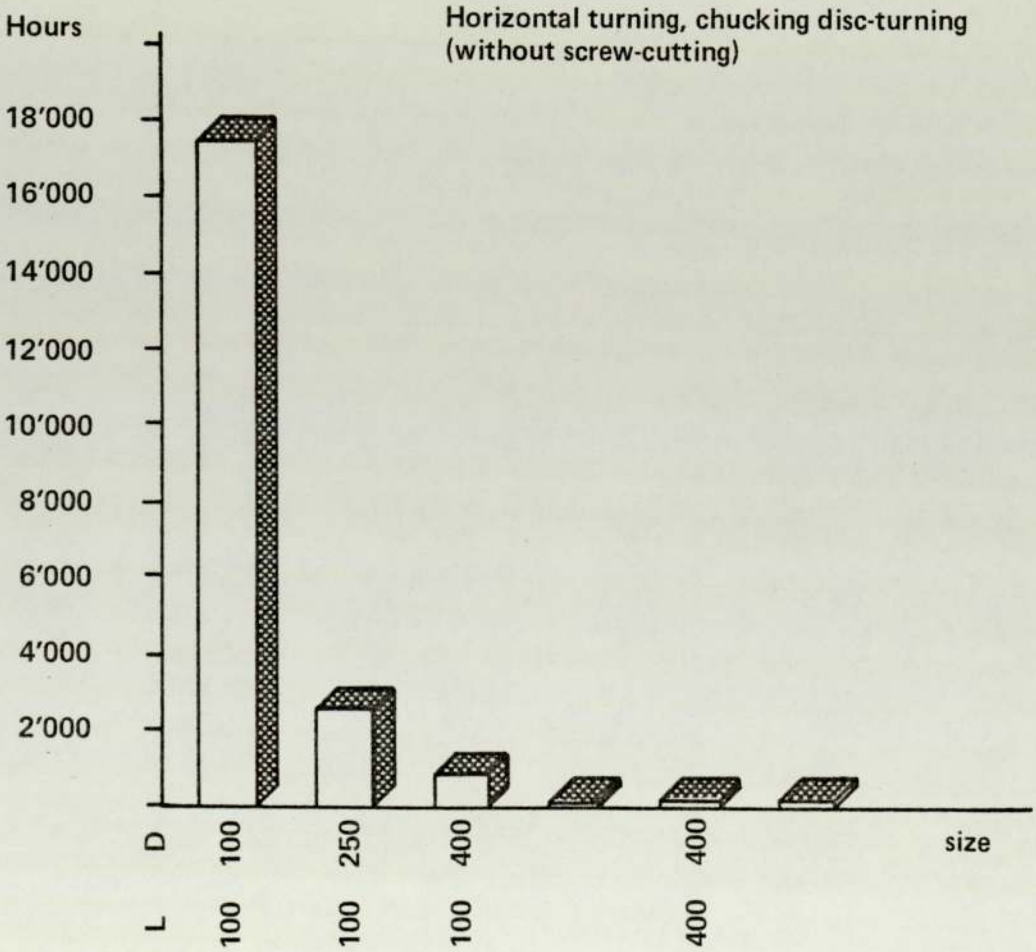


FIG. 54 HORIZONTAL TURNING

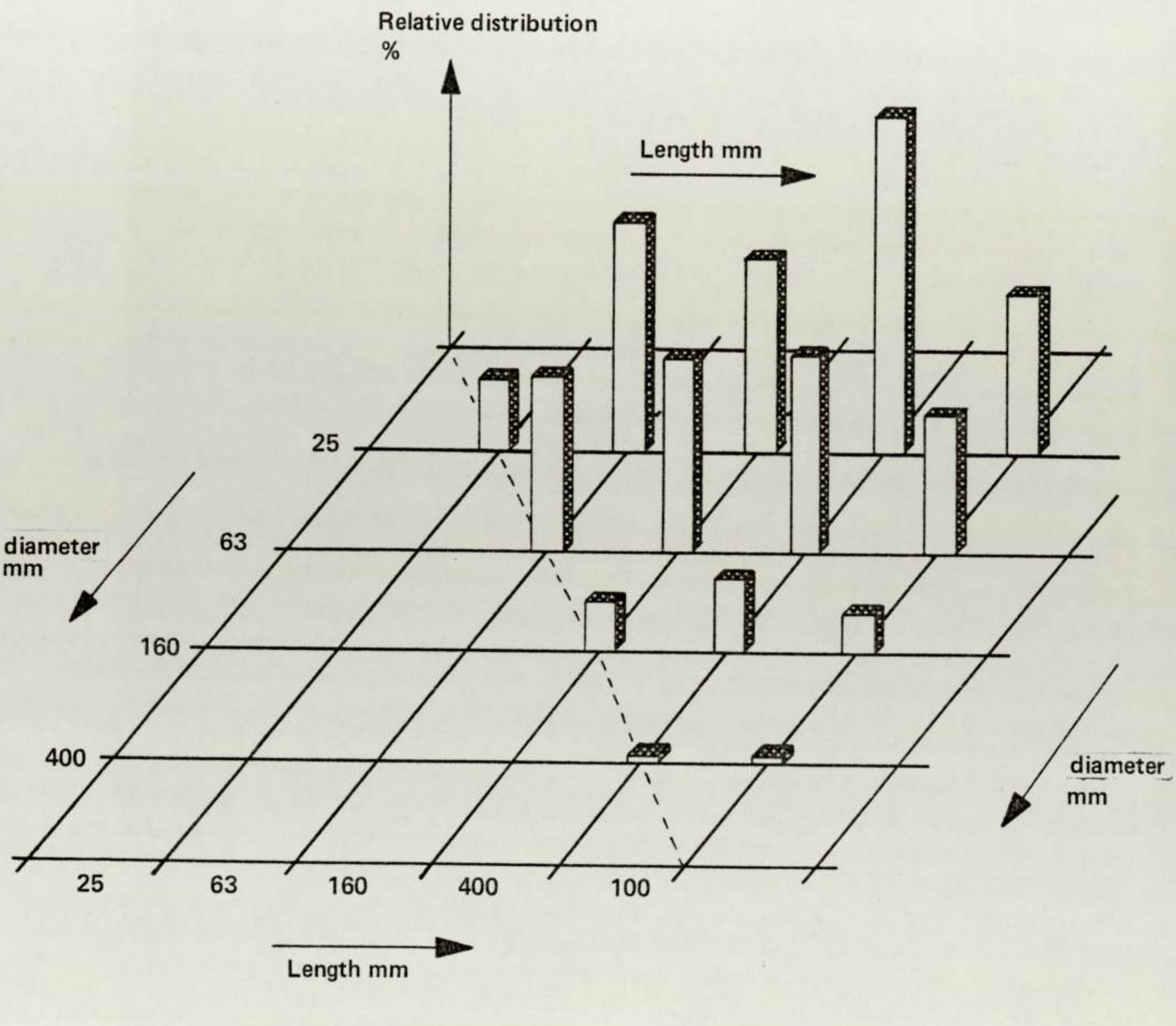


FIG. 55 ROTATIONAL MACHINING REQUIREMENTS

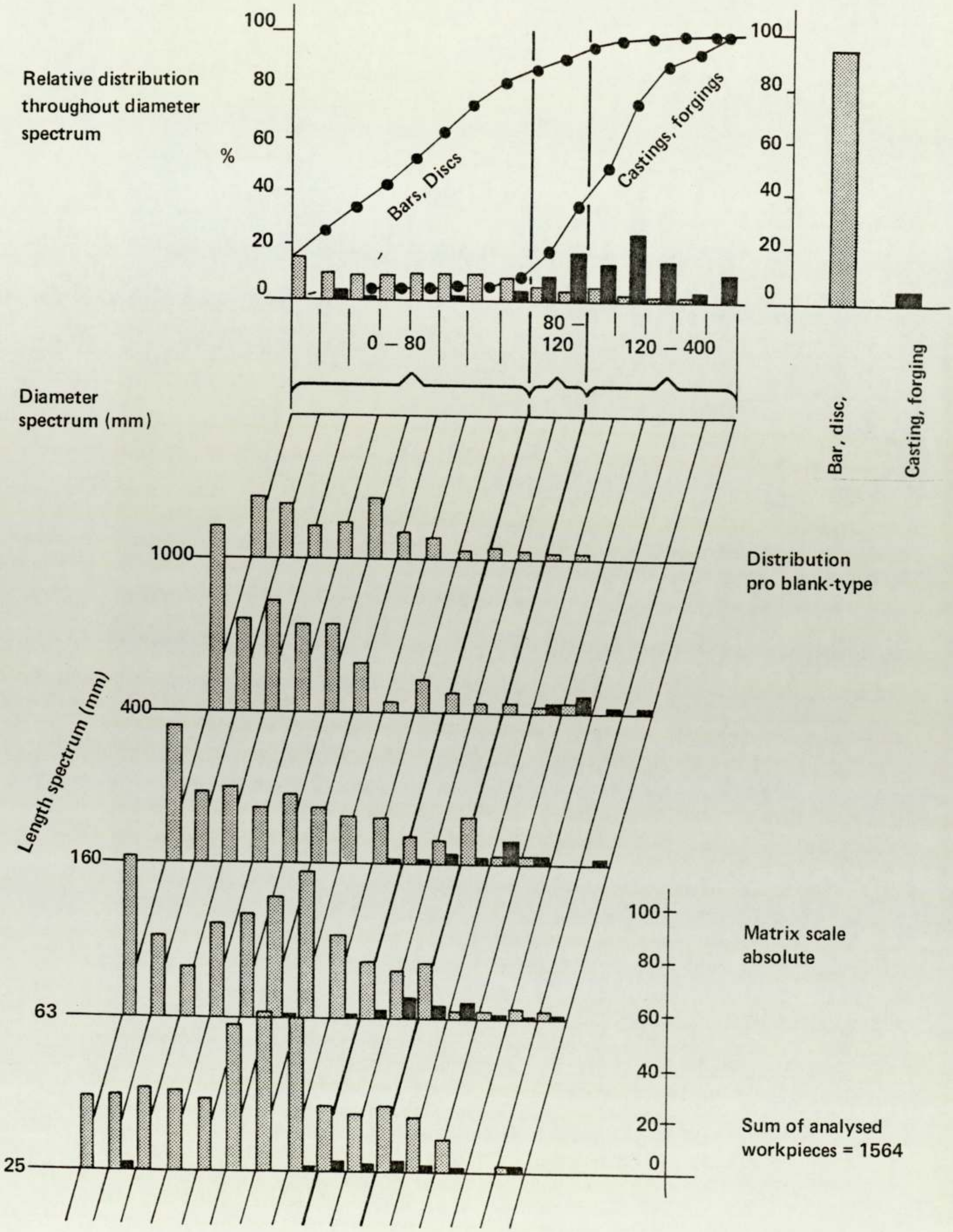
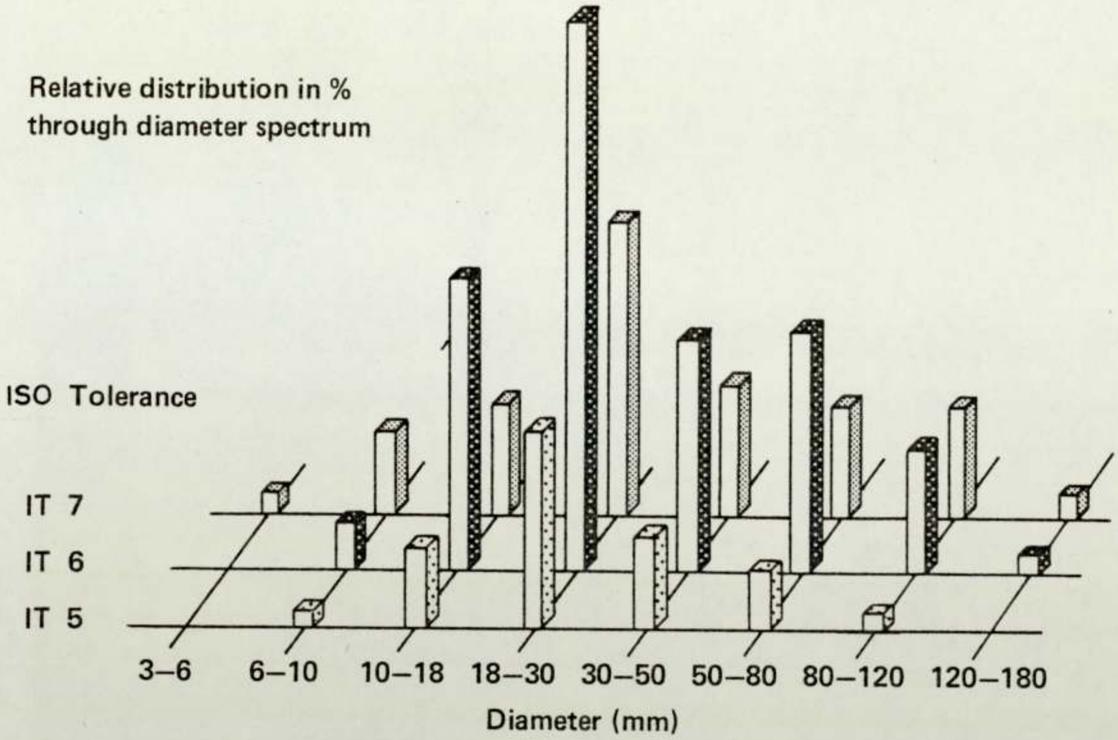
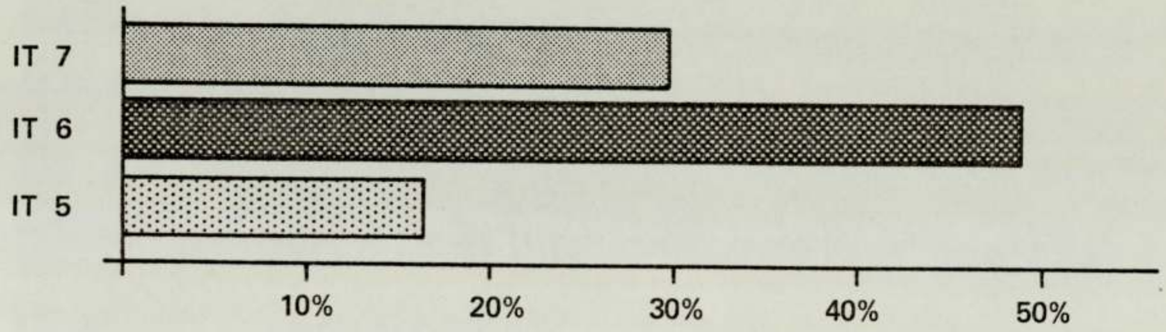


FIG. 56 WORKPIECE-BLANK PROFILE



Relative frequency distribution



	Basic tolerances in						(0.001 mm)	
Ø mm	3–6	6–10	10–18	18–30	30–50	50–80	80–120	120–180
IT 7	12	15	18	21	25	30	35	40
IT 6	8	9	11	13	16	19	22	25
IT 5	5	6	8	9	11	13	15	18

FIG. 57 MACHINING REQUIREMENTS (QUALITY STRUCTURE)

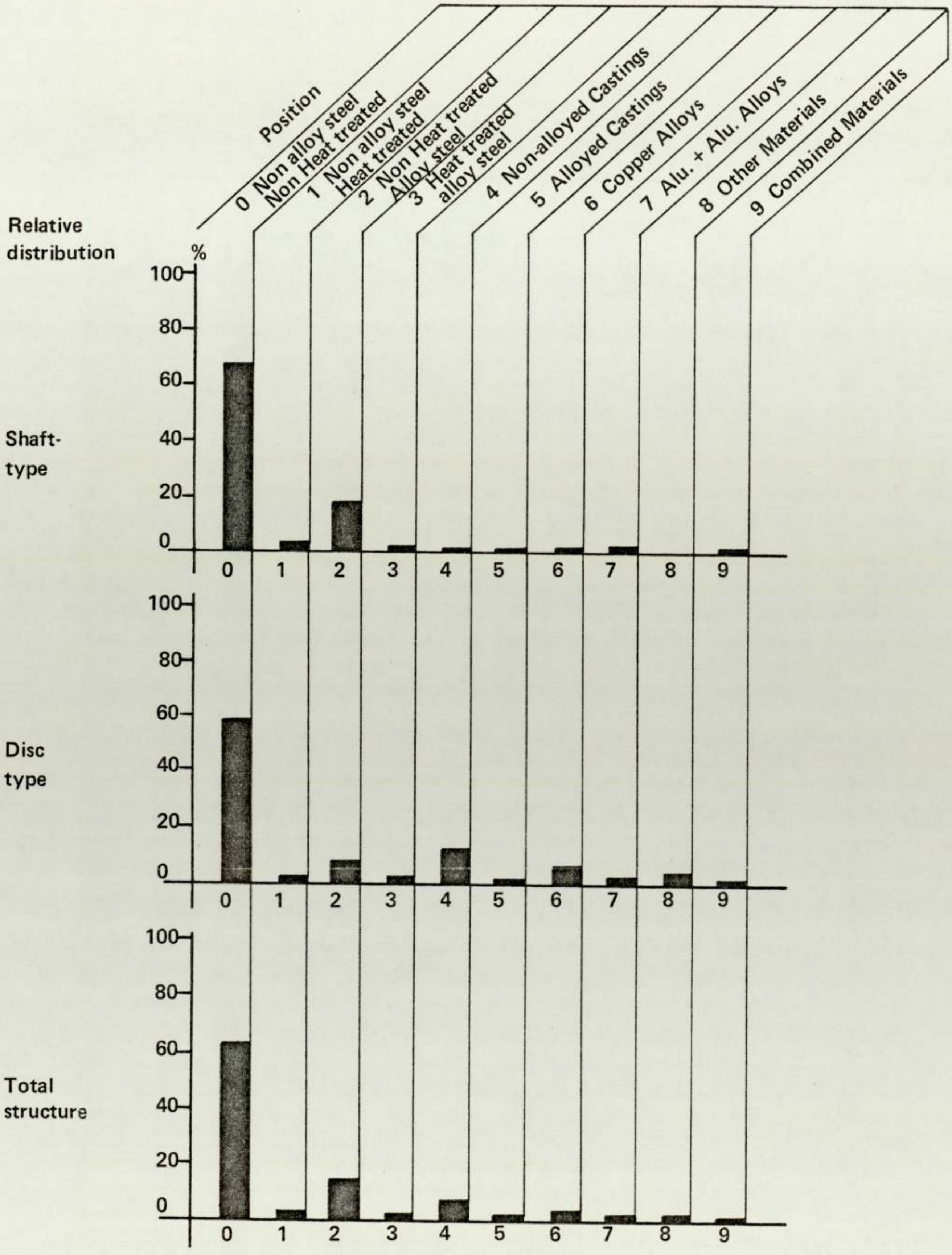


FIG. 58 MACHINING REQUIREMENTS (MATERIAL STRUCTURE)

FIG. 58

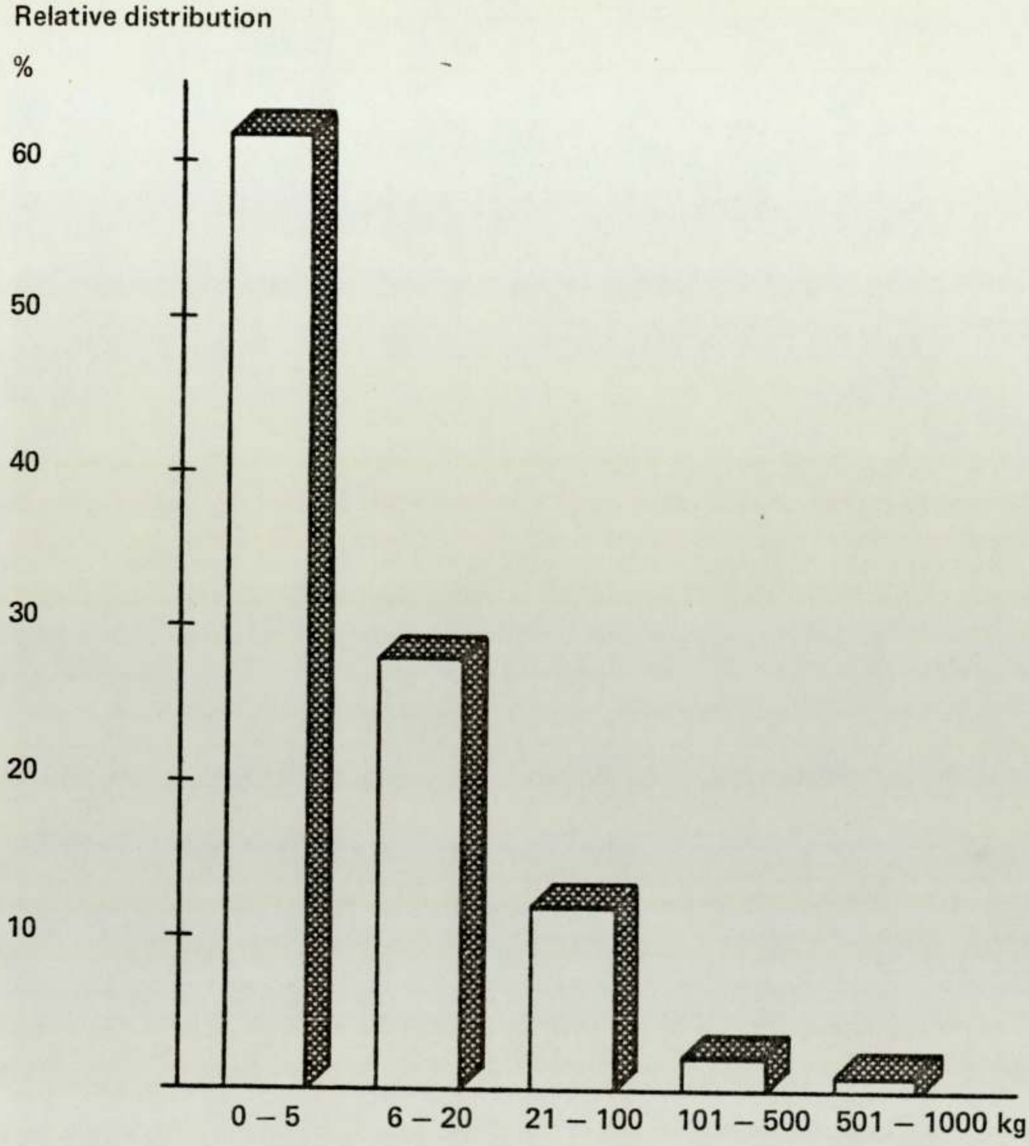


FIG. 59 MACHINING REQUIREMENTS (WEIGHT STRUCTURE)

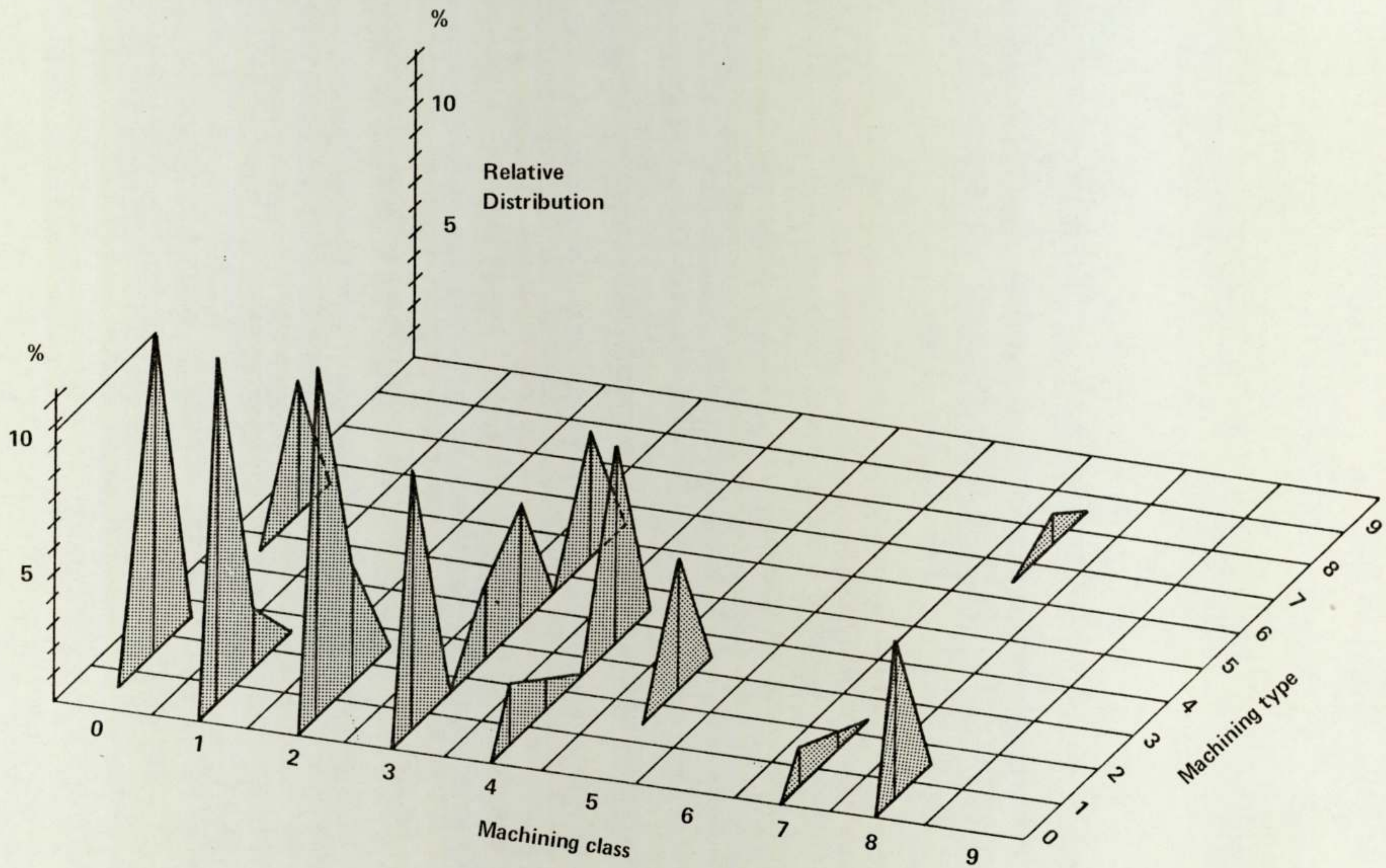


FIG. 60 MACHINING STRUCTURE OF THE PRODUCT T 180

FIG. 60

FIG. 61 A VIEW IN THE ASSEMBLY DEPARTMENT

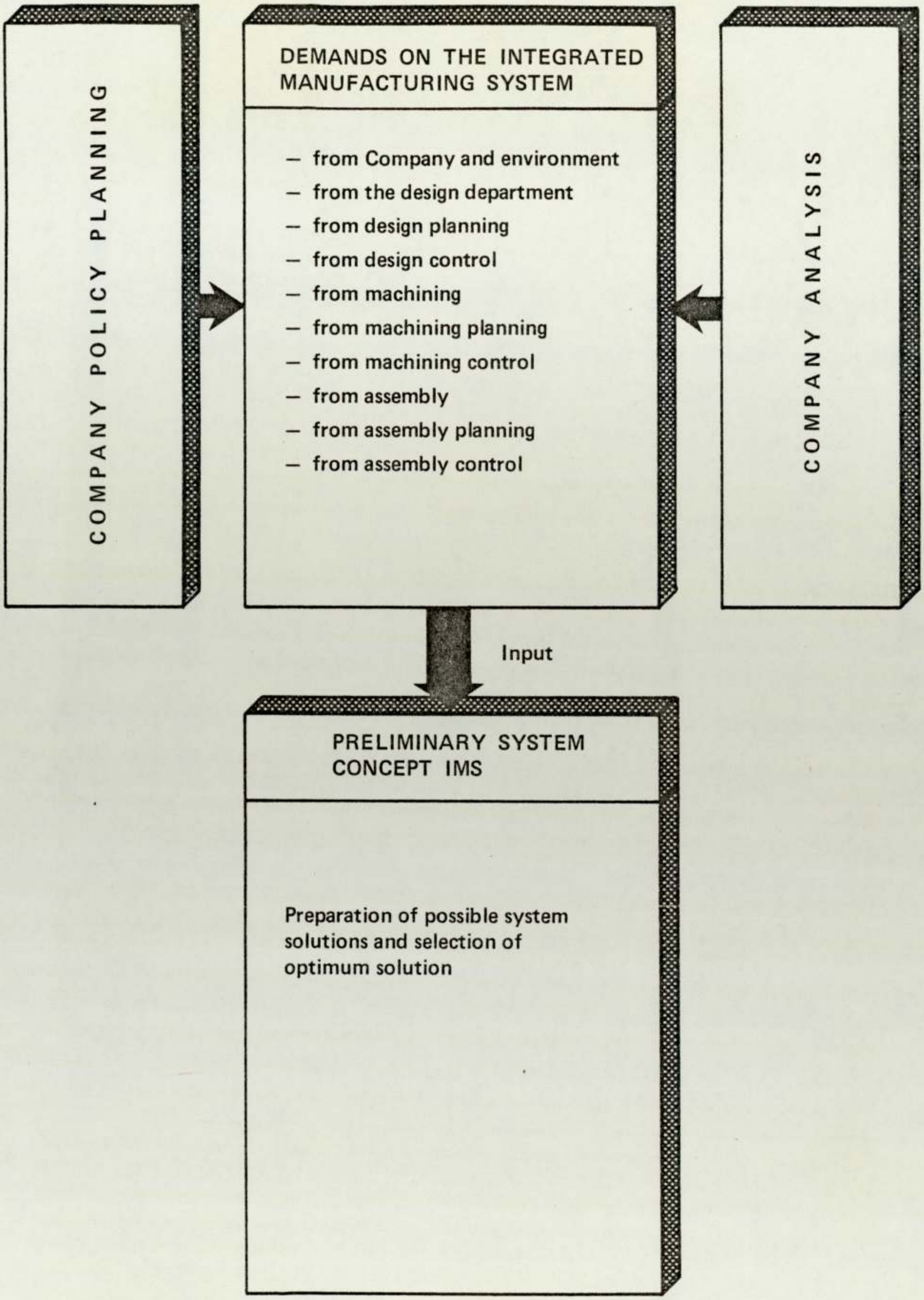


FIG. 62 SYSTEM REQUIREMENTS AS INPUT FOR THE PHASE "SOLUTION CONCEPT"

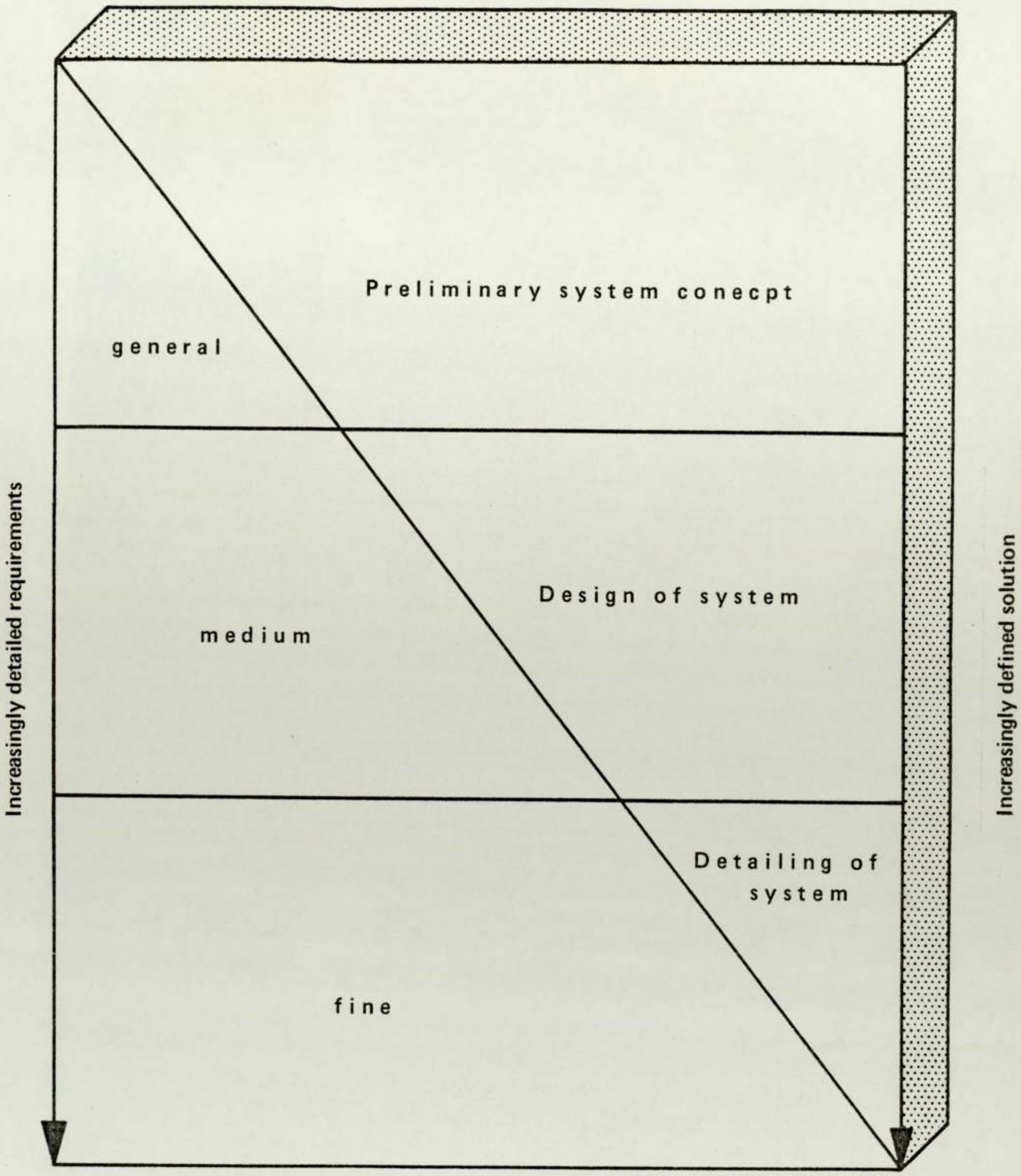


FIG. 63 PROGRESSIVE DEVELOPMENT OF SYSTEM REQUIREMENTS AND SOLUTIONS

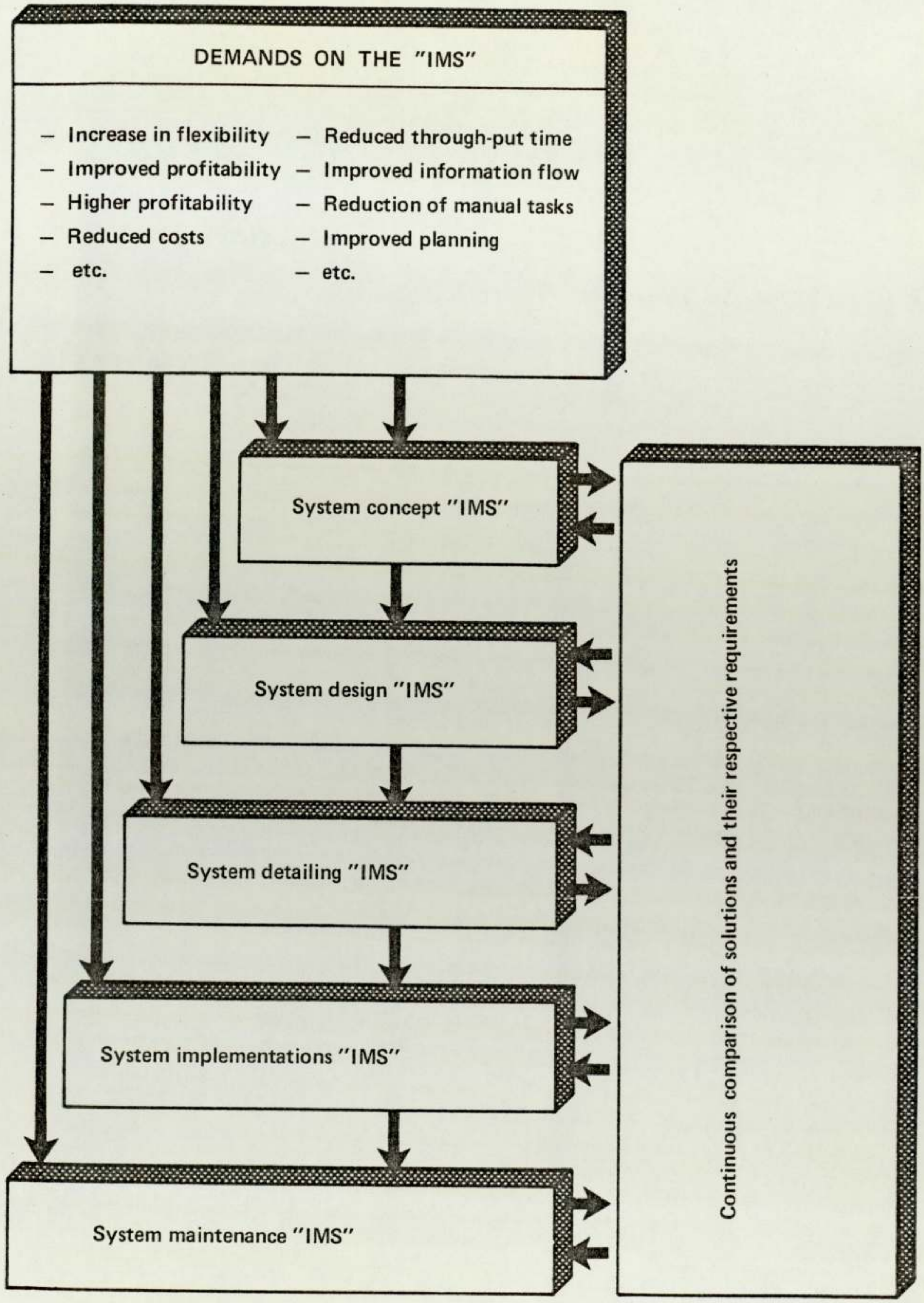


FIG. 64 INFLUENCE OF THE SYSTEM DEMANDS ON THE SYSTEM DEVELOPMENT

1. GENERAL OVERALL SYSTEM IMS

- Improve productivity
- Increase flexibility
- Raise profitability
- Reduce cost
- Conform to government legislation
- Be compatible with overall company policy
- Enable the integration of other solutions
- Improve employee motivation
- Raise product quality
- Minimise paperwork and bureaucracy
- Enable inexpensive introduction

2. DESIGN

- A reduction of at least 30 % in time spent on indirect design activities
- Improvement in the information availability from drawings, parts-lists and standards.
- Systematic structuring of drawings and parts-lists system.
- The reduction of draughting time for the detailing of rotational and prismatic components.
- Increased standardisation of detail drawings
- Standardisation of functional modules and functional elements
- Reduction of time spent with routine calculations
- Improvement in planning functions
- Improvement in control functions

3. MACHINING

- Reduction of job through put time in the machining sector $\geq$ 35 %
- Increase in the productivity of rotational machining $\geq$ 30 %
- Increase in the productivity of flat machining $\geq$ 30 %
- Increase in the productivity of bore machining $\geq$ 30 %
- Reduction in general manual work $\geq$ 50 %
- Improvement in plant compatibility to component spectrum
  - — rotational workpieces
  - — prismatic workpieces
  - — sheet metal workpieces
- Plant-layout better suited to components classes (Group Technology)
- Improvement in tooling systems
- Improvement in jig and fixture design
- Increase in machining quality
- Reduction in plant breakdown delays
- Increase in automation and modernisation where technically meaningful and economically justified
- No increase in personnel
- Linkage of information flow with drawing office and assembly dept.
- Improvement in work sheet preparation
- Improvement in capacity planning
- Improvement in job-loading and scheduling
- Improvement in machining-data collection
- Standardisation of similar and identical machining processes

4. ASSEMBLY

- Rduction in the scraping, filing, and bedding-in of parts $\geq$ 50 %
- Reduction in assembly through put time $\geq$ 35 %
- Improvement in assembly planning
- Linkage of information flow with drawing office and machining dept.
- Improvement in data collection in assembly
- Improvement in quality in assembly
- Application of modern information systems
- Improvement in assembly planning
- Improvement in assembly control
- Application of modern working aids

FIG. 65 REQUIREMENTSCATALOGUE

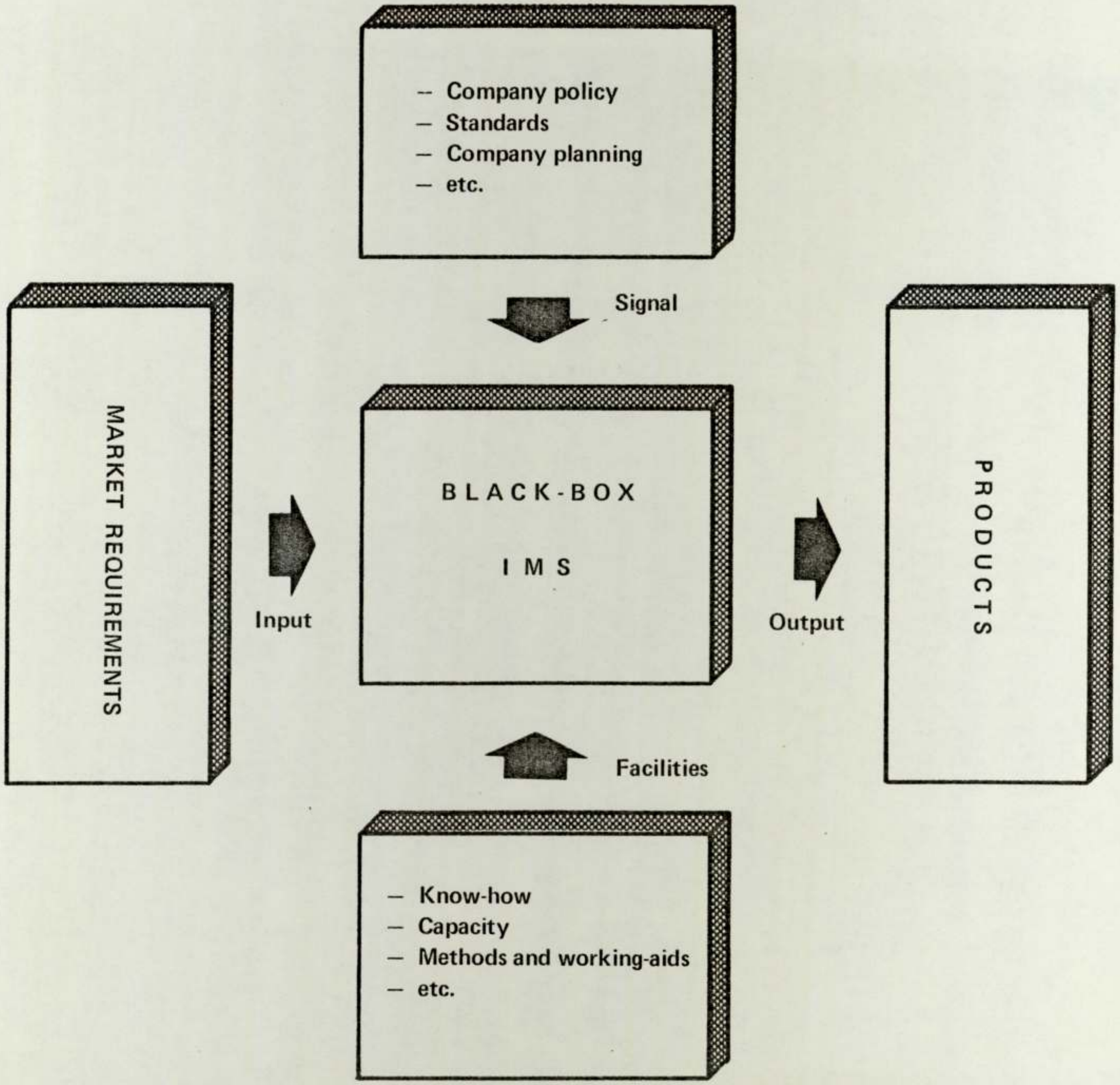


FIG. 66 THE IMS AS A "BLACK-BOX"

FIG. 66

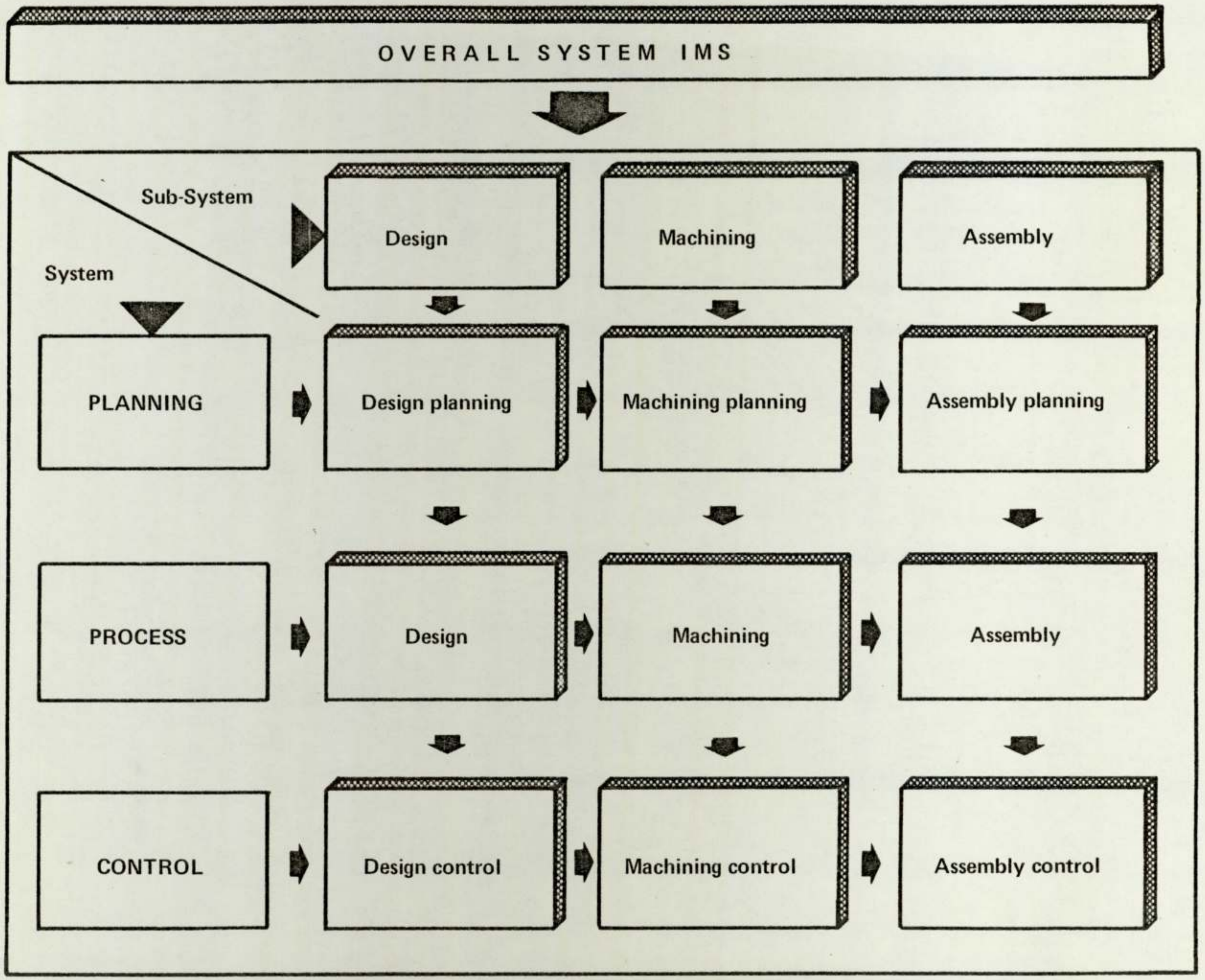
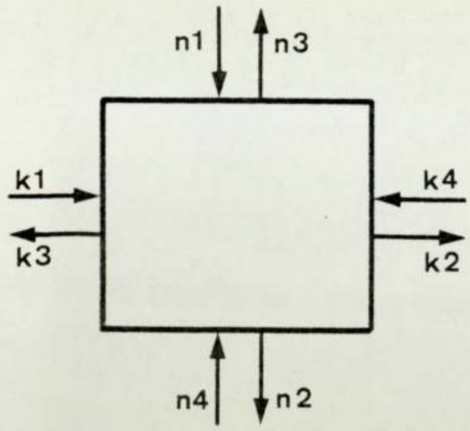


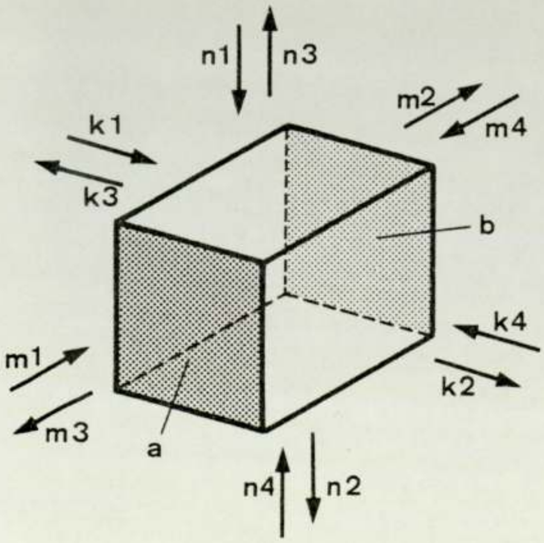
FIG. 67 STRUCTURAL BREAKDOWN OF THE OVERALL SYSTEM IMS

FIG. 67



k 1	Input from machining planning
k 2	Input for maching control
k 3	Feed-back from machining
k 4	Feed-back from machining control
n 1	Input from design
n 2	Input in assembly
n 3	Feed-back from machining
n 4	Feed-back from assembly

FIG. 68 TWO-DIMENSIONAL (X, Y) MODEL-BUILDING BLOCK



m 1	Input from development stage A
m 2	Input from development stage A+2
m 3	Feed-back from development stage A+1
m 4	Feed-back from development stage A+2

FIG. 69 THREE DIMENSIONAL (X, Y, Z) MODEL-BUILDING BLOCK

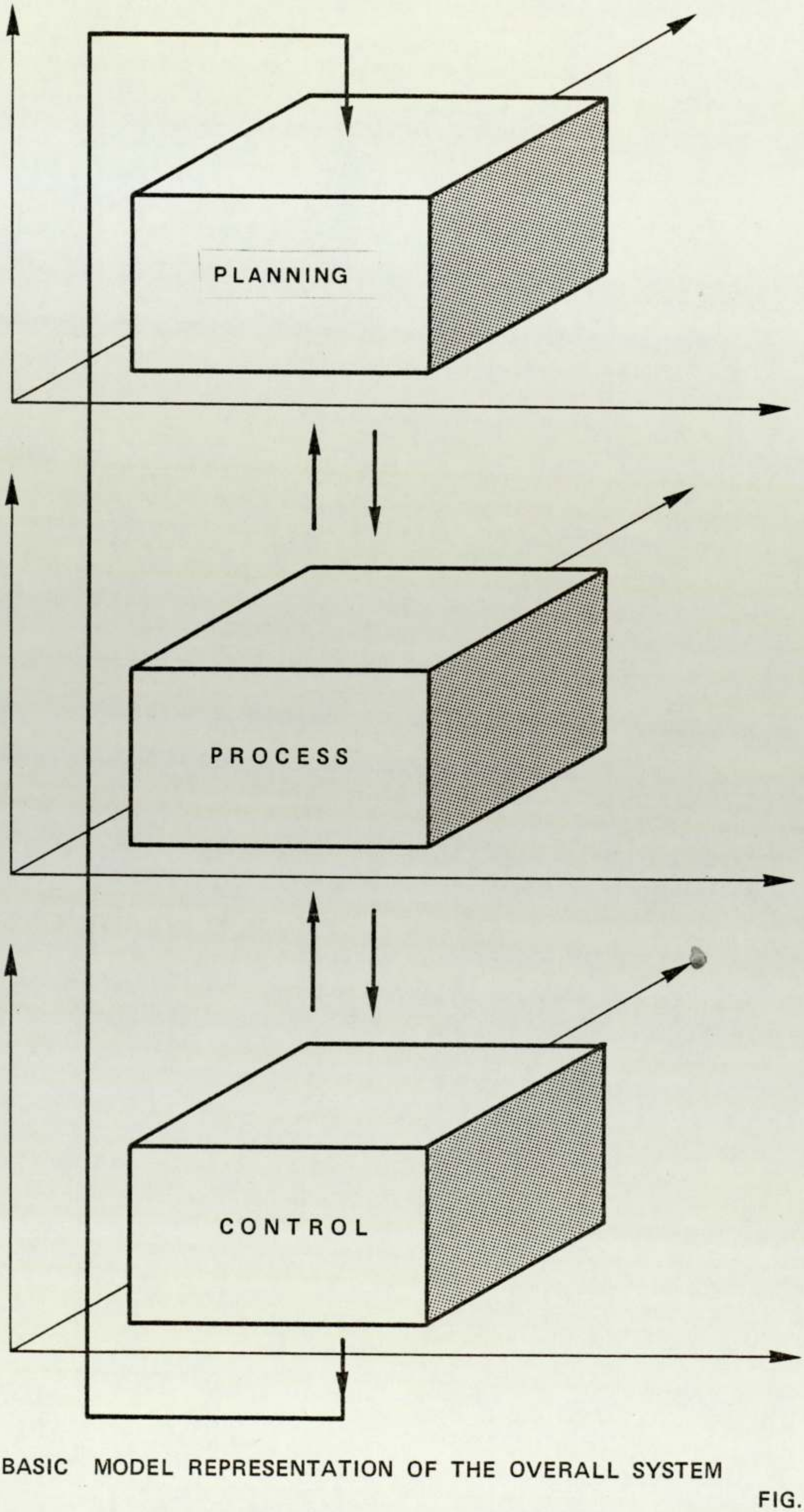


FIG. 70 BASIC MODEL REPRESENTATION OF THE OVERALL SYSTEM

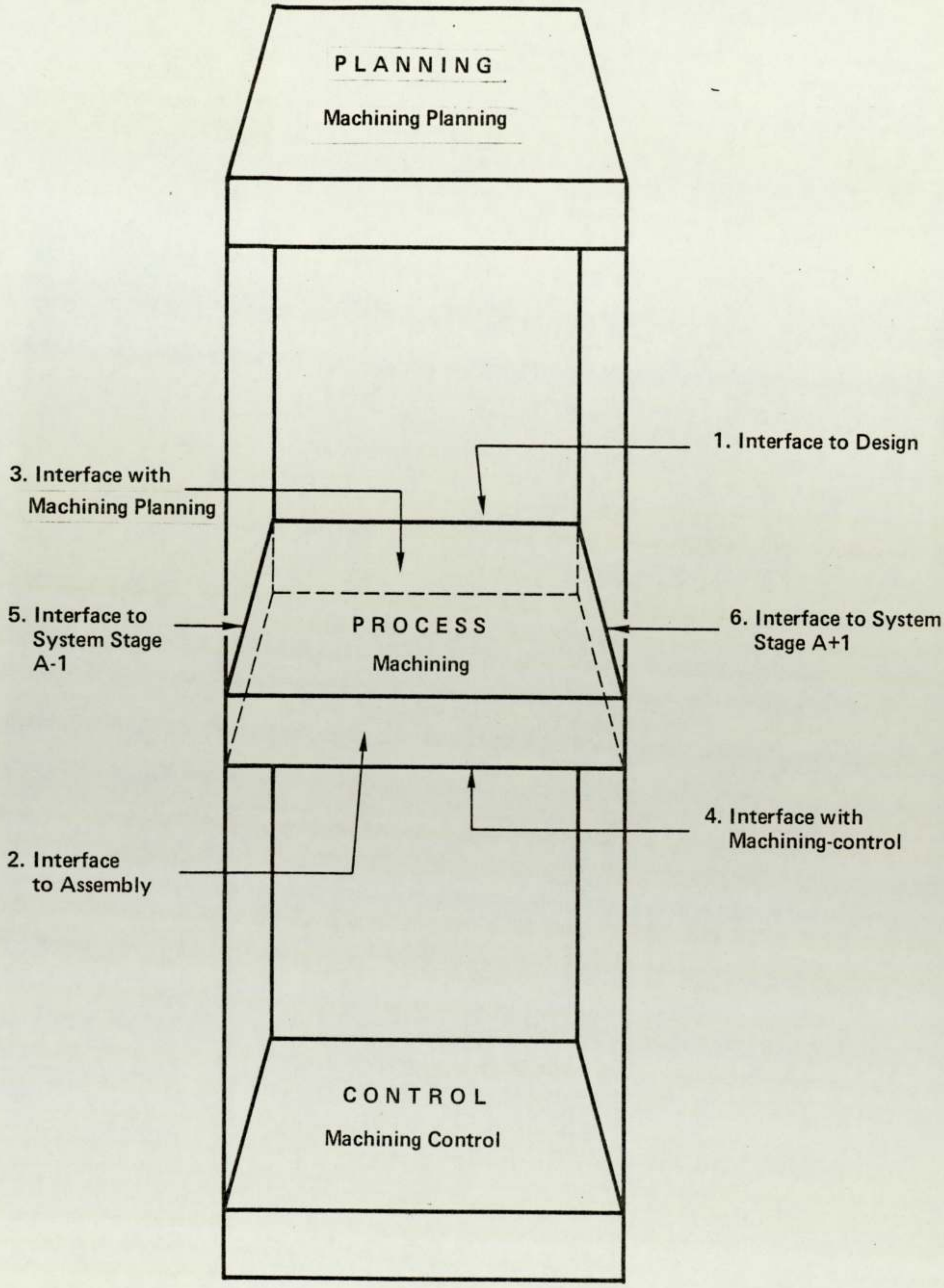


FIG. 71 ONE SYSTEM OF THE OVERALL SYSTEM "IMS"

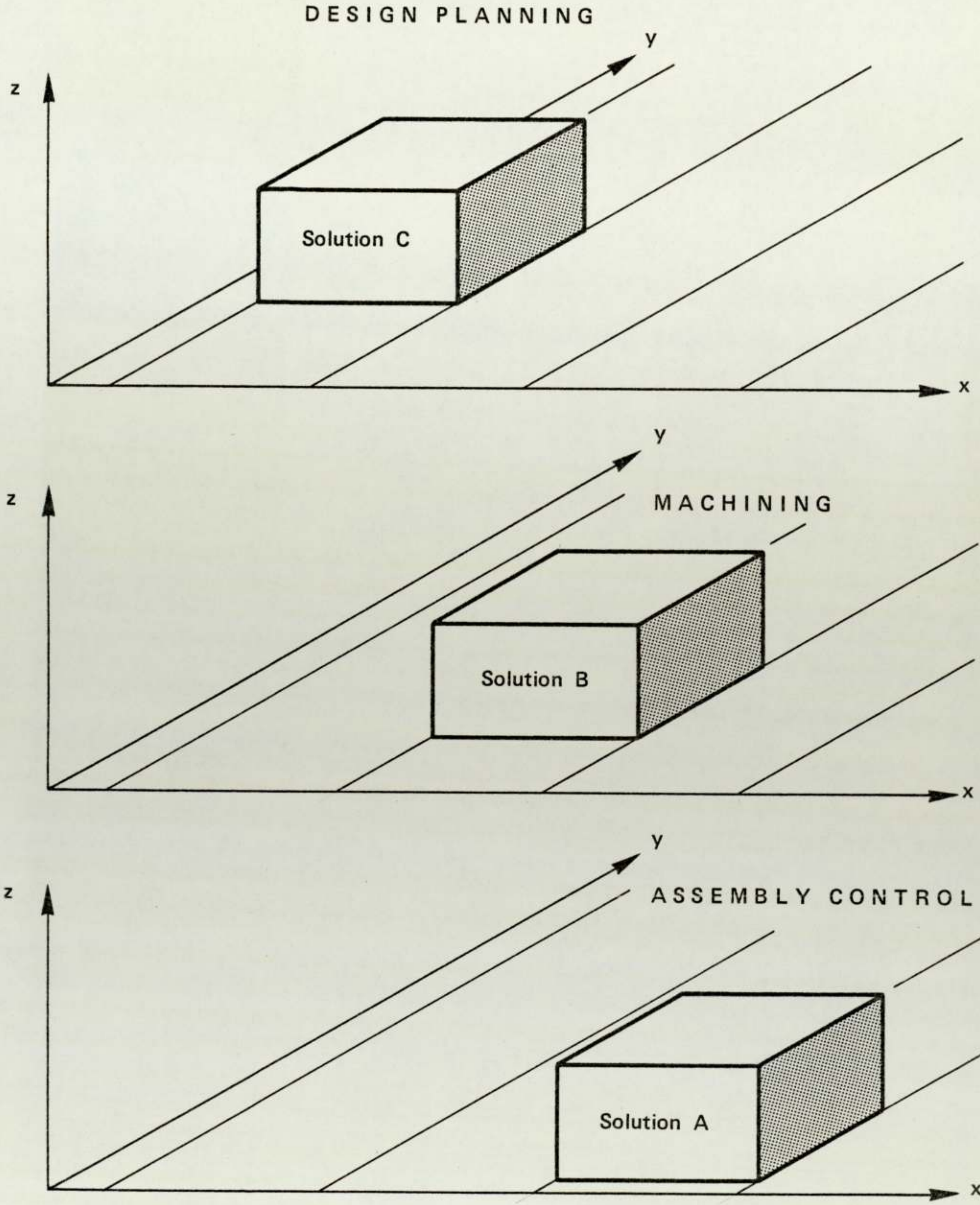


FIG. 72 SUBSYSTEM EXAMPLES OF THE OVERALL SYSTEM "IMS"

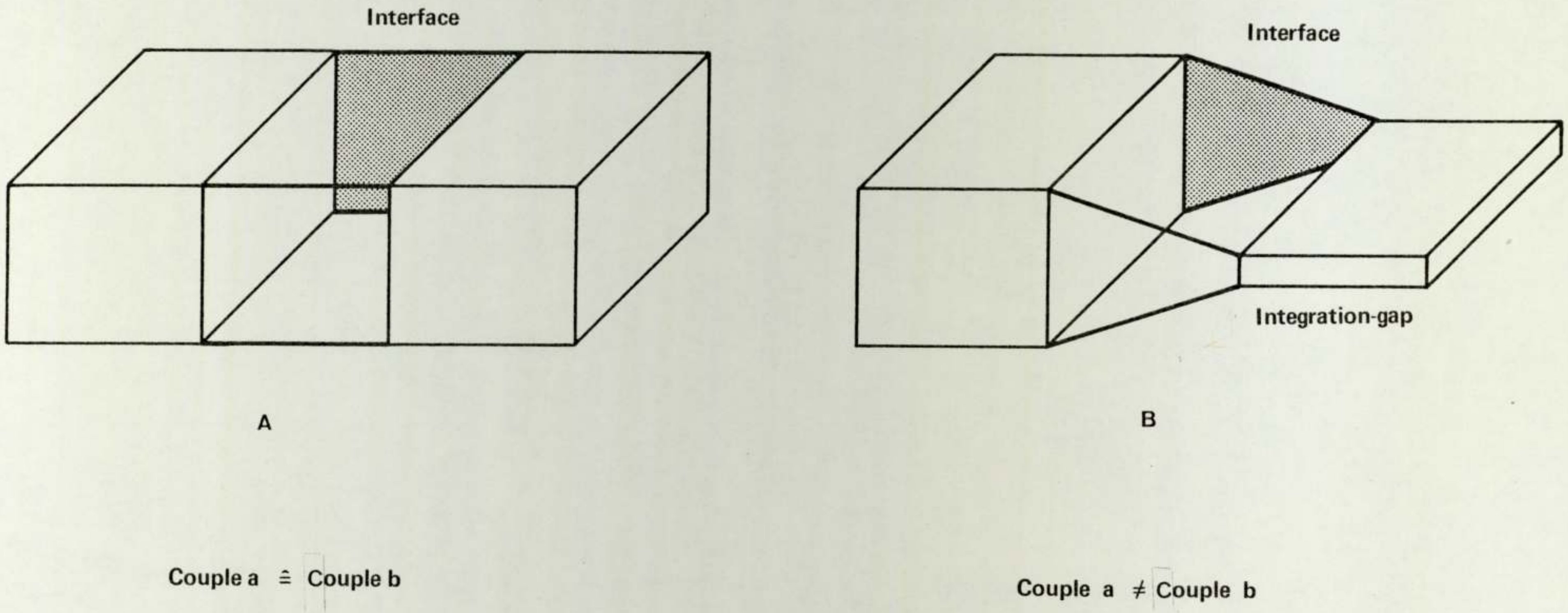
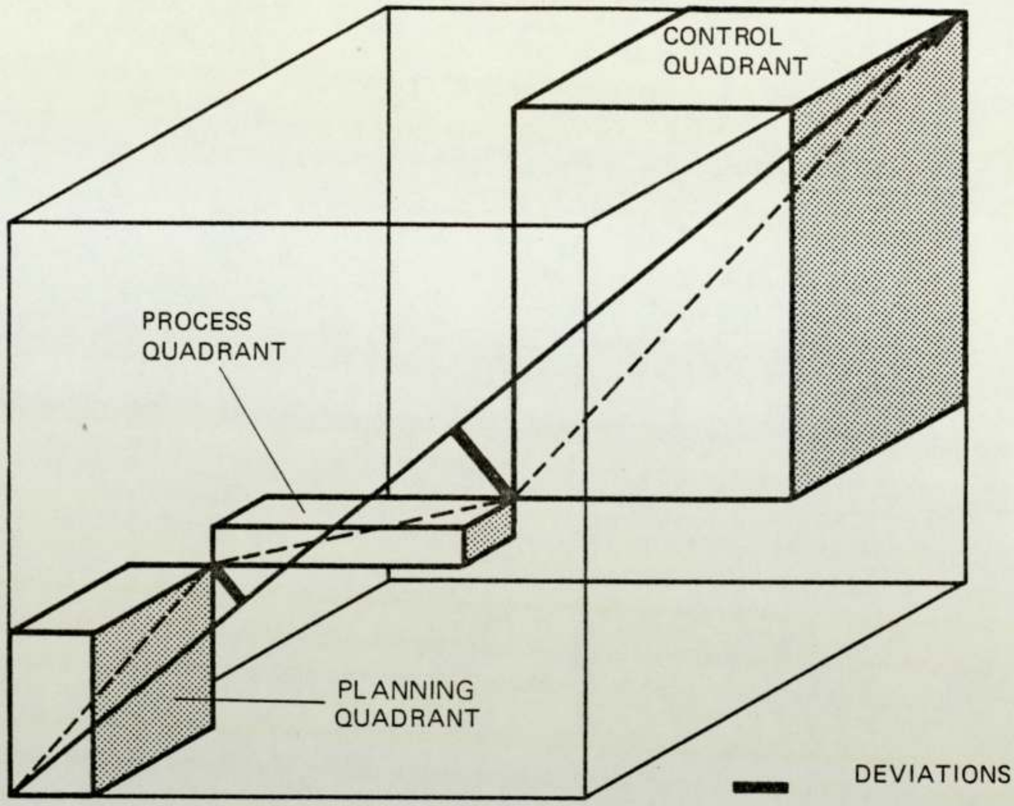


FIG. 73 INTEGRATION GAP

FIG. 73

MODEL OF AN UNBALANCED OVERALL SYSTEMSOLUTION



MODEL OF A BALANCED OVERALL SYSTEMSOLUTION

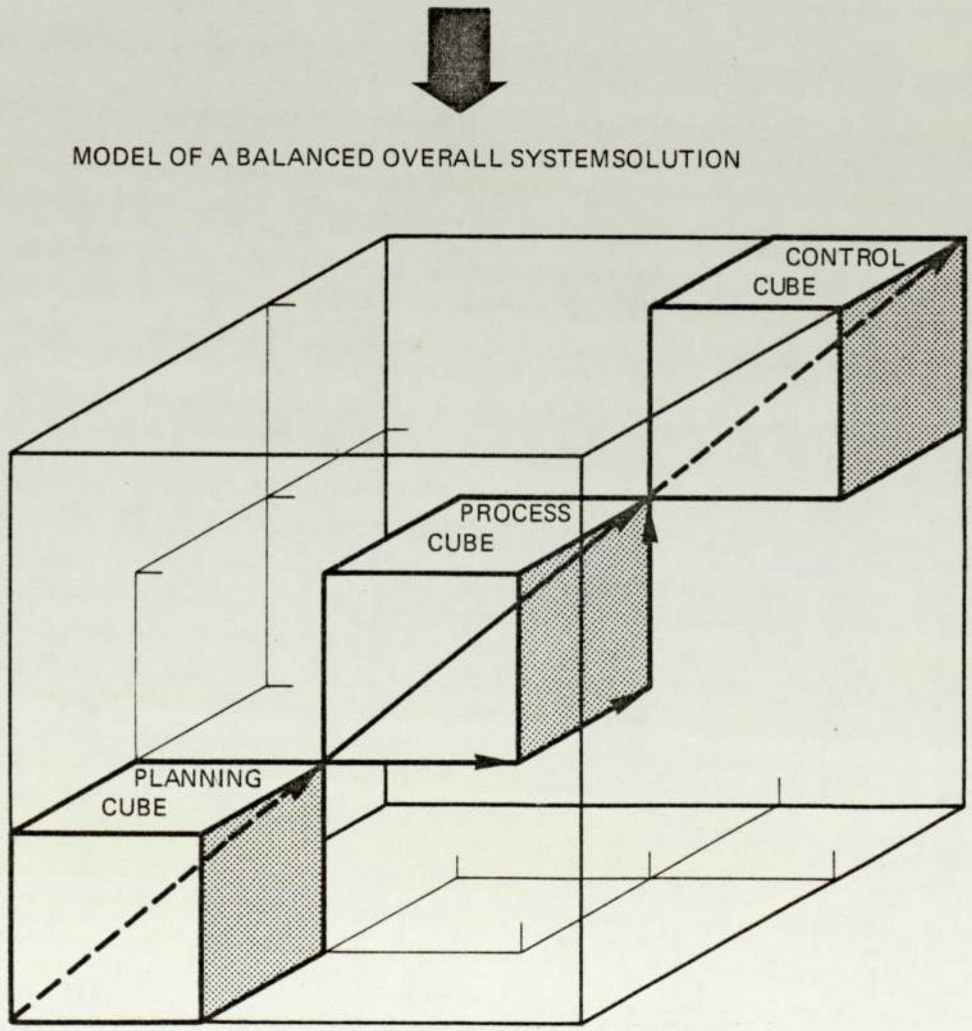


FIG. 74 MODEL OF SYSTEM SOLUTION

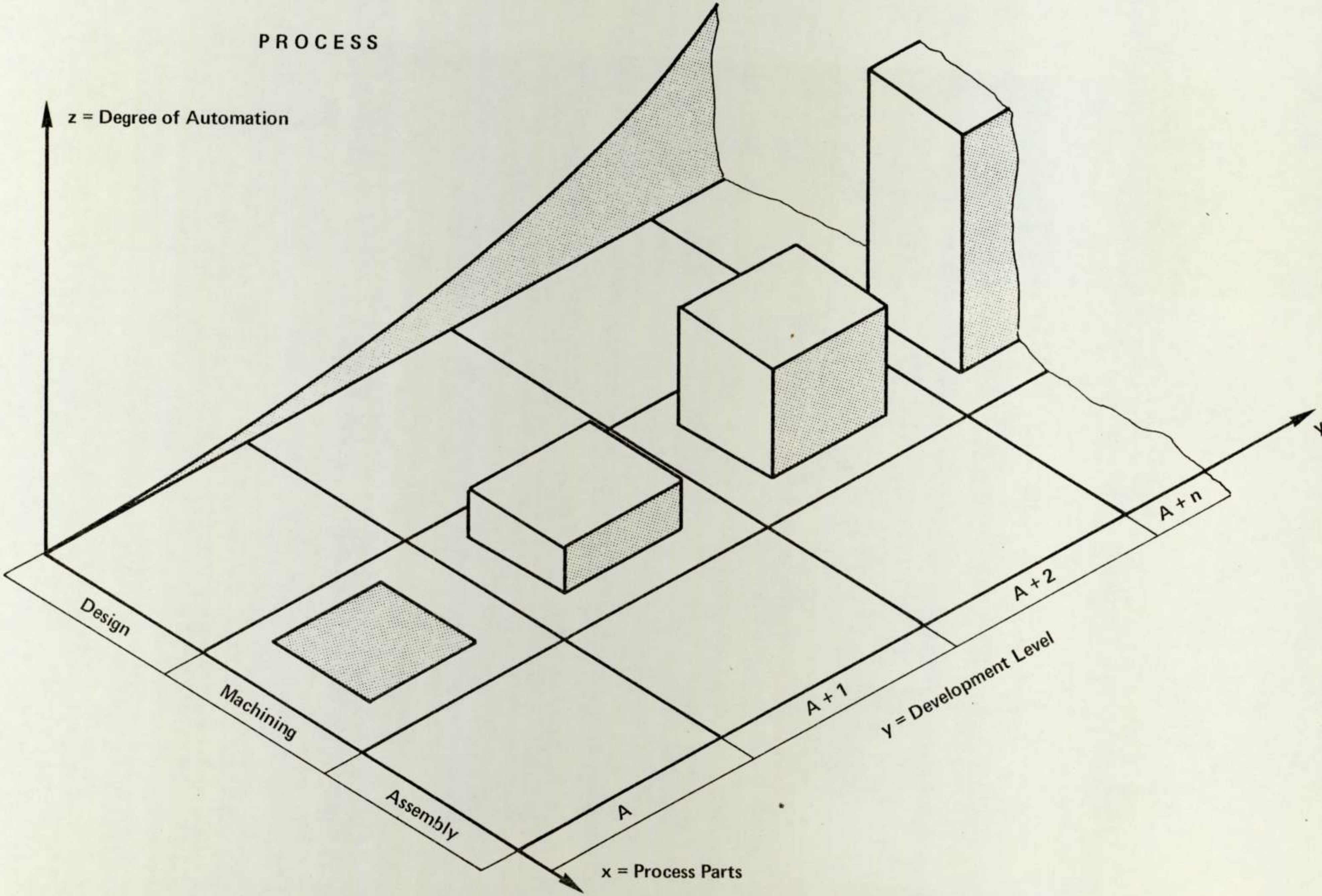


FIG. 75 SYSTEM DEVELOPMENT COORDINATE MODEL

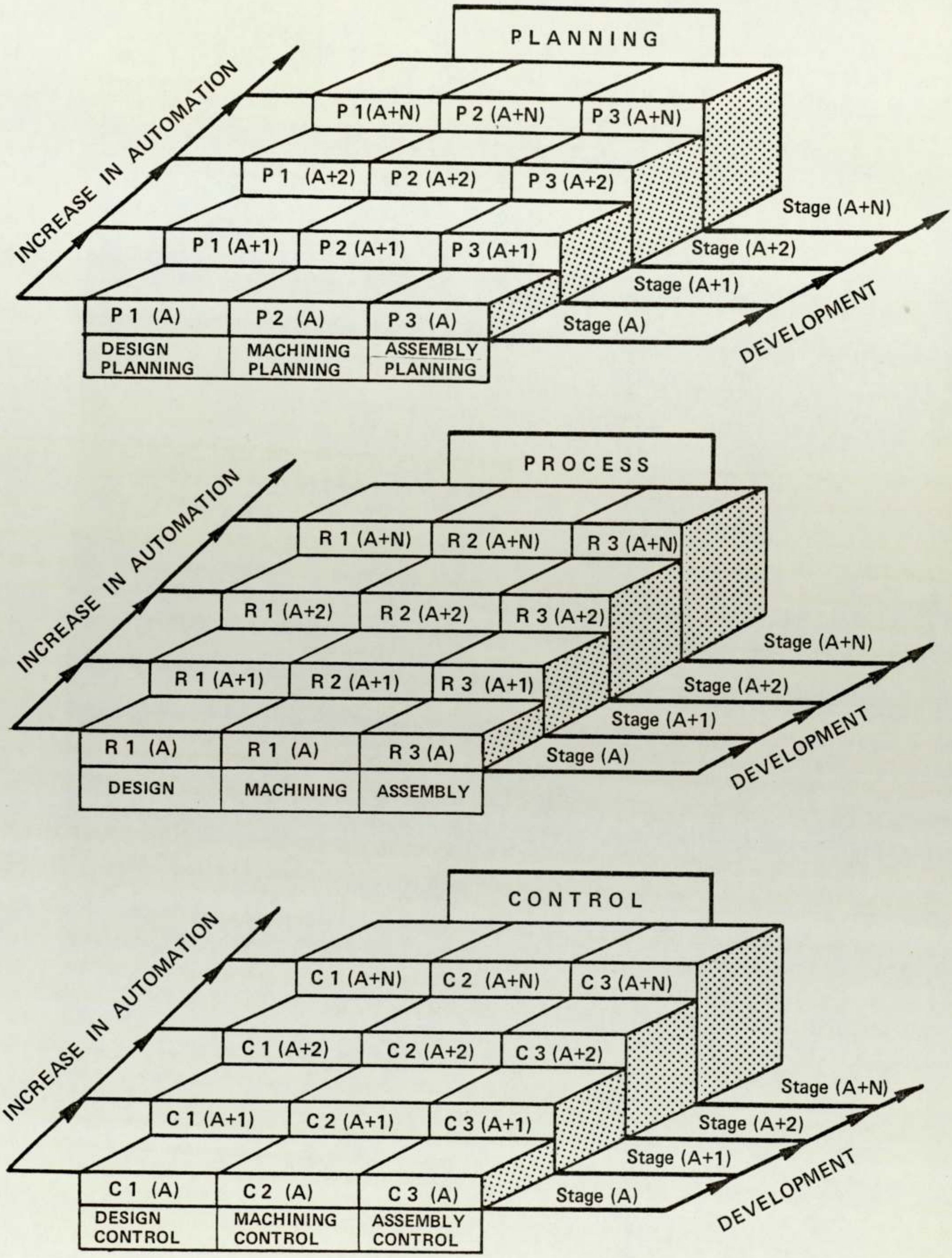


FIG. 76 SYSTEMMODEL IMS

FIG. 76

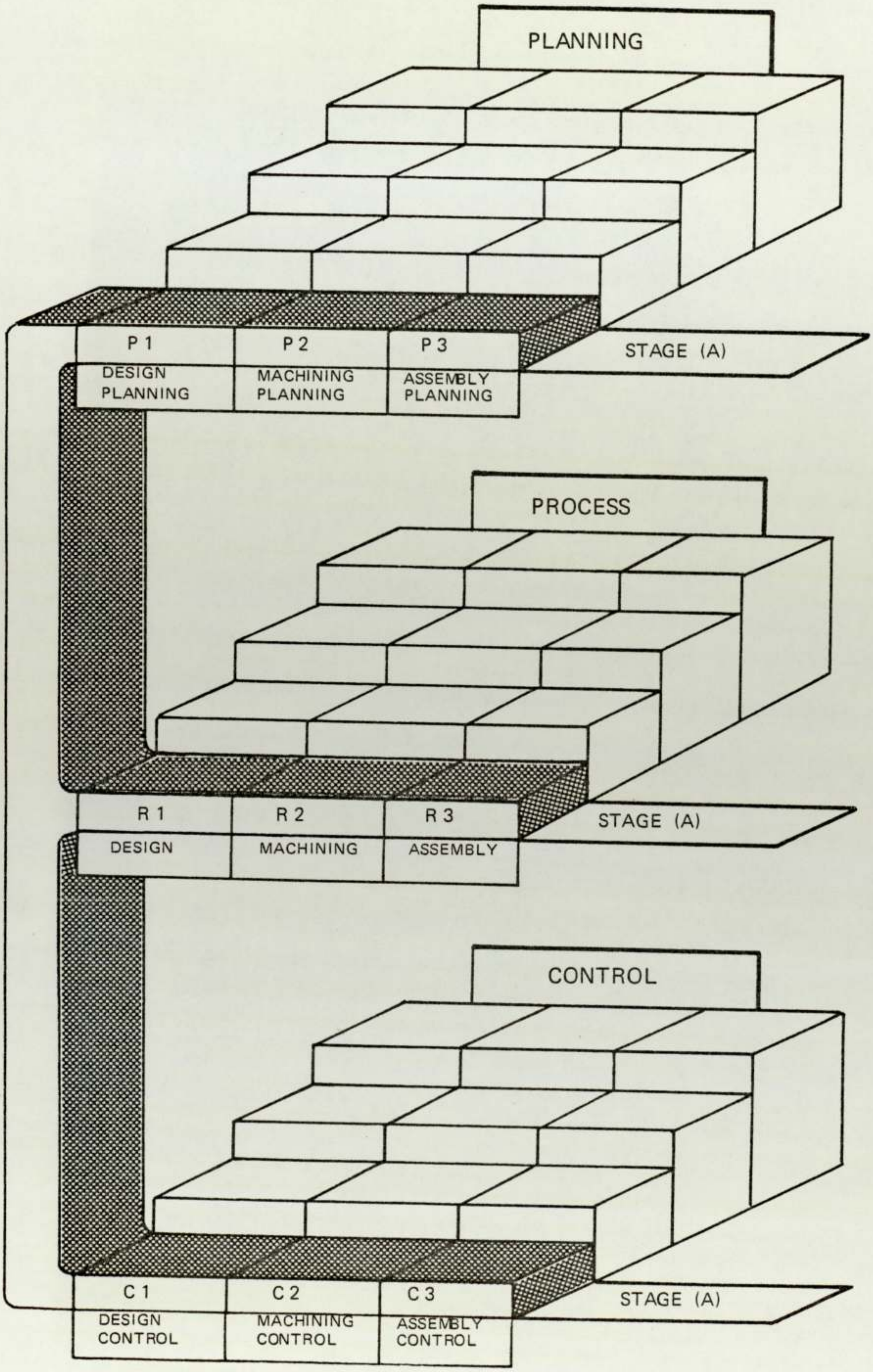


FIG. 77 STAGE BY STAGE SYSTEM INTEGRATION

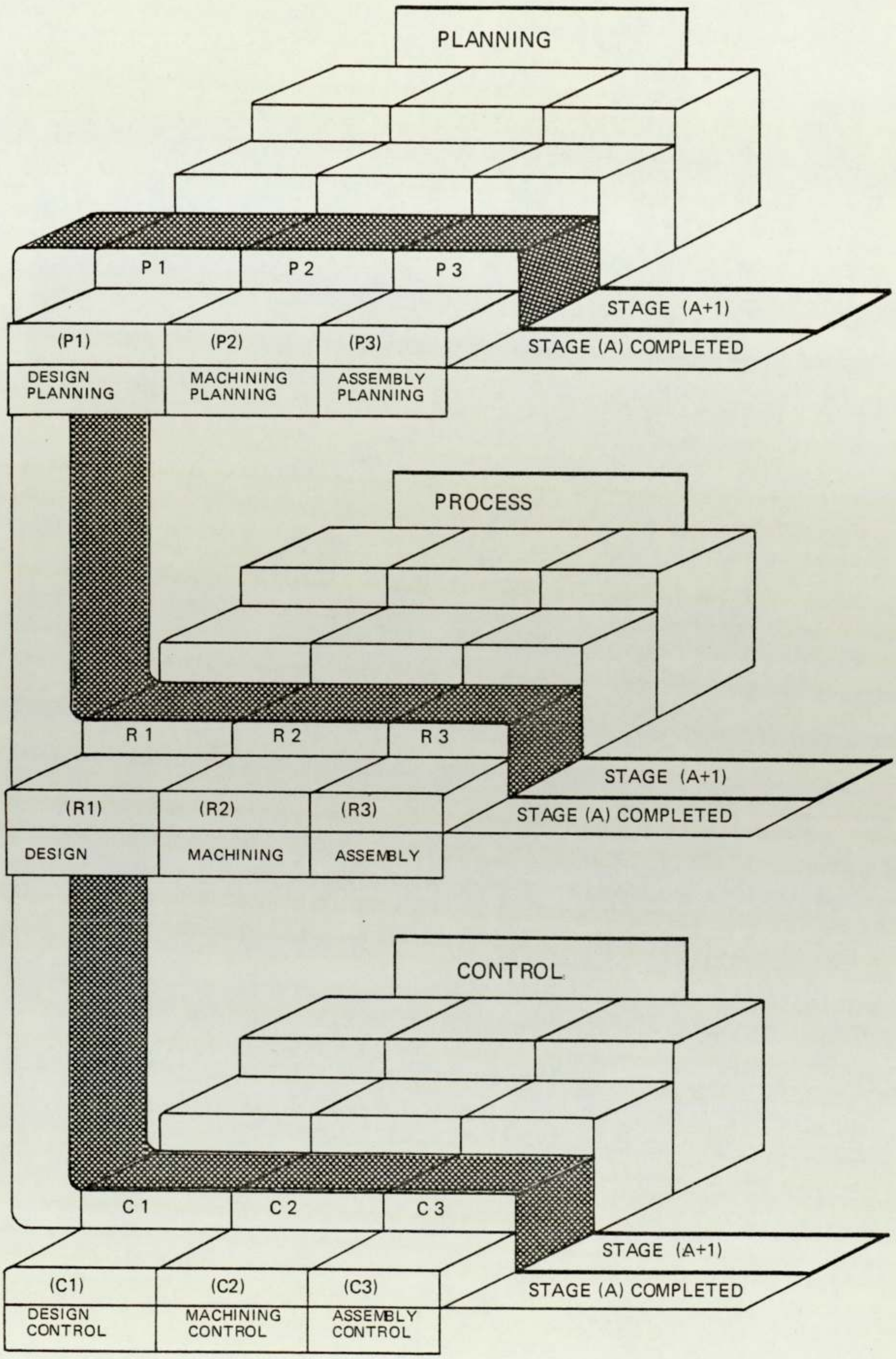


FIG. 78 SYSTEM INTEGRATION SECOND STAGE

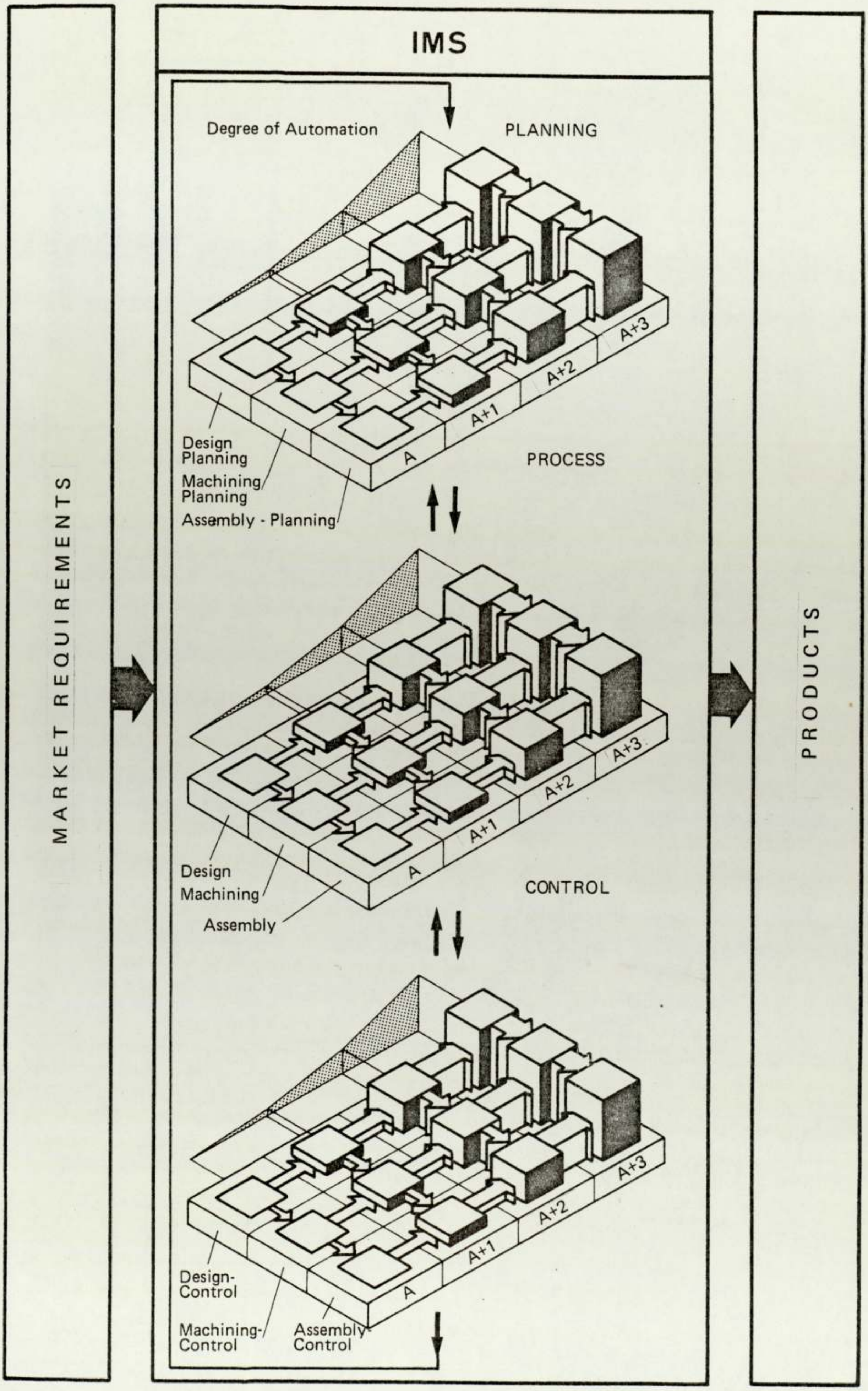


FIG. 79 SYSTEM– MODEL IMS

Solution-possibilities / Functions	POSSIBILITY 1 Conventional Solution	POSSIBILITY 2 Low degree of automation	POSSIBILITY 3 Medium degree of automation	POSSIBILITY 4 High degree of automation
	A	A + 1	A + 2	A + 3
realise design	1	2	3	4
realise machining	10	20	30	40
realise assembly	100	200	300	400

FIG. 80 STRUCTURE OF THE SOLUTION MATRIX

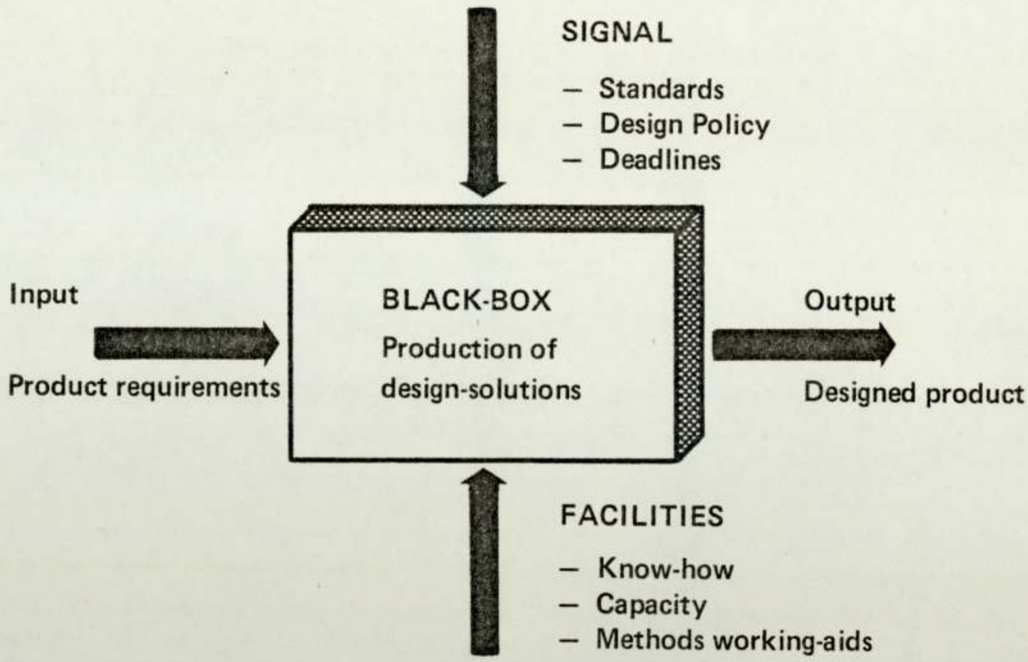


FIG. 81 THE DESIGN SYSTEM AS A "BLACK BOX"

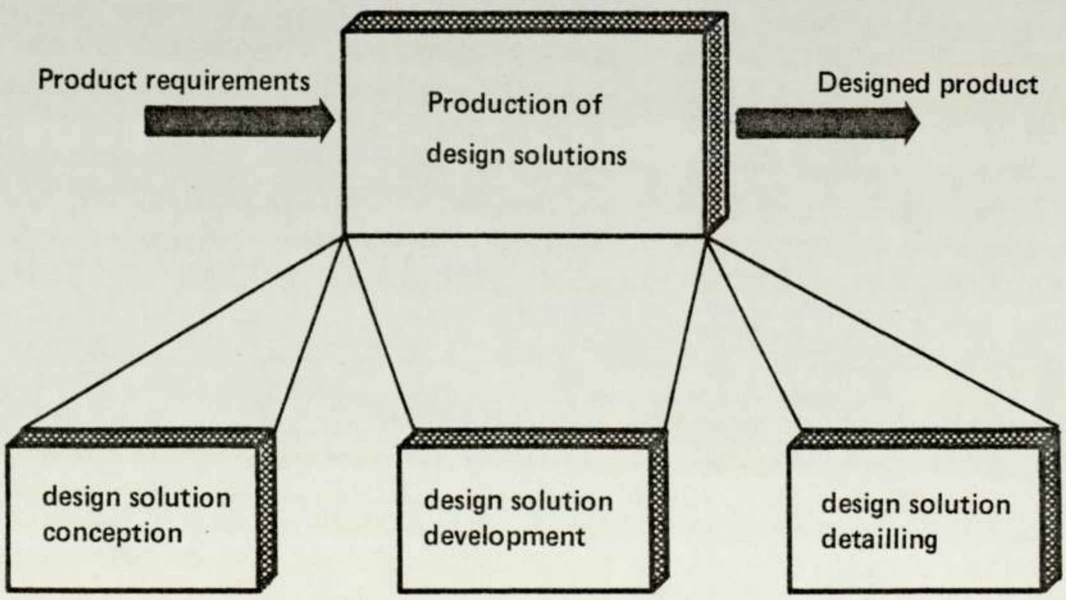


FIG. 82 FUNCTIONAL BREAKDOWN OF THE DESIGN-SYSTEM

FIG. 83: SOLUTION MATRIX FOR THE DESIGN PROCESS

Functions \ Solution possibilities	Possibility 1 Conventional solution	Possibility 2 Low degree of automation	Possibility 3 Medium degree of automation	Possibility 4 High degree of automation
PART–SOLUTIONS FOR "CONCEPTION" PHASE OF DESIGN PROCESS	. Solution–finding through intuition . manual calculation . manual draughting of the concept . usage of conventional tables, standards - sheets, etc.	. Solution–finding through intuition . computer–aided calculation . manual draughting of the concept . usage of computer-based and conventionally stored information	. Solution–finding through intuition and logic flow chart methods . computer–aided calculation . computer–aided draughting of the concept in dialogue mode	. Computer–aided solution–finding in dialogue mode with designer . computer–aided calculation . computer–aided draughting of the concept in dialogue mode . application of interactive computer systems
PART–SOLUTIONS FOR „DESIGNING" PHASE OF DESIGN PROCESS	. Solution–finding through intuition . manual calculation . manual draughting of the layout drawing . usage of conventional tables, standards–sheets etc.	. Solution–finding through intuition . computer–aided calculation . manual draughting of the layout drawing . usage of computer-based and conventionally stored information	. Solution–finding through intuition and logic flow–chart methods . computer–aided calculation . computer–aided draughting of the layout drawing	. Computer–aided solution–finding in dialogue mode with designer . computer–aided calculation . computer–aided draughting of the layout drawing . application of interactive computer-systems
PART–SOLUTIONS FOR „DETAILING" PHASE OF DESIGN PROCESS	. Manual draughting of detail drawings . manual control of detail drawings . usage of conventional tables, standards-sheets etc.	. Manual draughting of detail drawings . manual control of detail drawings . application of repeat workpiec e catalogue . application of computer–based information systems	. Computer–aided draughting of detail drawings . computer–aided control of detail drawings . application of computer–based information systems	. Computer–aided daughting and control of detail drawings . computer–aided preparation of NC machining data . application of computer–aided information systems

FIG. 83

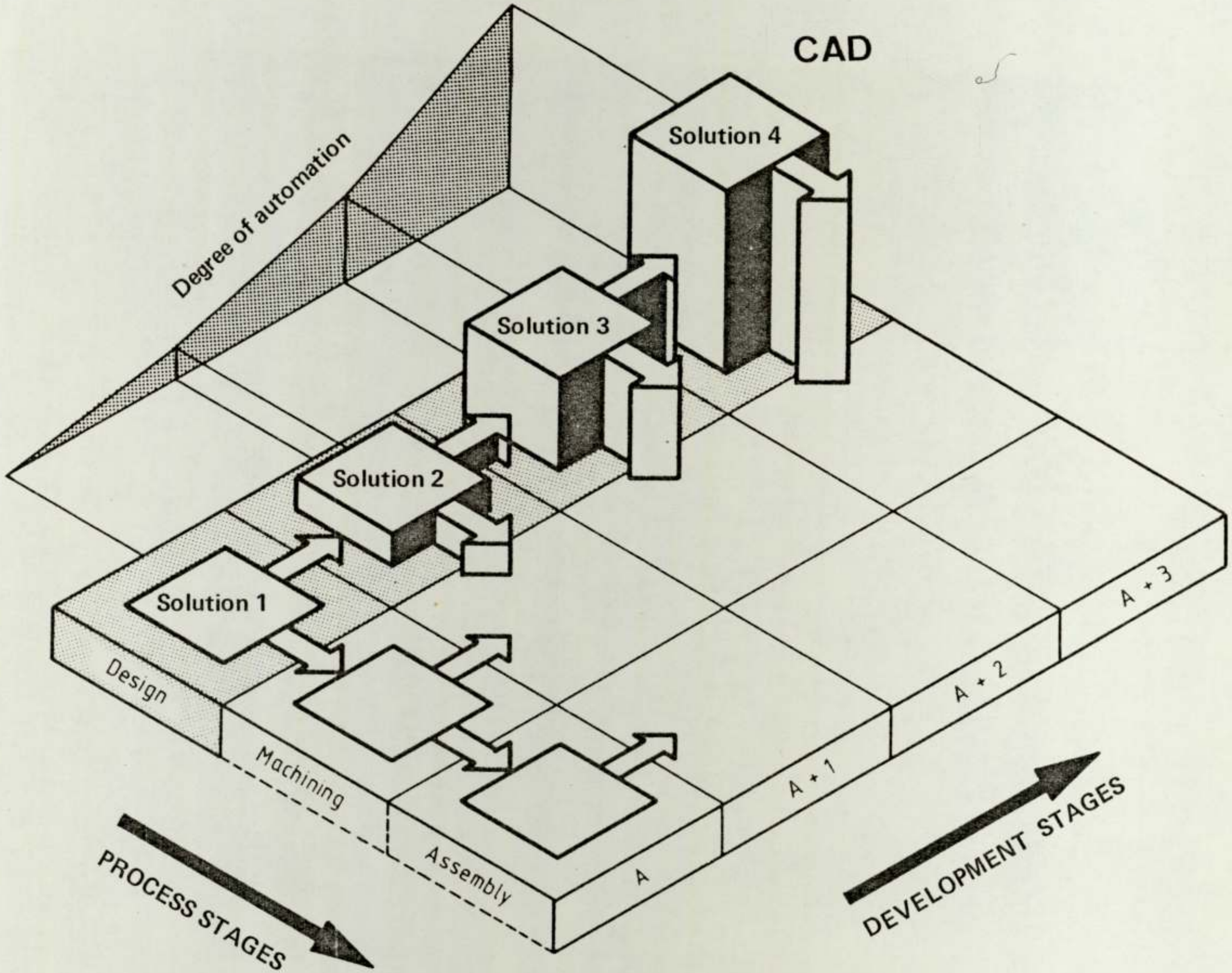


FIG. 84 DESIGN PROCESS SHOWING STAGE-BY-STAGE CAD SOLUTION CONCEPT

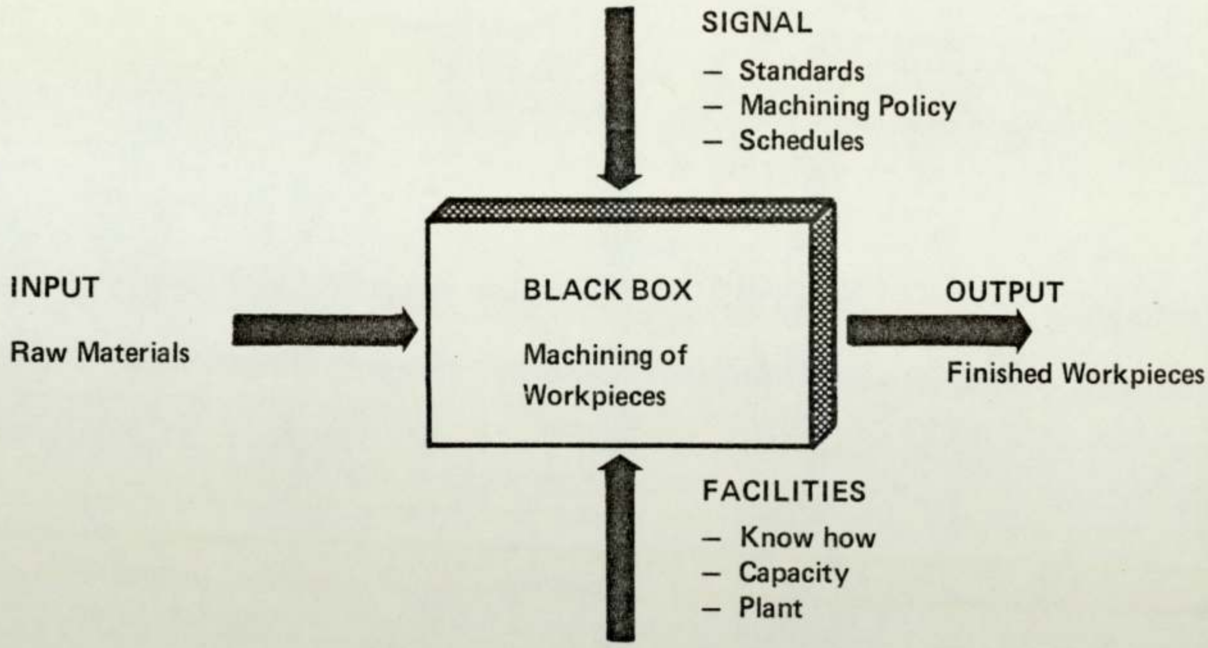


FIG. 85 THE MACHINING PROCESS AS A "BLACK BOX"

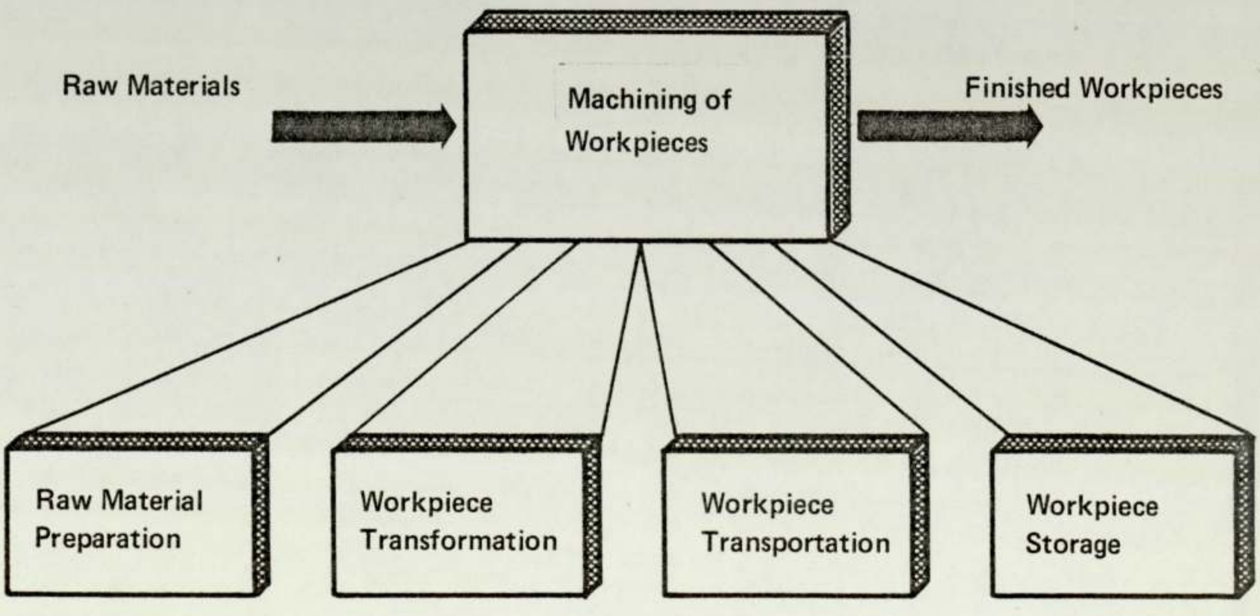


FIG. 86 FUNCTIONAL BREAKDOWN OF THE MACHINING PROCESS

FIG. 87: SOLUTION MATRIX FOR THE MACHINING PROCESS

Functions \ Solution possibilities	Possibility 1 Conventional solution	Possibility 2 Low degree of automation	Possibility 3 Medium degree of automation	Possibility 4 High degree of automation
RAW MATERIAL PREPARATION	. Conventional methods (pallettes, boxes, etc.) . manual information flow	. Combination of conventional methods and special stacking fixtures for robot application	. Combination of conventional methods and pallette systems . partially computer-aided information flow	. Automatically linked and palletted . computer–controlled information flow
WORKPIECE TRANSFORMATION	. Application of conventional machine tools . application of inflexible tooling . application of fixed jigs	. Application of NC machine tools . application of flexible tooling systems . application of modular jig – building systems . partial robot loading/unloading	. Application of DNC control . application of flexible tooling systems . application of modular jig–building systems . partial robot loading/unloading combined with coupled transport system	. Application of flexible machine systems . application of flexible tooling systems . application of modular palletted jig systems . application of robots and automated transport system
WORKPIECE TRANSPORTATION	. Flexible transport methods (fork – lifts, cranes, etc.) . manual information flow	. Flexible transport methods . partially computer aided information flow	. Combination of flexible and automatically linked systems . computer – aided information flow	. Application of automatically linked transport systems . computer – controlled information flow
WORKPIECE STORAGE	. Conventional methods (shelving, bins, etc.) . manual information flow	. Conventional methods . manual information flow	. Combination of conventional methods and pallettised storage systems . partial computer-aided information flow	. Coupled transport system / storage system . computer – controlled information flow

FIG. 87

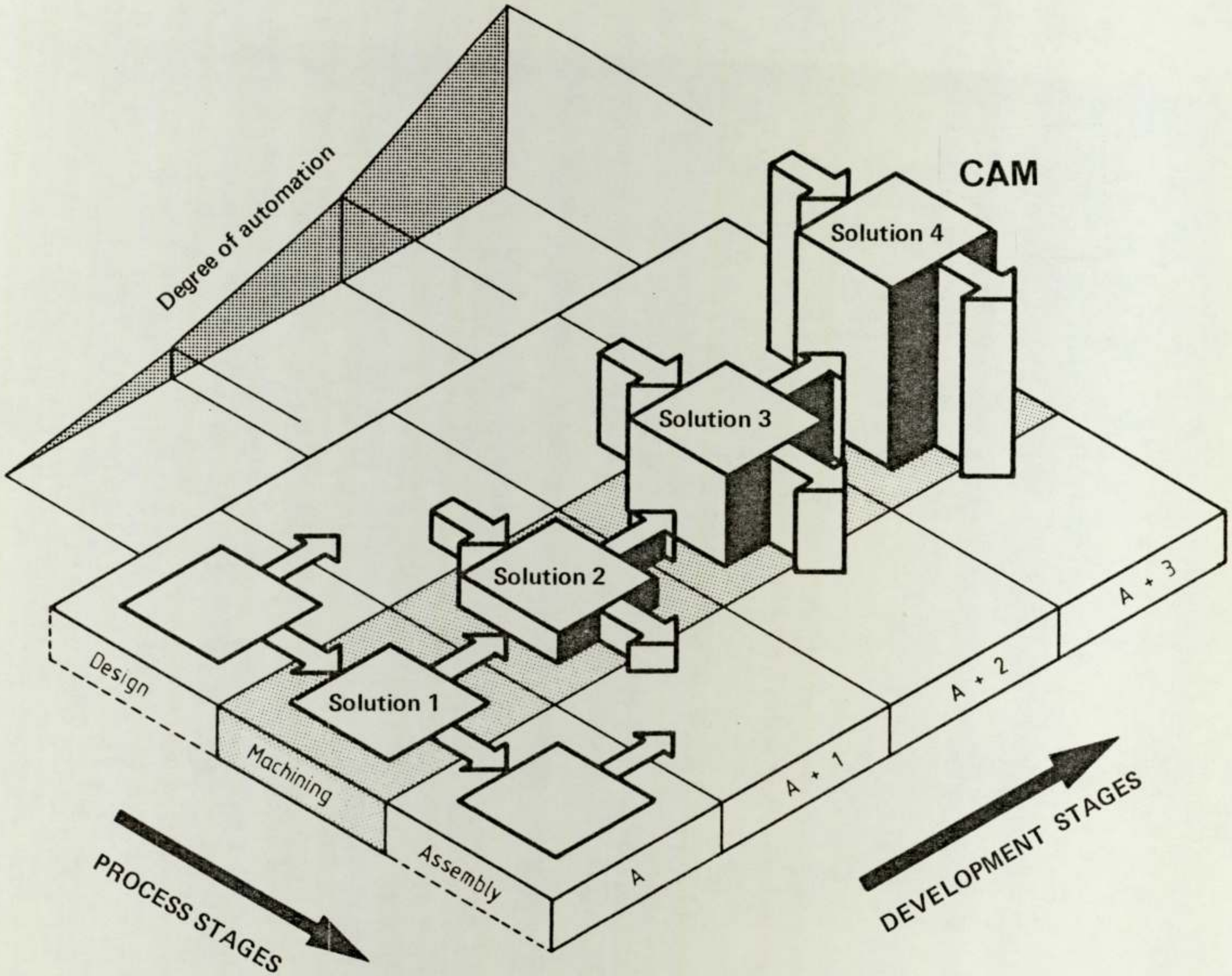


FIG. 88 MACHINING PROCESS SHOWING STAGE-BY-STAGE CAM SOLUTION CONCEPT

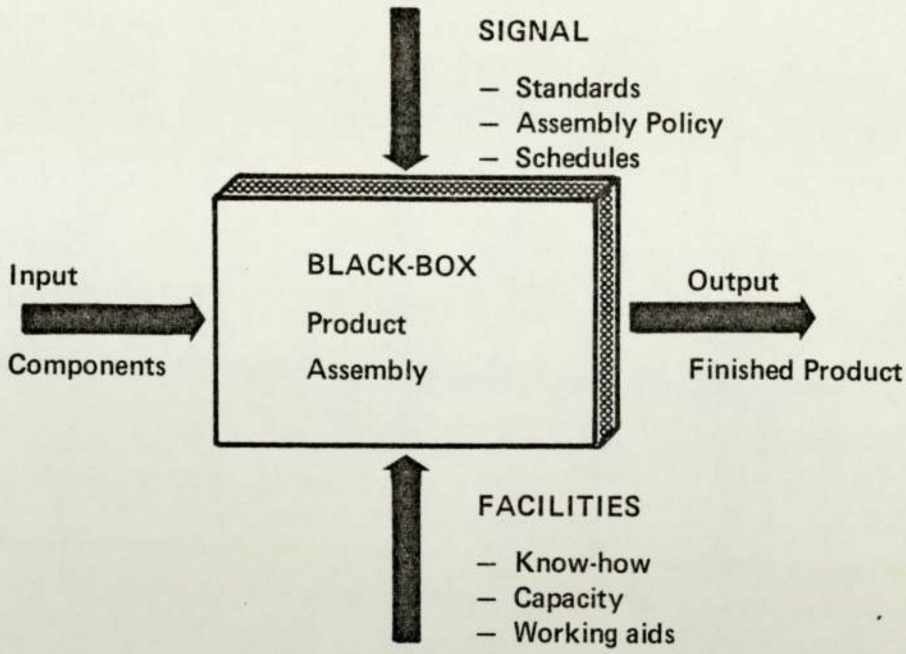


FIG. 89 THE ASSEMBLY PROCESS AS A "BLACK BOX"

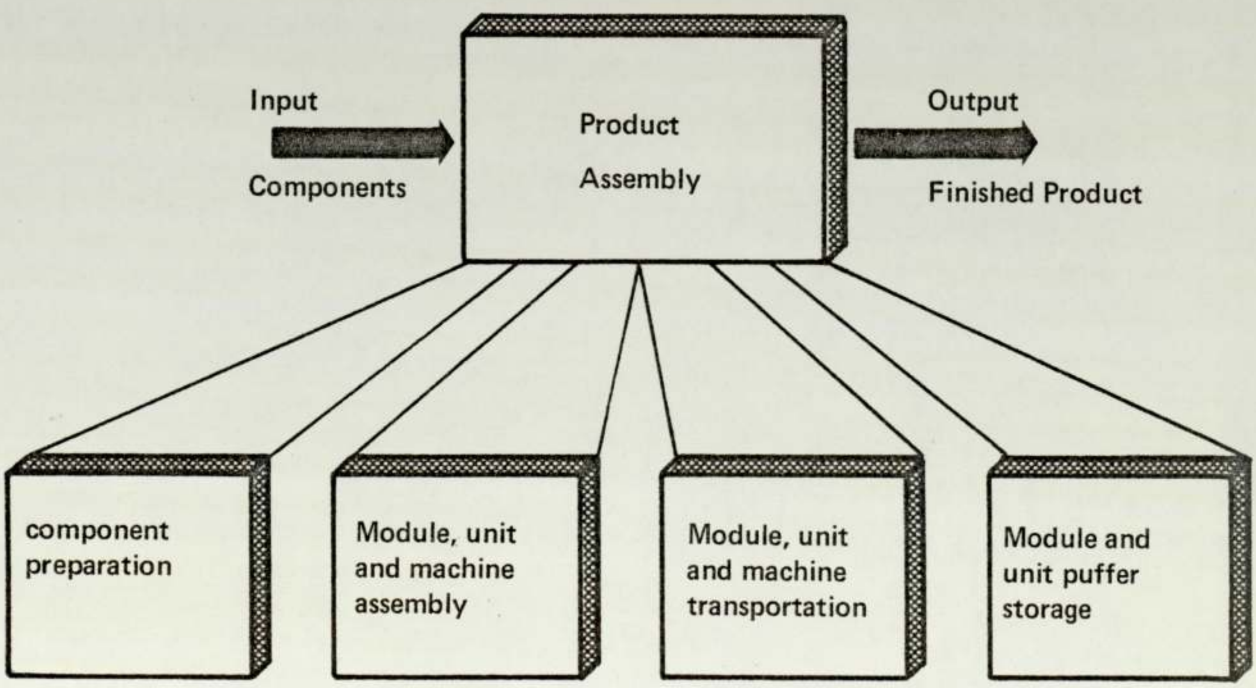


FIG. 90 FUNCTIONAL BREAKDOWN OF THE ASSEMBLY PROCESS

FIG. 91: SOLUTION MATRIX FOR THE ASSEMBLY PROCESS

Functions \ Solution possibilities	Possibility 1 Conventional solution	Possibility 2 Low degree of automation	Possibility 3 Medium degree of automation	Possibility 4 High degree of automation
COMPONENT PREPARATION	. Conventional methods (boxes etc.) grouped according to product structure breakdown . manual information flow	. conventional methods grouped to product structure breakdown . manual information flow	. Combination of conventional methods and pallette – systems . partially computer-aided information flow	. Automatically linked and palletted . computer – controlled information flow
MODULE, UNIT AND MACHINE ASSEMBLY	. Manual assembly . application of conventional assembly tooling . application of conventional assembly jigs . assembly procedure according to product structure breakdown	. Combination of manual assembly and computer – aided assembly instructions . application of conventional assembly tooling . application of conventional assembly jigs . computer – aided information flow	. Combination of manual and automated assembly technologies (e.g. assembly robots) . application of flexible assembly tooling systems . partial application of flexible assembly-jig systems . computer – aided information flow	. Application of flexible automatically linked assembly systems . application of assembly – robots and transport systems . application of flexible assembly tooling systems . application of flexible assembly jig system . computer – controlled information flow
MODULE, UNIT AND MACHINE TRANSPORTATION	. Flexible transport methods (fork – lifts, crans, etc.) . manual information flow	. Flexible transport methods . partially computer-aided information flow	. Combination of flexible and automatically linked systems . computer – aided information flow	. Application of automatically linked transport systems . computer – controlled information flow
MODULE AND UNIT PUFFER STORAGE	. Conventional methods (shelving) . manual information flow	. Conventional methods . manual information flow	. Combination of conventional methods and pallettised storage systems . partial computer-aided information flow	. Coupled transport system / storage system . computer – controlled information flow

FIG. 91

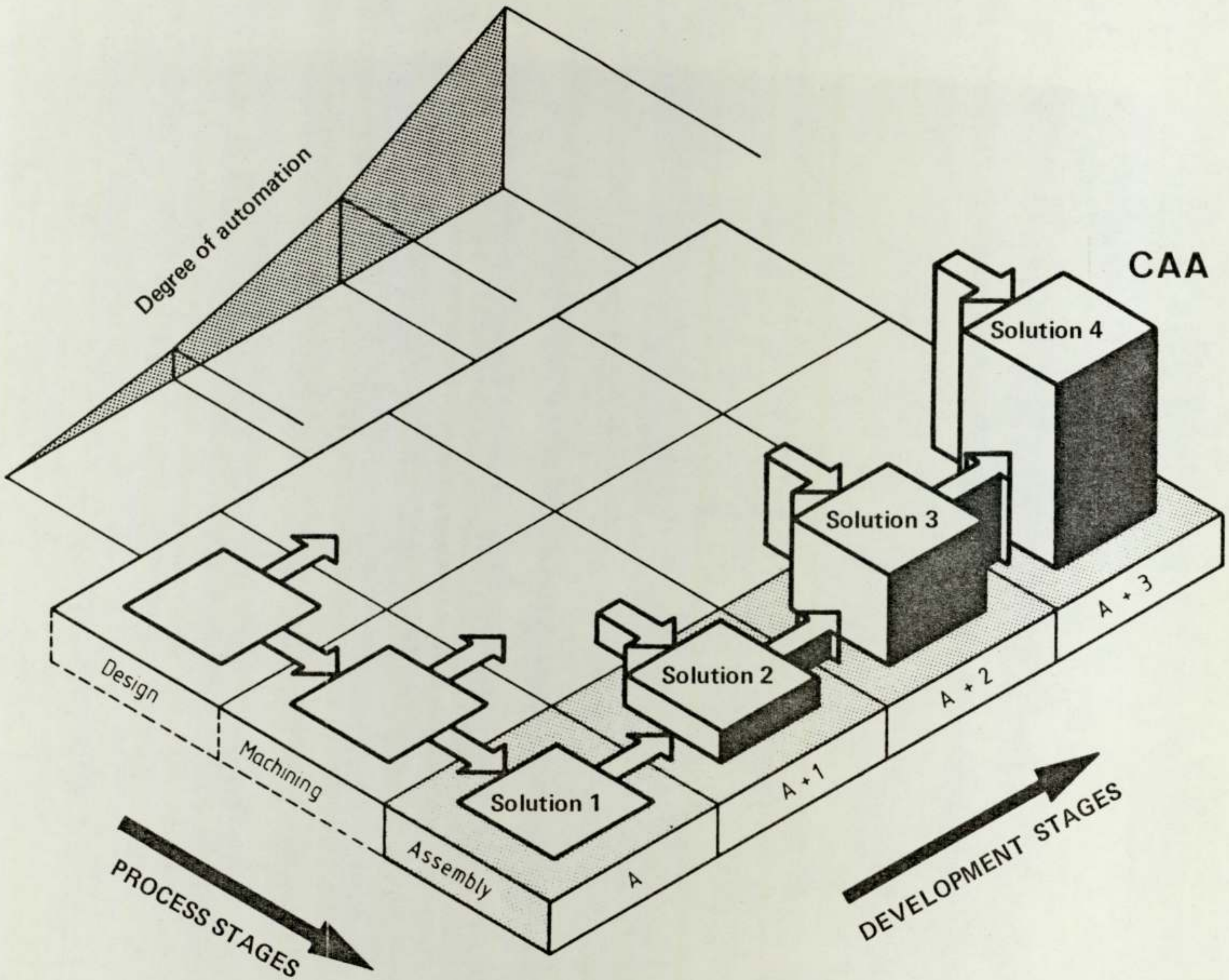


FIG. 92 ASSEMBLY PROCESS SHOWING STAGE-BY-STAGE CAA SOLUTION CONCEPT

FIG. 92

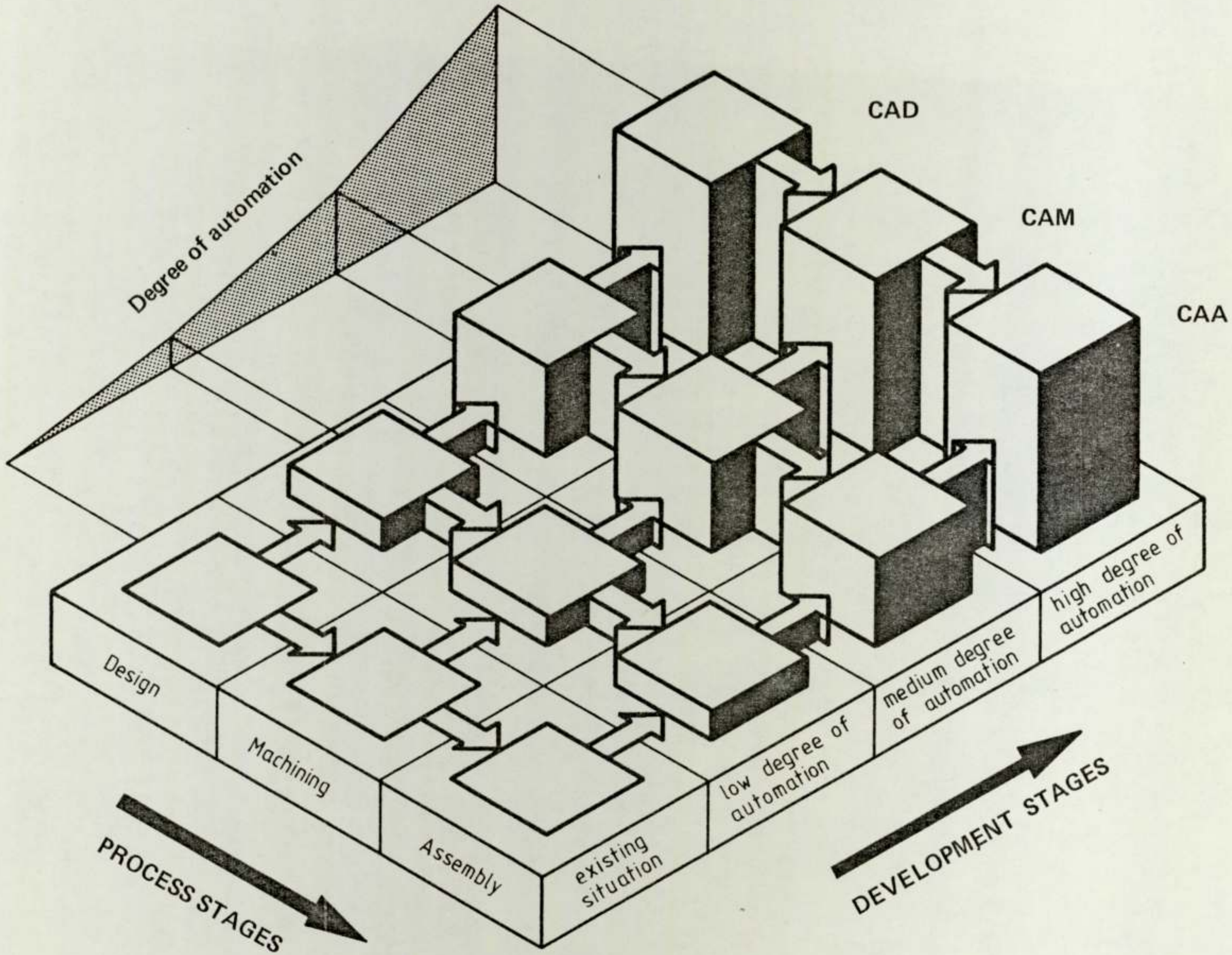


FIG. 93 SOLUTION-CONCEPT FOR THE OVERALL PROCESS CAD, CAM, CAA

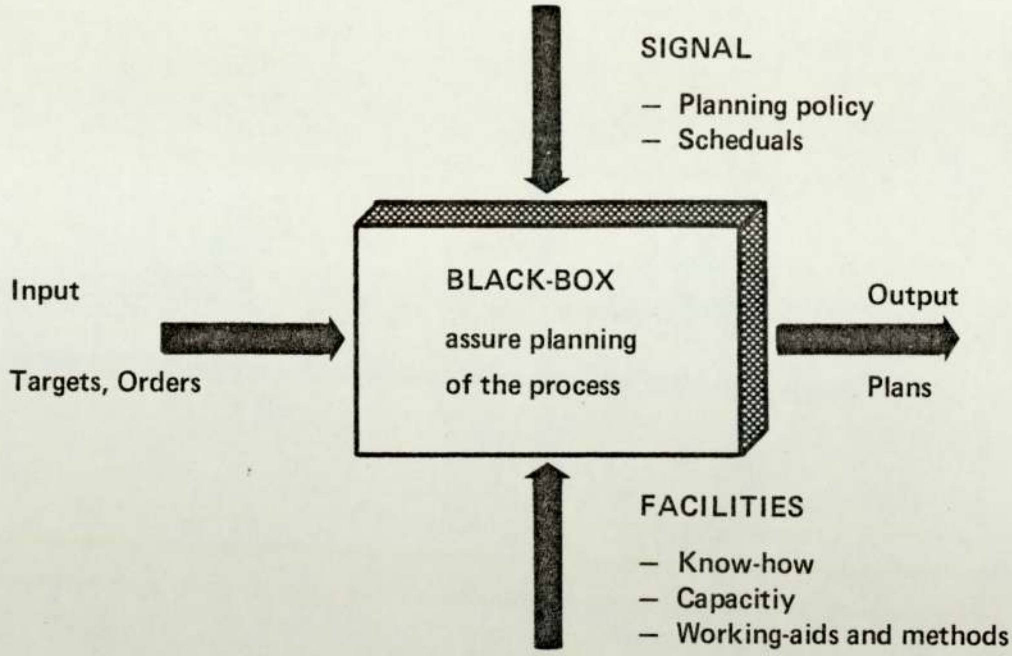


FIG. 94 PLANNING AS A "BLACK-BOX"

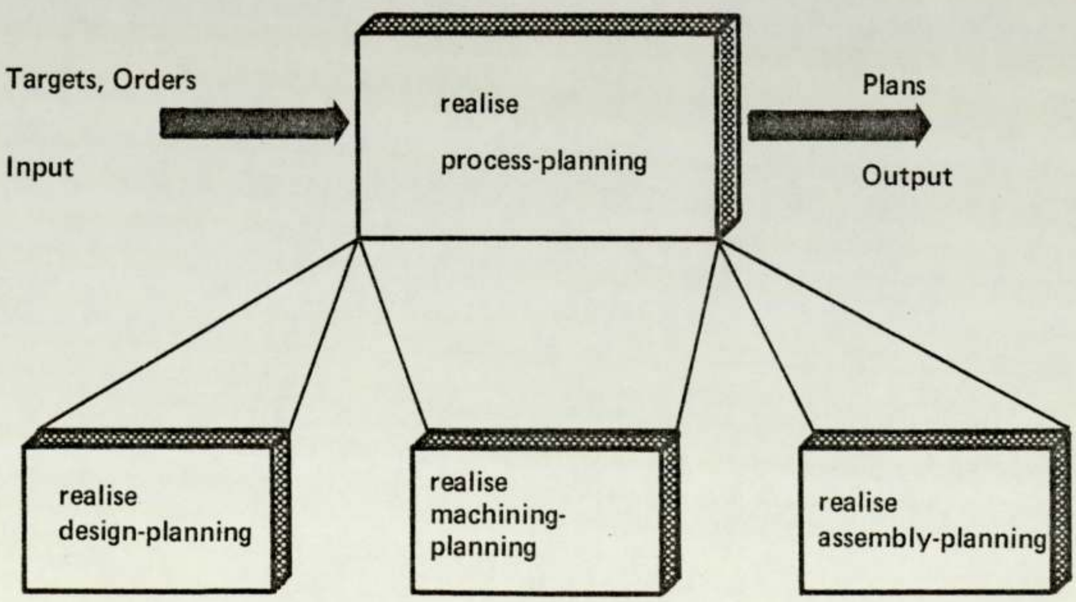


FIG. 95 FUNCTIONAL BREAKDOWN OF "PLANNING"

FIG. 96: SOLUTION MATRIX FOR THE "PLANNING" SUB – SYSTEMS

Functions \ Solution possibilities	Possibility 1 conventional solution	Possibility 2 low degree of automation	Possibility 3 medium degree of automation	Possibility 4 high degree of automation
DESIGN PLANNING	– Design costs planning-manual – Capacity planning manual – Schedualing manual – Design work preparation manual – Information system manual	– Design costs planning manual – Capacity planning manual – Schedualing manual – Design work preparation and computer – aided – Computerised information systems	– Design costs planning manual – Capacity planning and Schedualing computer-aided – Design work preparation computer – aided – Computerised information systems	– Design costing, capacity planning and schedualing in computer – aided dialogue – mode – Design work preparation in dialogue mode – Information systems in dialogue – mode
MACHINING PLANNING	– Machining costs planning manual – Operations – sheet preparation manual – Capacity planning man. – Schedualing manual – Materials management manual – Administrative work manual – Information systems manual	– Machining costs planning manual – Capacitiy planning and Schedualing manual / automated – Materials management and administrative work manual – Computer – aided preparation of operations-sheets – Computerised information systems	– Design costs,planning, Capacity planning and schedualing in computer dialogue – mode – Materials management in computer dialogue mode – Computer – aided preparation of operations-sheets – Computerised information systems	– Machining costs planning, capacity planning and schedualing in computer dialogue – mode – Materials management and administrative work in computer dialogue – mode – Operation – sheets preparation in dialogue – mode – Information systems in dialogue – mode
ASSEMBLY PLANNING	– Assembly costs planning manual – Assembly plan preparation manual – Capacity planning man. – Schedualing manual – Materials management and administrative work manual – Information systems manual	– Assembly costs planning manual – Capacity planning and schedualing manual – Materials management and administrative work manual – Computer – aided assembly plan preparation – Computerised information systems	– Assembly costs,planning, capacity and schedualing in computer dialogue – mode – Materials management and administrative work in computer dialogue mode – Computer – aided assembly plan preparation – Computerised information systems	– Assembly cost planning, capacity planning and schedualing in computer dialogue – mode – Assembly plan preparation in computer dialogue – mode – Information systems in dialogue – mode

FIG. 96

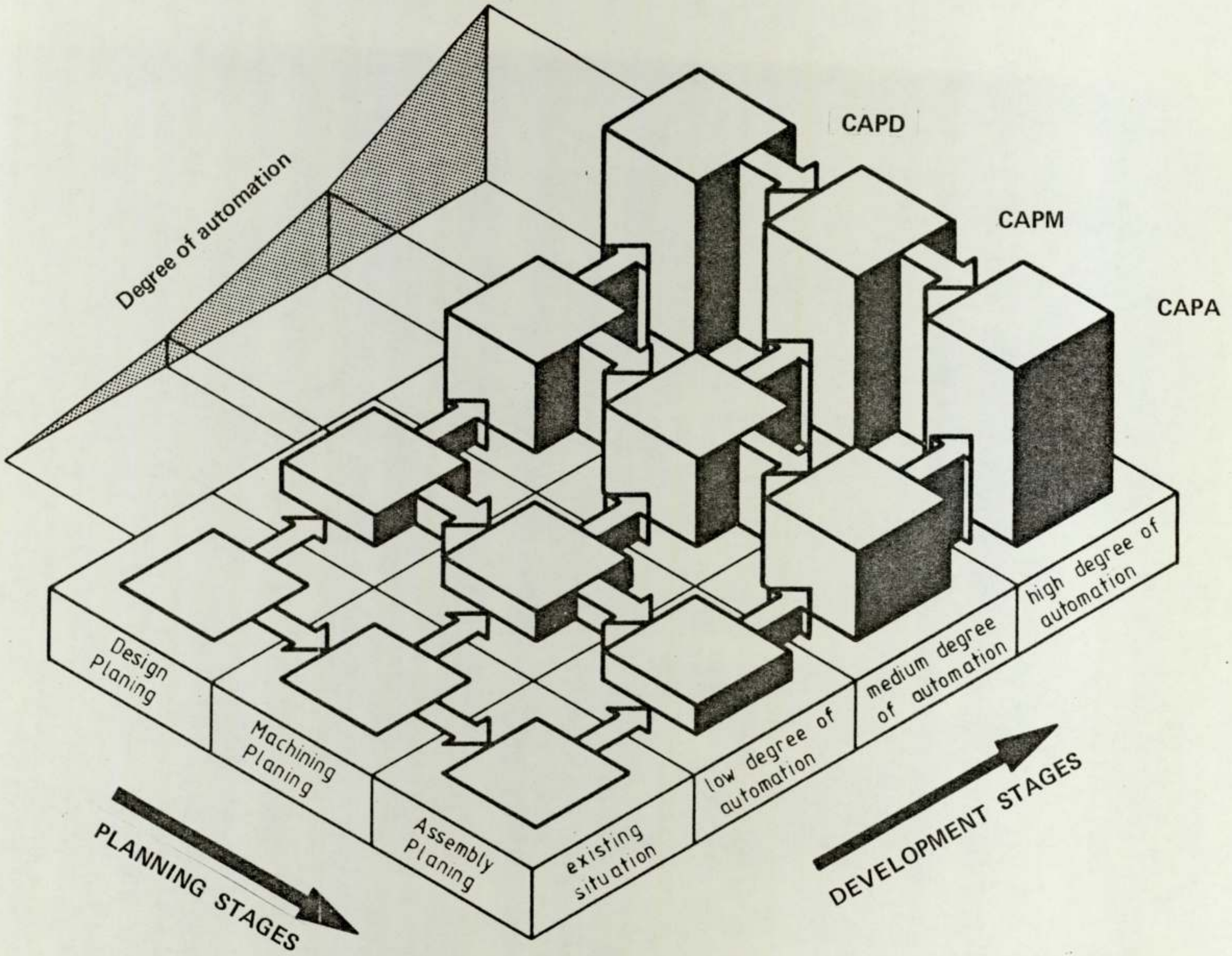


FIG. 97 OVERALL SOLUTION CONCEPT FOR PLANNING CAP (CAPD, CAPM, CAPA)

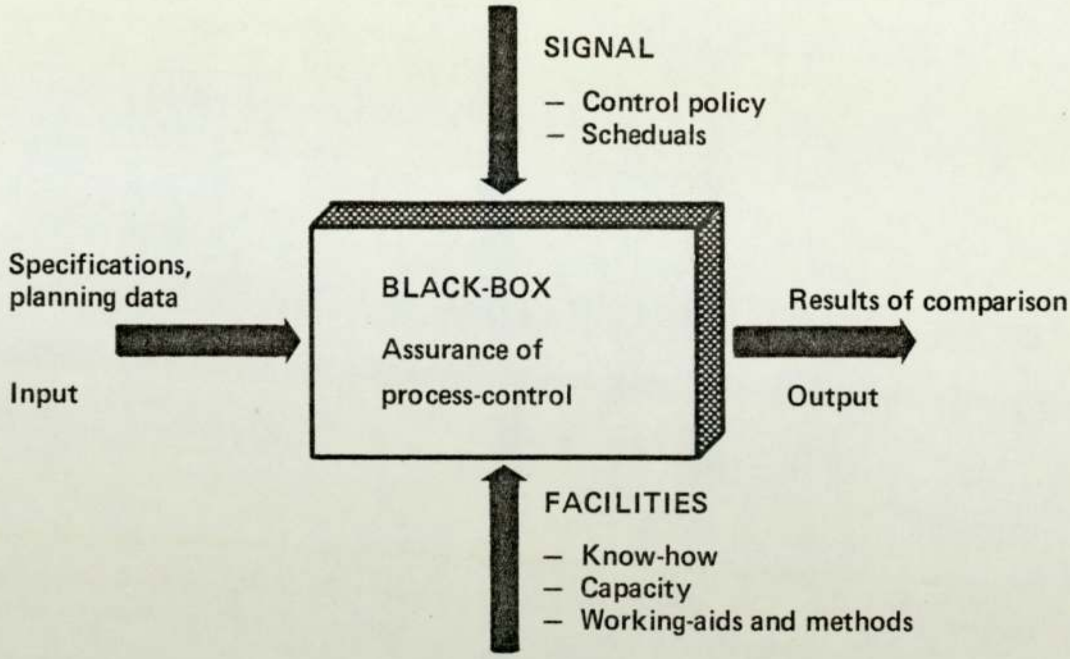


FIG. 98 CONTROL AS A "BLACK-BOX"

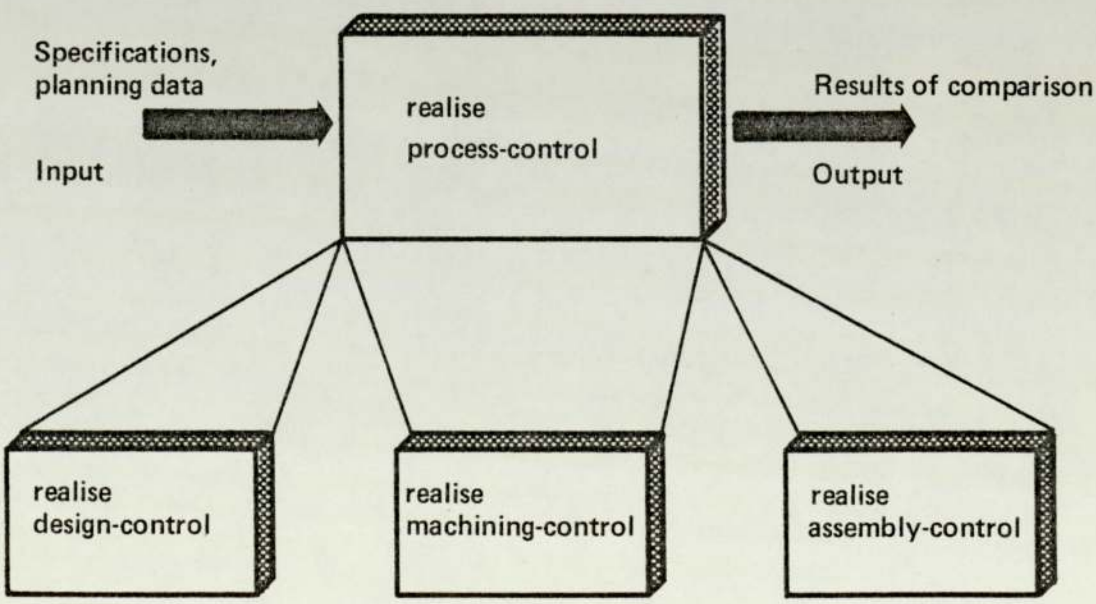


FIG. 99 FUNCTIONAL BREAKDOWN OF "CONTROL"

Solution possibilities / function	Possibility 1 conventional solution	Possibility 2 low degree of automation	Possibility 3 medium degree of automation	Possibility 4 high degree of automation
DESIGN CONTROL	– Data retrieval manual (times, quantities . . .) – Standards control of drawings and parts-lists manual – Costing control manual – Data evaluation manual – Schedualing control manual – Information systems manual	– Design costing schedualing manual – Standards control of drawings and parts-lists manual/automated – Data retrieval and processing manual/automated – Application of computerised information systems	– Data retrieval and processing automated in computer dialogue-mode – Standards control of drawings and parts-lists manual/automated – Application of computerised information systems	– Data retrieval and processing automated in computer dialogue-mode – Standards control of drawing and parts-lists computer - aided – Application of dialogue – mode information systems
MACHINING CONTROL	– Data retrieval manual (times, quantities . . .) – Schedualing control manual – Quality control manual – Information systems manual	– Schedualing control manual – Quality control manual + NC measuring machine – Data retrieval and processing semi – automated – Application of computerised information systems	– Data retrieval and processing automated in computer dialogue-mode – Quality control manual + NC measuring machine – Application of computerised information systems	– Data retrieval and processing automated in computer dialogue-mode – Quality control with computer – aided NC measuring machines – Application of dialogue – mode information systems
ASSEMBLY CONTROL	– Data retrieval manual (times, quantities . . .) – Schedualing control manual – Quality control and inspection manual – Data evaluation manual – Information systems manual	– Schedualing control manual – Quality control and inspection manual – Data retrieval and processing semi – automated – Application of computerised information systems	– Data retrieval and processing automated in computer dialogue-mode – Qualitiy control and inspection manual/automated – Application of computerised information systems	– Data retrieval and processing automated in computer dialogue-mode – Quality control and inspection with computer – aided test machine – Application of dialogue – mode information systems

FIG. 100: SOLUTION MATRIX FOR THE „CONTROL" SUB–SYSTEMS

FIG. 100

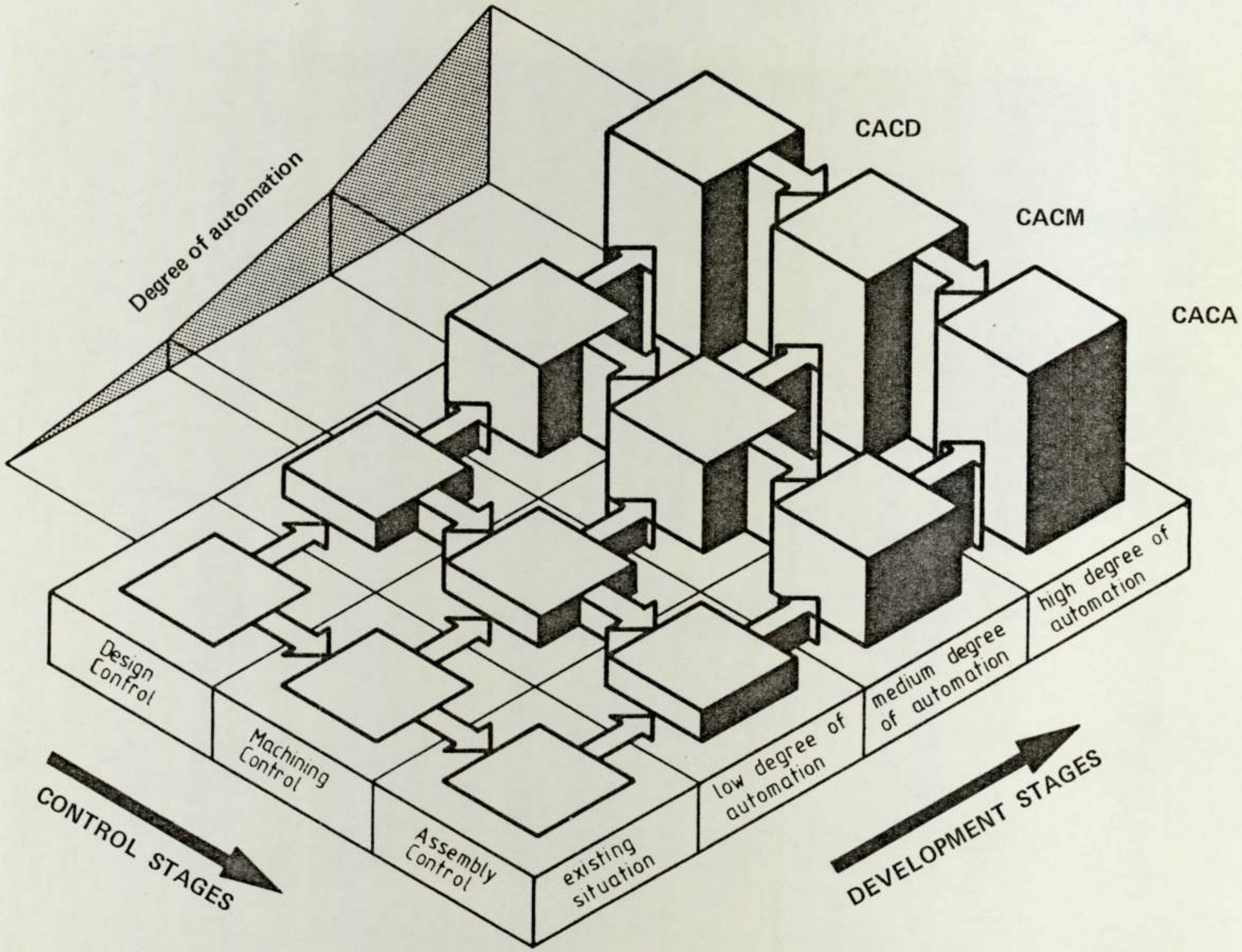


FIG. 101 OVERALL SOLUTION CONCEPT FOR CONTROL CAC (CACD, CACM, CACA)

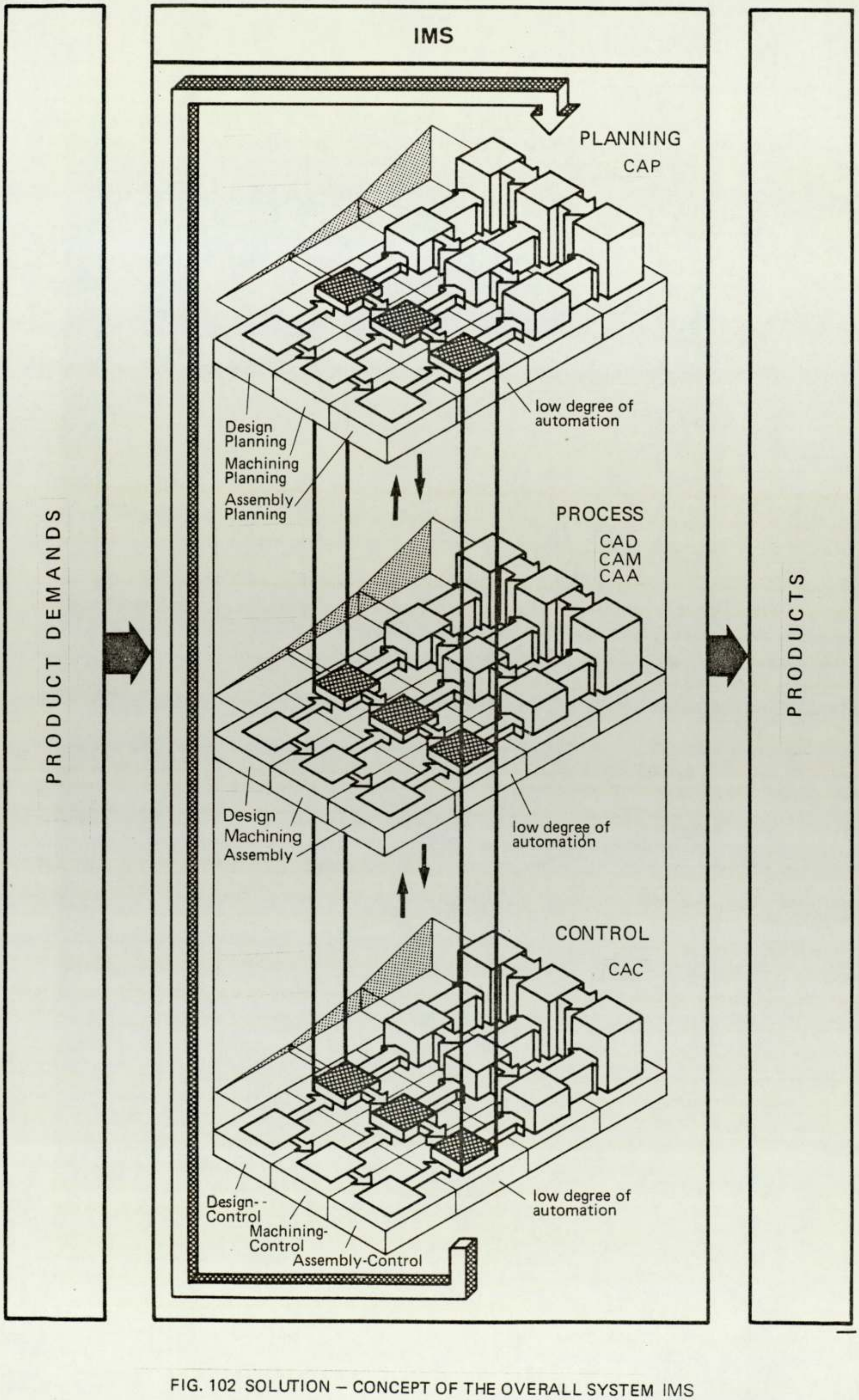


FIG. 102 SOLUTION – CONCEPT OF THE OVERALL SYSTEM IMS

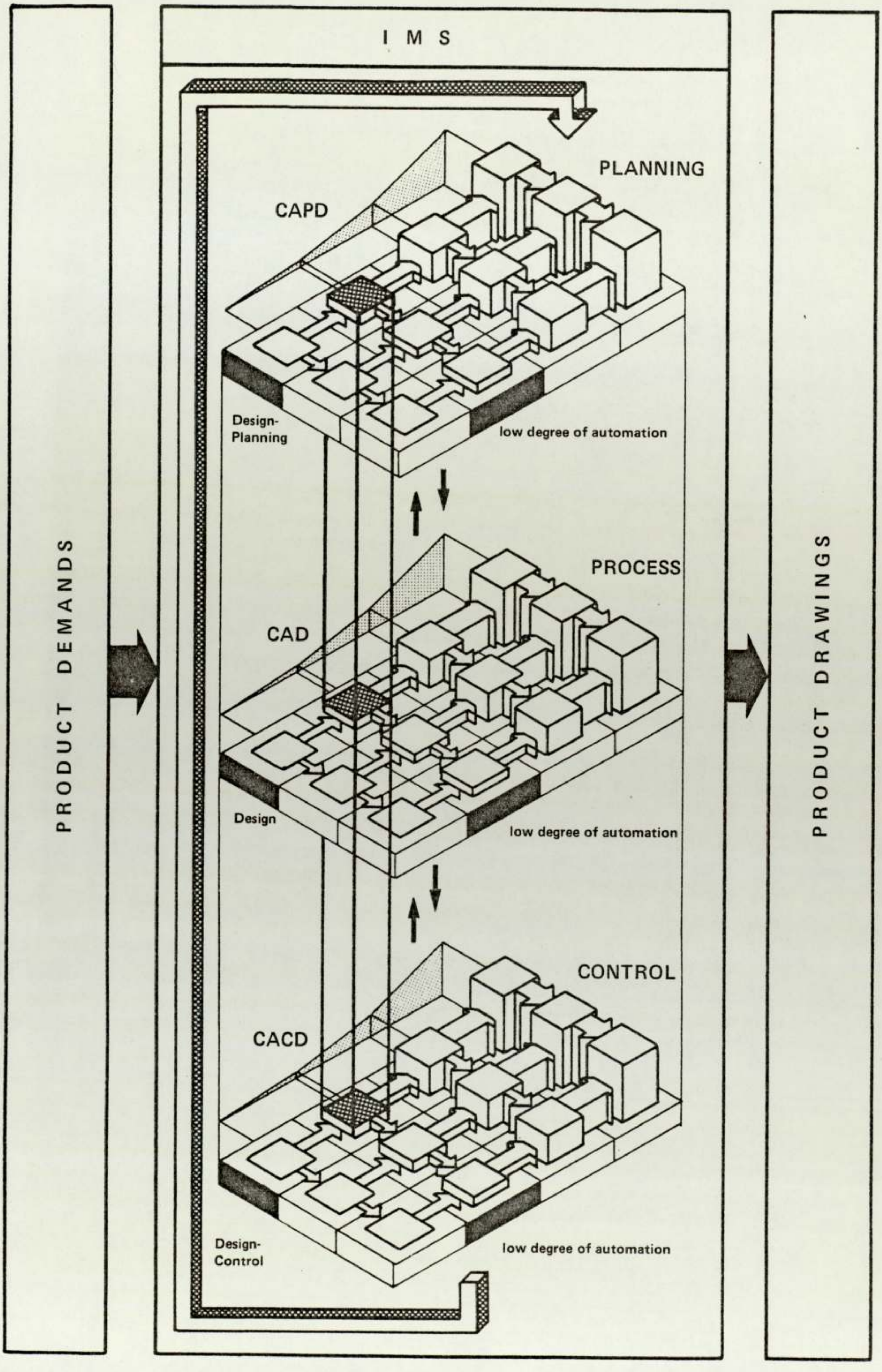


FIG. 103 DESIGN SYSTEM OF THE IMS

FIG. 103

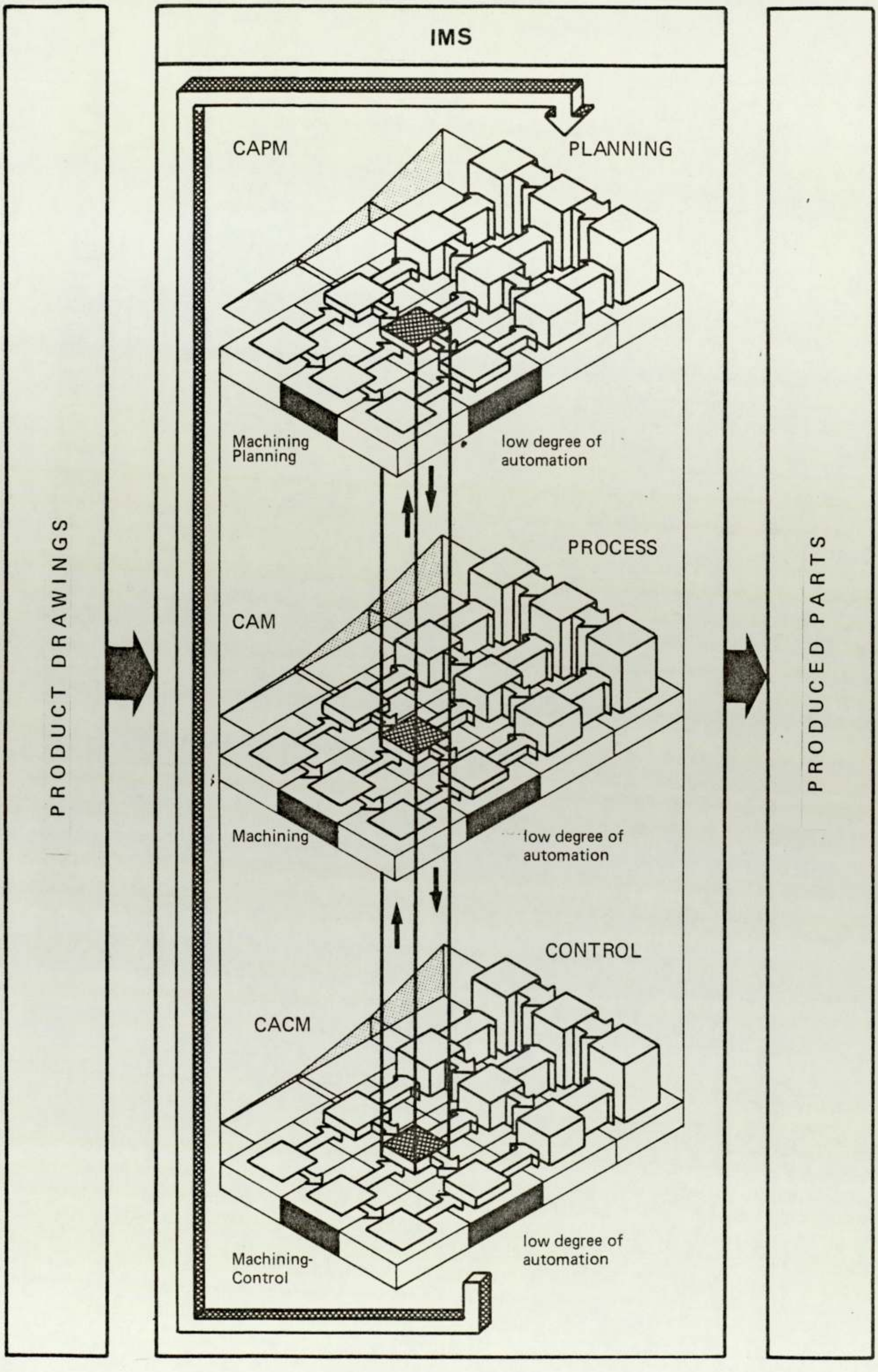


FIG. 104 MACHINING SYSTEM OF THE IMS

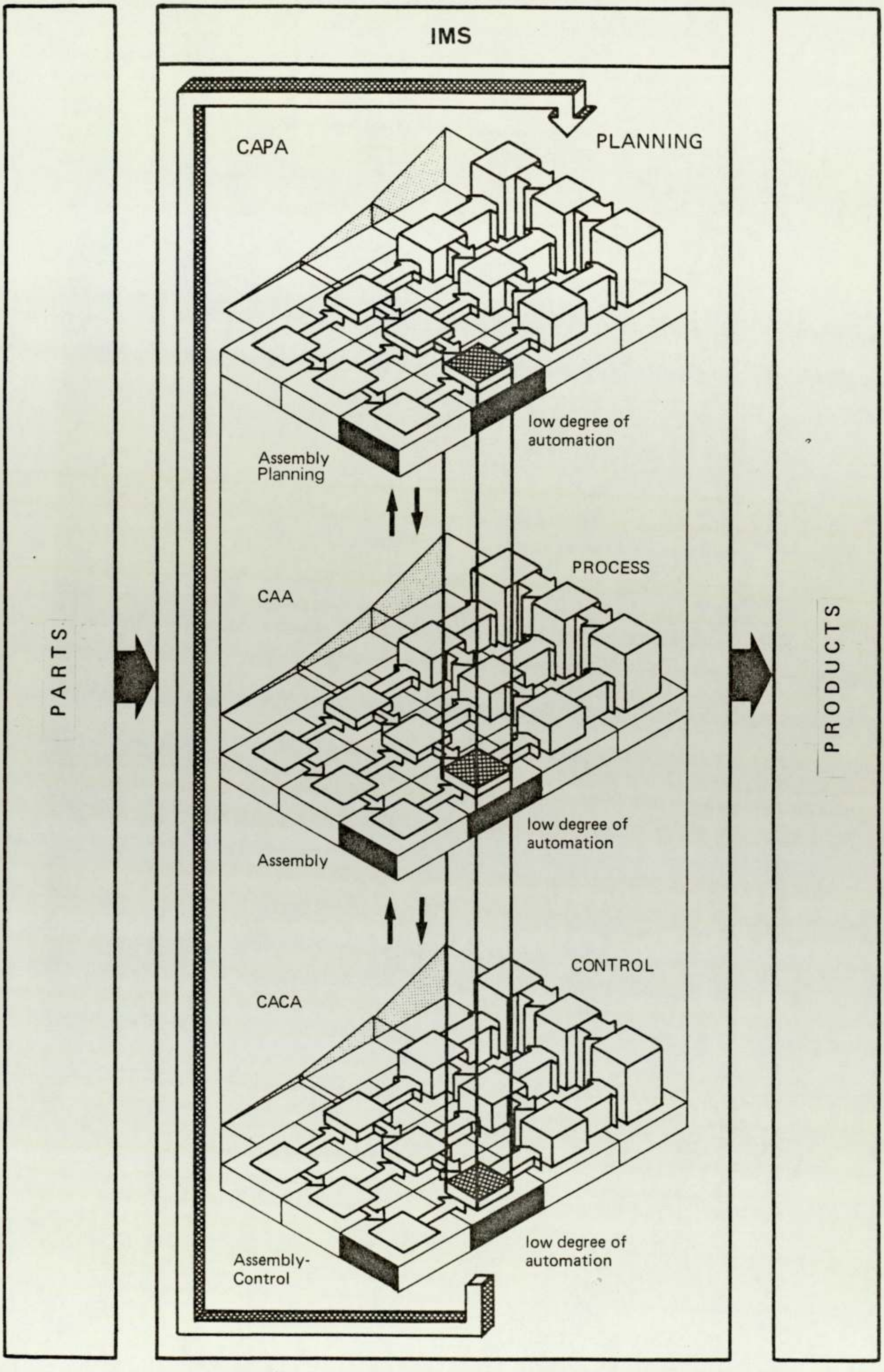


FIG. 105 ASSEMBLY SYSTEM OF THE IMS

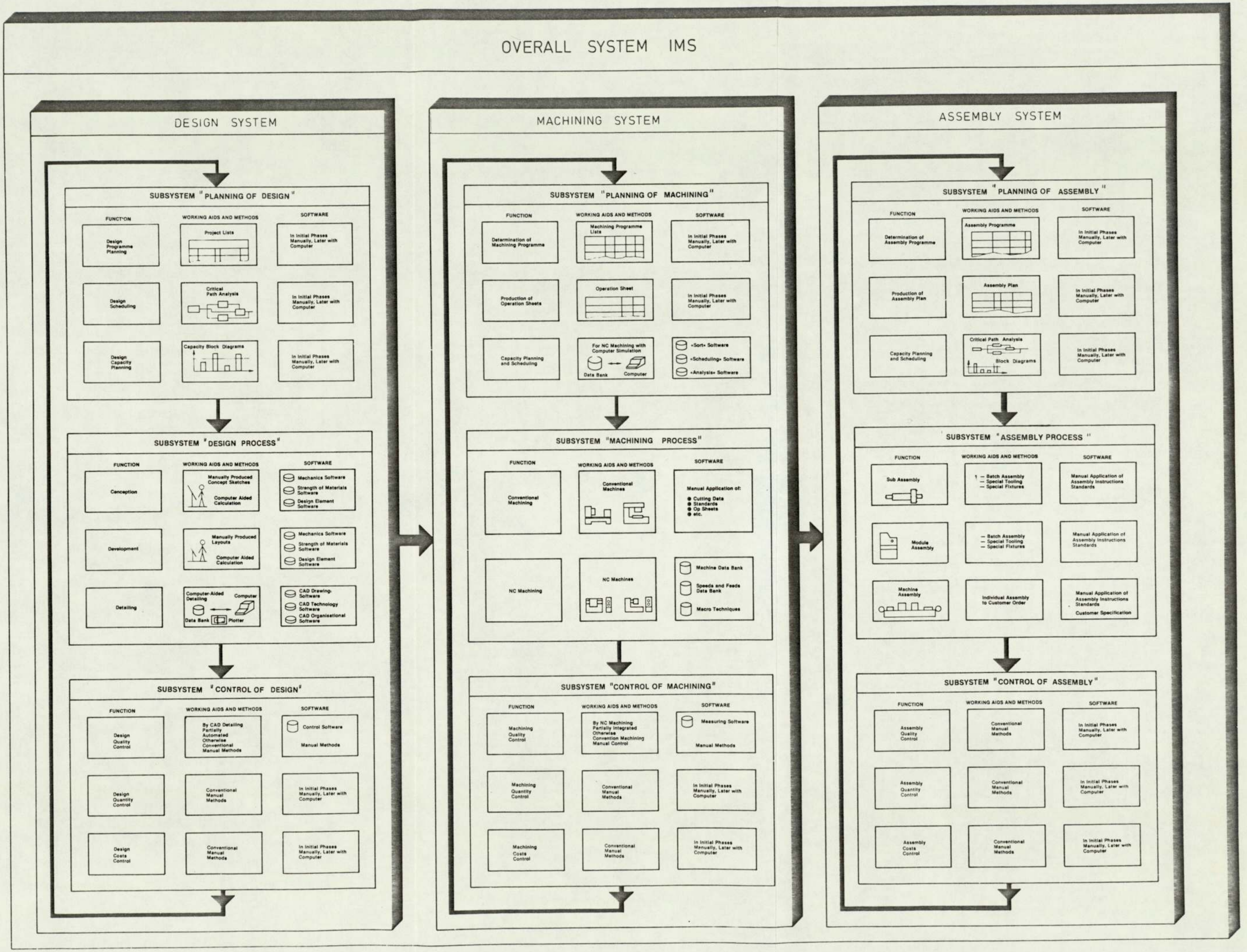


FIG. 106 OVERALL SOLUTION IMS

FIG. 106

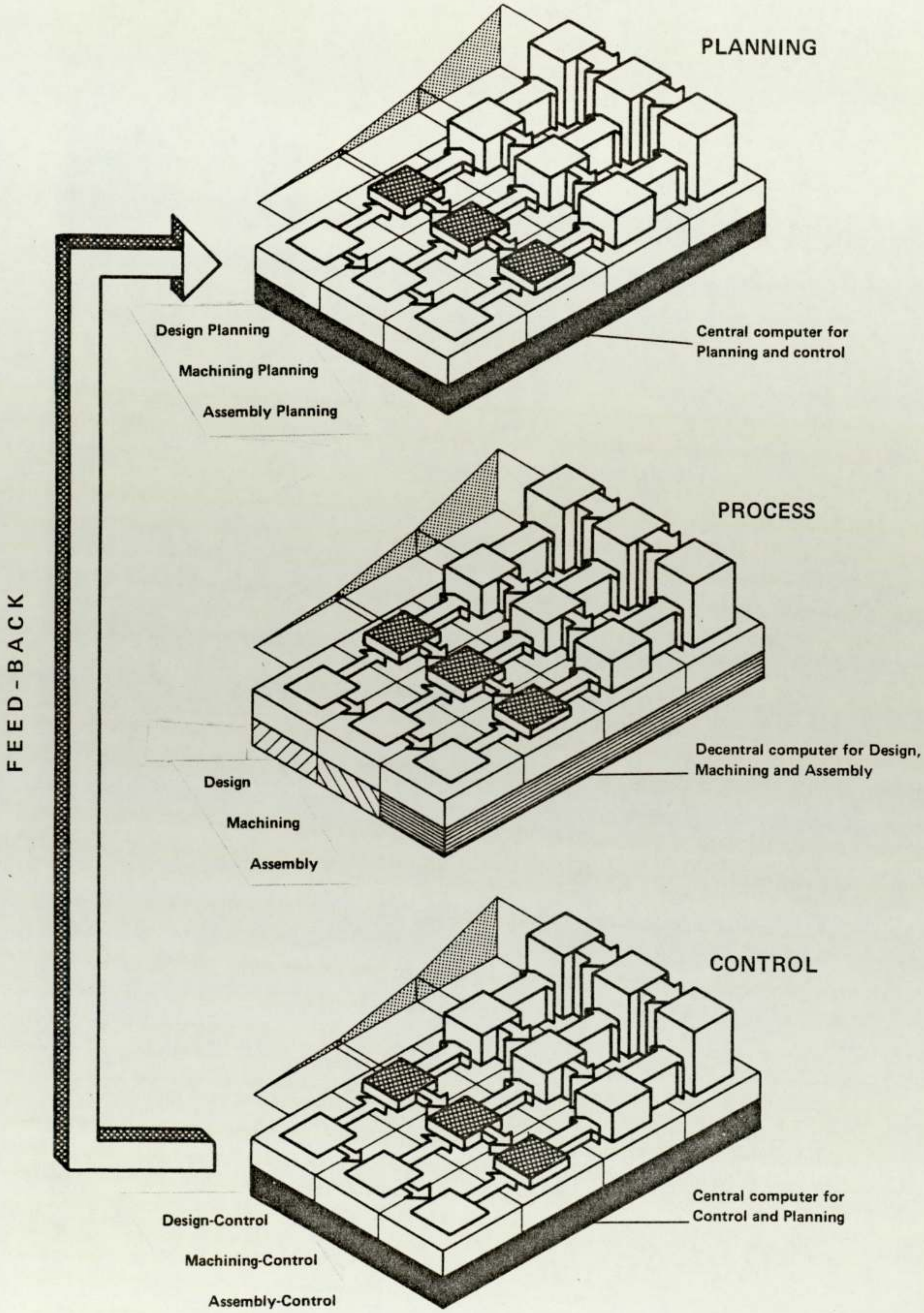


FIG. 107 CONCEPT FOR COMPUTER HARDWARE APPLICATION

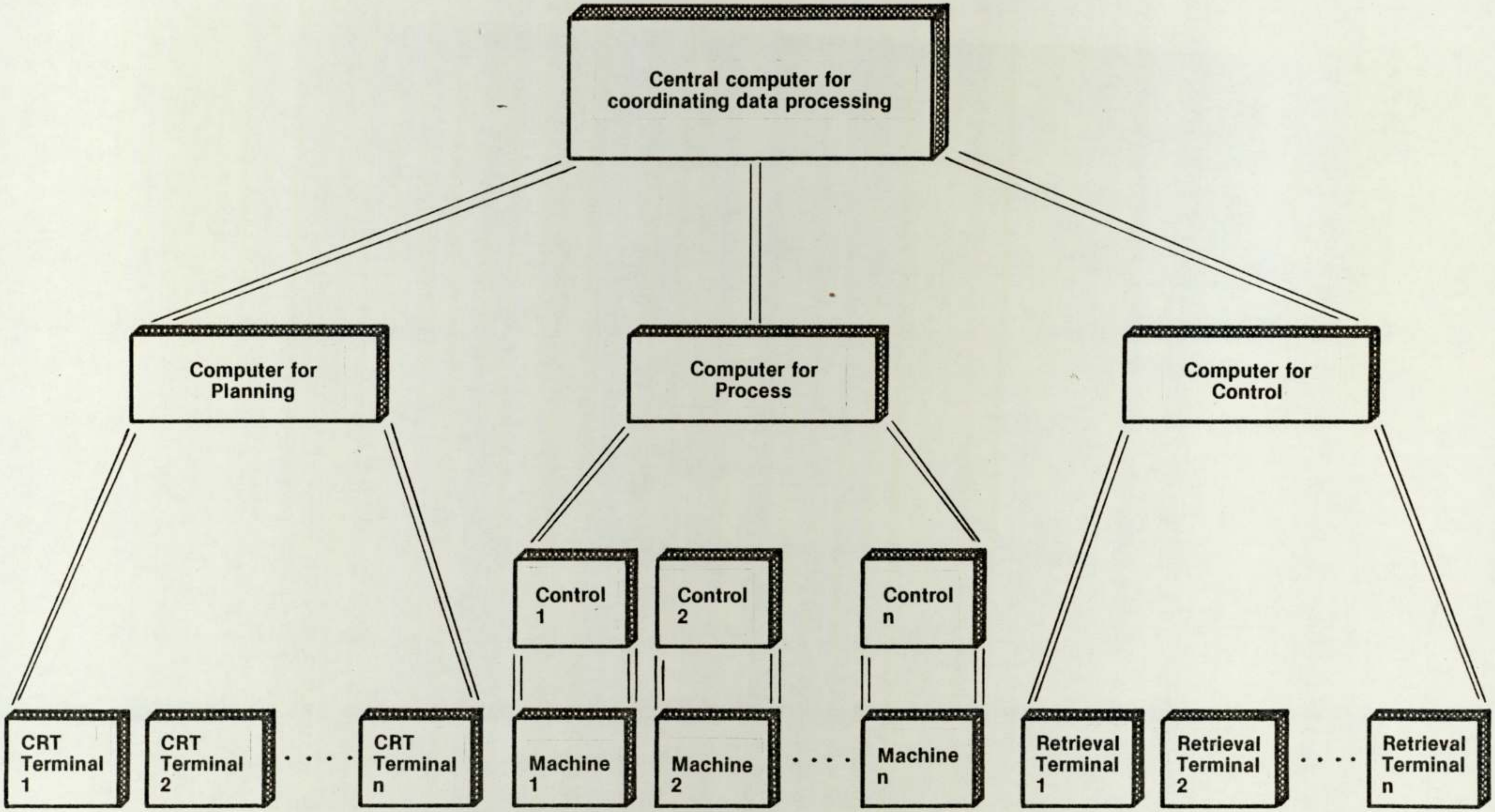


FIG.108 COMPUTER HARDWARE APPLICATION FOR THE PROCESS

FIG.108

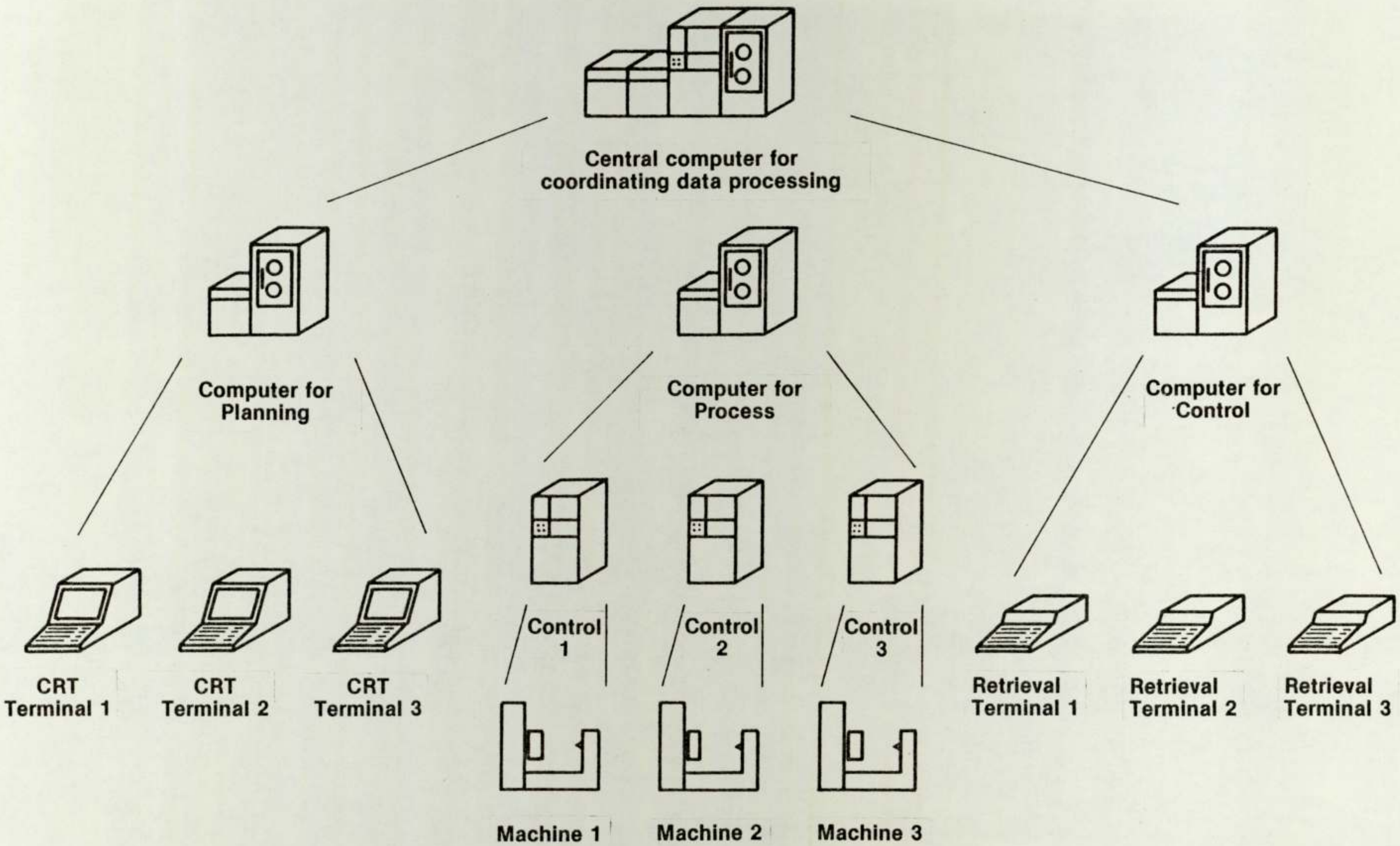


FIG. 109

FIG. 109 COMPUTER HARDWARE APPLICATION: TERMINALS, NC-MACHINES, etc.

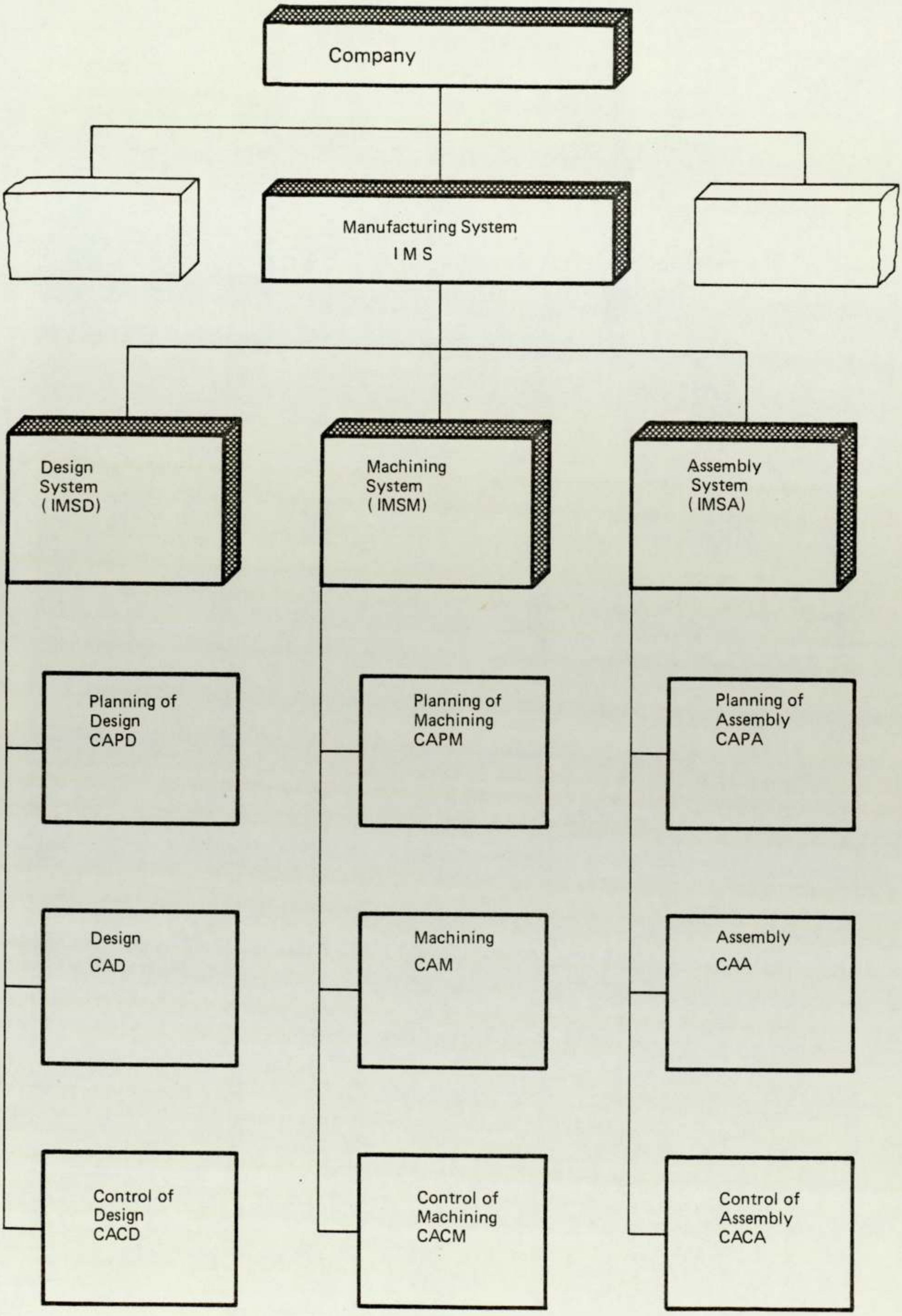


FIG. 110 ORGANISATION OF THE MANUFACTURING SYSTEM IMS

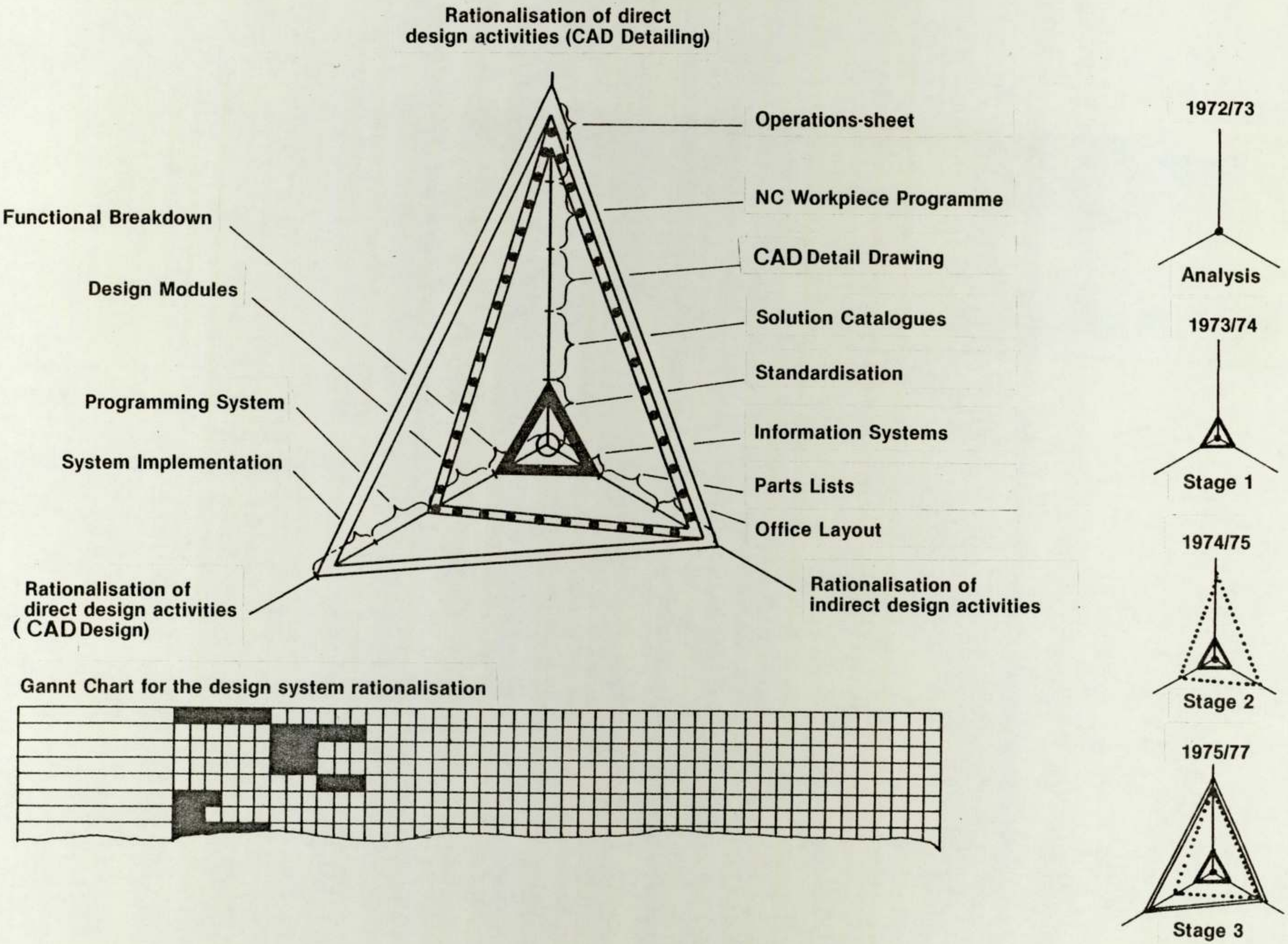


FIG. 111 RATIONALISATION PROJECT FOR THE DESIGN-SYSTEM

FIG. 111

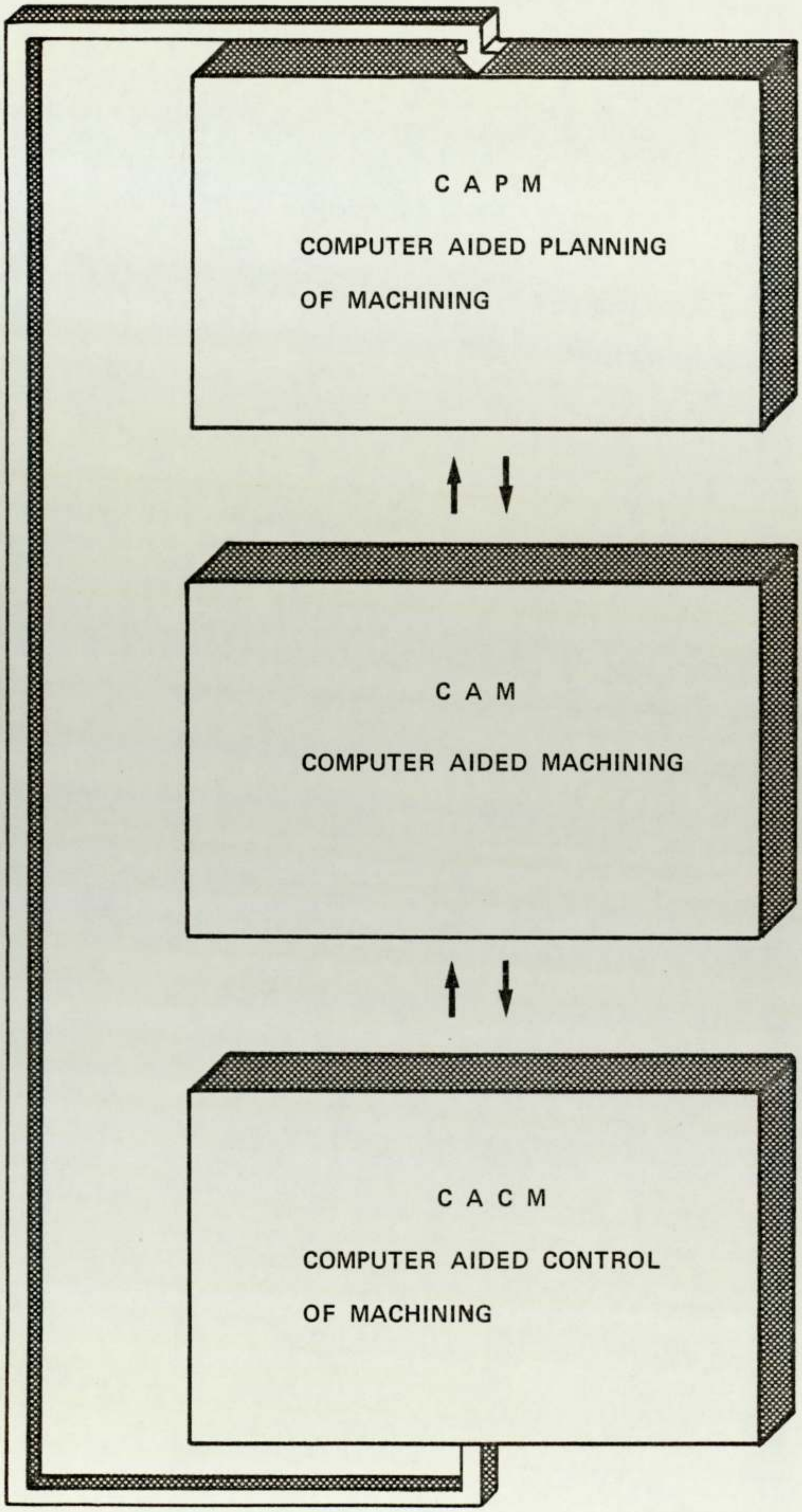


FIG. 112 MACHINING-SYSTEM

Workpiece spectrum / Batch size	Rotational components	Prismatic components	Sheet – metal components	
„One–offs" Batch size 1	conventional machining with universal machines	conventional machining with universal machines	conventional machining methods	
Small Batch 2 – 6	conventional and NC – machines (combination)	conventional and NC – machines (combination)	conventional machining methods	
Medium Batch 6 – 30	NC–machining centres	NC lathes NC grinders	NC sheet – metal nibblers	
Large Batch 30+	NC–machining centres with palletted loading	NC turning cells with auto loading NC grindres	NC nibblers NC presses	

FIG. 113 MACHINING METHODS AND WORKPIECE GROUPINGS

FIG. 113

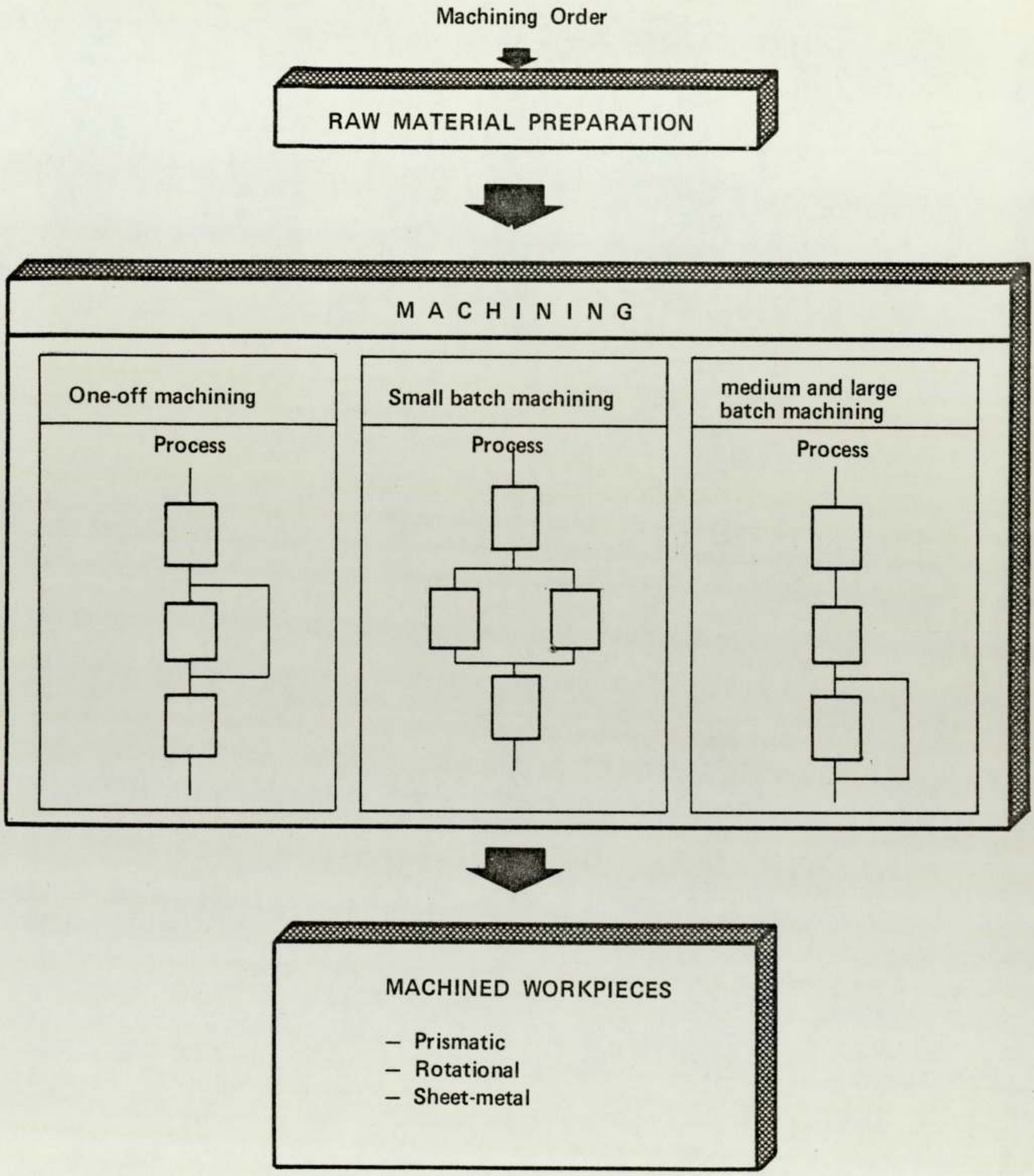


FIG. 114 BREAKDOWN OF THE MACHINING PROCESS

MEDIUM AND LARGE BATCH MACHINING

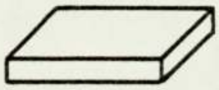
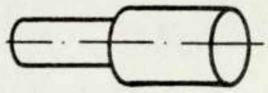
Machining operation	Prismatic workpieces 		Rotational workpieces 	
	conventional	NC	conventional	NC
ROTATIONAL MACHINING				
• Turning between centres			●	●
• Chuck-turning				●
• Bar-feed-turning				●
• Eccentric-turning			●	
• External-grinding				●
• Internal-grinding			●	
• etc.				
FLAT-MACHINING				
• Horizontal-milling		●		
• Vertical-milling		●		
• Keyway-milling	●	●		
• Flat-grinding	●			
• Deburring	●			
• etc.				
BORE-MACHINING				
• Boring		●		
• Drilling		●		
• Milling		●		
• Reaming		●		
• Taping		●		
• etc				

FIG. 115 MACHINING OPERATIONS AND MACHINING METHODS FIG. 115

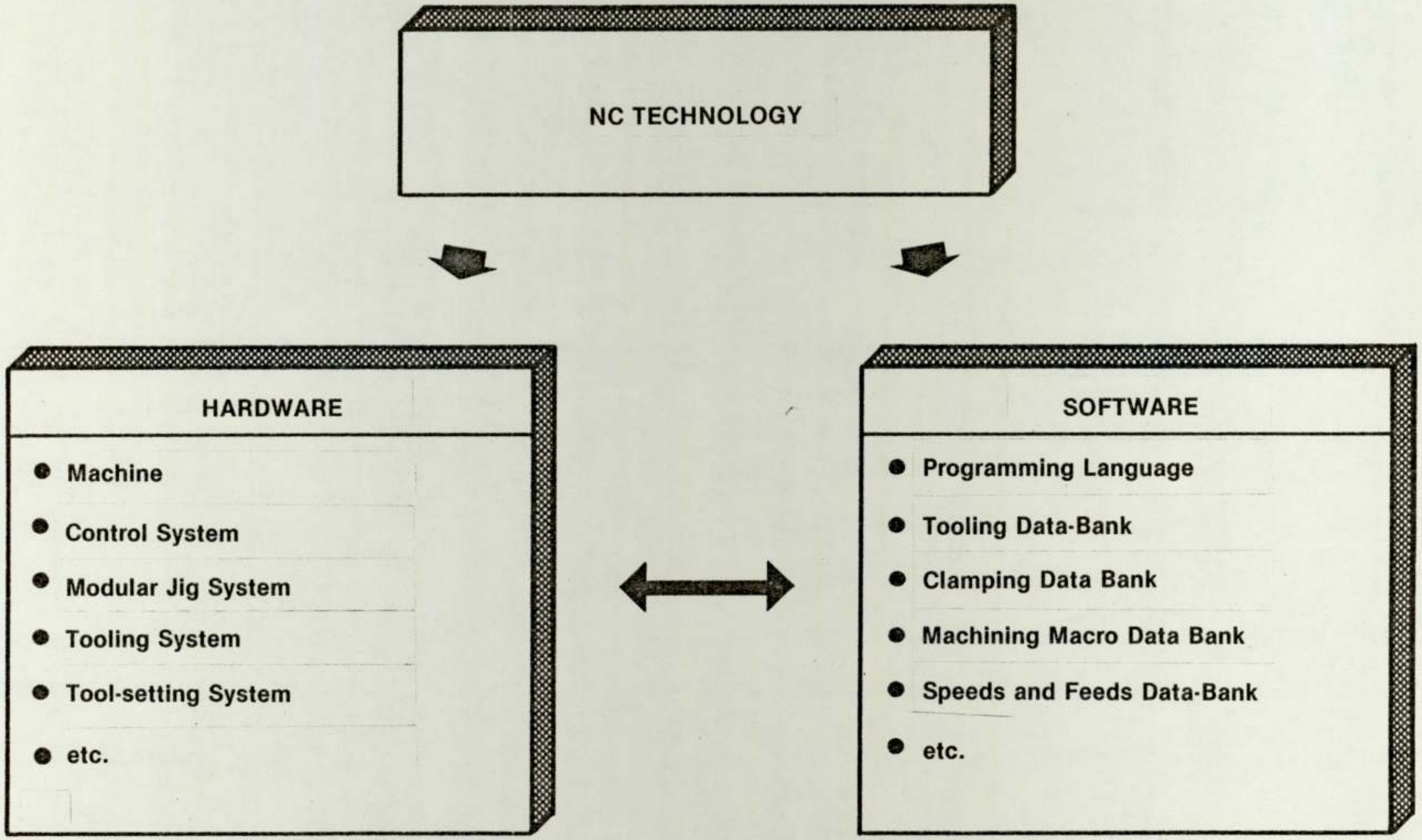


FIG. 116 PRIMARY FACTORS OF NC TECHNOLOGY

FIG.116

FIRM SPECIFICATIONS (HARDWARE)

1. Automation of the rotational machining and preceeding operations
2. Standardised control-system for all machines
3. Standardised tooling system after VDI 3425
4. Automated tool-change
5. Automated diameter measurement inside work-area
6. Automated swarf removal
7. Linkage to centralised coolant system
8. Lubrication mediums to company standards
9. Standardised control elements
10. Linkage to automated production data collection system
11. Centralised extraction of heat, gases and fumes
12. Observation of standard safety precautions
13. Tool setting during machine primary-time

MINIMUM SPECIFICATIONS

1. Production volume conventional 47 000 h + 28 % = 60 000 h for NC machining	≥ 80 %
2. Automatic loading/unloading of shaft type workpieces of disc type workpieces	 ≥ 90% ≥ 90 %
3. Guaranteed precision of workpieces all diameters diameters over 30 mm	 ≥ IT 7 ≥ IT 6

ADDITIONAL SPECIFICATIONS

1. Automated blank preparation
2. Automated workpiece transport to and from machine
3. DNC operation

FIG. 117

EXTRACT FROM THE SPECIFICATION SHEET FOR HARDWARE FOR THE MACHINING OF ROTATIONAL WORKPIECES

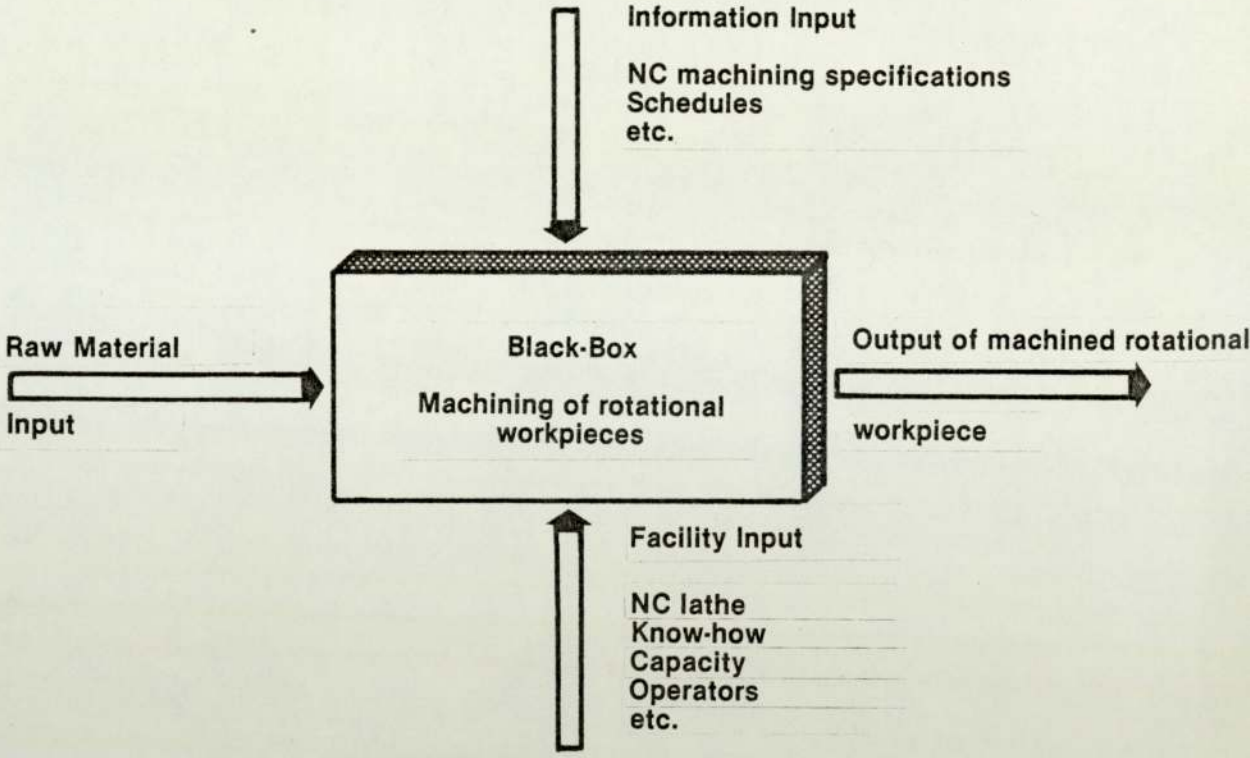


FIG. 118 ROTATIONAL MACHINING AS A «BLACK-BOX»

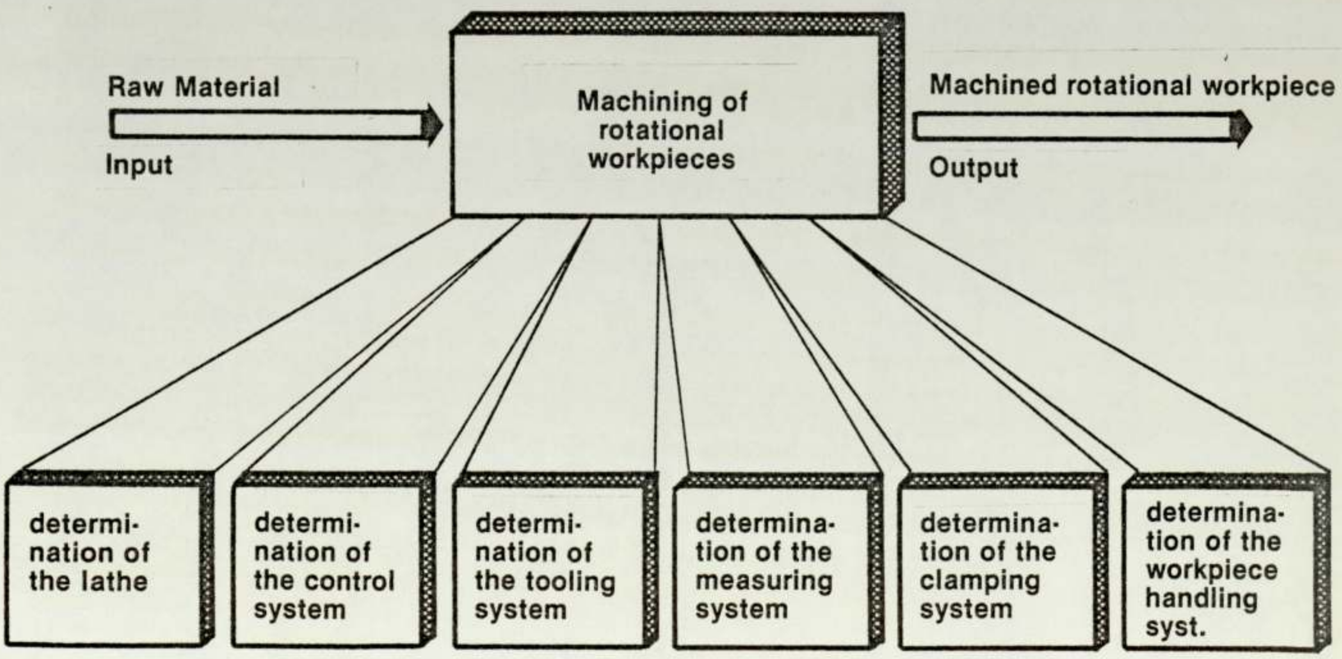


FIG. 119 FUNCTIONAL BREAKDOWN OF ROTATIONAL MACHINING

FIG. 120: SOLUTION MATRIX: HARDWARE FOR ROTATIONAL WORKPIECE TURNING

Solution possibilities / Function	Possibility 1	Possibility 2	Possibility 3	
Determination of the NC lathe	Short machine with bar-feed	Long machine	Universal machine with bat-feed	
Determination of the control system	Conventional path control	CNC path control		
Determination of the tooling system	Already fixed Standardised system			
Determination of the measuring system	Manual outside machine	Automated inside machine		
Determination of the clamping system	Conventional with chuck and between-centres	Auto-chuck-change clamping outside machine		
Determination of the handling system	Manual	Roboter and manual	Roboter transport-system and manual	

FIG. 120

Time calculation disc-type workpieces	Machining time in hours		Ratio
	conventional	NC	
Setting time	9.9	14.1	0.7 : 1
Floor to floor time	180.7	30.5	5.92 : 1
Ratio	1 : 18.25	1 : 2.16	

FIG. 121 TIME CALCULATION FOR DISC- TYPE WORKPIECES

Total spectrum disc-type workpieces	Machining time in hours		Ratio
	conventional	NC	
Setting time	955	1365	0.7 : 1
Floor by floor time	17445	2950	5.91 : 1
Ratio	1 : 18.27	1 : 2.16	

FIG. 122 CAPACITY REQUIREMENTS FOR TOTAL SPECTRUM OF DISC-TYPE WORKPIECES

Time calculation shaft-type workpieces	Machining time in hours		Ratio
	conventional	NC	
Setting time	28.8	24.7	1.17 : 1
Floor to floor time	661.7	68.1	9.72 : 1
Ratio	1 : 22.98	1 : 2.76	

FIG. 123 TIME CALCULATION FOR SPINDLE-TYPE WORKPIECES

Total spectrum shaft-type workpieces	Machining time in hours		Ratio
	conventional	NC	
Setting time	800	692	1.16 : 1
Floor to floor time	18400	1900	9.68 : 1
Ratio	1 : 23	1 : 2.75	

FIG. 124 CAPACITY REQUIREMENTS FOR TOTAL SPECTRUM OF SPINDLE-TYPE WORKPIECES

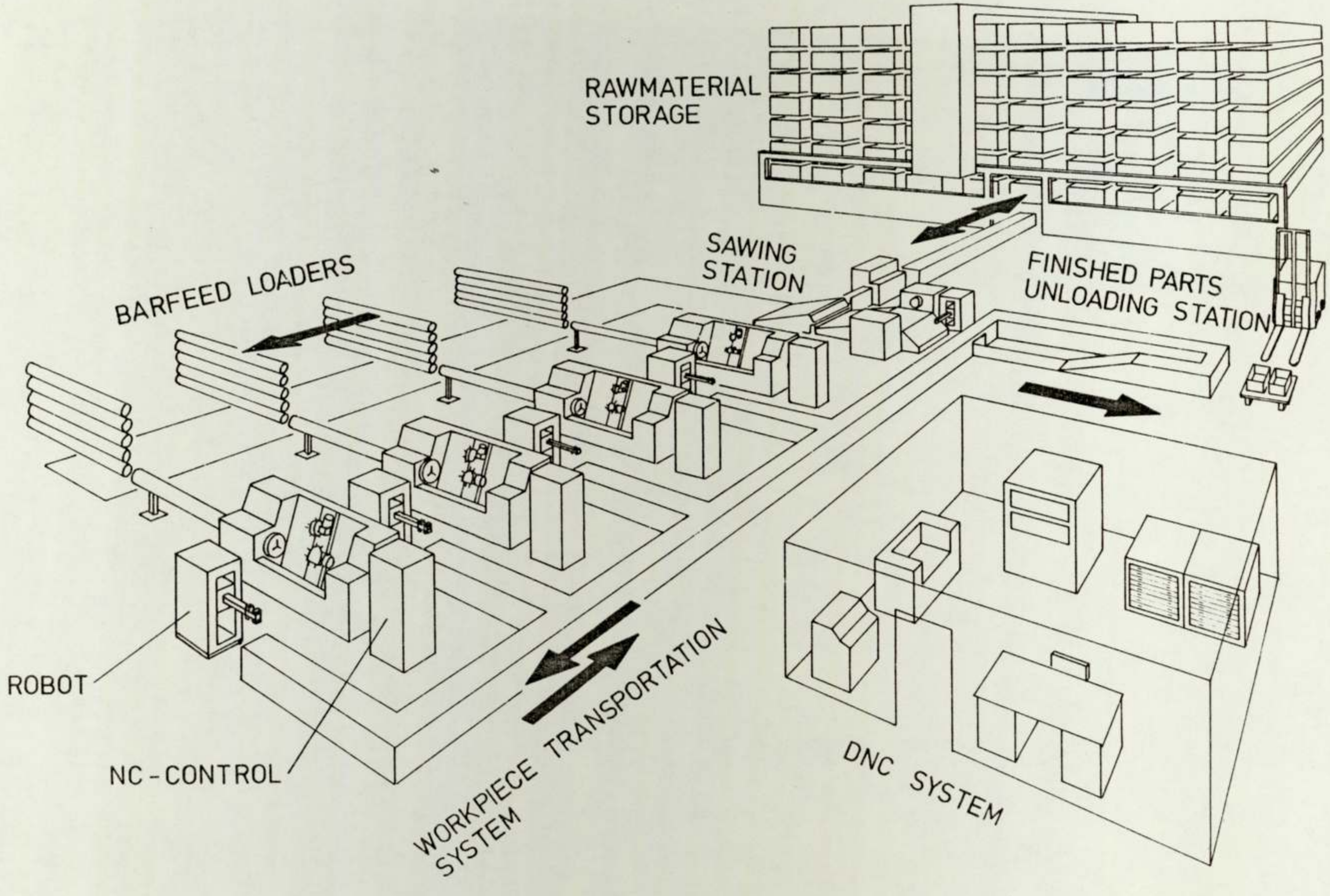


FIG. 125 MANUFACTURING SYSTEM FOR ROTATIONAL PARTS

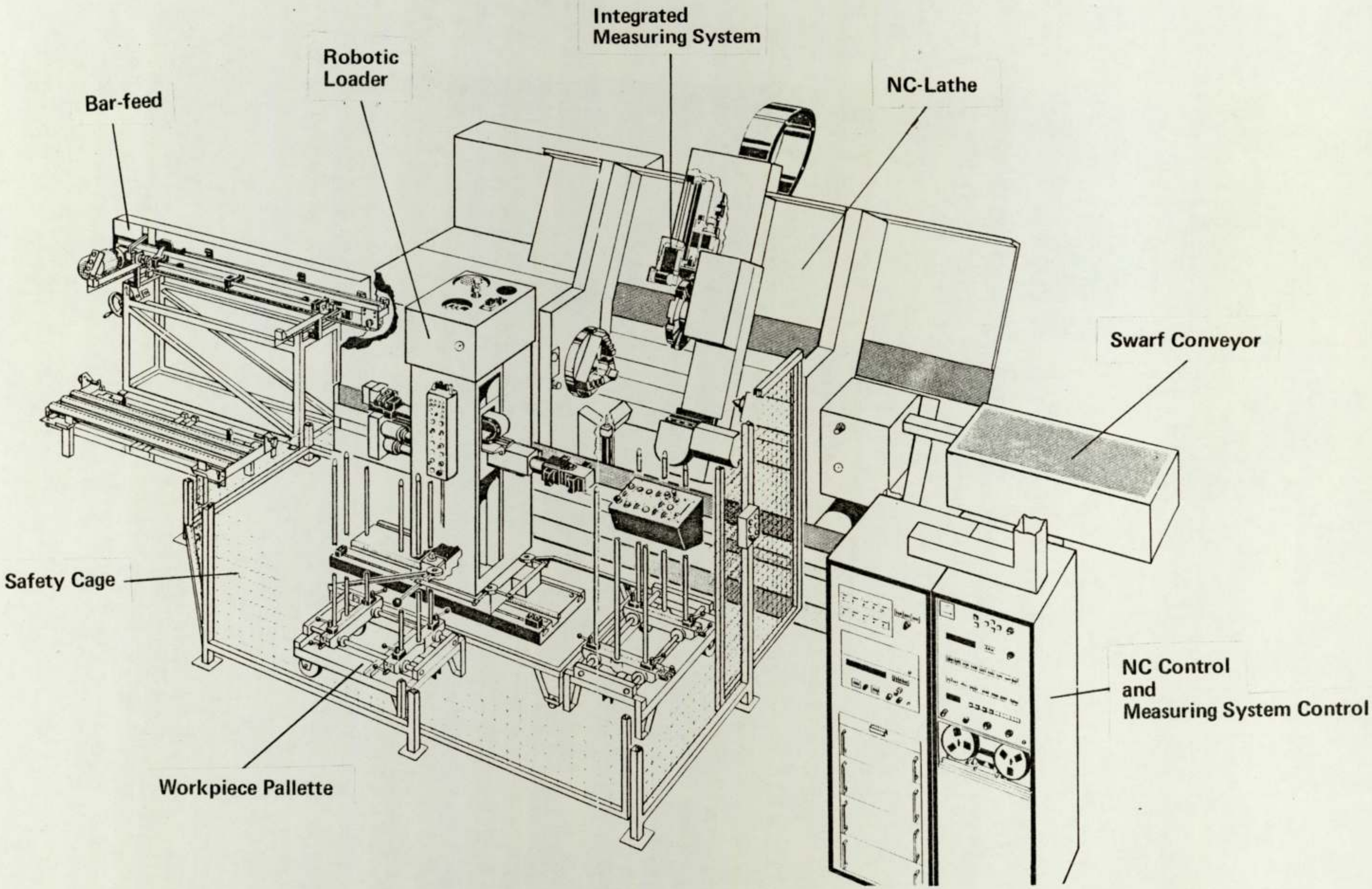
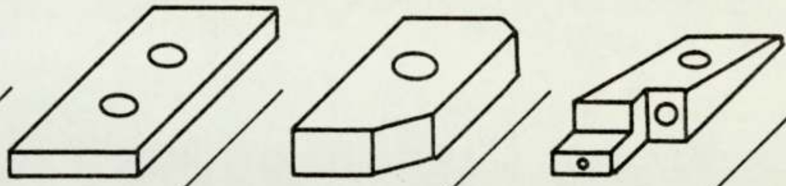


FIG. 126 THE NC ROTATIONAL MACHINING CELL

FIG. 126



Complexity Grouping / Size Grouping	Simple Workpieces	Average Workpieces	Complex workpieces	
x = 1—400 mm y = 1—400 mm z = 1—400 mm	65 %	20 %	15 %	100 %
x = 400—800 mm y = 400—600 mm z = 400—600 mm	20 %	50 %	30 %	100 %
x = 600—1200 mm y = 500—1000 mm z = 400—1000 mm	15 %	30 %	55 %	100 %
	100 %	100 %	100 %	

FIG. 127

DISTRIBUTION OF PRISMATIC WORKPIECES IN SIZE AND COMPLEXITY GROUPINGS

FIRM SPECIFICATIONS (HARDWARE)

1. Automation of the boring and milling operations
2. Standardised control-system for all machines
3. Standardised tooling system
4. Automated tool change
5. Linkage to centralised coolant system
6. Lubrication mediums to existing company standards
7. Standardised control elements
8. Linkage to automated production-data collection system
9. Centralised extraction of heat, gases and fumes
10. Observation of standard safety precautions.

MINIMUM SPECIFICATIONS

1. Production volume conventional 120 000 h + 28 % For NC machining	$\geq$ 80 %
2. Guaranteed precision workpieces	$\geq$ IT 5
3. Noise limit (mean value)	$\geq$ 75 dB(A)

ADDITIONAL SPECIFICATIONS

1. Automated workpiece loading and unloading
2. DNC operation

FIG. 128

EXTRACT FROM THE SPECIFICATION SHEET FOR HARDWARE FOR THE MACHINING OF PRISMATIC WORKPIECES

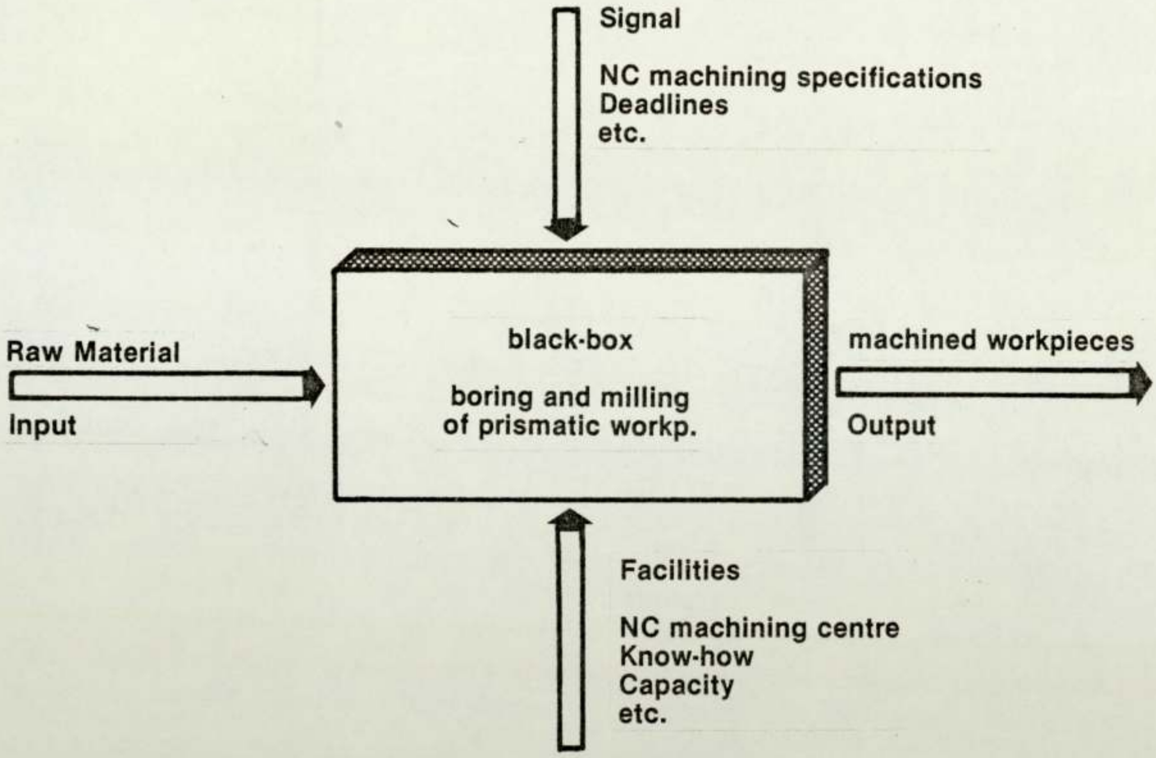


FIG 129. PRISMATIC WORKPIECE BORING AND MILLING AS «BLACK-BOX»

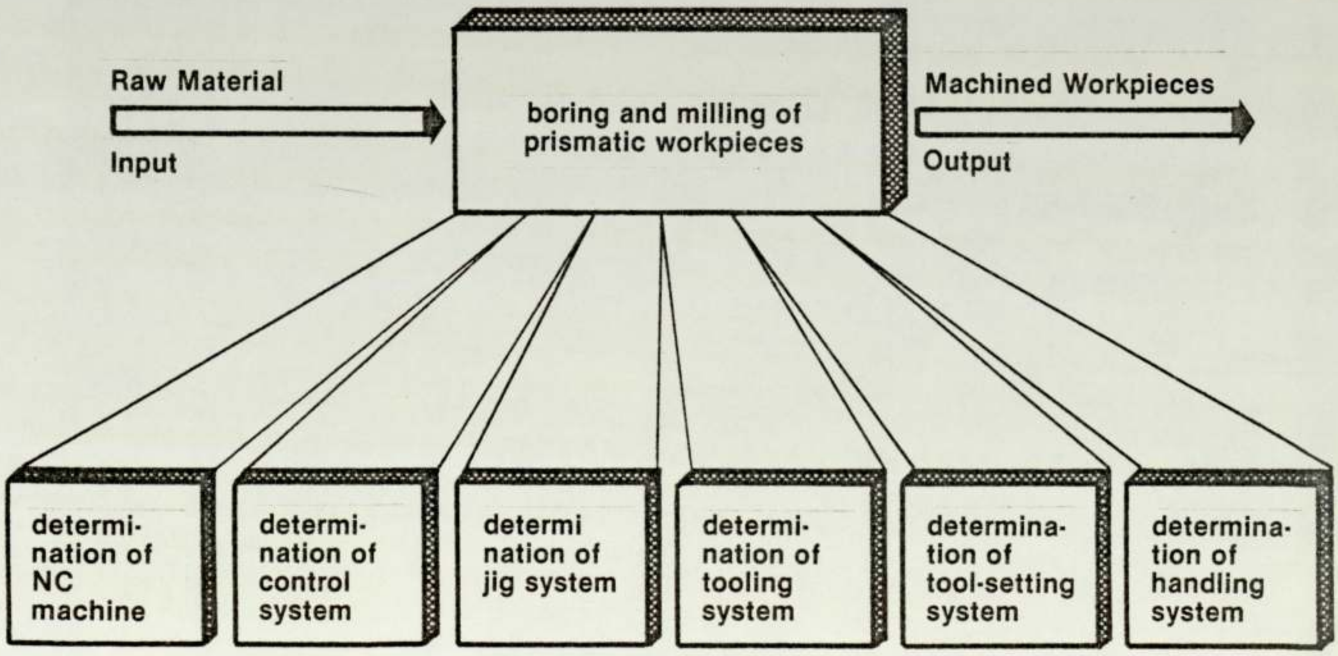


FIG.130 FUNCTIONAL BREAKDOWN OF PRISMATIC WORKPIECE BORING AND MILLING

FIG. 131: SOLUTION MATRIX: HARDWARE FOR PRISMATIC WORKPIECE MACHINING

Solution possibilities / function	Possibility 1	Possibility 2	Possibility 3	Possibility 4
Determination of NC Machines	horizontal spindel with automatic tool-change (NC machining centre)	vertical spindel with automatic tool – change (NC machining centre)		
Determination of control system	point to point control conventional	path control conventional	incremental path control conventional	CNC control
Determination of jig system	entirely modular system	mixed system	entirely permanent system	
Determination of tooling system	entirely standardised system	mixed standardised and special tooling system	free, requirement orinentated system	
Determination of tool setting system	on machine	off machine		
Determination of handling system	manual	Platten shuttle	Platten with industrial robot	Platten with automated transport system

FIG. 131

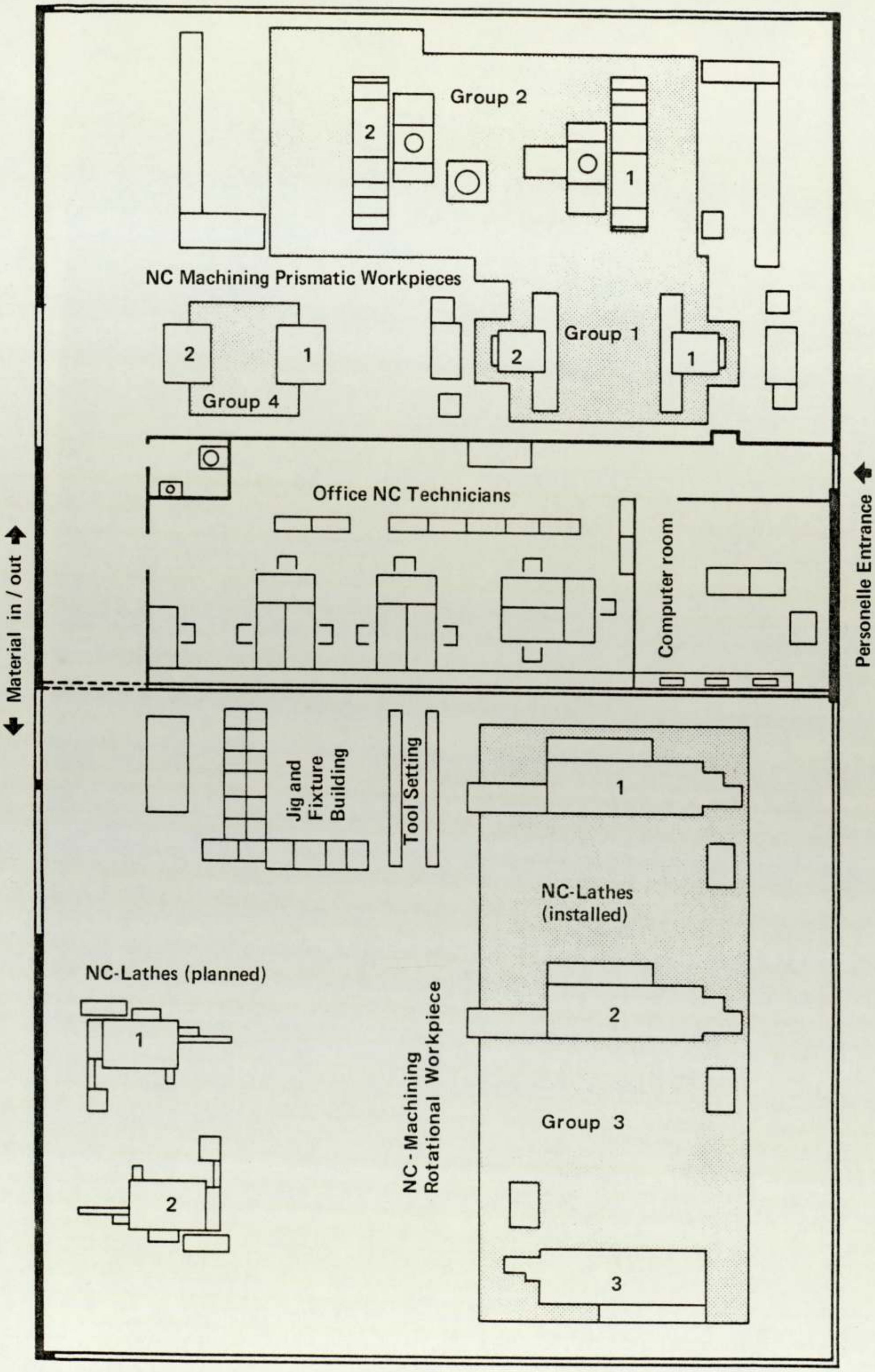


FIG. 132 NC-MACHINING LAY OUT

DECISION CRITERIA

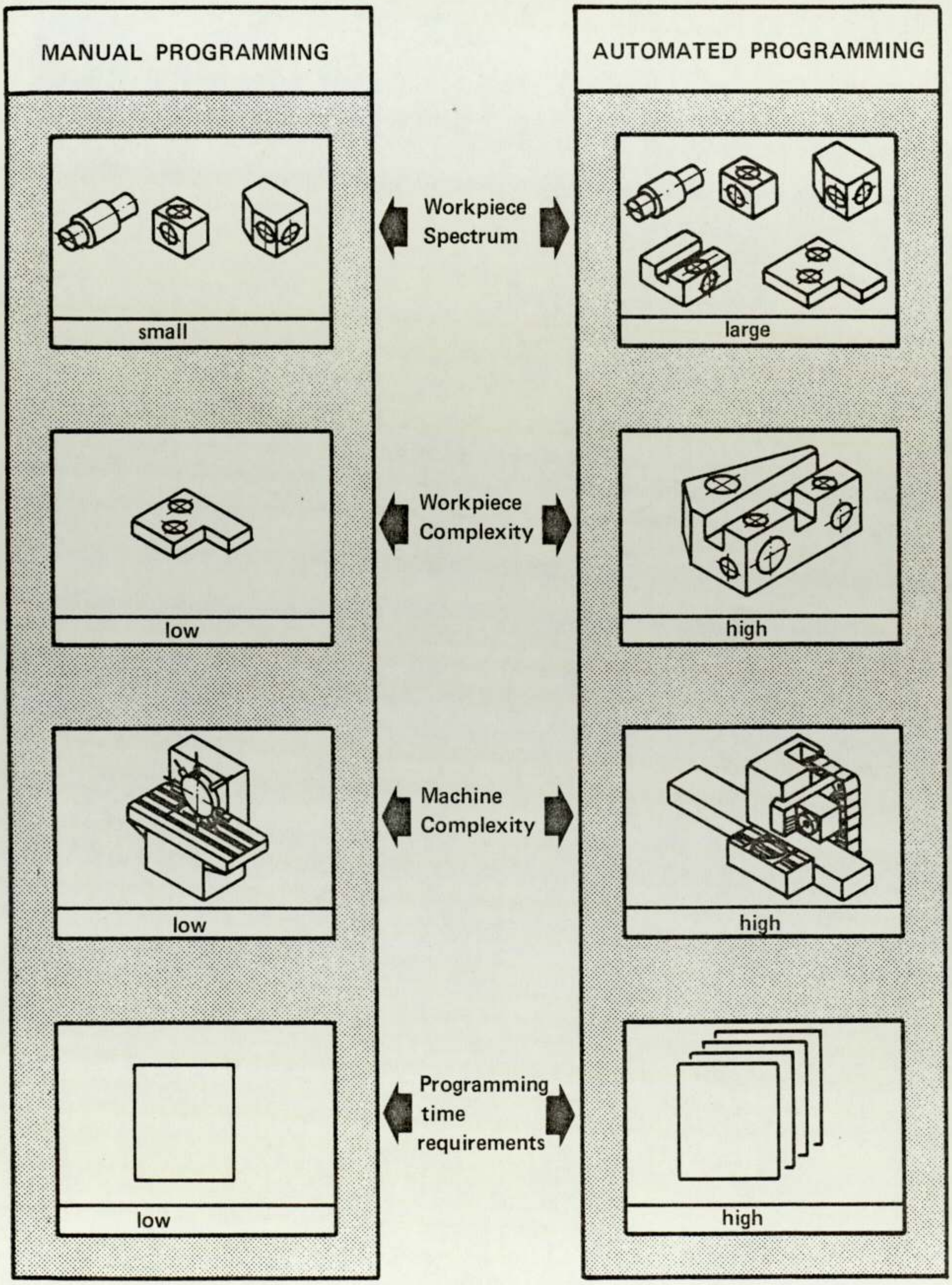


FIG. 133 DECISION CRITERIA FOR THE SELECTION OF A PROGRAMMING METHOD

FIG. 133

FIRM SPECIFICATIONS (SOFTWARE)

1. Universal programming system for both rotational and prismatic workpieces
2. Integration of the CAD software in the programming system
3. Uniform input and output formating
4. Unlimited development possibility
5. Independance from software suppliers
6. Simple rational correction and modification of programmes

MINIMUM SPECIFICATIONS

1. Maximum average programming time	$\geq$ 15 h/day
2. Degree of automation of system	$\geqq$ 0.4

ADDITIONAL SPECIFICATIONS

1. Easy «learnability» for programmers

FIG. 134

EXTRACT FROM THE SPECIFICATION SHEET FOR SOFTWARE FOR THE PROGRAMMING OF ROTATIONAL AND PRISMATIC WORKPIECES

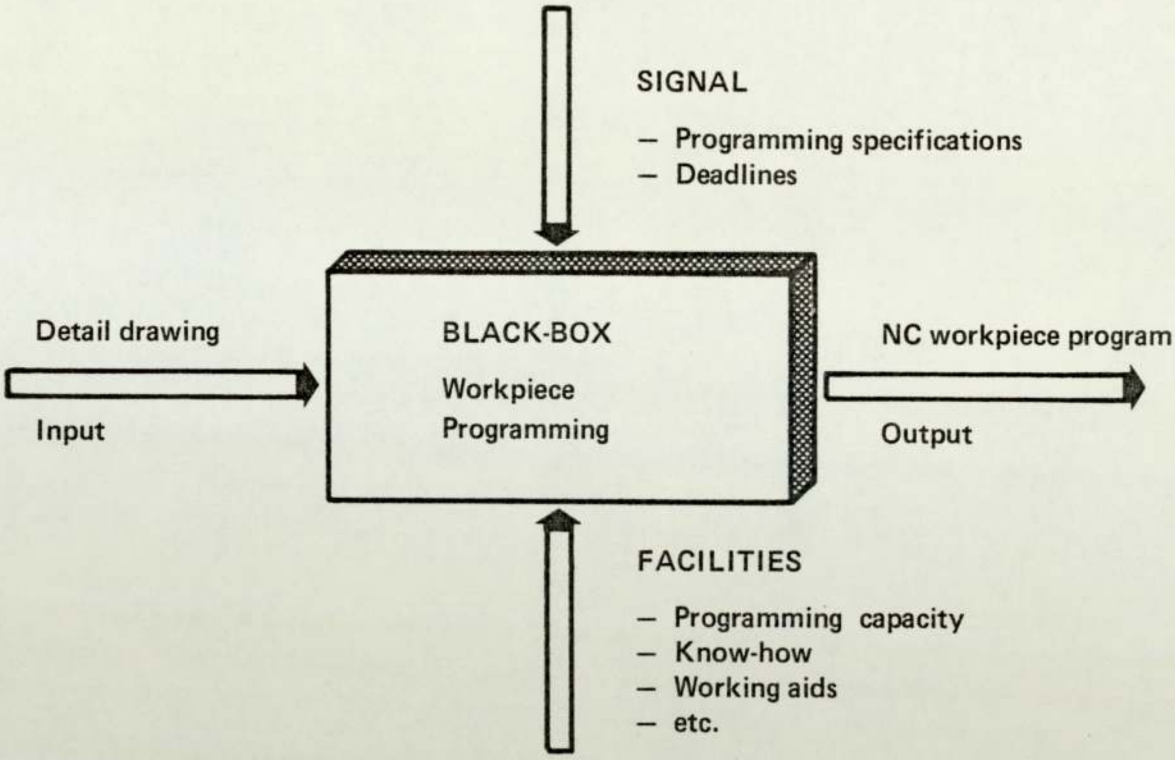


FIG. 135 WORKPIECE PROGRAMMING AS "BLACK-BOX" ABSTRACTION

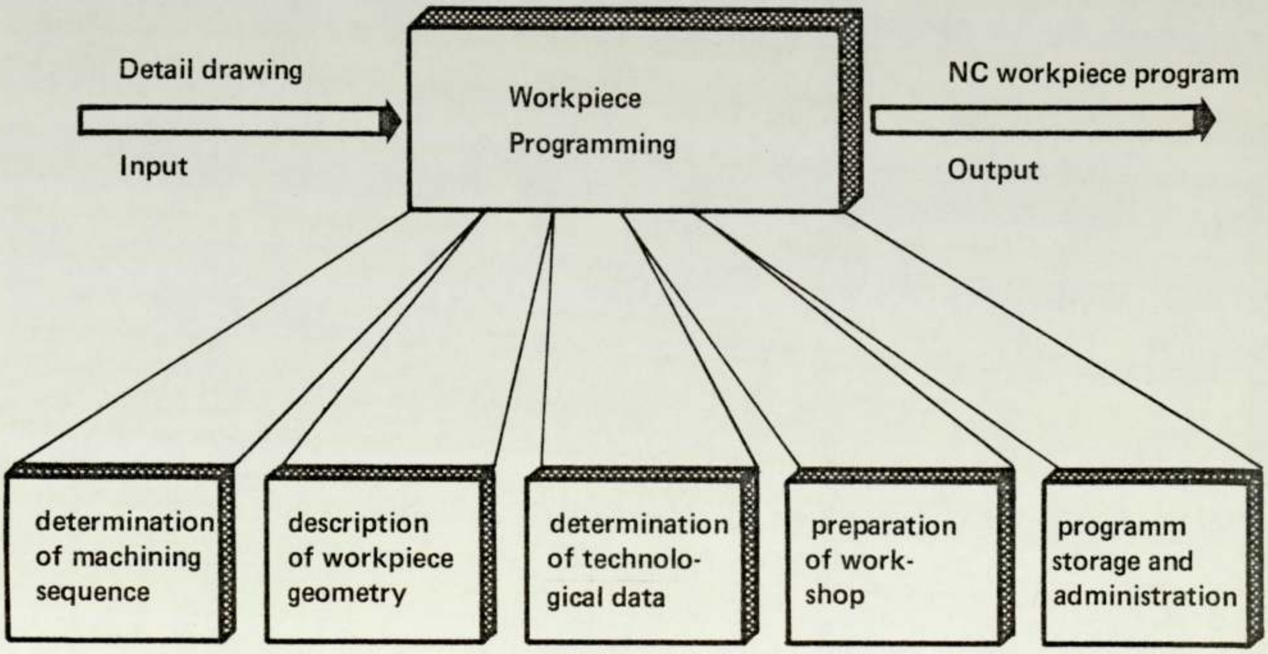


FIG. 136 FUNCTIONAL BREAKDOWN OF WORKPIECE PROGRAMMING

Solution possibilities / function	Possibility 1	Possibility 2	Possibility 3	Possibility 4
Determination of machining sequence	manual with conventional working – aids	computer – aided, independant of CAD	computer – aided, coupled to CAD system	
Description of workpiece geometry	manual direct machine coordinate orientated	automatated direct machine coordinate orientated	universal automated workpiece orientated	
Determination of technological data	. manual speeds and feeds data with tables charts etc. . tool selection manual	. automated speeds and feeds data . automated tool selection		
Preparation of work-shop documentation	manual	semi-automated	fully automated	
Programme storage and administration	manual	semi-automated	fully automated (DNC-System)	

FIG. 137: SOLUTION MATRIX FOR „PROGRAMMING FOR NC MACHINES"

FIG. 137

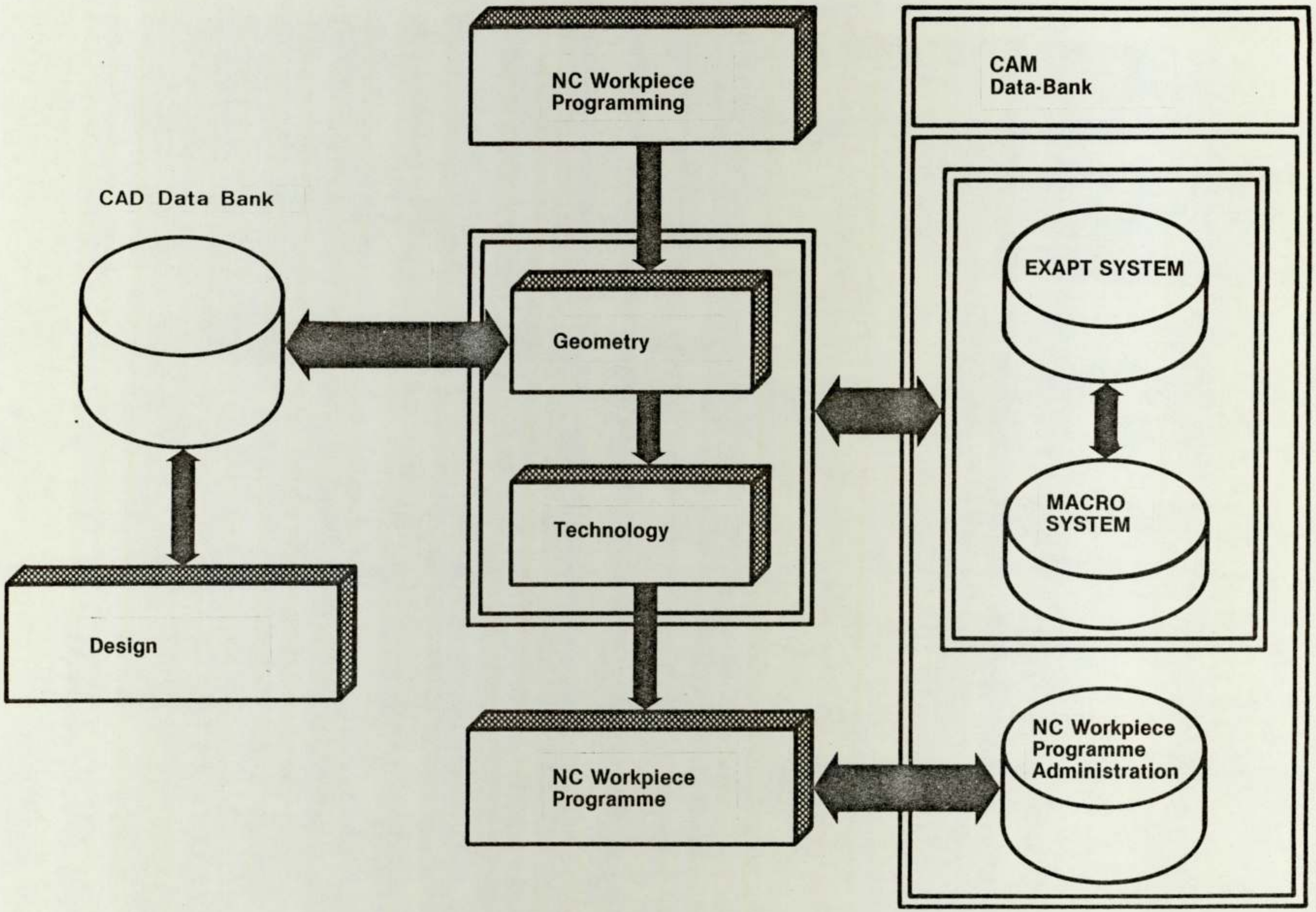


FIG. 138 NC-SOFTWARE REALISATION PHASE 3

FIG. 138

FIRM SPECIFICATIONS «MACHINING PLANNING»

1. Full consideration of NC technology aspects
2. Integration of CAPM and CACM
3. Input and Output procedures user-orientated
4. Output data orientated to assist decision making
5. Si mulation of different loading and scheduling possibilities must be guaranteed
6. Identification of not yet programmed workpieces or new programmed workpieces for testing
7. Output of results per machine group
8. Computer-aided system operated in dialogue mode
9. Guarantee of high degree of flexibility

MINIMUM SPECIFICATIONS

1.	Update of the production situation	≥ 2x/week
2.	Accuracy of the capacity data	≥ 90 %
3.	Level of automation	≥ 0.3
4.	Similarity planning	≥ 50 %

ADDITIONAL SPECIFICATIONS

1. No increase in planing workforce
2. Reduction of machining costs through better planing

FIG. 139

EXTRACT FROM THE REQUIREMENTS SHEET FOR «MACHINING-PLANNING»

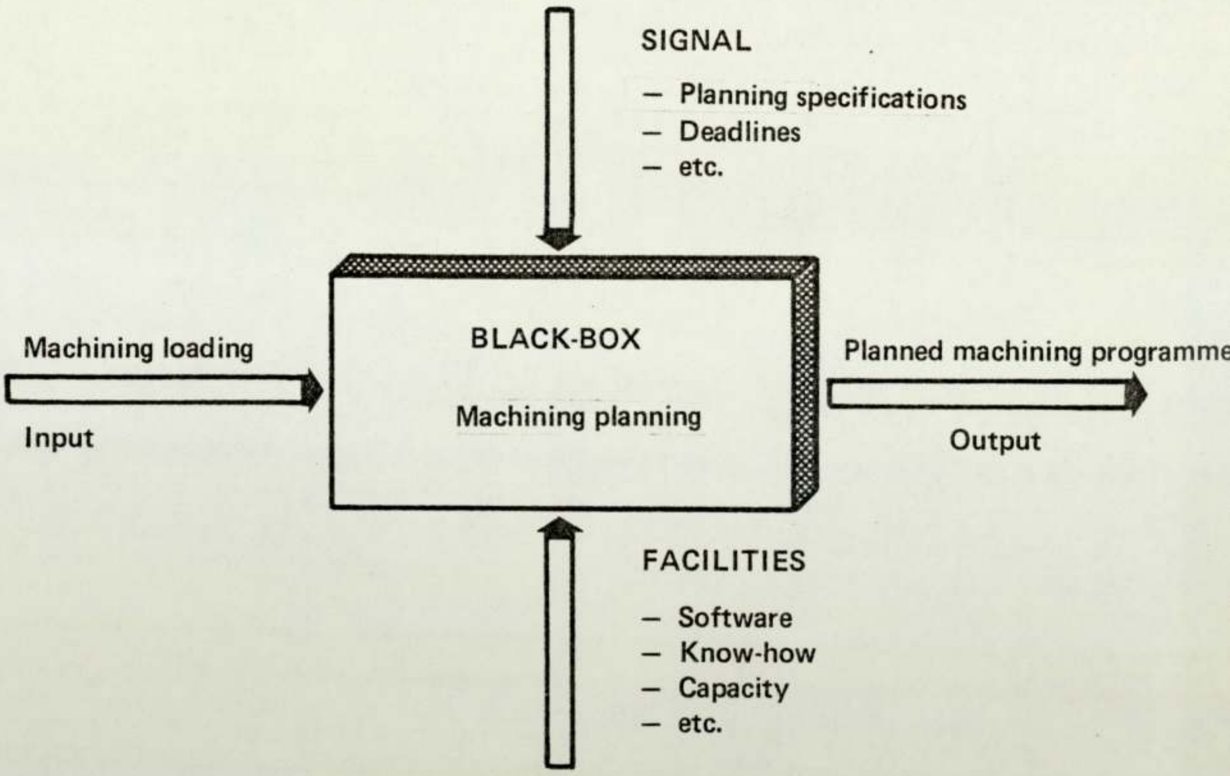


FIG. 140 MACHINING-PLANNING AS "BLACK-BOX" ABSTRACTION

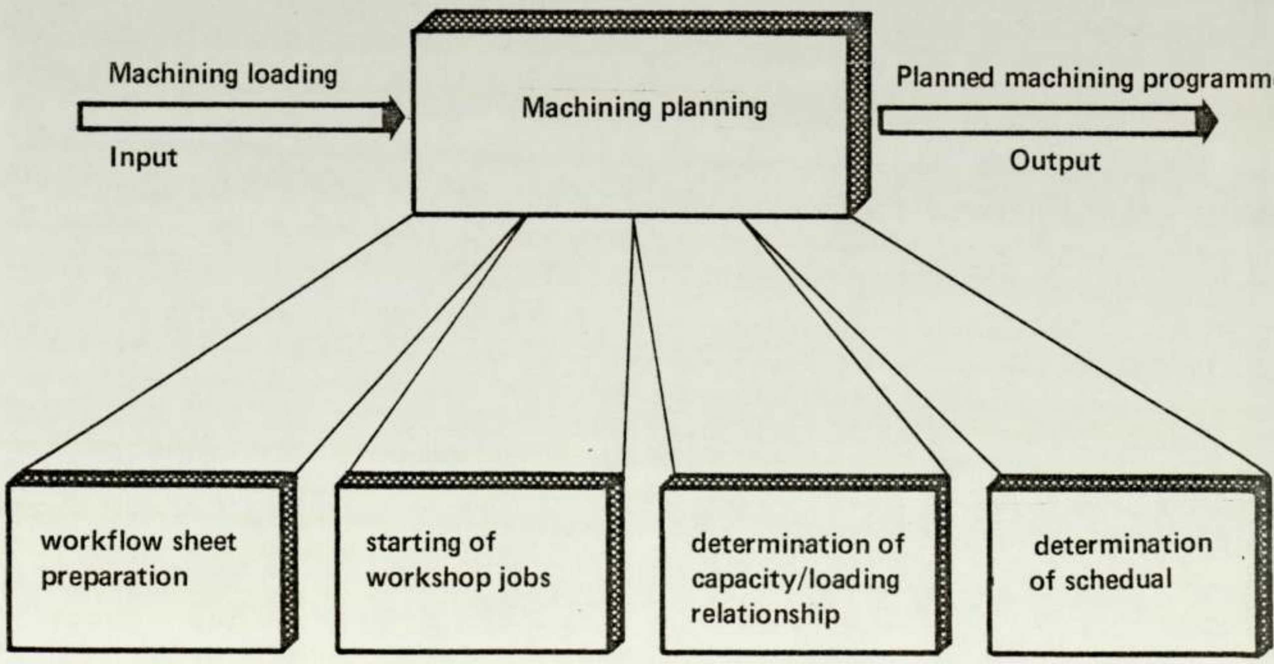


FIG. 141 FUNCTIONAL BREAKDOWN OF "MACHINING-PLANNING"

Solution possibilities / Sub-Functions	Possibility 1 Conventional solution	Possibility 2 Low degree of automation	Possibility 3 Medium degree of automation	Possibility 4 High degree of automation
OPERATIONS-SHE ET PREPARATION	. Manual	. Automated, based on similarity group principle	. Fully automated, based on new – plan principle	. Automated combination of both methods
JOB CARD PREPARATION	. Manual . variable data filled-in by hand . manual sorting	. Partially automated . computer output variables . manual sorting	. Fully automated . computer output variables . sorting of similarity groups autommated	
CAPACITY / LOADING COMPARISON	. Manual, based on job – time per main operation and costing – unit	. Partially automated based on setting and production times per main operation and costing – unit	. Fully automated based on individual setting and pcoduction times per operation and costing – unit	
SCHEDUALING	. Manual . reverse schedualing with average fixed values	. Automated reverse – schedualing with planned actual values		

FIG. 142: SOLUTION MATRIX FOR THE FUNCTION „PLANNING OF MACHINING"

FIG. 142

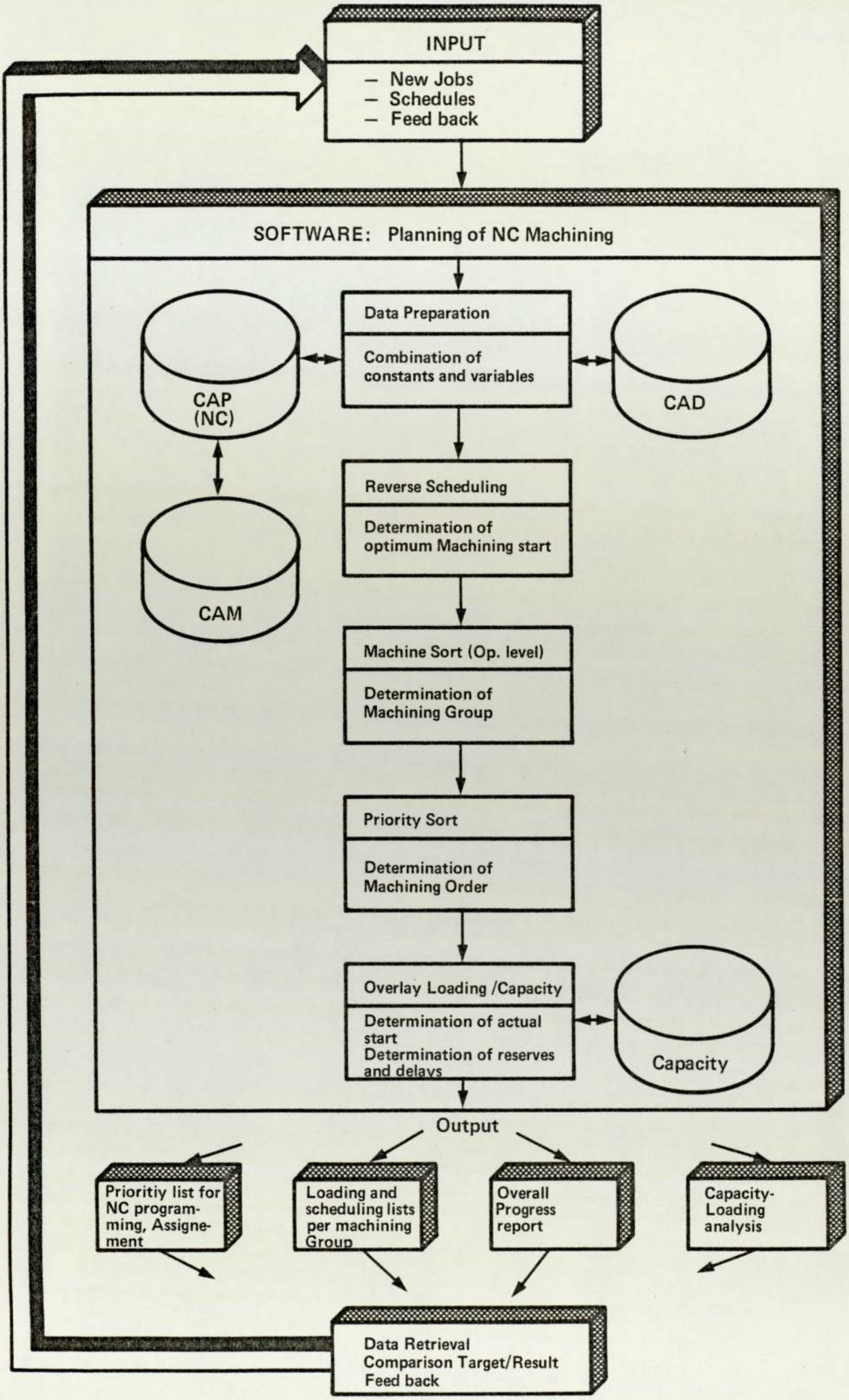


FIG. 143 FUNCTIONAL STRUCTURE OF THE "PLANNING OF THE NC MACHINING" SOFTWARE

FIG. 143

FIRM SPECIFICATIONS «CONTROL OF MACHINING»

1. Full consideration of NC technology
2. Integration of CAPM and CACM
3. Integration of accounting system
4. Guarantee of high degree of flexibility
5. Input and output data user-orientated
6. Output data orientated to assist decision making
7. Promote an increase in machining quality

MINIMUM SPECIFICATIONS

1. Inspection of workpiece quality	$\geq$ 90 %
2. Accuracy of data collection	$\geq$ 90 %
3. Degree of automation	$\geq$ 0.3

ADDITIONAL SPECIFICATIONS

1. No increase in control workforce
2. Increase in the «self-inspection» contribution of process workforce

FIG. 144 EXTRACT FROM THE REQUIREMENTS SHEET FOR THE SUB-SYSTEM CONTROL OF MACHINING

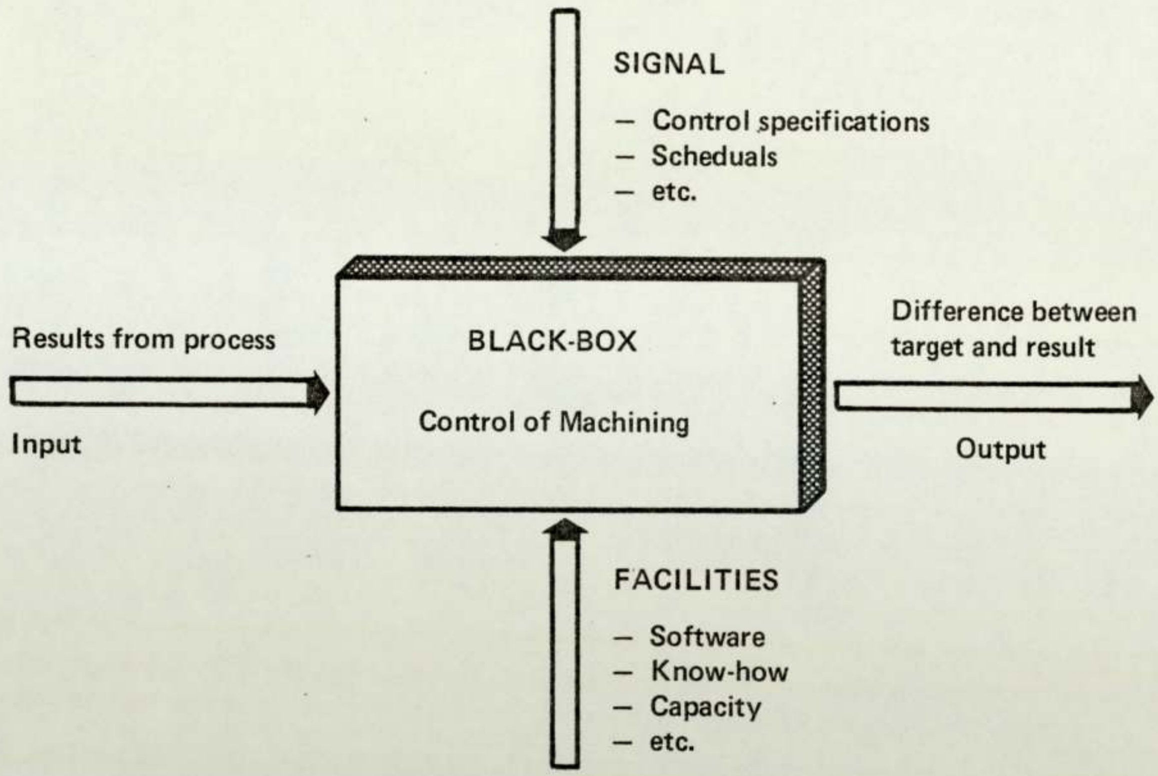


FIG. 145 CONTROL OF MACHINING AS A BLACK-BOX ABSTRACTION

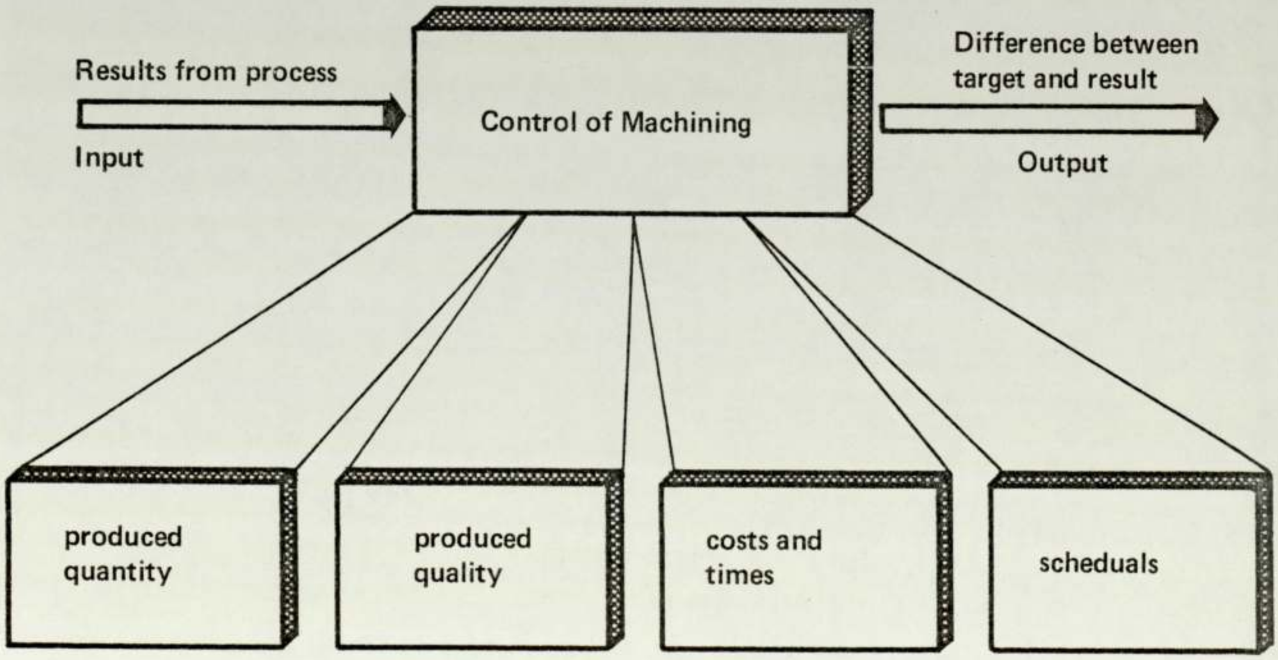


FIG. 146 FUNCTIONAL BREAKDOWN OF CONTROL OF MACHINING

FIG. 147 SOLUTION MATRIX FOR THE FUNCTION CONTROL OF MACHINING

Function \ Solution Possibility	Possibility 1 Measurement outside process	Possibility 2 Measurement outside process	Possibility 3 Measurement outside process	Possibility 4 Measurement inside process
Machining quality control	Manual measuring methods with conventional Instruments	Partly manual partly NC measuring methods	Full application of NC measuring machines	combined with NC Measuring machines
Machining quantity control	manual written	automated Input by hand electronically processed		
machining times control	manual written	automated Input by hand electronically processed		
machining schedules control	manual written	automated Input by hand electronically processed		

FIG. 147

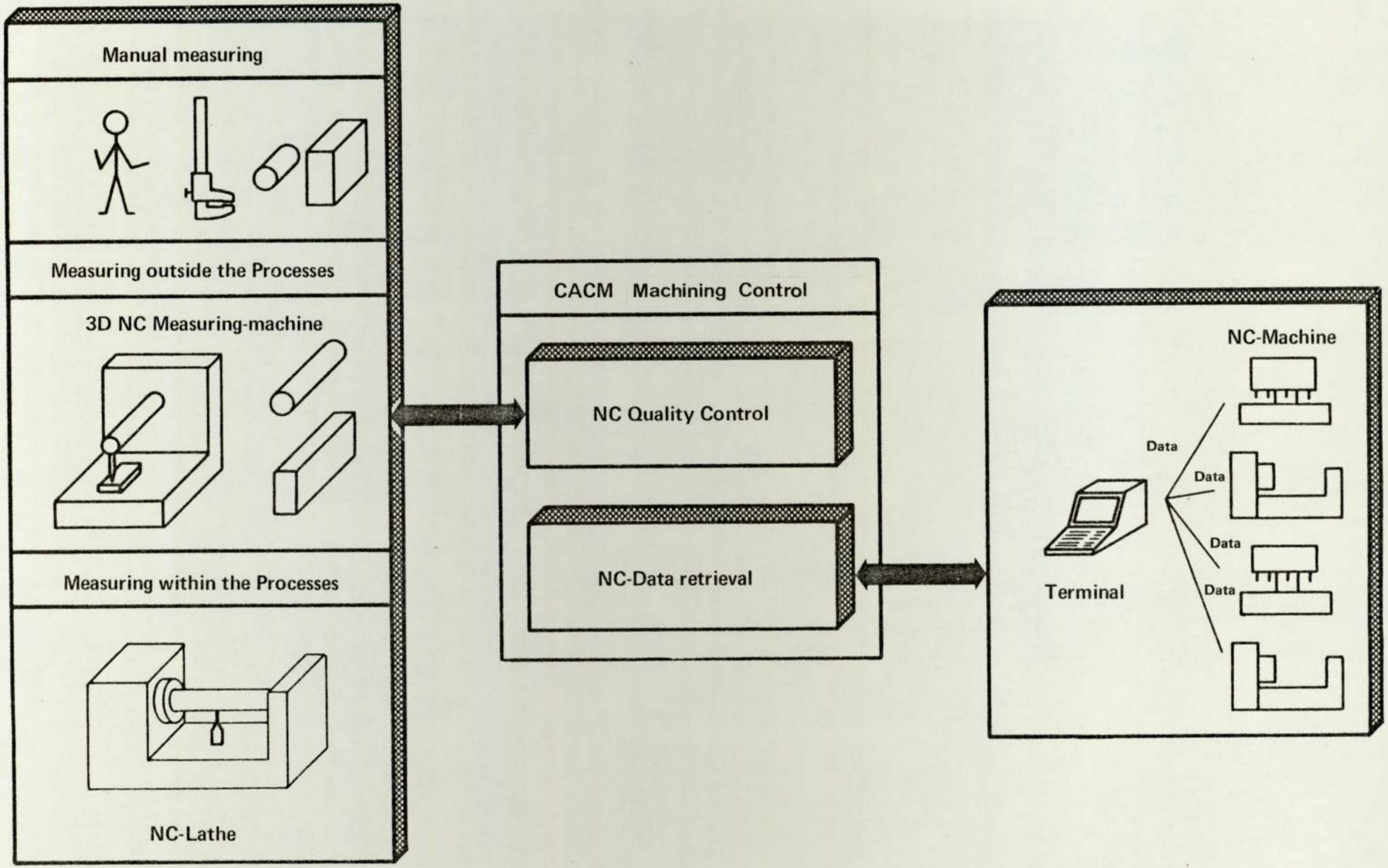


FIG. 148 FUNCTIONAL STRUCTURE OF MACHINING CONTROL

FIG. 148

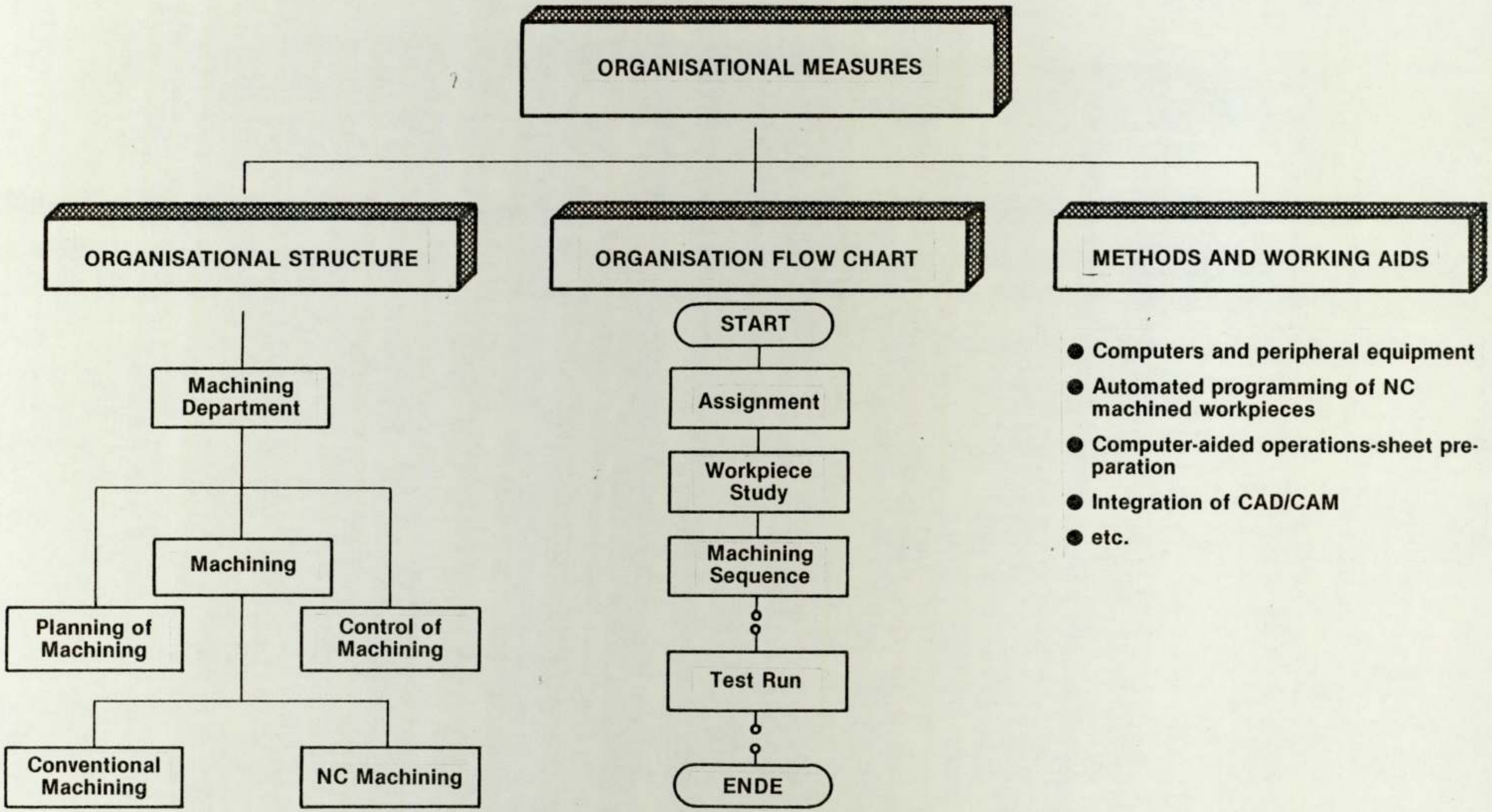


FIG.149 ORGANISATION OF THE MACHINING SYSTEM

FIG.149

NC Technology \ Design Phase	Functional Analysis	Phase Concept	Develop-ment	Detailing
Worpiece Size		◌	●	
Workpiece Geometry			●	◌
Machining Data			●	◌
Clamping Possibilities			●	◌
Form Element			◌	●
Tolerances			◌	●
Material				●
Dimensioning				●

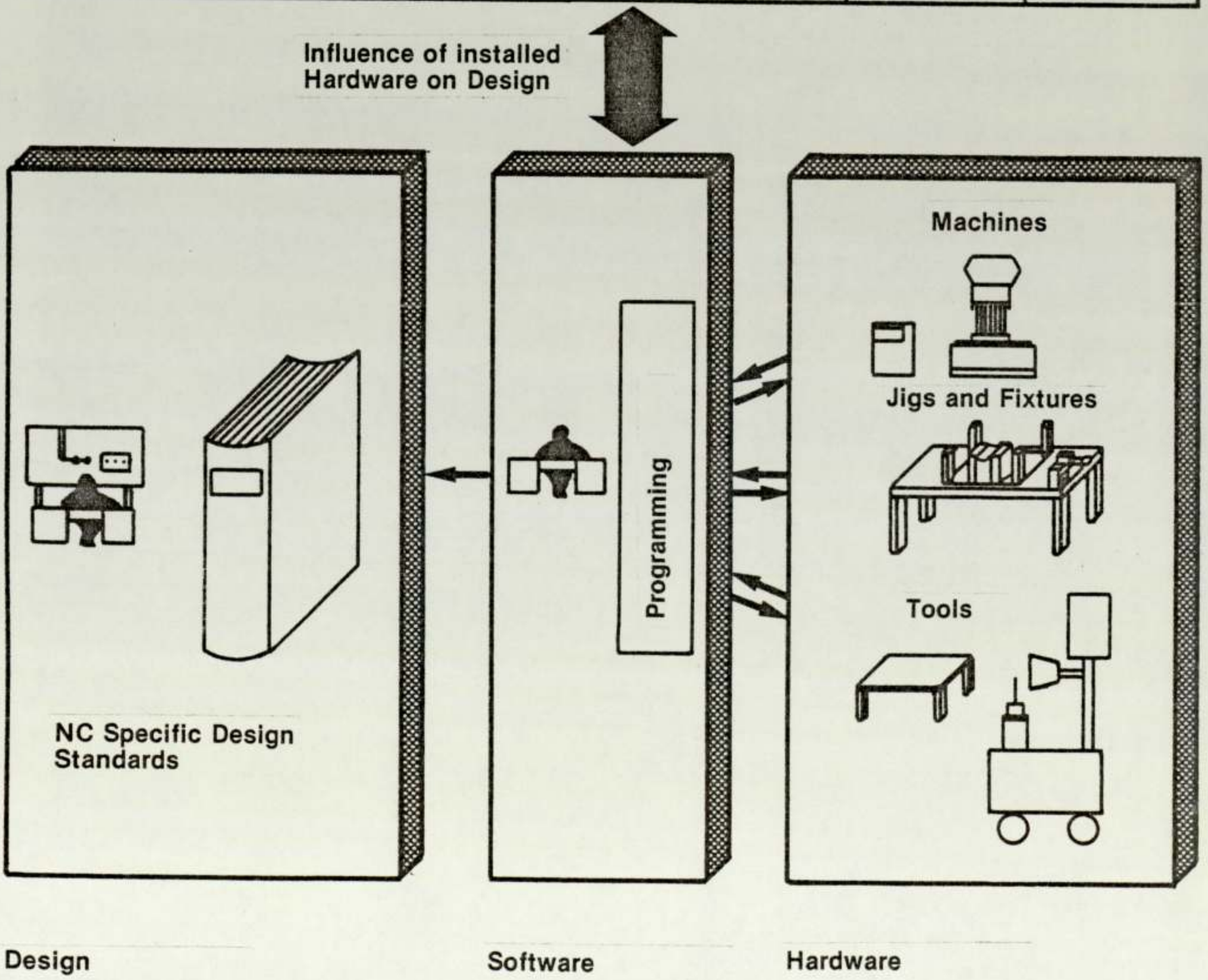


FIG. 150 THE INFLUENCE OF NC TECHNOLOGY ON THE DESIGN PROCESS

FIG.150

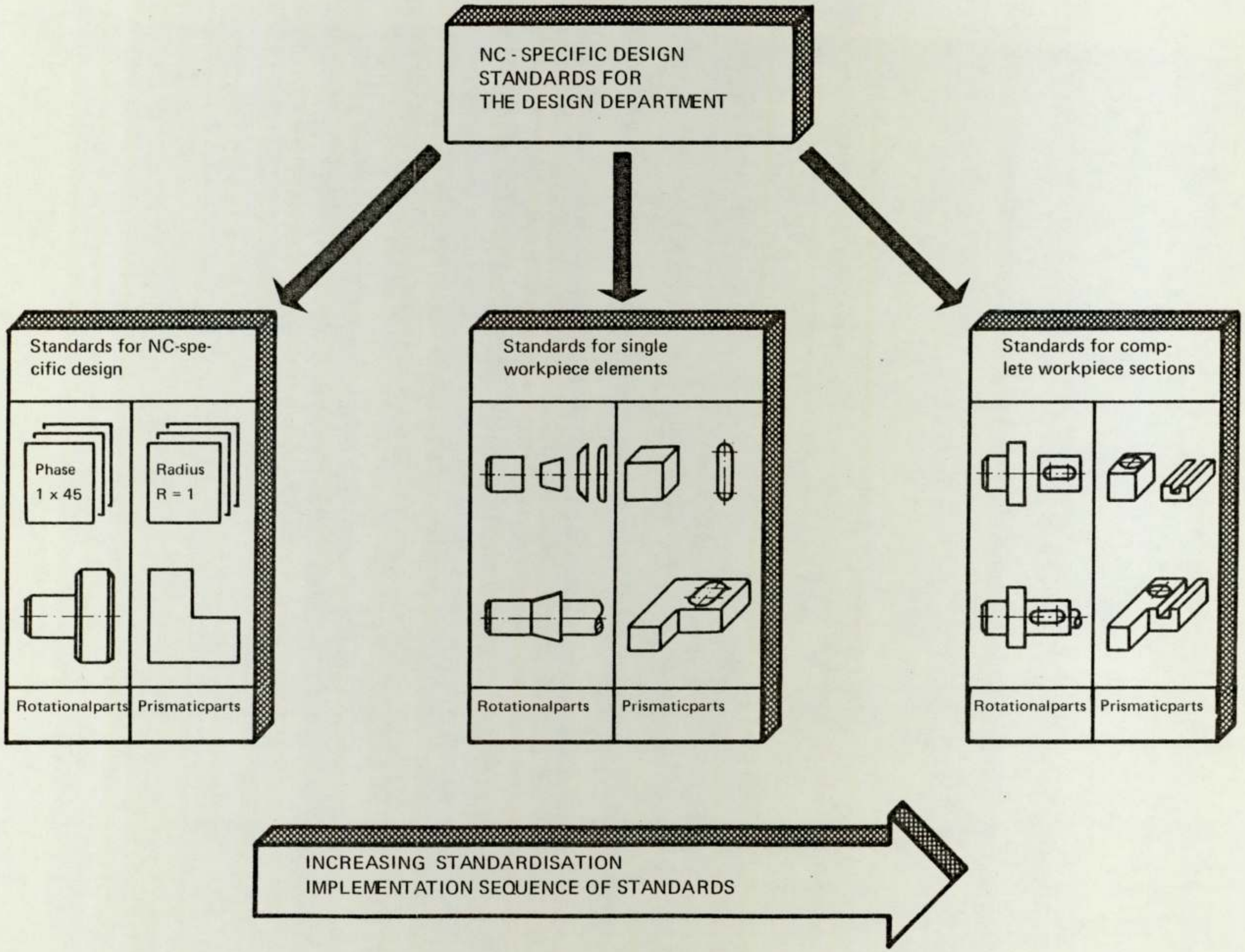


FIG. 151 DESIGN STANDARDS FOR EFFECTIVE NC UTILISATION

FIG. 151

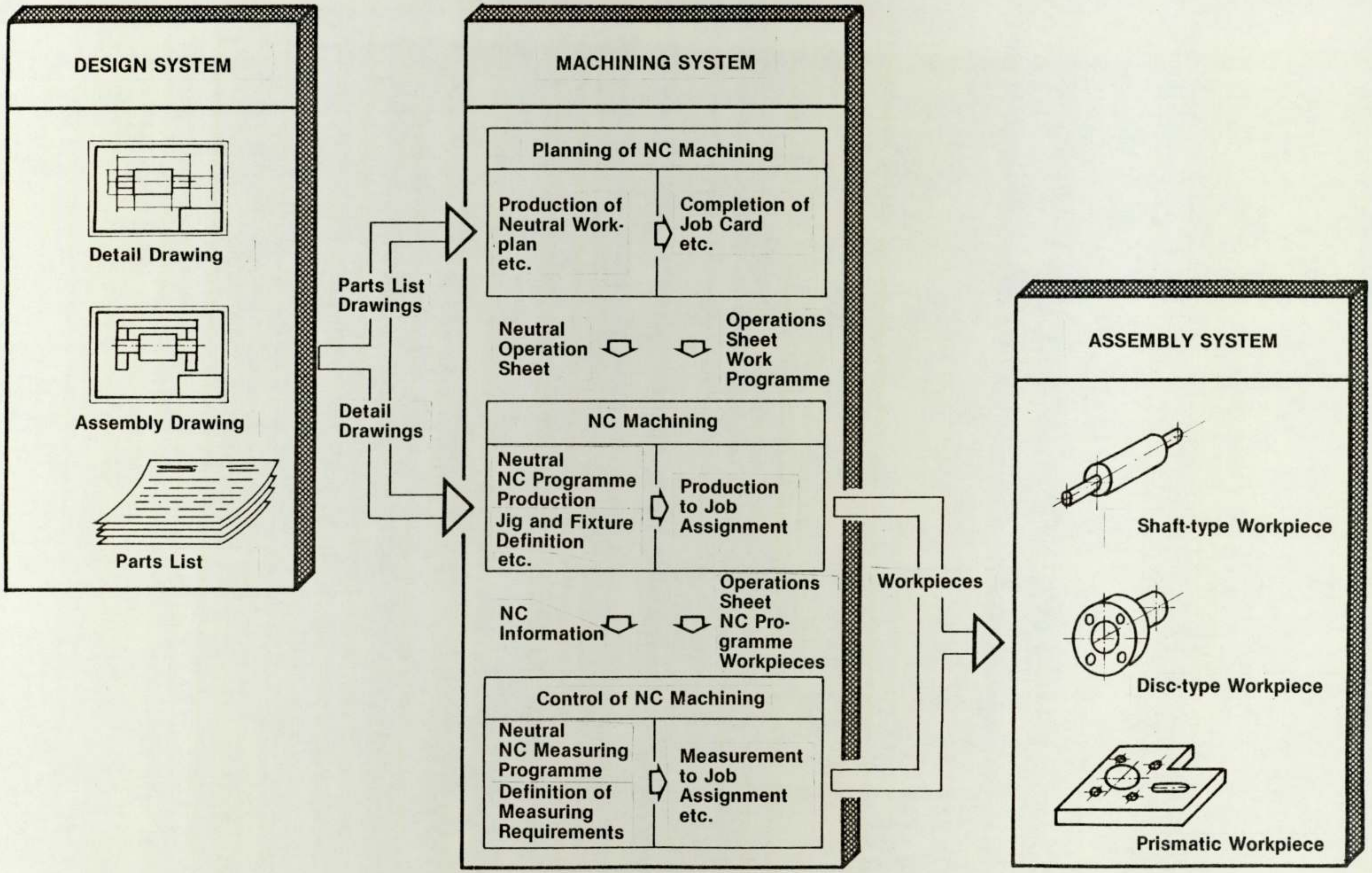


FIG. 152 THE NC MACHINING SYSTEM AND ITS INTEGRATION IN THE PROCESS

FIG 152

FIG. 153 CAD INPUT FORM

Bild 001014

gallus	Datenerfassungsformular zur Detaillierung	Benennung:	Blatt:
		Bearbeiter:	von:

Generelles Oberflächenzeichen: ␣␣␣

Element Nr.		Elementebeschreibung
1 2 3	4	5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 … 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

1
2
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28
29

FIG. 153

FIG. 154 CAD INPUT ELEMENT LIST (SHAFT ELEMENTS)

gallus

Ferd. Rüesch AG
Maschinenfabrik
9004 St.Gallen

Eingabeliste (welle

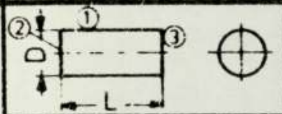
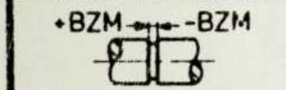
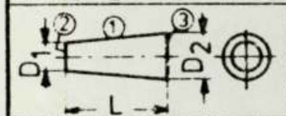
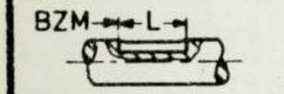
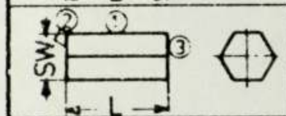
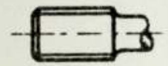
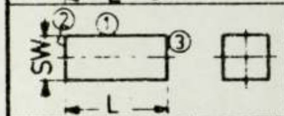
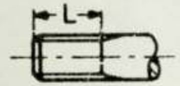
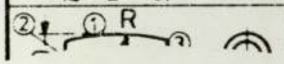
Hauptelemente			Nebenelemente er	
Skizze	Eingabe	Element	Skizze	Eing
	XXX ␣ ZYL / L,D . / TL = / TD= / B1=...	Zylinder		XXX ␣ EINSTS / ± E
	XXX ␣ CON / L,D1,D2 / TL = / B1 = ..	Kegel		XXX ␣ NUT / L.
	XXX ␣ 6KT / L,SW / TL = / B1 = ...	Sechskant		XXX ␣ GEW /
	XXX ␣ 4KT / L,SW / TL = / B1 = ...	Vierkant		XXX ␣ GEWL / L
	XXX ␣ TON / L,D,R / TL = / B1 = ...	Tonnenform		XXX ␣ GEWR / L

FIG. 154

```
GENERELLES OBERFLAECHENZEICHEN  2

AUSSEN-KONTUR
-------------

100 ZYL/22,30/TD=*K5/B1=3
200 ZYL/85,35/TL=-0.1/TD=*H6/B1=3
300 ZYL/175,45/TL=+0.1
400 ZYL/88.5,35/TD=*H6/B1=3
500 ZYL/16,30/TL=-0.1/TD=*K5/B1=3
600 ZYL/34.5,25/TD=*H6/B1=3
110 FASL/
120 EINSTS/-16/TBZM=-0.1
130 FASR/3,15
210 NUT/70,11
220 FASR/3,15
410 FASL/3,15
420 NUT/70,4
510 FASL/3,15
610 FASL/3,15
620 NUT/30,2.5
630 FASR/



FOLGENDE WELLENELEMENTE WERDEN ABGESPEICHERT

AUSSEN-KONTUR
-------------

100 ZYL/22,30/TD=*K5/B1=3
110 FASL/
120 EINSTS/-16/TBZM=-0.1
130 FASR/3,15
200 ZYL/85,35/TL=-0.1/TD=*H6/B1=3
210 NUT/70,11
220 FASR/3,15
300 ZYL/175,45/TL=+0.1
400 ZYL/88.5,35/TD=*H6/B1=3
410 FASL/3,15
420 NUT/70,4
500 ZYL/16,30/TL=-0.1/TD=*K5/B1=3
510 FASL/3,15
600 ZYL/34.5,25/TD=*H6/B1=3
610 FASL/3,15
620 NUT/30,2.5
630 FASR/


BITTE PLOTTER EINSCHALTEN

MASSTAB  =  1 / 2
```

FIG. 155 CAD INPUT LIST (SHAFT-TYPE-ELEMENTS)

FIG. 156 CAD INPUT LIST (TECHNOLOGY AND ORGANISATION)

gallus Datenerfassungsformular zur Detaillierung

Benennung: ____________ Blatt:

Bearbeiter: ____________ Datum: ____________ von:

Nur bei Verzahnung ausfüllen:

			Standardwerte
Zähnezahl	z =	␣␣␣␣␣␣␣	d_o/m_s
Normalmodul	m_n =	␣␣␣␣␣␣␣	m_s
Eingriffswinkel	α =	␣␣␣␣␣␣␣	20°
Schrägungswinkel	β =	␣␣␣␣␣␣␣	0°
Verdrehflankenspiel total	j_t =	␣␣␣␣␣␣␣	} Muss in jedem Falle eingegeben werden
Rundlauffehler	f_r =	␣␣␣␣␣␣␣	
Profilverschiebung	x·m =	␣␣␣␣␣␣␣	0

Zentrierung: ␣ Keine = 0 ;nur rechts = 1 ;nur links = 2 ;beidseitig = 3

...ung gewünscht:

Allgem. Bemerkung... ␣␣␣␣␣␣␣

␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣

␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣

Benennung: ␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣

Bearbeitungszeichnung: JA / NEIN

Falls „NEIN" Zeichnungsart: ␣␣

Alternativen:

Vorbearbeitungszeichnung	02	Betriebsmittelzeichnung	12
Vorbearb.-zeichn.f. Schw.-teile	03	Rohteilzeichnung	22
Nacharbeitszeichnung	04		

Material: ␣␣␣␣ (evtl. weitere)

Alternativen:

■ Ck 45	20	GG-35	Al 99	G-Al Si 12
■ 9 S Mn 28	2'	GGG-38	Al Mn	G-Al Si 9 M
▼ Ck 45 K	C	GGG-42	Al R Mg 0,5	G-Al Si 5 Mgwa
Blank	C	GGG-50	Al R Mg 1	G-Al Si 7 Mgwa
Geschliffen	(	GGG-60	Al Mg 1	G-Al Si 10 Mg
▼ 45 S 20	(7	GGG-70	Al Mg 2	G-Al Mg 3
▼ 14 Ni Cr 14	(	GTW-35	Al Mg 3	G-Al Cu 4 Ti
▼ 42 Cr Mo 4	(	...45	Al Mg 4,5 Mn	G-Al Cu 4 Ti Mi
9 S 20	(		...5	Cu Zn 40 Pb 3
9 S Mn Pb 28	:	Al ...		Cu Zn 38 Pb 1
...Mn 36	(	Al 99,5	Al Zn...	
		; ▼ Lagerhaltig		G-CuA 19 Ni

Wird kein standard... ...ndet, ist einzugeben:

spezifisches Gewicl... ␣␣␣␣␣

10-te Stelle des T...

Alternativen:

0 - Stahl, unlegiert, ...	5 - Gusseisen legiert Temperguss
1 - Stahl, unlegiert, ...	6 - Cu und Cu-Legierungen
2 - Stahl, legiert, ohn...	7 - Al und Al-Legierungen
3 - Stahl, legiert, mit ...	8 - sonstige Werkstoffe
4 - Gusseisen unlegi...	9 - mehrere Werkstoffe

Falls mit Innenkontur ...

EXAPT-Programm :

GALLUS-X Familie :

Arbeitsplan

FIG. 156

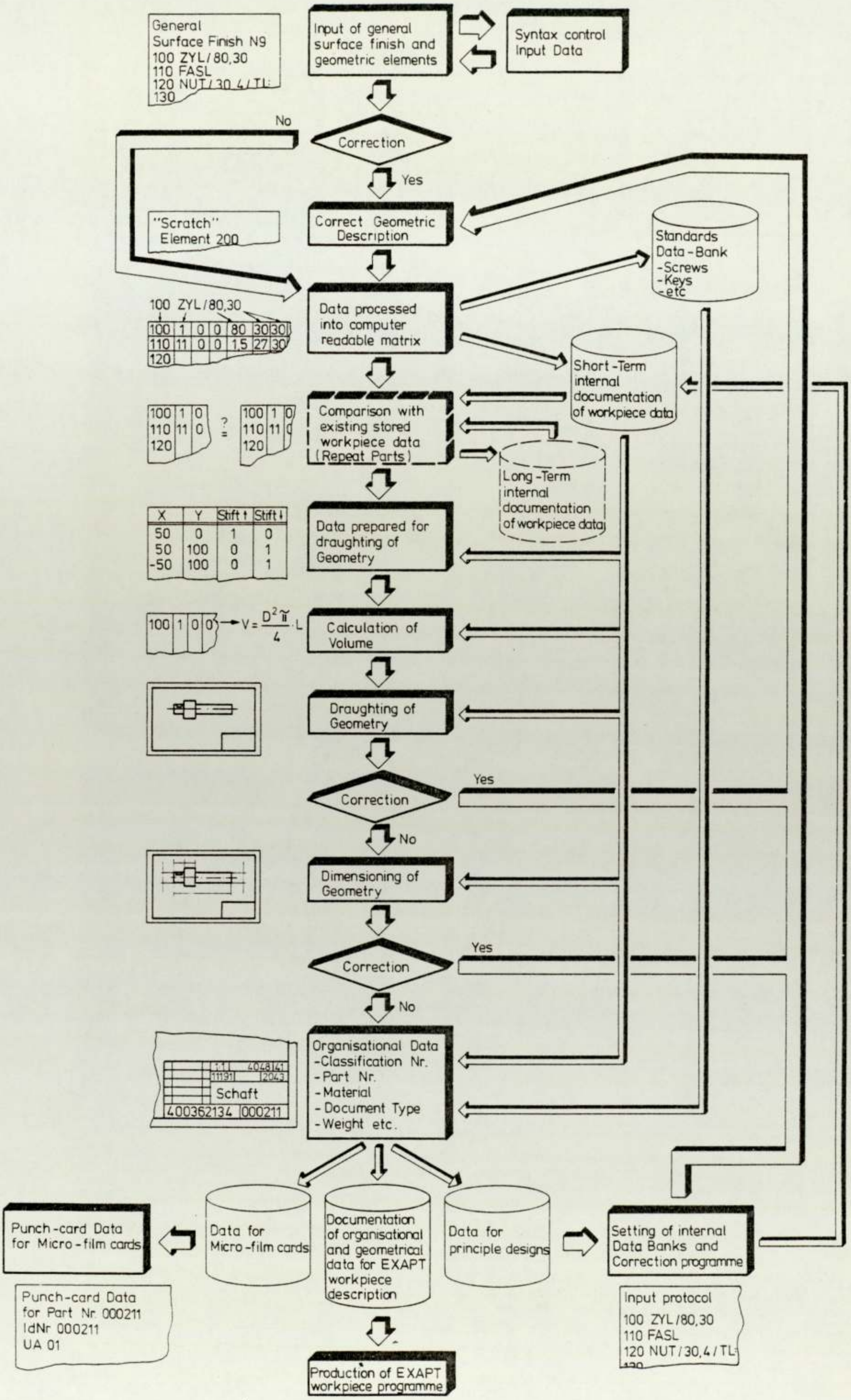


FIG. 157 CAD PROGRAMME FLOWCHART

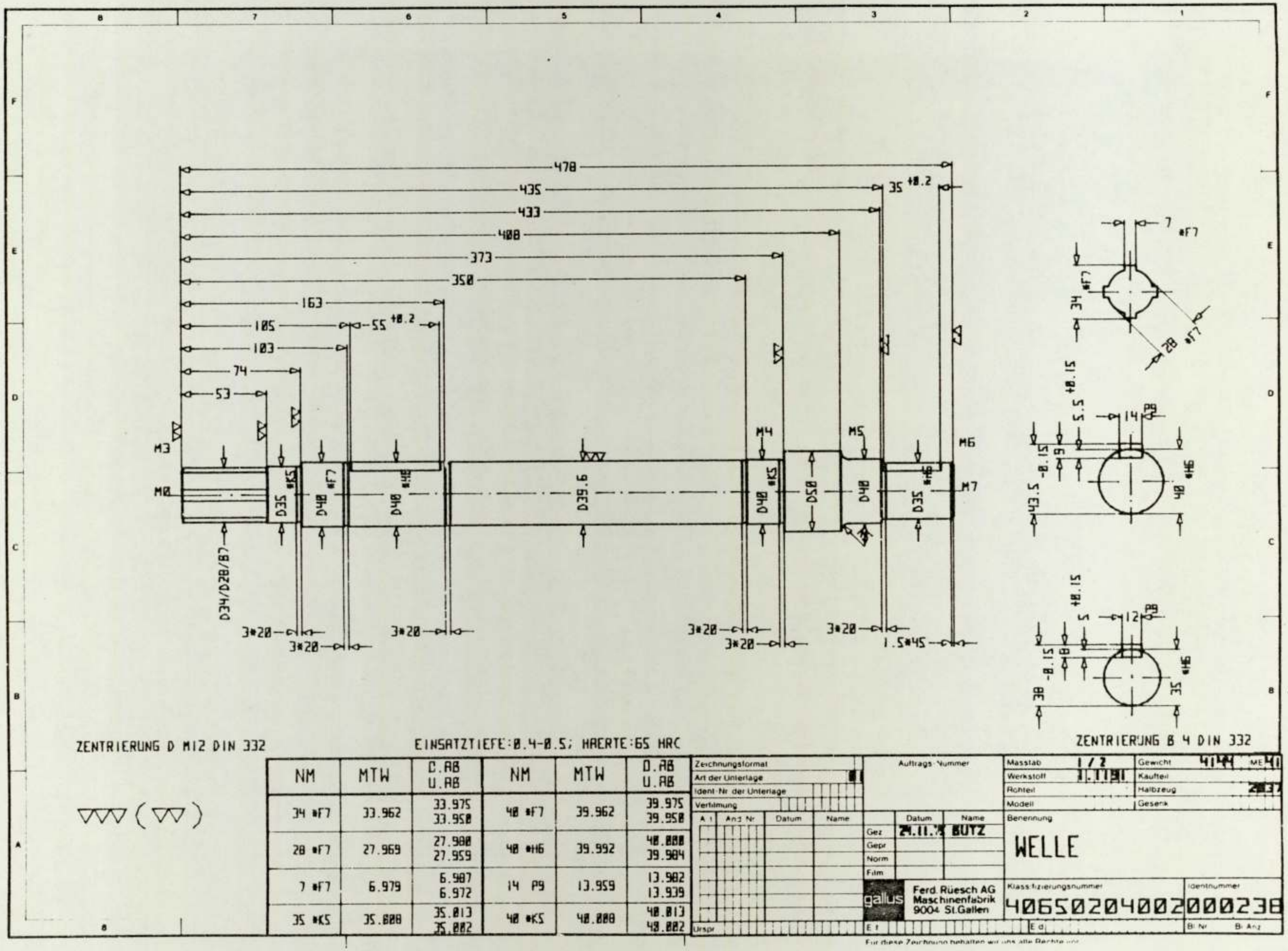


FIG.158 CAD OUTPUT FOR CAM (SHAFT-WORKPIECE)

FIG. 158

FIG. 159 CAD HARDWARE CENTRE FOR THE DESIGN DEPARTMENT

FIG. 159

FIG. 160 CAM HARDWARE CENTRE FOR THE MACHINING DEPARTMENT

FIG. 160

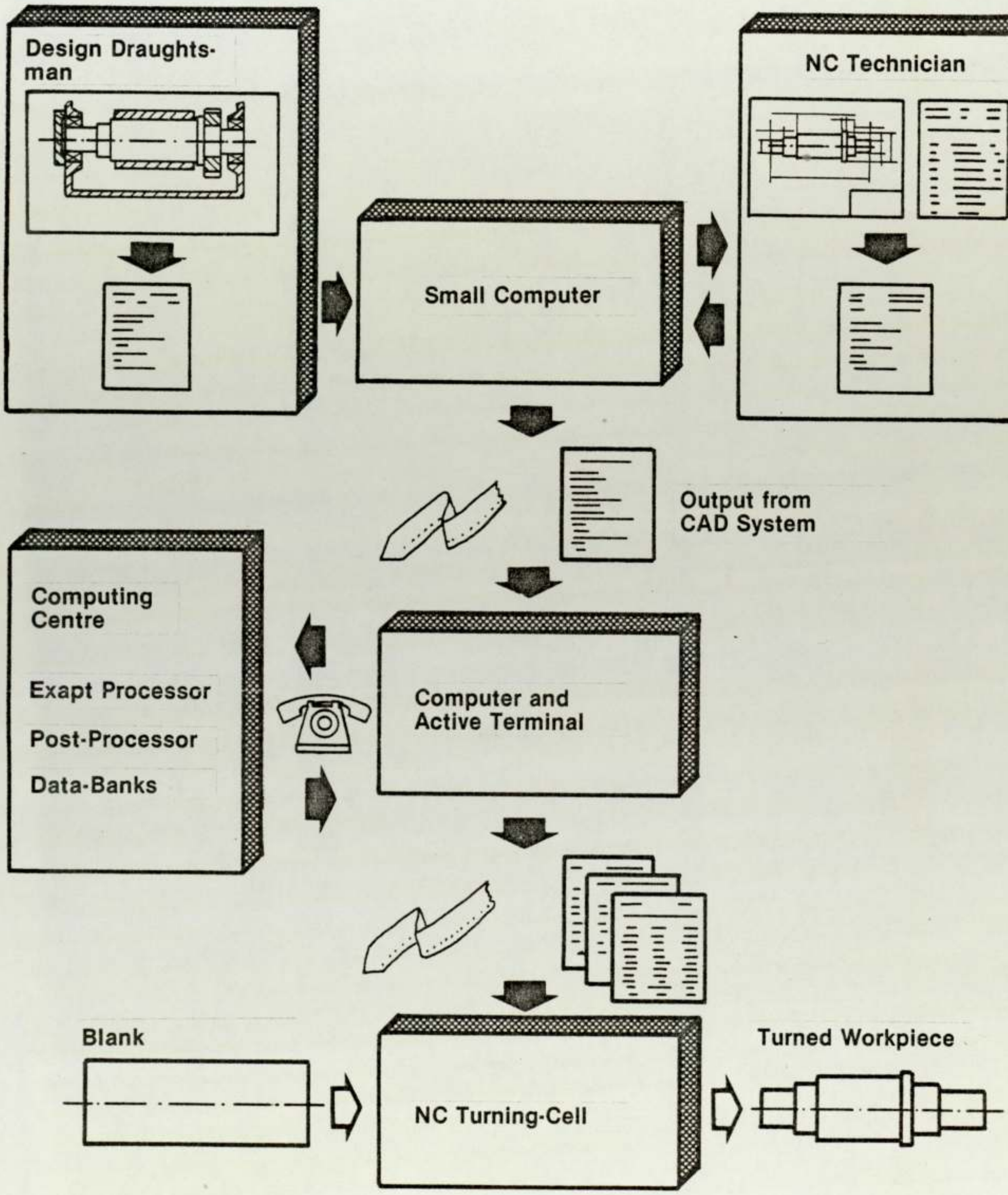


FIG. 161 FLOW OF INFORMATION FROM DESIGN LAYOUT TO NC TURNING-CELL

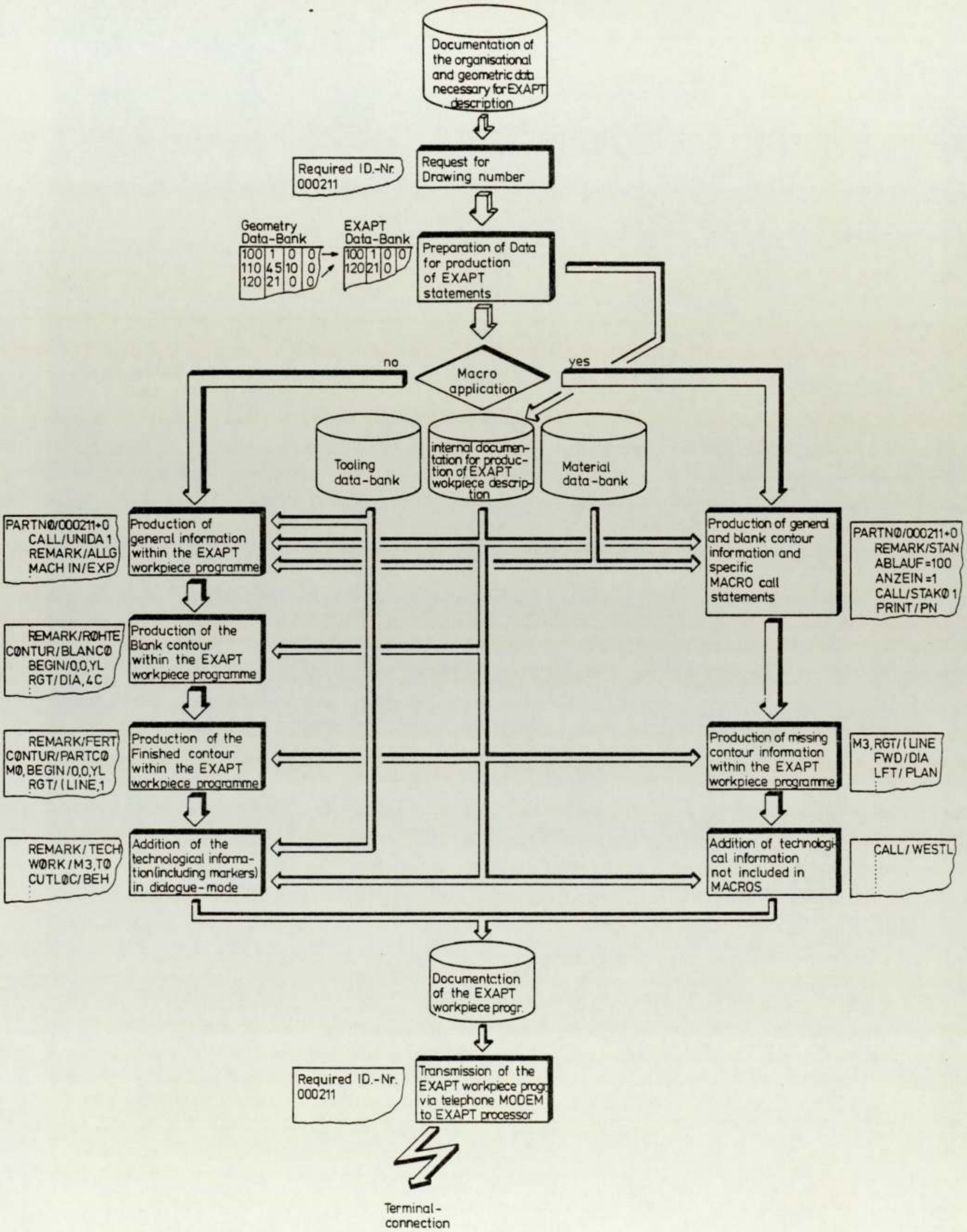


FIG. 162 PRODUCTION OF AN EXAPT-2 NC-WORKPIECE PROGRAMME FROM A CAD BASED DATA STRUCTURE

FIG. 163a CAD OUTPUT FOR CAM (SHAFT-TYPE WORKPIECE)

```
ERSTELLUNG DES EXAPT2-TEILEPROGRAMMES
=====================================

ALTERNATIVEN
============
   WELLENTEIL                 =1
   FUTTERTEIL                 =2
   NEUTRALE PROGRAMMIERUNG    =3

   10 PARTNO/000255+WELLE +OP+5+6+15/12/75+ARM
   20         CALL/WELKO1
   30         REMARK/WELLENTEILE
   40         ABLAUF=300
   50         ANZEIN=2
   60         PPRINT/ PN600 DATUM15/12/75
   70         PPRINT/ PN600  NAMEARM
   80         PPRINT/ PN600MATERL1.1191
   90         PPRINT/ PN600BLANCODIA 55 X 421
  100         PPRINT/ PN600SPA-BZ STIRNMITNEHMER
  110         PPRINT/ PN600FDRUCK20
  120         PPRINT/ PN600PDRUCK1.5
  130         PPFUN / PN600,GREIFR,100,100,2,2
  140         REMARK/***SONDERMODIFIKATOREN
  150         CALL/CALC
  160         REMARK/***GEOMETRISCHE ANGABEN
  170         REMARK/***OBLIGATORISCH
  180         RD1   =55
  190         FL1   =420.95
  200         FL10  =106.95
  210         FL10XX=282
  220         REMARK/***TECHNOLOGISCHE ANGABEN
  230         REMARK/***OBLIGATORISCH
  240         STIRNM=45
  250         WERKST=800
  260         SURFIN/FIN
  270         FINELI=1
  280         FINERE=1
```

```
STANDARDEINGABEWERTE-AENDERUNG NUR BEI BEDARF
=============================================
   SICHAB=    1   CLDIST
   FINAM =   0.2 OVSIZE FIN
   FINEAM=   0.2 OVSIZE FINE
   ZREFPO=1490   REF.PO.MASCH.Z-ACHSE


SICHAB=          1.5

  290            SICHAB=1.5
  300            CALL/WELKO2
  310            REMARK/***KONTURBESCHREIBUNGEN
  320            REMARK/ROHTEILBESCHREIBUNG
  330 CONTUR/BLANCO
  340            BEGIN/0,0,YLARGE,PLAN,0
  350            RGT/DIA,55
  360            RGT/PLAN,421
  370            RGT/DIA,0
  380 TERMCO
  390            REMARK/FERTIGTEILKONTUR
  400 CONTUR/PARTCO
  410 M0,        BEGIN/0,0,YLARGE,PLAN,0
  420            RGT/(LINE/0,13.5,1.5,15.003)
  430 M3,        FWD/DIA,30.007,FINE
  440            RGT/(LINE/19,15.003,22,14.196),ROUND,0.8
  450            LFT/PLAN,22,BEVEL,0.5
  460            RGT/DIA,34.992,FINE
  470            RGT/(LINE/103.95,17.496,106.95,16.696),ROUND,0.8
  480            LFT/PLAN,106.95,BEVEL,0.5
  490 M4,        RGT/DIA,45,BEVEL,0.5
  500 M5,        RGT/PLAN,282,ROUND,0.8
  510            LFT/(LINE/282,16.696,285,17.496)
  520            FWD/DIA,34.992,FINE,BEVEL,0.5
  530            RGT/PLAN,370.5,ROUND,0.8
  540            LFT/(LINE/370.5,14.196,373.5,15.003)
  550            FWD/DIA,30.007,FINE,BEVEL,0.5
  560            RGT/PLAN,386.45,ROUND,0.8
  570            LFT/(LINE/386.45,11.696,389.45,12.496)
  580            FWD/DIA,24.993,FINE
  590            RGT/(LINE/419.45,12.496,420.95,11)
  600 M6,        RGT/PLAN,420.95
  610 M7,        RGT/DIA,0
  620 TERMCO
  630            REMARK/TECHNOLOGISCHE DATEN
```

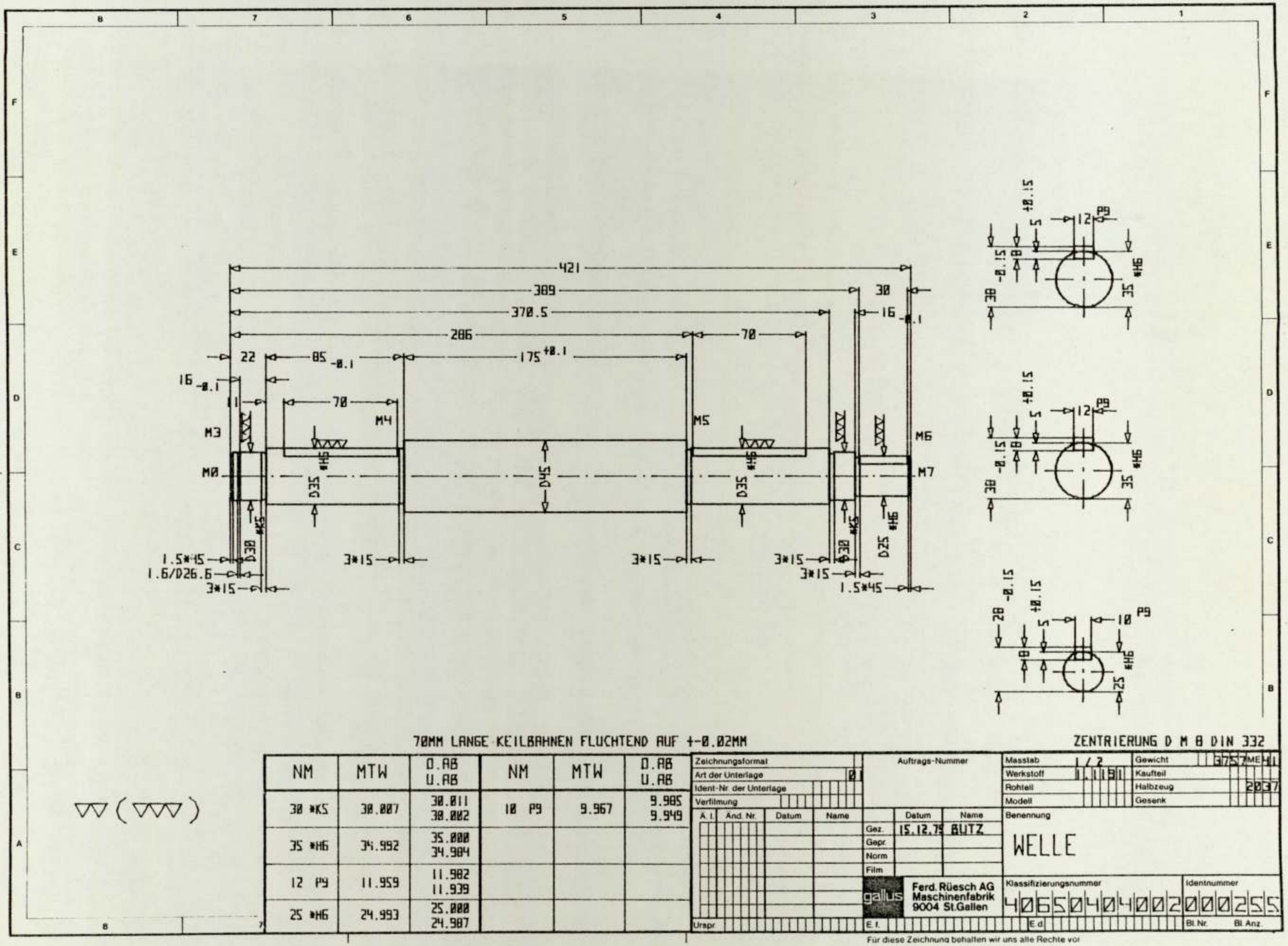


FIG. 163b CAD DRAWING SHAFT-WORKPIECE

FIG. 163b

FIG. 163c CAD DRAWING DISC-WORKPIECE

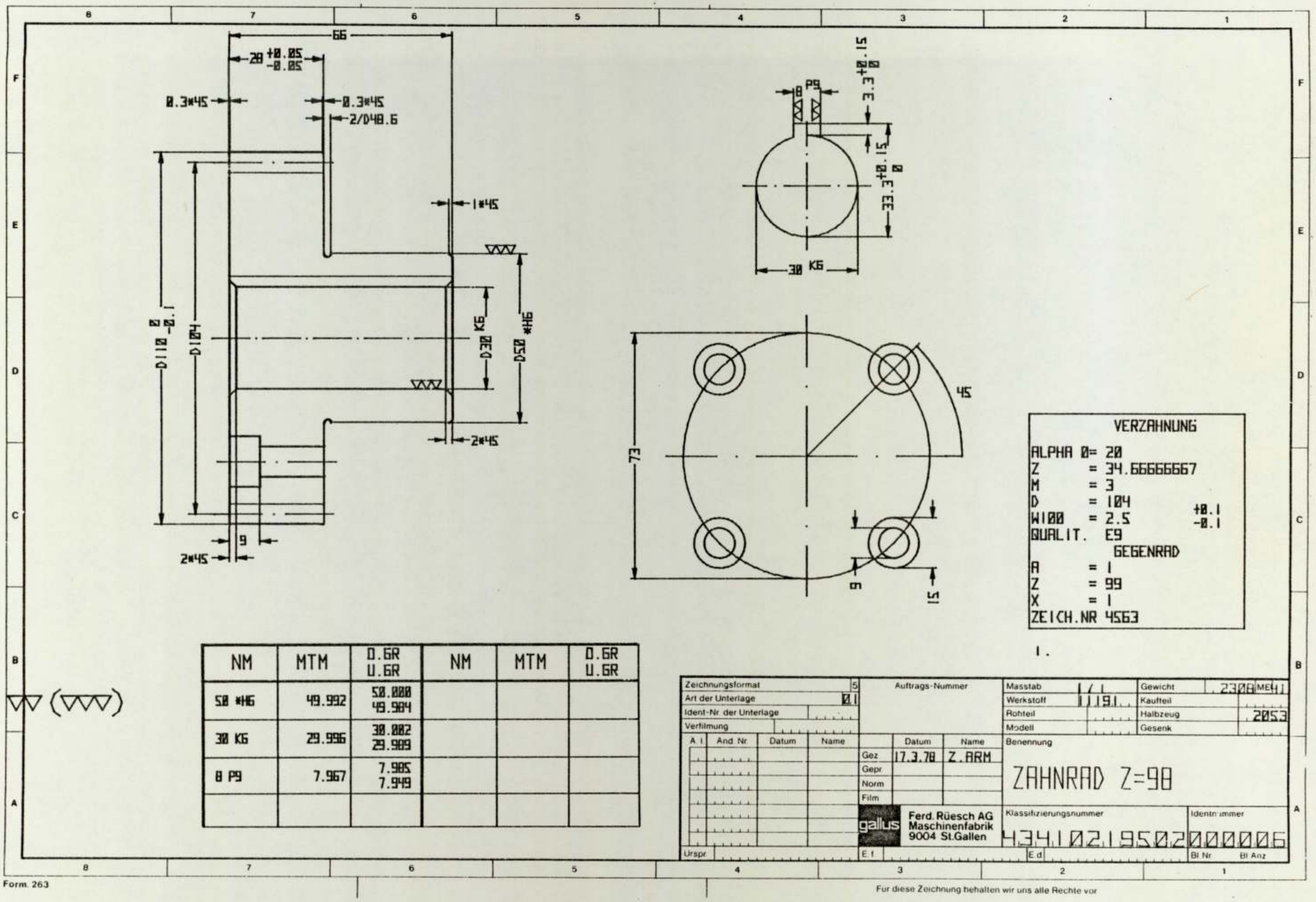


FIG. 163c

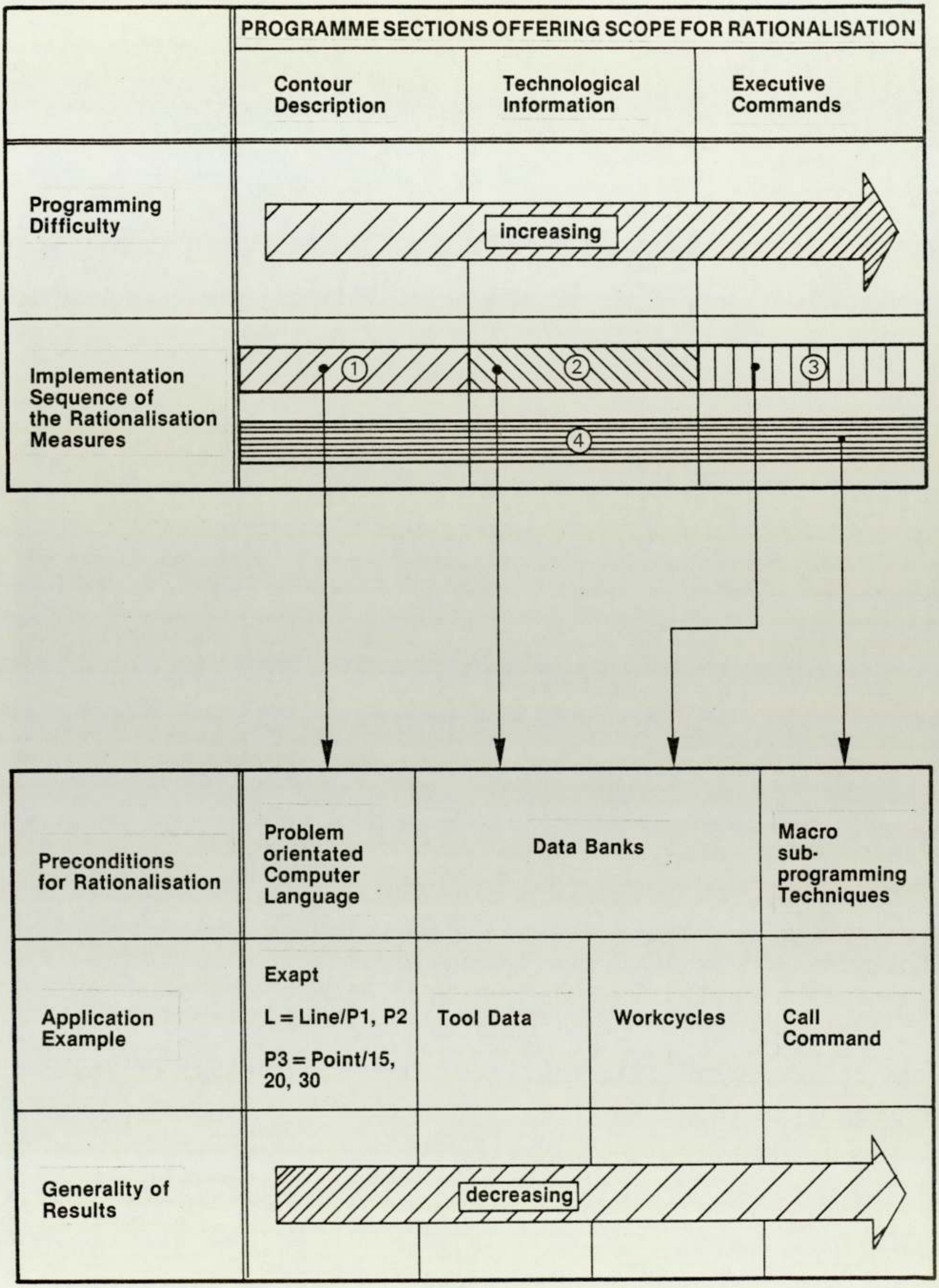


FIG. 164

PRECONDITIONS AND IMPLEMENTATION SEQUENCE FOR NC PROGRAMMING RATIONALISATION

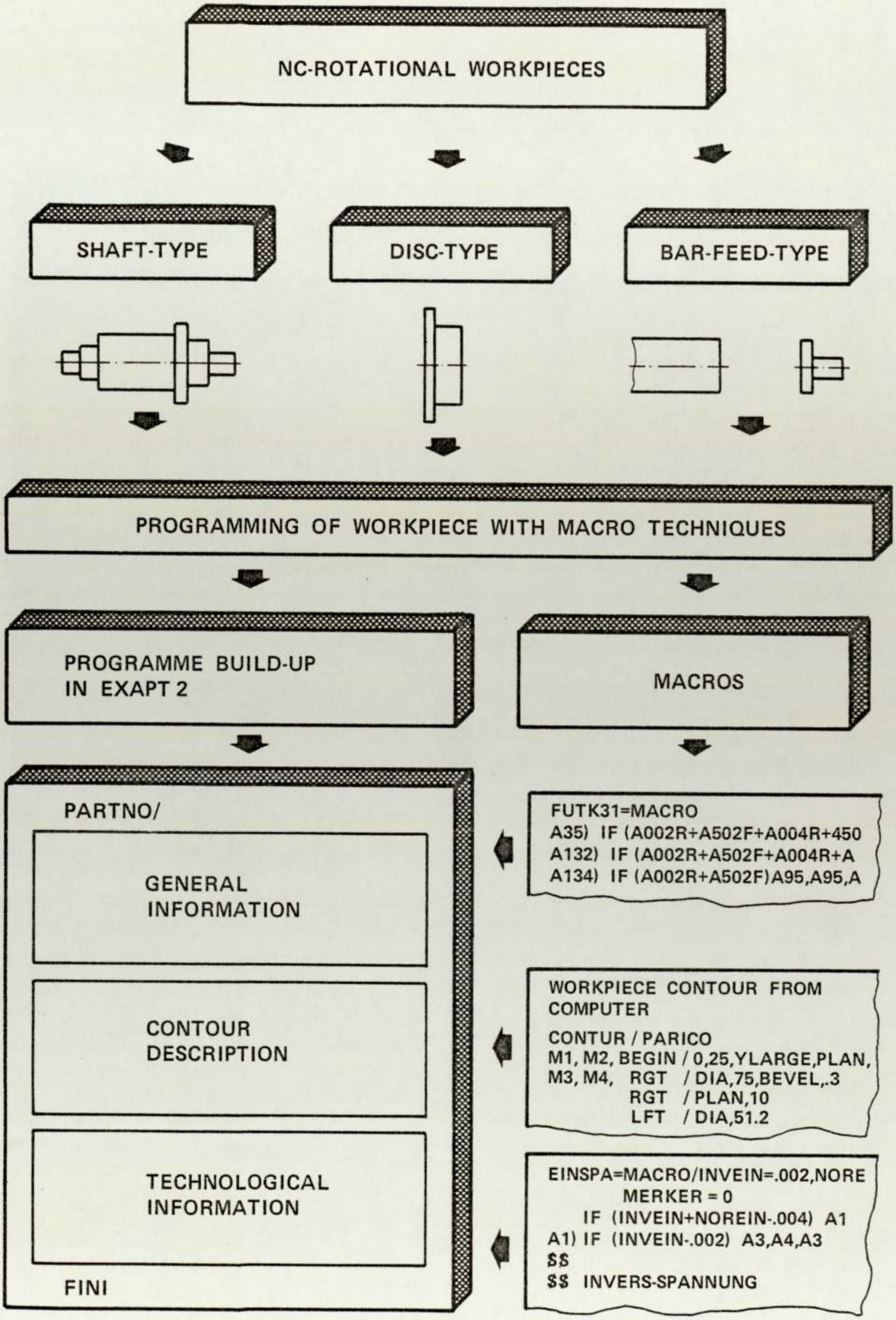


FIG. 165 THE APPLICATION OF THE MACRO-TECHNIQUE

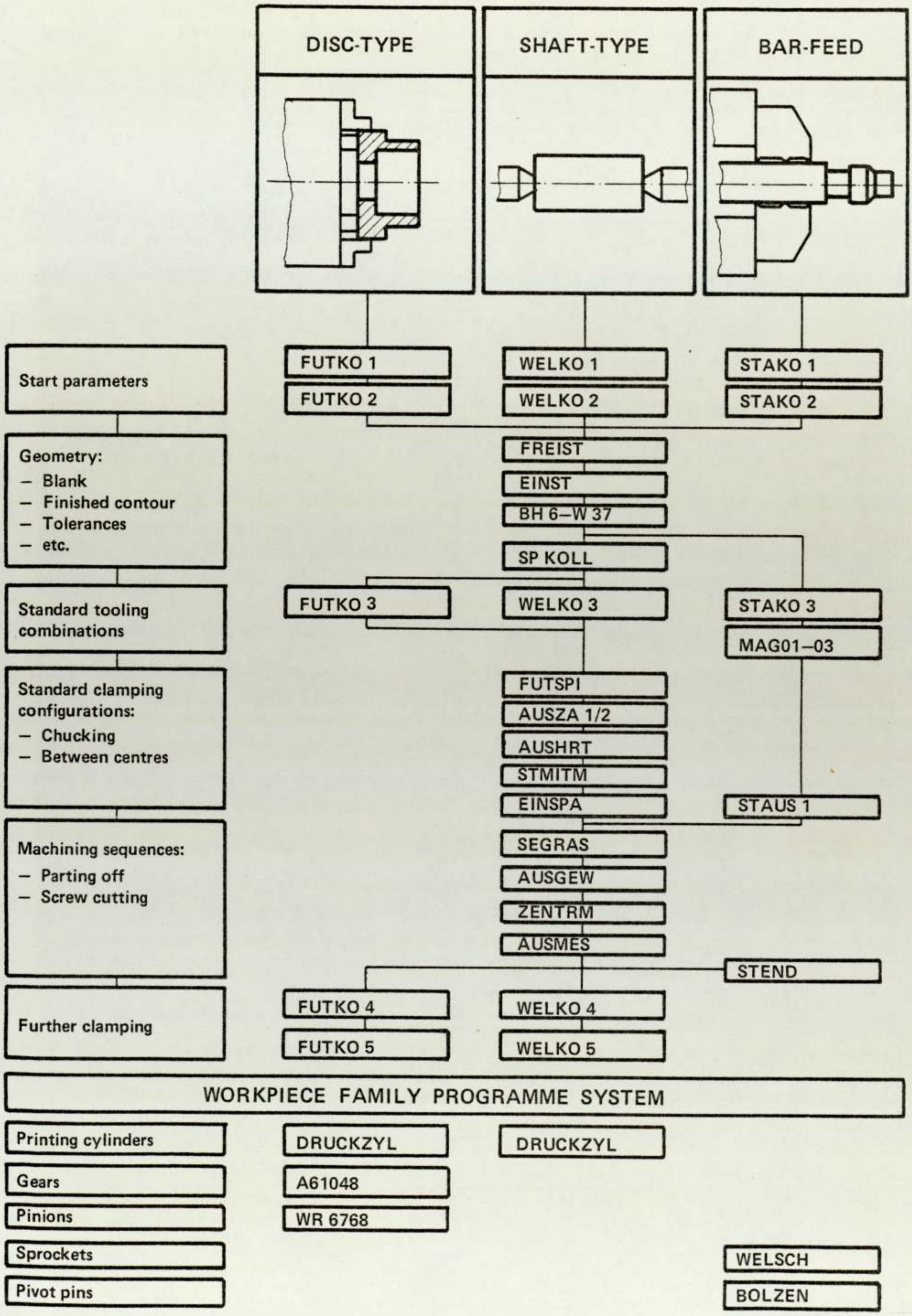


FIG 166. EXAPT 2 MACROS FOR ROTATIONAL WORKPIECES

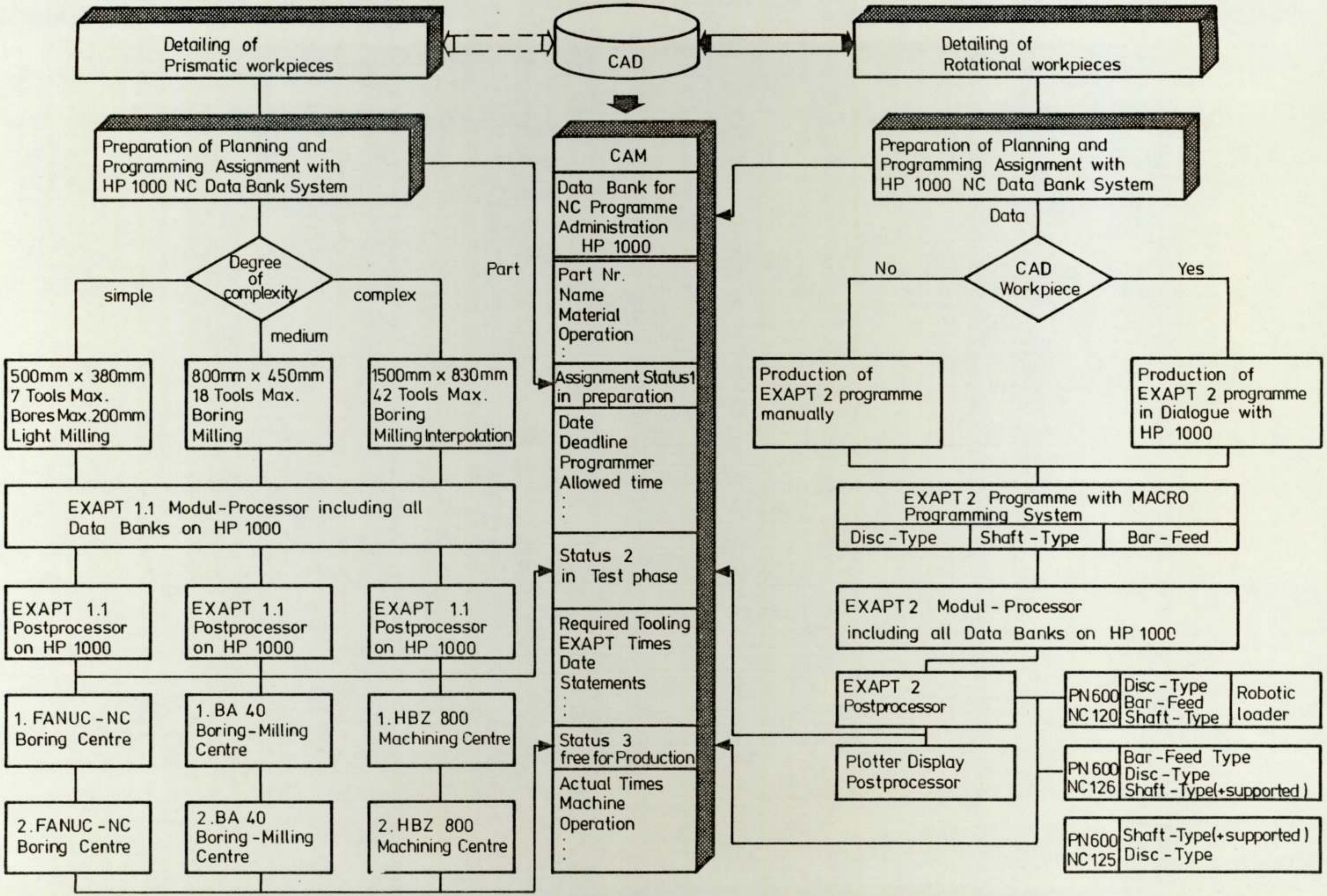


FIG.167

FIG.167 CAM / NC PROGRAMMING SYSTEM

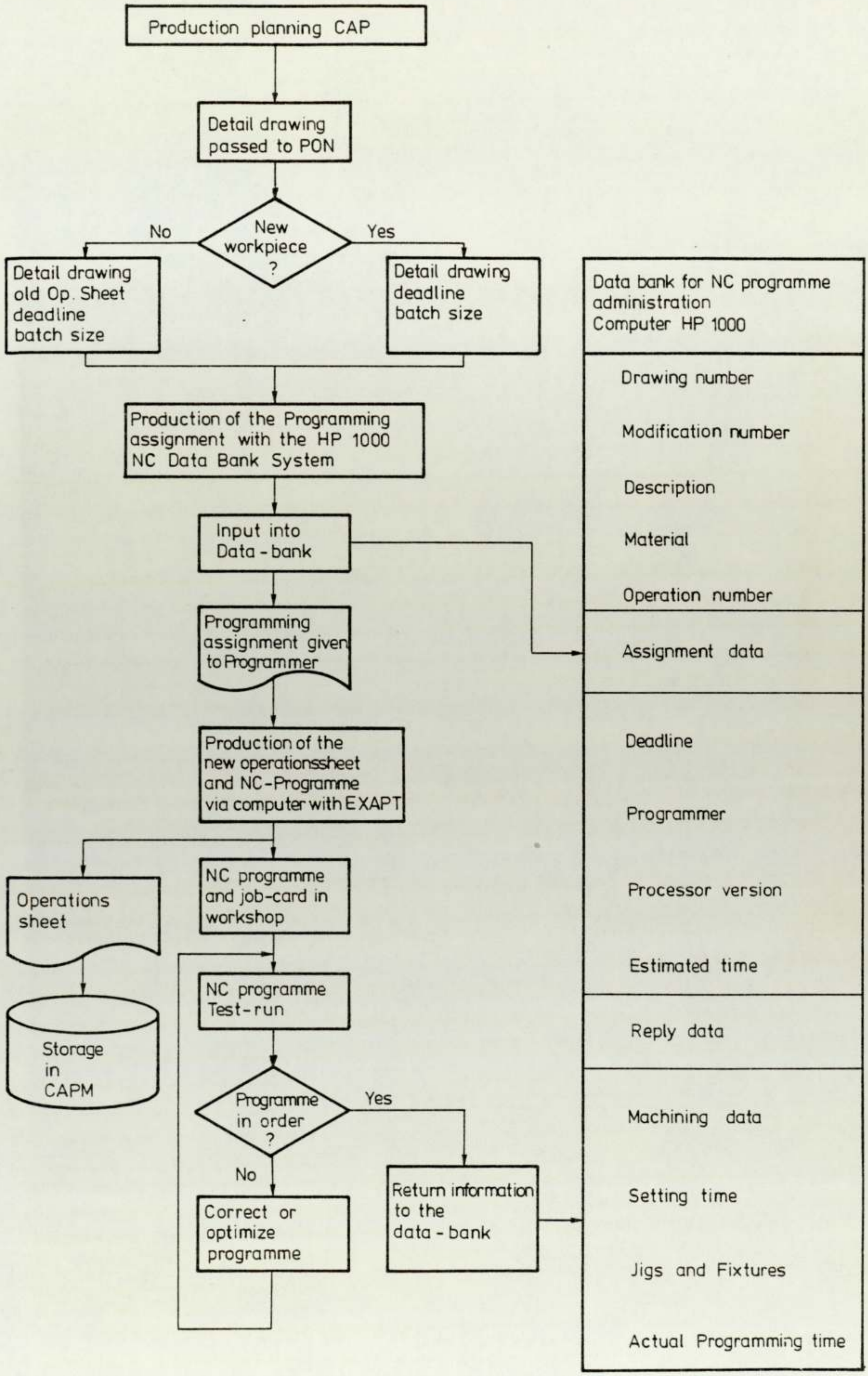


FIG. 168 NC WORKPIECE PROGRAMMING PLANNING SYSTEM

FIG. 168

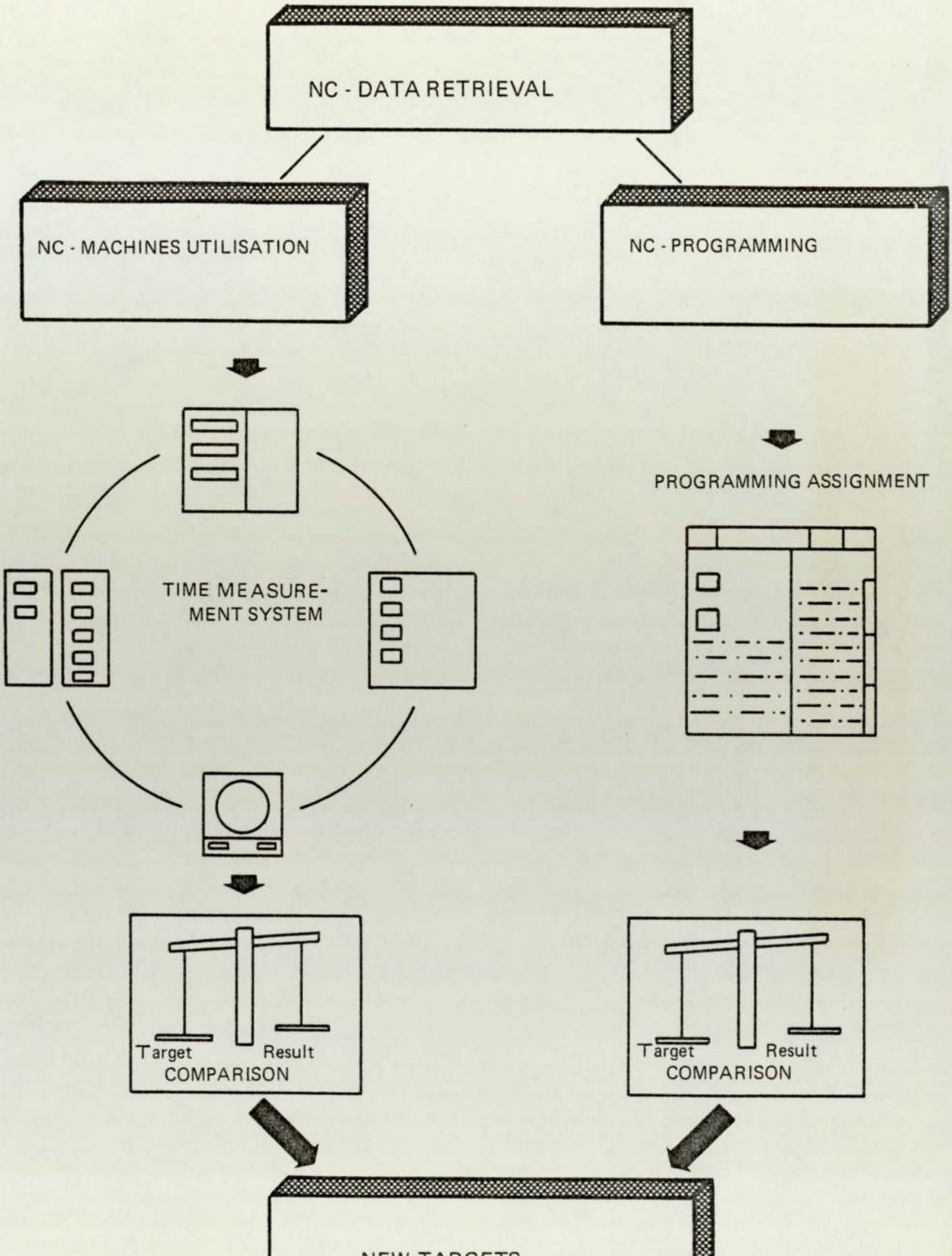


FIG. 169 NC DATA RETRIEVAL SYSTEM

FIG. 170 NC MACHINING CONTROL (DATA RETRIEVAL)

FIG. 170

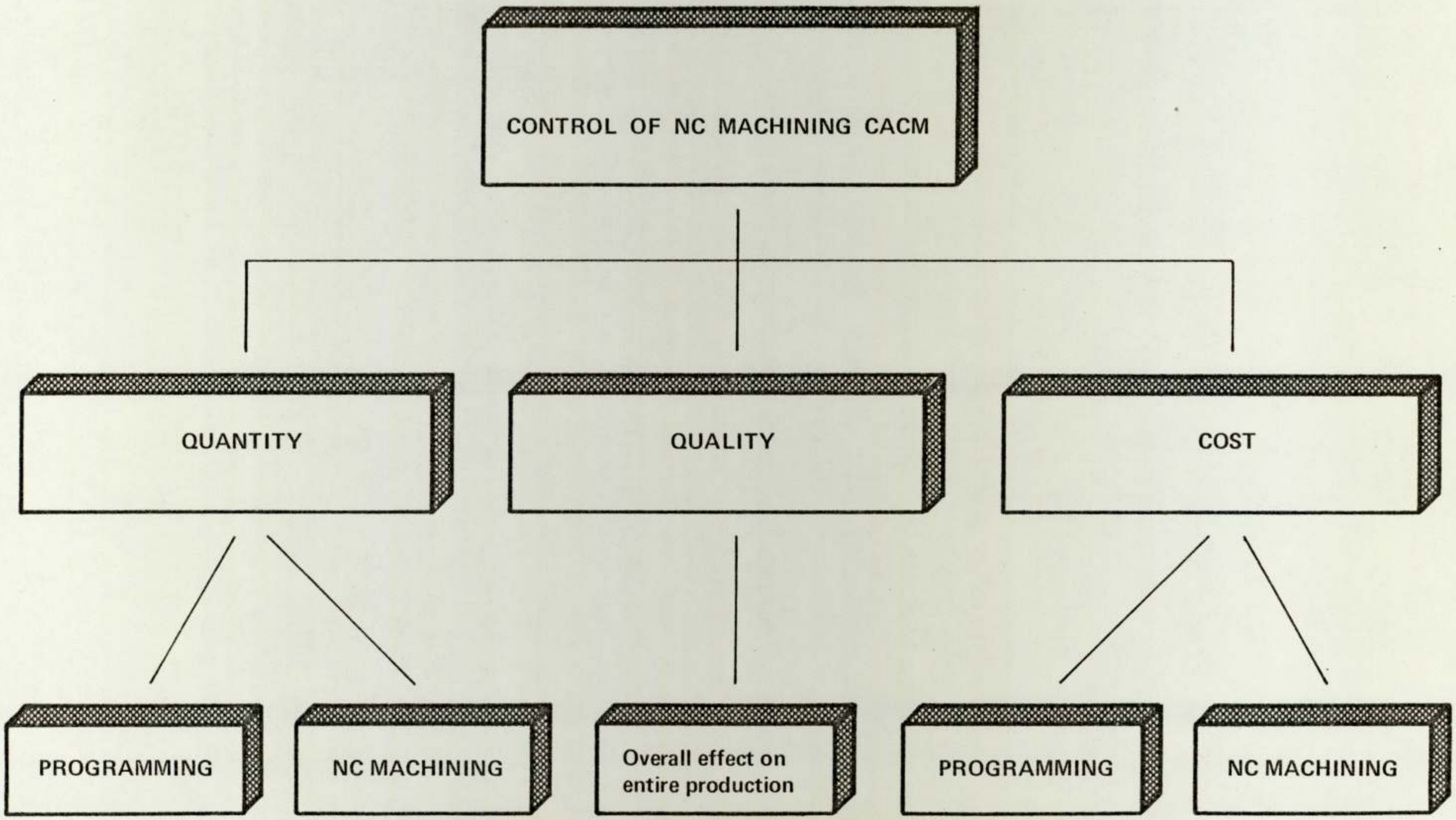
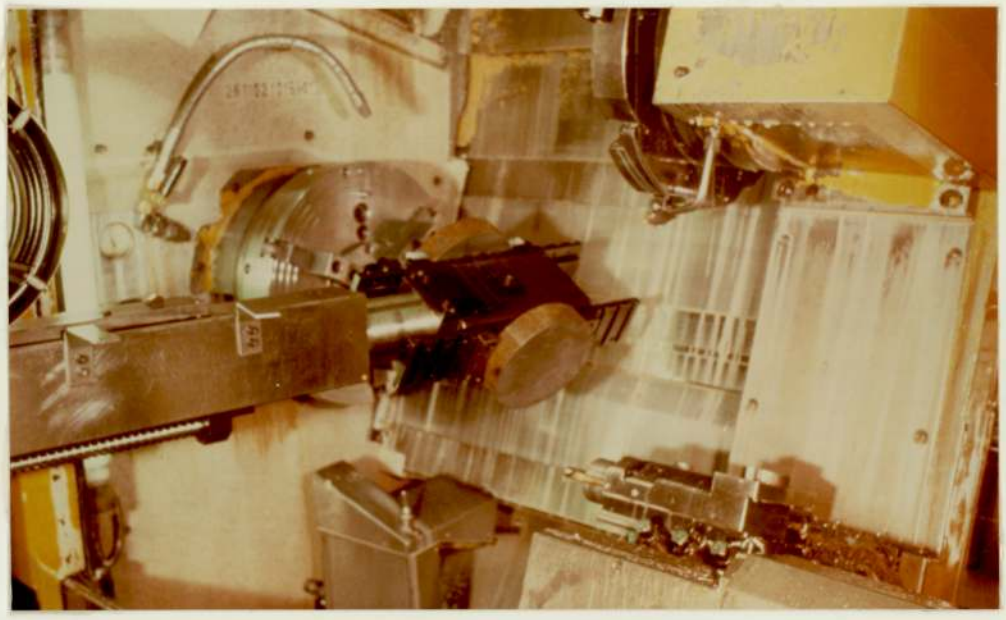


FIG. 171 EVALUATION CRITERIA OF NC MACHINING SYSTEM PRODUCTIVITY

FIG. 171



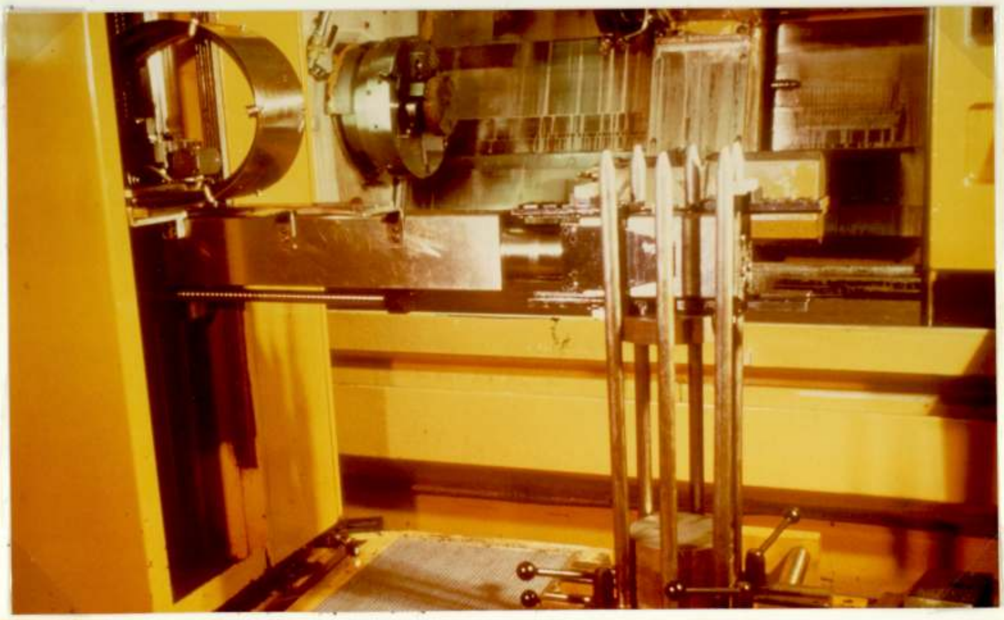
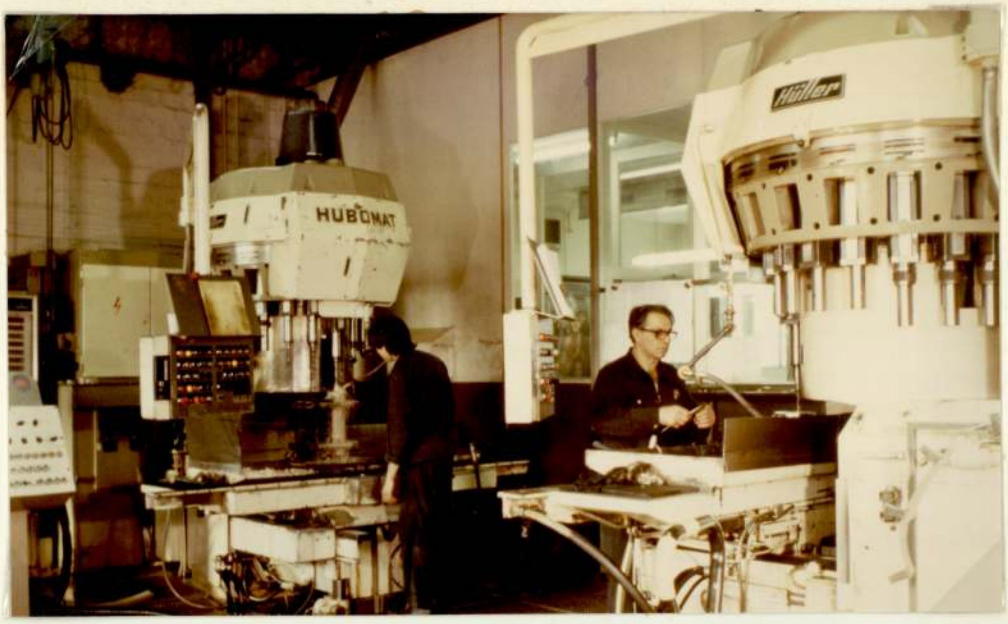
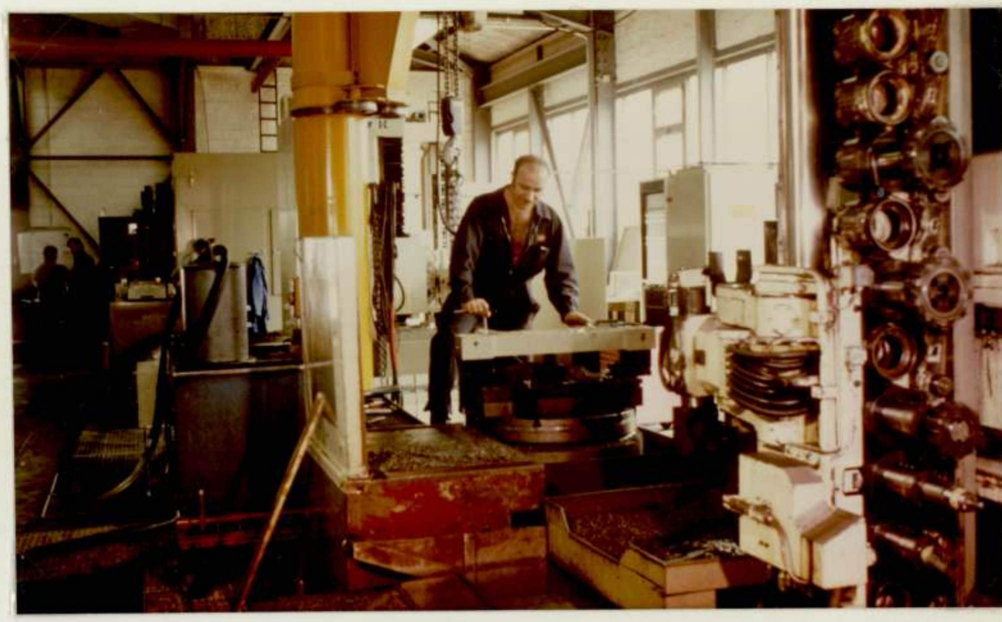


FIG. 172 NC-LATHES, ROBOT LOADING AND UNLOADING WORKPIECE

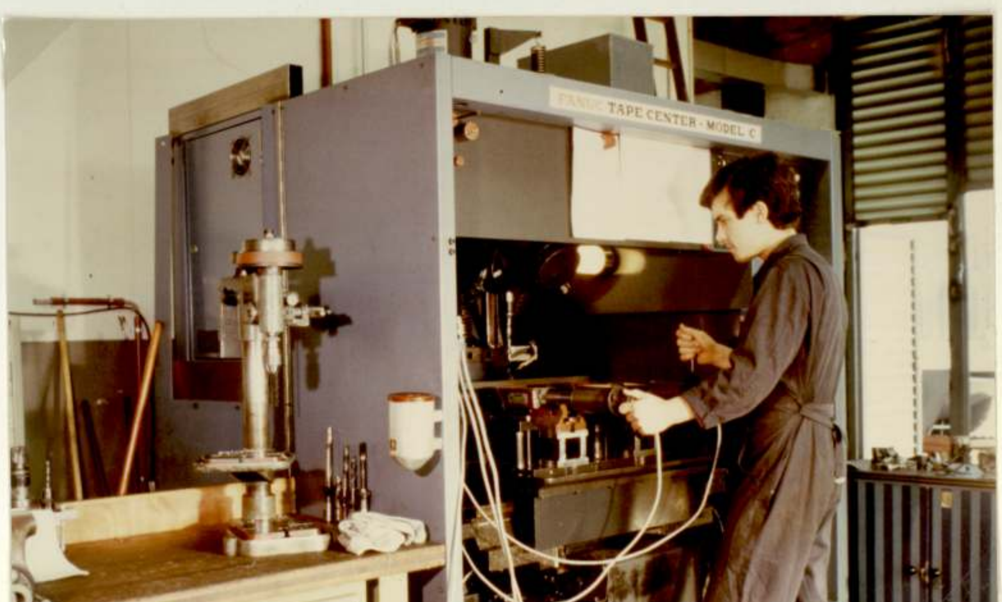
FIG. 172



173a NC BORING-MILLING CENTRES



173b NC MACHINING CENTRES

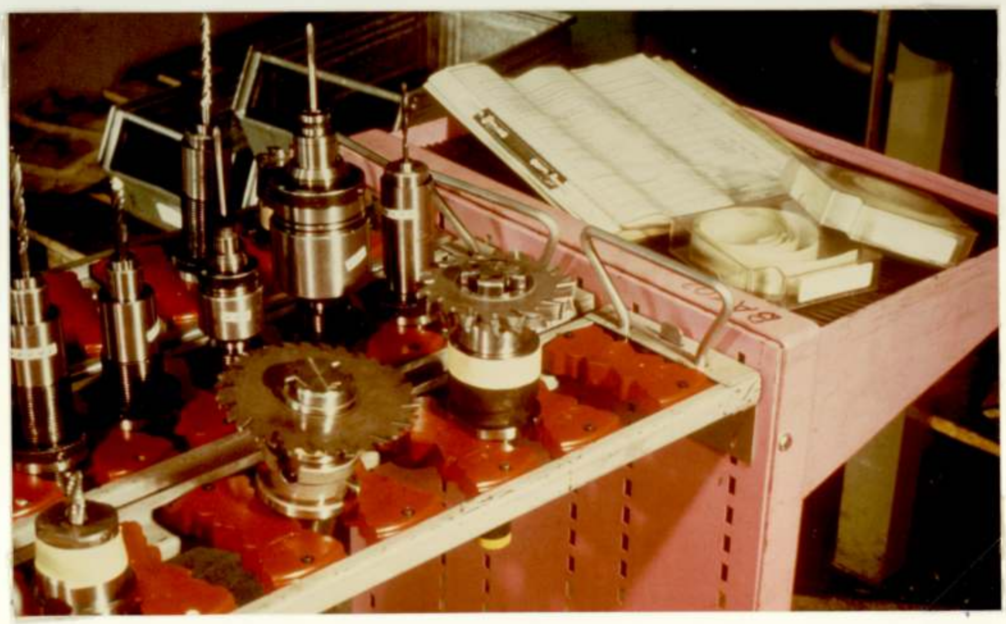


173c NC BORING CENTRES

FIG. 173

174a TURNING-TOOL PRESETTING

174b BORING-BAR PRESETTING



174c PREPARED TOOLING FOR THE JOB

FIG. 174

FIG. 175 MODULAR JIG AND FIXTURE BUILDING AREA

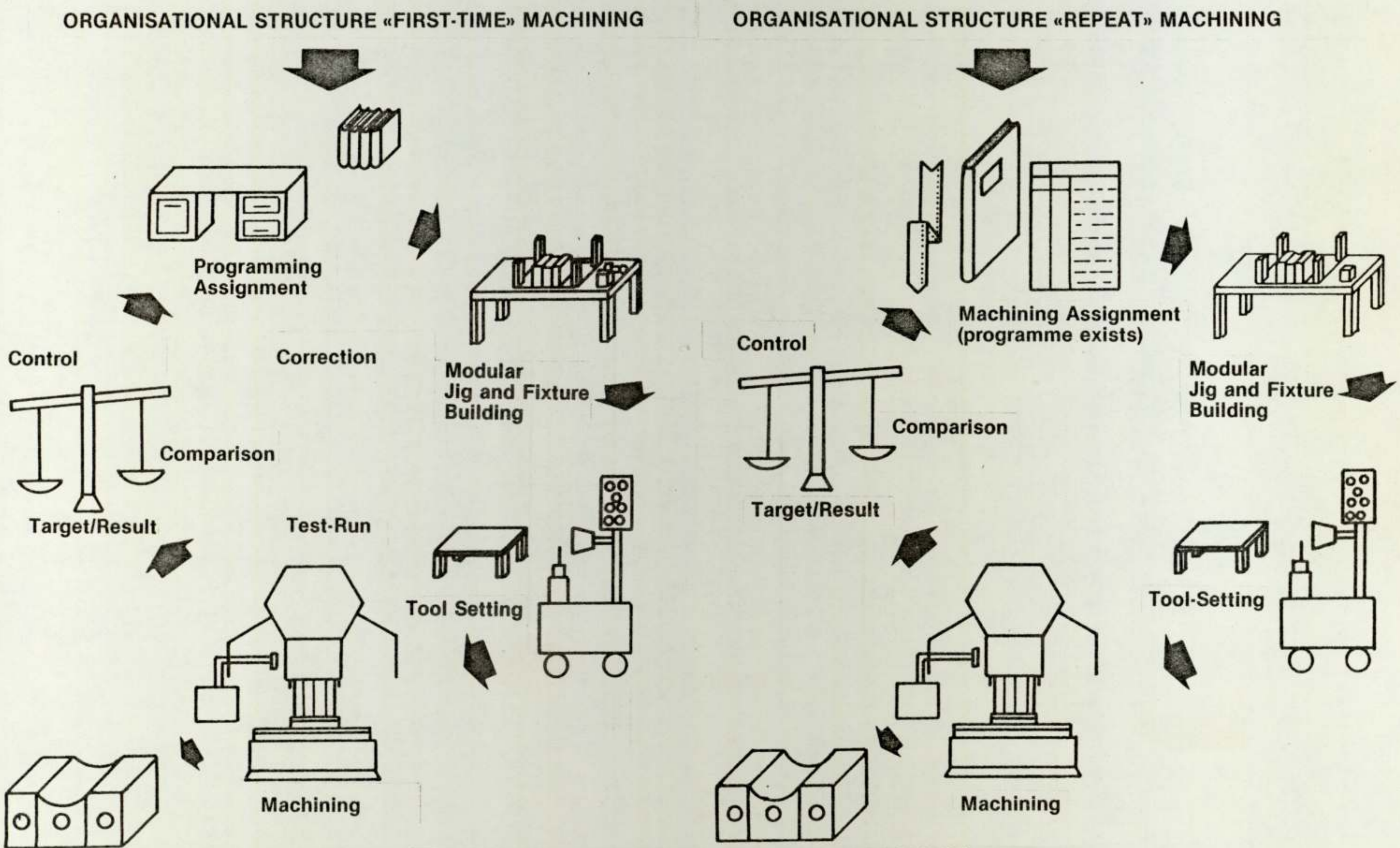


FIG. 176 NC ORGANISATION PROCESS BREAKDOWN CHART

FIG. 176

NC-Employee Groups \ Activities	Programming	Test Run	Jig Design	Quality Control	Machine Maintenance	Tool Setting	Machine Setting	Machine Operation	Deburring	Stripping Down	Cleaning
NC-Technician	●	●	●	●	●	◒	◒	○			
NC-Craftsman		◒	◒	●	●	●	●	◒	○		
NC-Operator			○	◒	◒	◒	◒	●	●	●	●

● Primary Activity ◒ Secondary Activity ○ Occasional Activity

FIG. 17.7 NC-EMPLOYEE ACTIVITIES

FIG. 178 A PART OF THE NC-TECHNICIANS OFFICE LOCATED BETWEEN THE NC-MACHINING WORKSHOPS

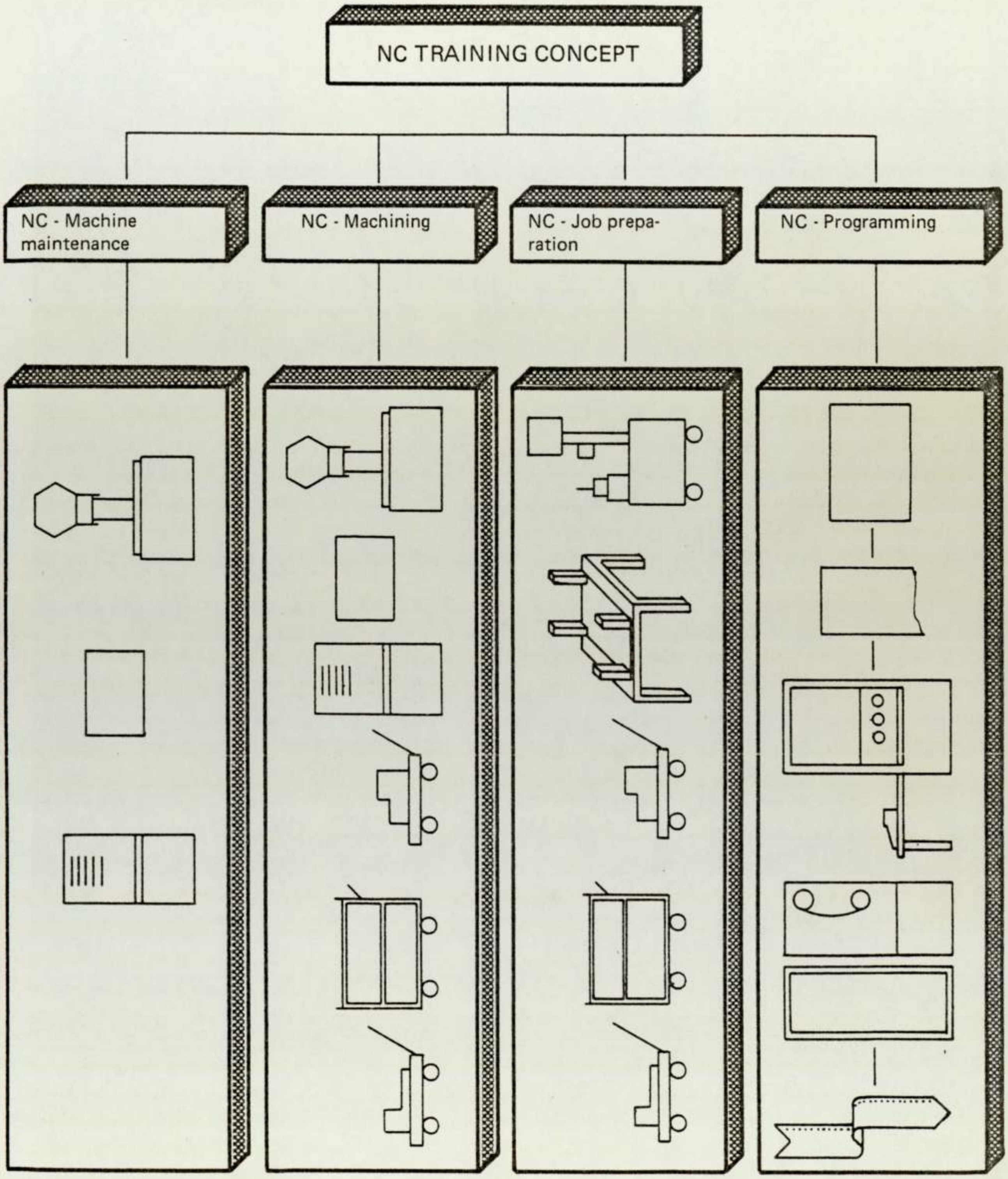


FIG. 179 TRAINING CONCEPT FOR THE NC - WORKFORCE

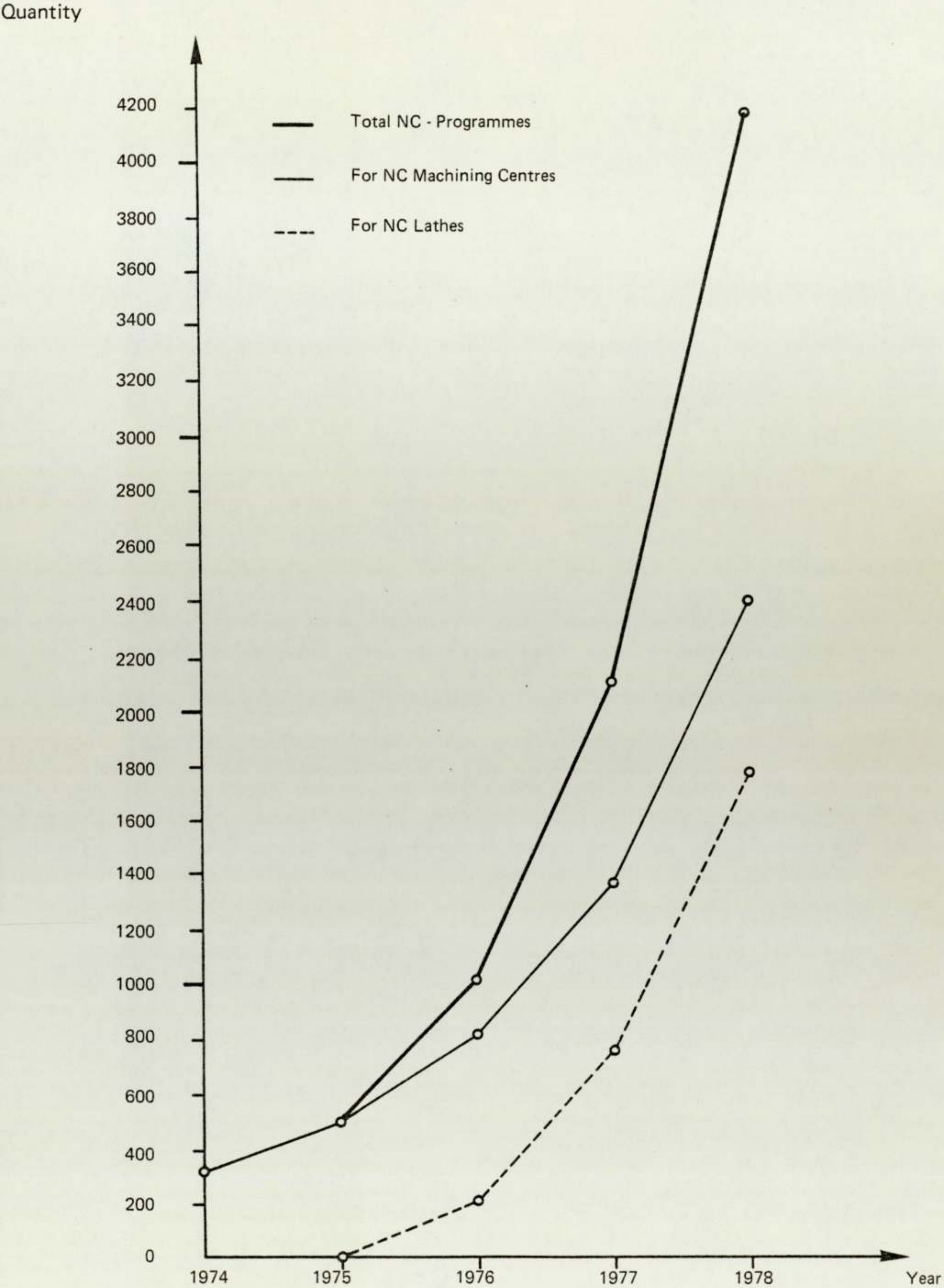


FIG. 180 CUMULATIVE TOTAL OF PRODUCED NC PROGRAMMES

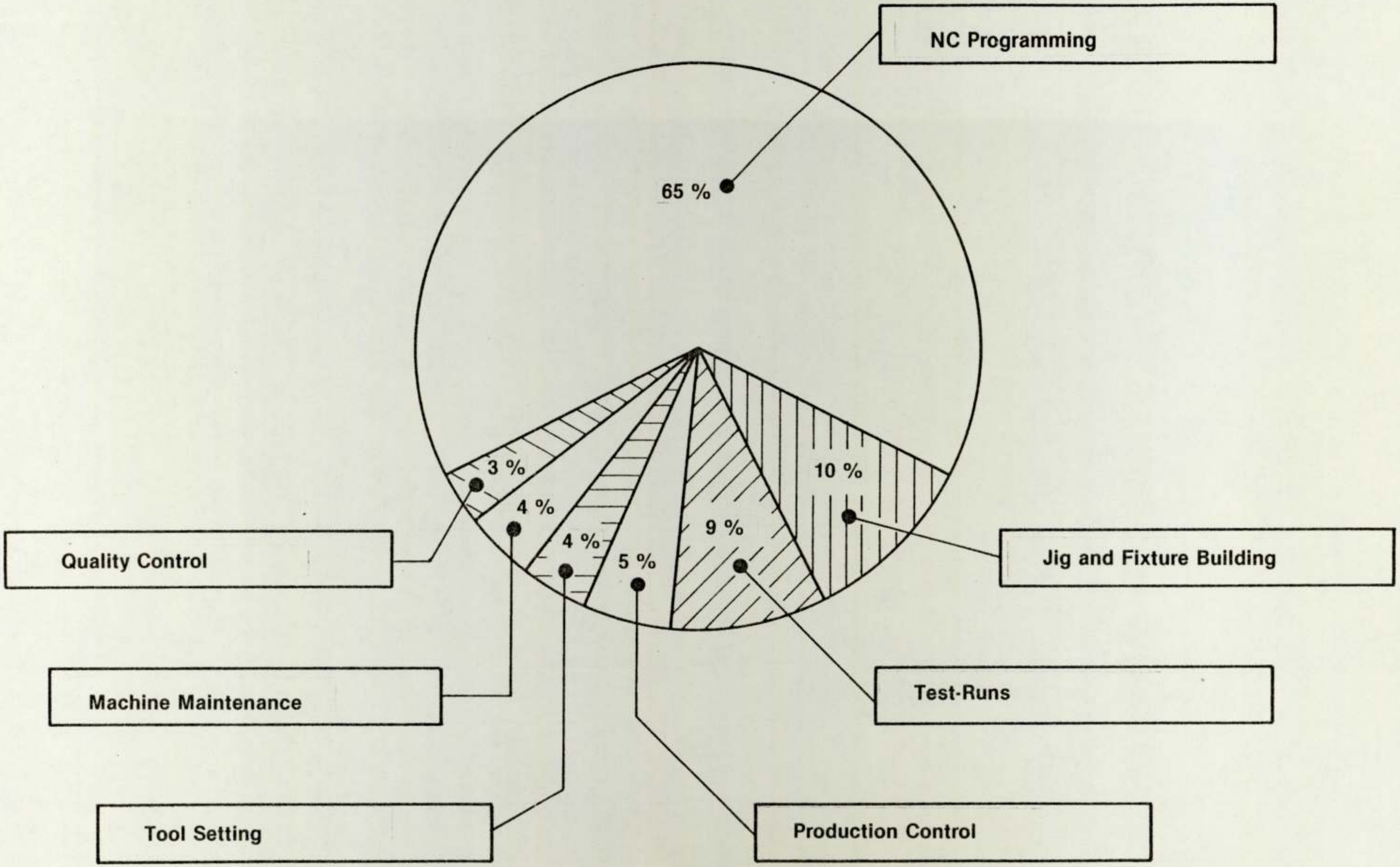


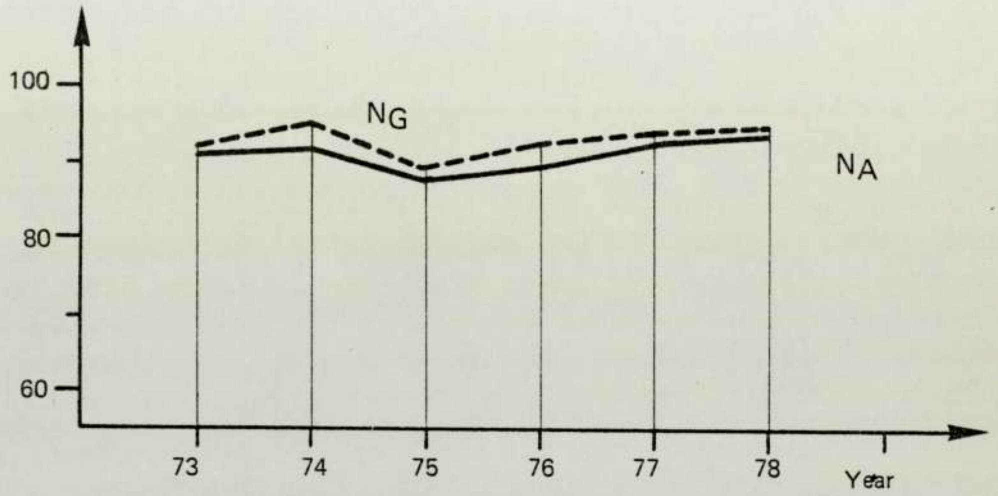
FIG. 181 DISTRIBUTION OF ACTIVITIES OF THE NC TECHNICIAN

1. Degree of utilisation (Fig. 173 a)

1.1. Pure production utilisation

1.2. Total utilisation (including Test-runs)

Year	73	74	75	76	77	78
N_A	91%	92%	88%	90%	93%	94%
N_G	92%	95%	90%	93%	94%	95%



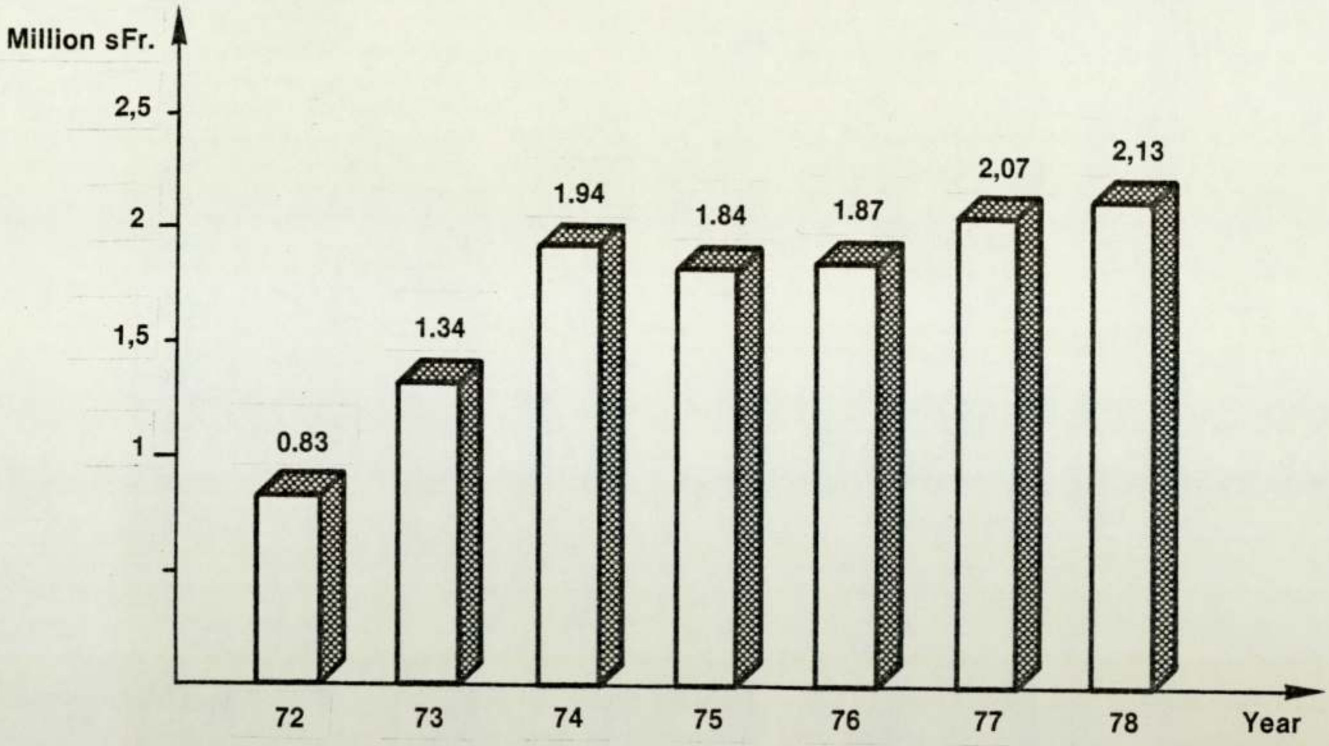
2. Average Production loss

2.1.	Technical grounds	A_T
2.2.	Organisational grounds	A_O
2.3.	Total	A_G

Year	73	74	75	76	77	78
A_T	2,8	2,0	5,7	2,3	1,1	0,9
A_O	4,2	3,9	4,1	3,6	2,2	2,3
A_G	7,0	5,9	9,8	5,9	2,7	3,5

FIG. 182 UTILISATION RESULTS OF THE MACHININGCENTERS GROUP 1

Capital Return, Machine Group 1
(Capital Return = Productive Time x Hour Rate.)



Comparison of the Absolute Values 1977/78

Data / Years		1977	1978	
T_B	h	10679.5	10812.50	+ 133.0
T_N	h	9895.61	10188.45	+ 292.84
T_T	h	113.34	60.70	— 52.64
N_A	%	93	94	+ 1
N_G	%	94	95	+ 1

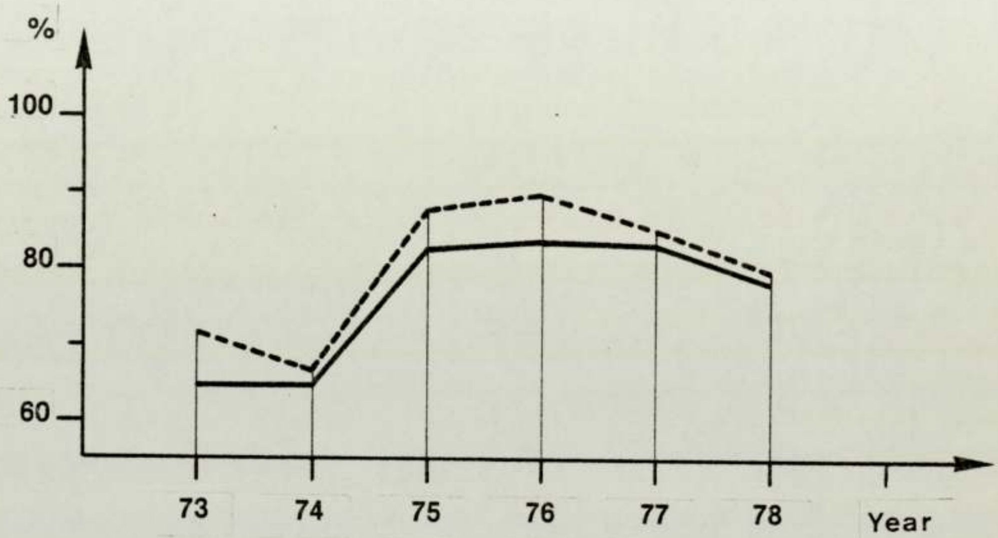
FIG. 183 CAPITAL RESULTS OF THE NC-MACHINING CENTERS GROUP 1

1. Degree of Utilisation (Fig. 173 b)

1.1. Pure Production Utilisation $$N_A\ \% = \frac{\Sigma T_N}{\Sigma T_B} \cdot 100$$

1.2. Total Utilisation (Including Test-Runs) $$N_G\ \% = \frac{\Sigma T_N + \Sigma T_T}{\Sigma T_B} \cdot 100$$

	73	74	75	76	77	78
N_A	65 %	65 %	83 %	84 %	83 %	78 %
N_G	73 %	67 %	88 %	90 %	85 %	80 %



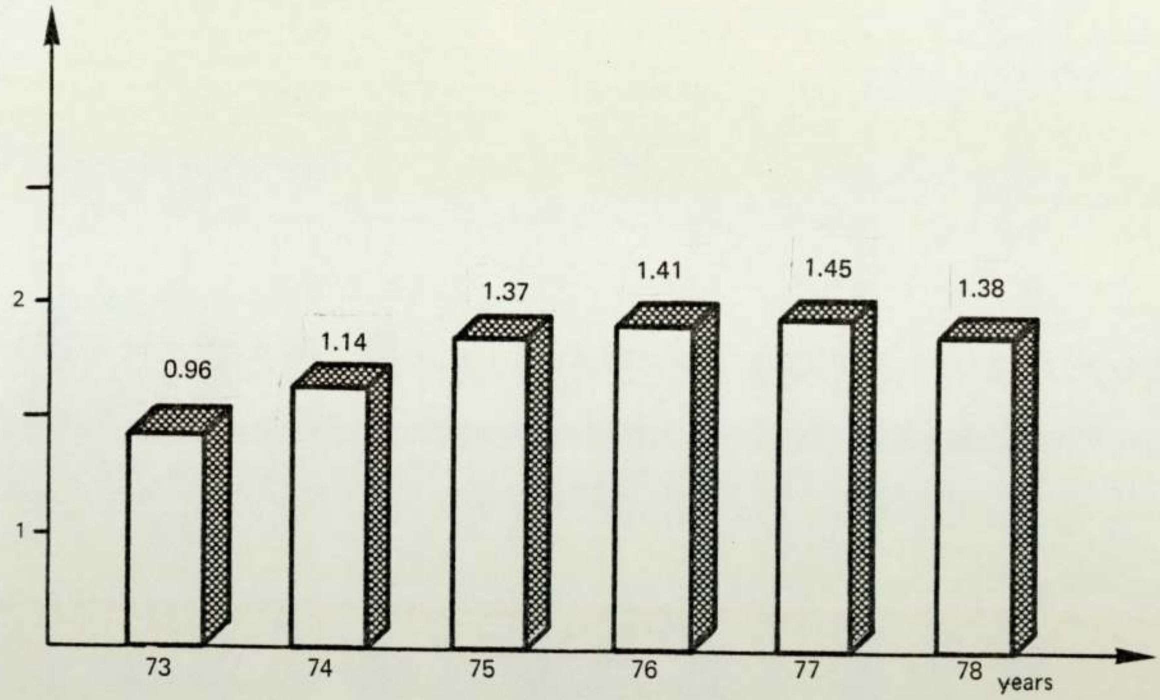
2. Average Production Loss

2.1. Technical Grounds A_T
2.2. Organisational Grounds A_O
2.3. Total A_G

Year	73	74	75	76	77	78
A_T %	21,5	30,7	7,3	6,5	7,7	15
A_O %	4,7	2,7	3,8	2,5	3,7	3,8
A_G %	26,5	32,3	11,1	9,0	11,4	18,8

FIG. 184 UTILISATION RESULTS OF THE NC-MACHINING-CENTERS GROUP 2

Capital return, Machine group 2
(Capital return = productive hours x hour rate)



Figures refer to one machine only - second machine operational since March 1979

Comparison of the absolute values 1977/78

Data \ Years		1977	1978	⊿
T_B	h	4'995.7	5'348.25	+ 352.55
T_N	h	4'128.77	4'187.80	+ 59.03
T_T	h	215.50	102.50	– 113.0
N_A	%	83	78	– 5
N_G	%	85	80	– 5

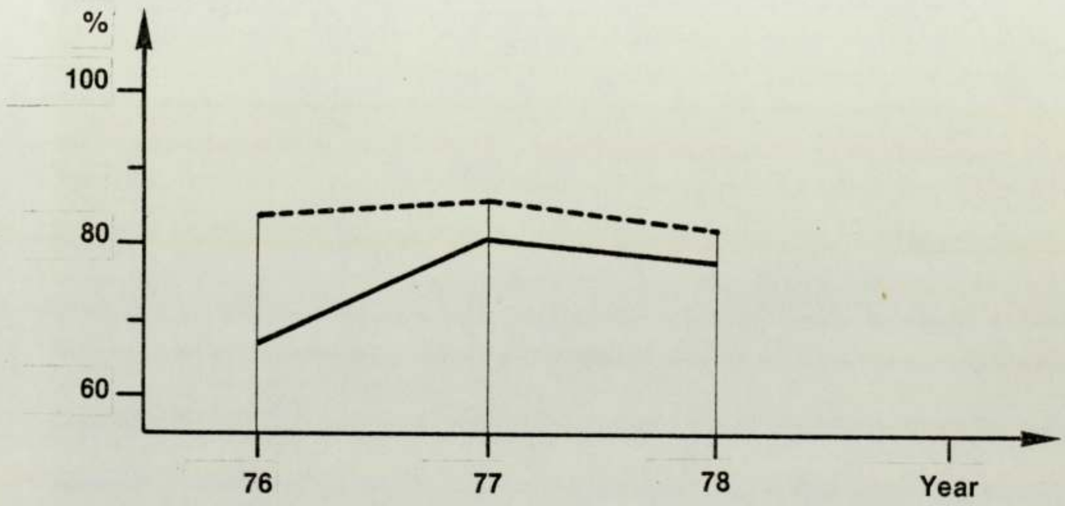
FIG. 185 CAPITAL RESULTS OF THE NC - MACHINING CENTERS GROUP 2

1. Degree of Utilisation (Fig. 172 a)

1.1. Pure Production Utilisation $N_A \% = \frac{\Sigma T_N}{\Sigma T_B} \cdot 100$

1.2. Total Utilisation (including Test-Runs) $N_G \% = \frac{\Sigma T_N + \Sigma T_T}{\Sigma T_B} \cdot 100$

	76	77	78
N_A	67 %	81 %	78 %
N_G	84 %	86 %	82 %



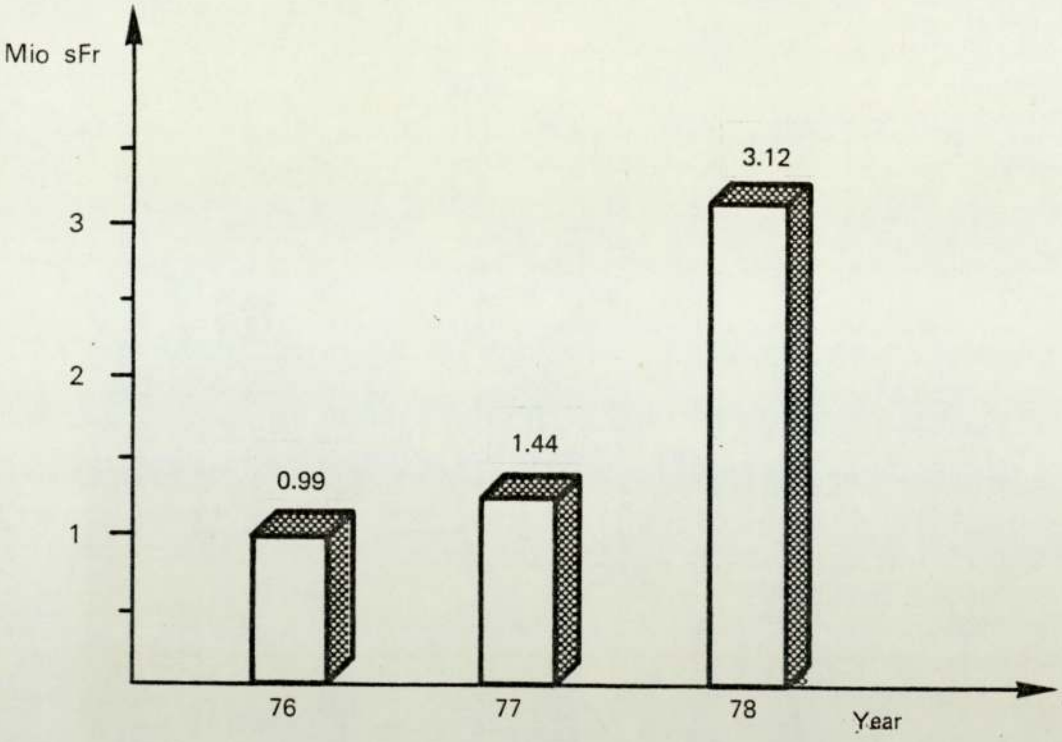
2. Average Production Loss

2.1. Technical Grounds A_T
2.2. Organisational Grounds A_O
2.3. Total A_G

Year	76	77	78
A_T	10,7 %	9,4 %	14,5
A_O	3,0 %	3,4 %	8,5 %
A_G	13,7 %,	11,8 %,	2,2 %

FIG.186 UTILISATION RESULTS OF THE NC-LATHES GROUP 3

Capital return, Machine group 3
(Capital return = productive hour x hourly rate)



Up until Oct. 1977 only one NC Lathe was in use, and after Jan. 1978 three NC Lathes were installed.

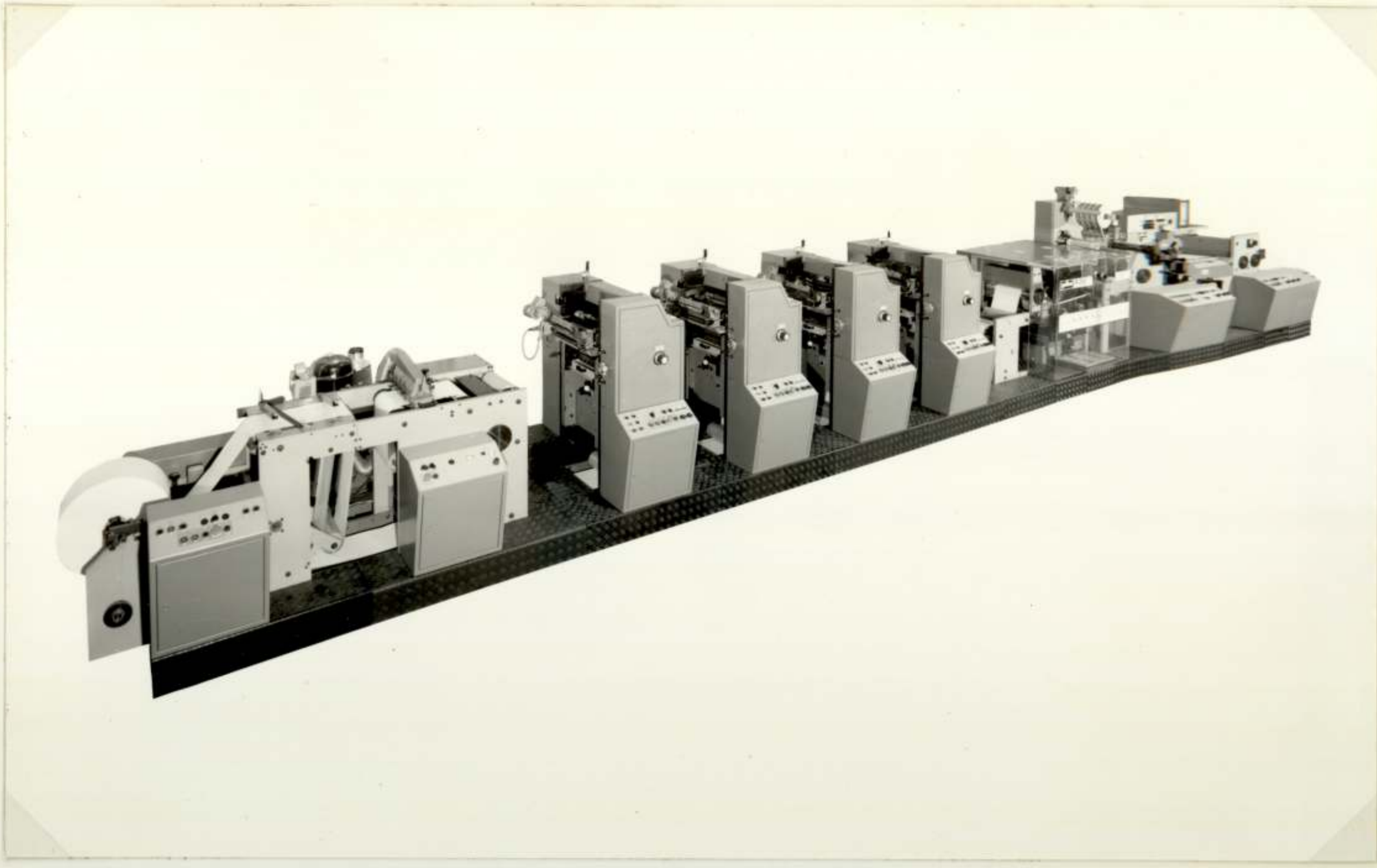
Caomparison of the absolute values 1977/78

Data \ Year		1977	1978	Δ
T_B	h	5'116.95	13'395.75	+ 8'278.8
T_N	h	4'134.08	8'925.50	+ 4'791.42
T_T	h	256.8	479.60	+ 222.8
N_A	%	81	88	+ 7
N_G	%	86	92	+ 6

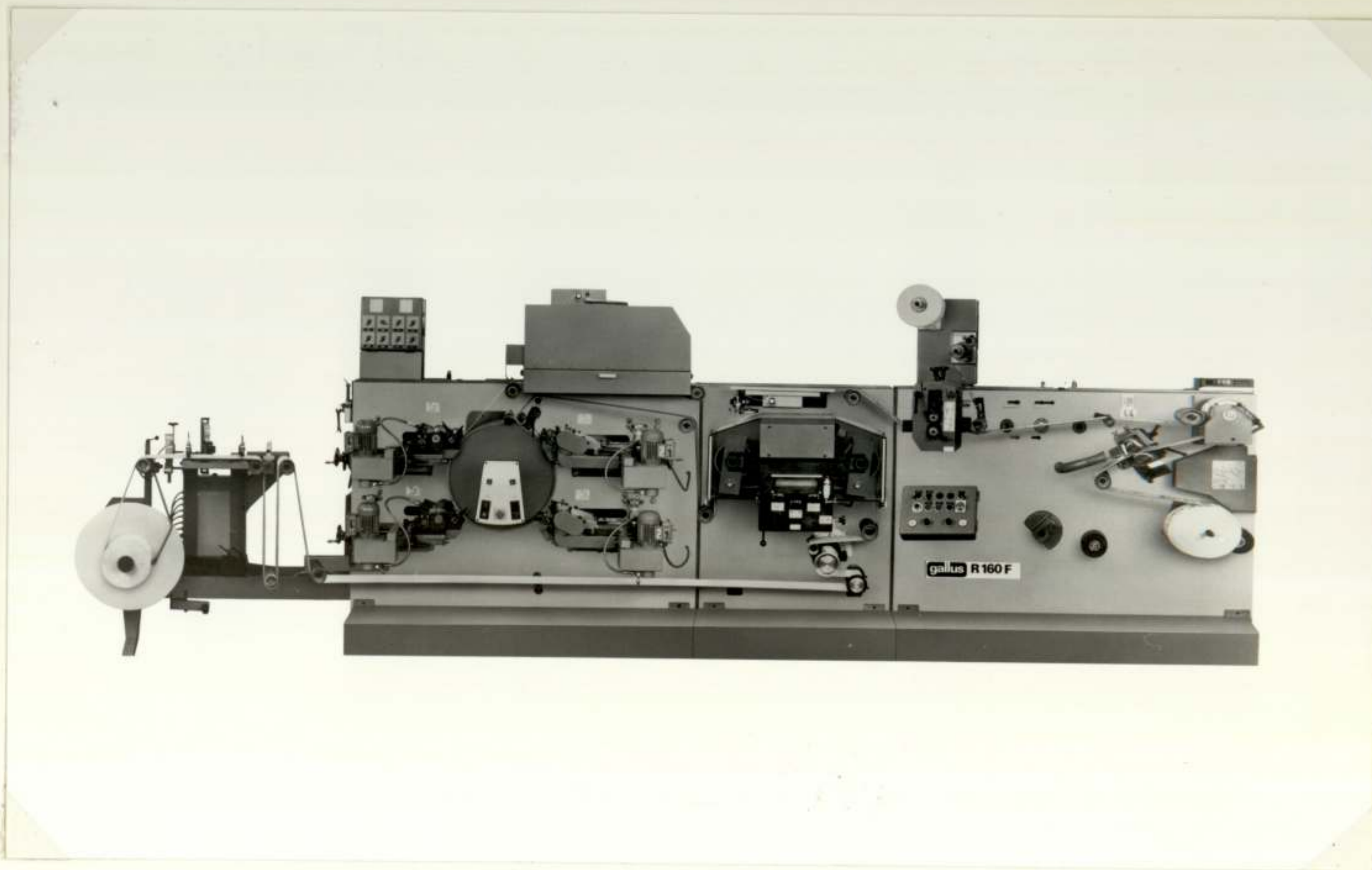
FIG. 187 CAPITAL RESULTS OF THE NC - LATHES GROUP 3

APPENDIX I

Examples of some GALLUS Label Printing Machines



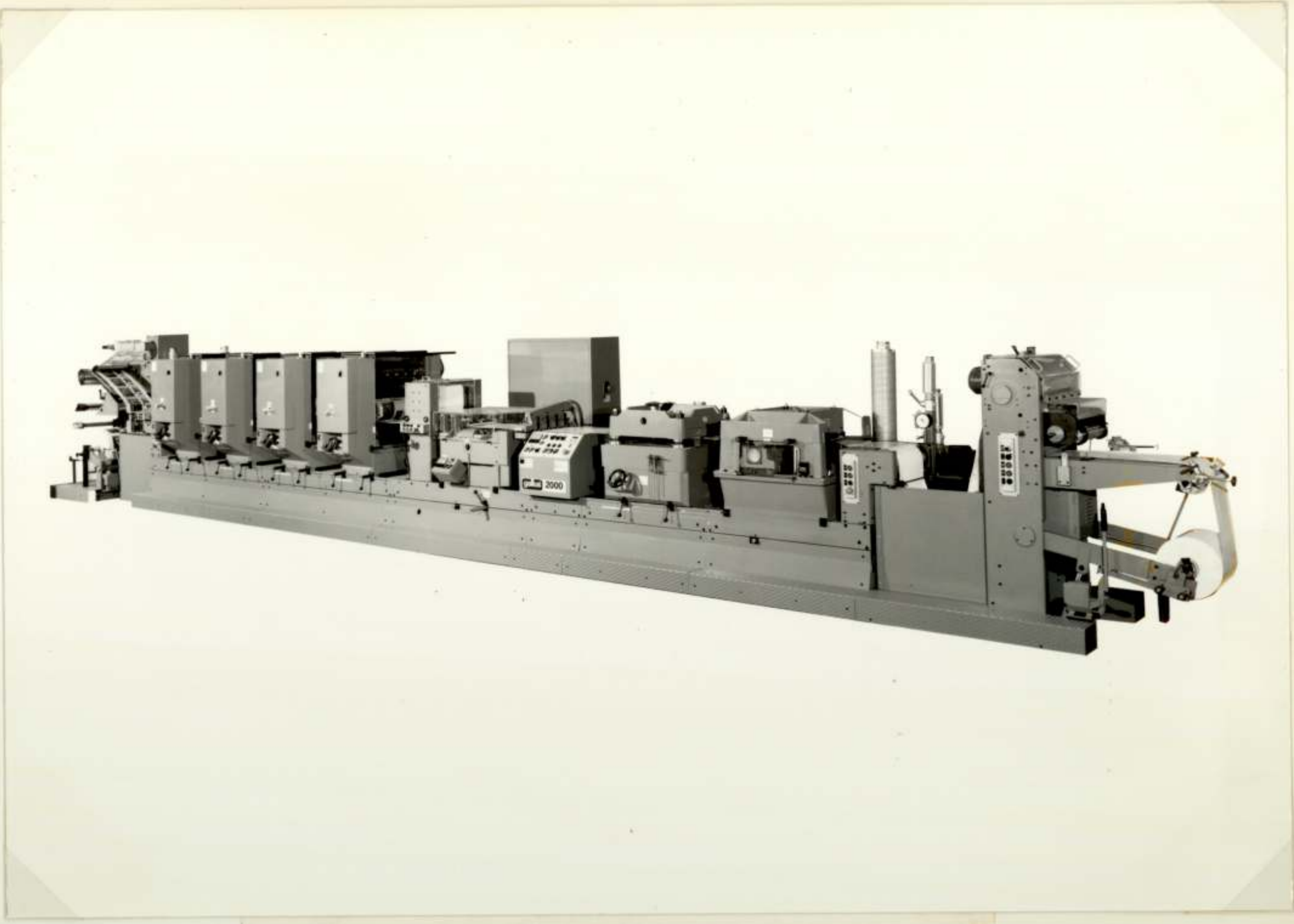
ROTARY LETTERPRESS PRINTING MACHINE R 250 B



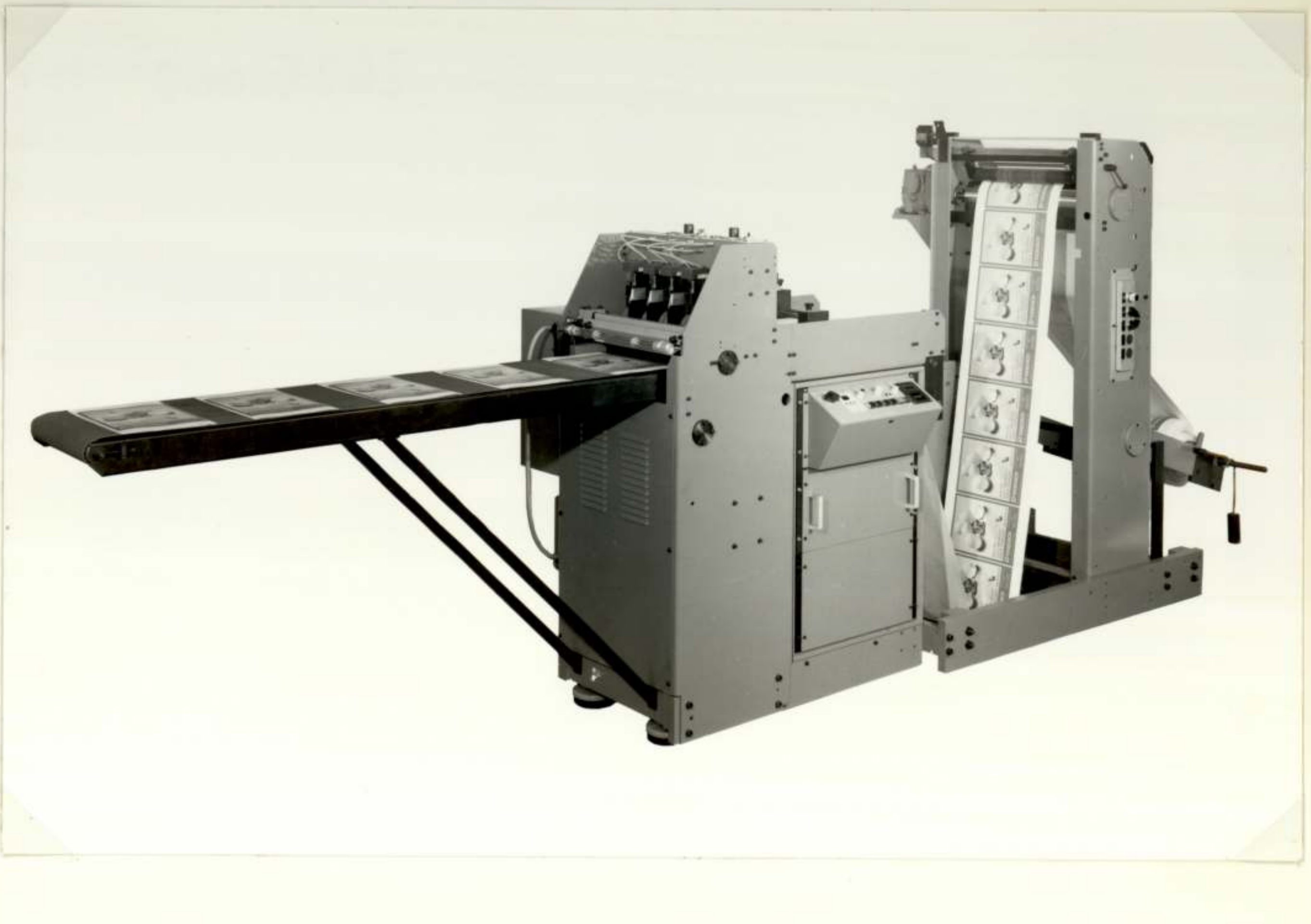
ROTARY FLEXOGRAPHIC PRINTING MACHINE R 160 F

FLAT LETTERPRESS PRINTING MACHINE T 180 B

FLAT SILKSCREEN PRINTING MACHINE T 180 S



ROTARY OFFSET PRINTING MACHINE V 330 O



OFF-LINE SHEET-CUTTING MACHINE