Feature Based Workshop Oriented

NC Planning

for Asymmetric Rotational Parts

By

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To my parents who taught me the merit of education and for the generous support they gave me through out my academic endeavour. To my wife and children, without whose moral support this work would not have been completed.

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Synopsis

This thesis describes research which is aimed at devising a framework for a feature based workshop oriented NC planning. The principal objective of this thesis is to utilize a feature based method which can rationalize and enhance part description and in particular part planning and programming on the shop-floor.

This work has been done taking into account new developments in the area of shop floor programming. The importance of the techniques and conventions which are addressed in this thesis stems from the recognition that the most effective way to improve and enhance part description is to capture the intent of the engineering drawing by devising a medium in which the recurring patterns of turned components can be modelled for machining. Experimental application software which allows the user to describe the workpiece and subsequently generate the manufacturing code has been realized.

ACKNOWLEDGMENTS

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Chapter 1

Introduction

Islands of automation have brought profound changes in the design and manufacturing functions and practices of the last few decades. Computers, an important element in automation, have significantly enhanced the various engineering functions from design to manufacture. The concept of CAM (*computer aided manufacture*) has culminated in NC which is recognized as the primary and most prevalent function whereby a product is pre-planed and programmed, and its production functions are processed, stored and finally executed with the aid of a computer. The principles of NC technology have been applied within the manufacturing industry beginning with the manufacturing cell to the total concept of computer integrated manufacture. The provision of sound techniques and concepts aimed at improving and streamlining NC part planning will undoubtedly have a significant impact on the functionality of elements that are essential for the success of computer integrated manufacture.

The scope of this research embraces the design of workshop oriented NC planning. This expression is coined to reflect the comprehensive nature of the approach pursued by the author, in which an effort is made to provide a unique method to address shop floor part programming. The scope of the issues researched is more extensive and goes well beyond the methods established and developed by the contemporary workshop oriented part programming systems. Therefore, the 'NC planning' terminology is selected so as to reflect the issues researched in the work. The experimental application software is designed to incorporate the NC planning approach for industrial use.

This thesis describes research which is aimed at devising a framework for a feature based workshop oriented NC planning. Experimental application software which allows the user to describe the workpiece and subsequently generate the manufacturing code is realized. This work is concerned with planning and subsequently generating manufacturing code by defining the workpiece, with predefined regions and features.

The primary objective of this thesis is to utilize a feature oriented method which can rationalize and enhance part description, and in particular part planning and programming, on the shop floor. This work has been done taking into account new developments in the area of shop floor programming. The importance of the techniques and conventions which are addressed in this thesis stems from the recognition that the most effective way to improve and enhance part description is to capture the intent of the engineering drawing by devising a medium in which the recurring patterns in the drawing can be modelled. Extensive research has been conducted into the area of feature technology, nevertheless it is fair to say that less research has been conducted in the area of MDI and workshop oriented part programming.

This thesis consists of seventeen chapters in which the research work is addressed. The literature survey in chapter 2 includes the principle concepts in design and manufacture. Chapter 3 represents feature technology and concepts in which the related research work on features is highlighted and different feature techniques are described and addressed. Chapter four describes the related research work that has been conducted in the area of process planning and NC code generation. Chapter five presents an essay on the present development and capability of the state of the art machine tools. In particular turning centres are discussed together with the new achievements in the field of CNC technology. Several MDI controllers which are principally based on the work shop approach are also reviewed and highlighted.

The main body of the thesis begins by stating the objectives of the research and the associated issues which have to be addressed so as to meet the objectives. The research objectives are explained in chapter six. Chapter seven describes the system task elements and overall architecture. Chapter eight describes the concept of 'feature' and 'region' as has been developed and used for the workshop oriented NC planning system. This chapter provides an elaborate classification tree to describe the predefined regions and features for an asymmetric rotational workpiece. Chapter nine is chiefly concerned with the geometric description of regions and features for part programming. The setup data as well as the technological user support system and operation planning tasks for each region & features are described in chapters 10, 11, and 12 respectively. Chapter 13 describes the importance of a parametric part family database and describes its function. Chapters 14, 15 and 16 describe the NC code generation activity, the experimental application software and the case study respectively. Finally chapter 17 states the concluding points and makes recommendations for further work.

Chapter 2

Literature survey

2.1 - Modelling of the Design Process

2.1.1 - Overview

Ever Since the earliest stages of history, people have been fascinated by the use of pictorial and symbolic representation as a powerful medium for design and communication. During the advancement of civilization, the quality of graphic representation and modelling has evolved and as a result of the growing need for finer quality products, the process of modelling and design has become an integral part of human life. With the invention of devises such as the computer, the functionality of design has improved considerably. CAD (*computer aided design*) has become a reality and has revolutionized the art and technique of modelling and hence influenced design and manufacture. The 1950's brought the advent of computer graphics and numerical control (*NC*) and provided designers and manufacturing engineers with a persuasive means to rationalize the economic and functionality of the design and manufacturing processes. Progressive improvement and innovation in the area of geometric modelling and NC gave birth to the concept of CAD/CAM. The last decade has seen concerted efforts by system and software designers to enhance and further refine the techniques of representation so as to develop more effective modelling methods to address the CAD/CAM issue.

2.1.2 - Concept of Modelling &Design

Designers have used models to apply a set of languages in order to describe and evaluate manufacturing components *[Des 89]*. Sketches, measured perspective, diagrams, maps, scale models, mathematics, geometry and trigonometry were used to model an object, or end product, and a variety of these modelling tools have been used by designers and scientists to display and convey ideas, such as Leonardo Davinci's prototype of the aeroplanes, helicopters, and parachutes in the fifteenth century *[Des. 89]*.

2.1.3 - Design Process for Product Design

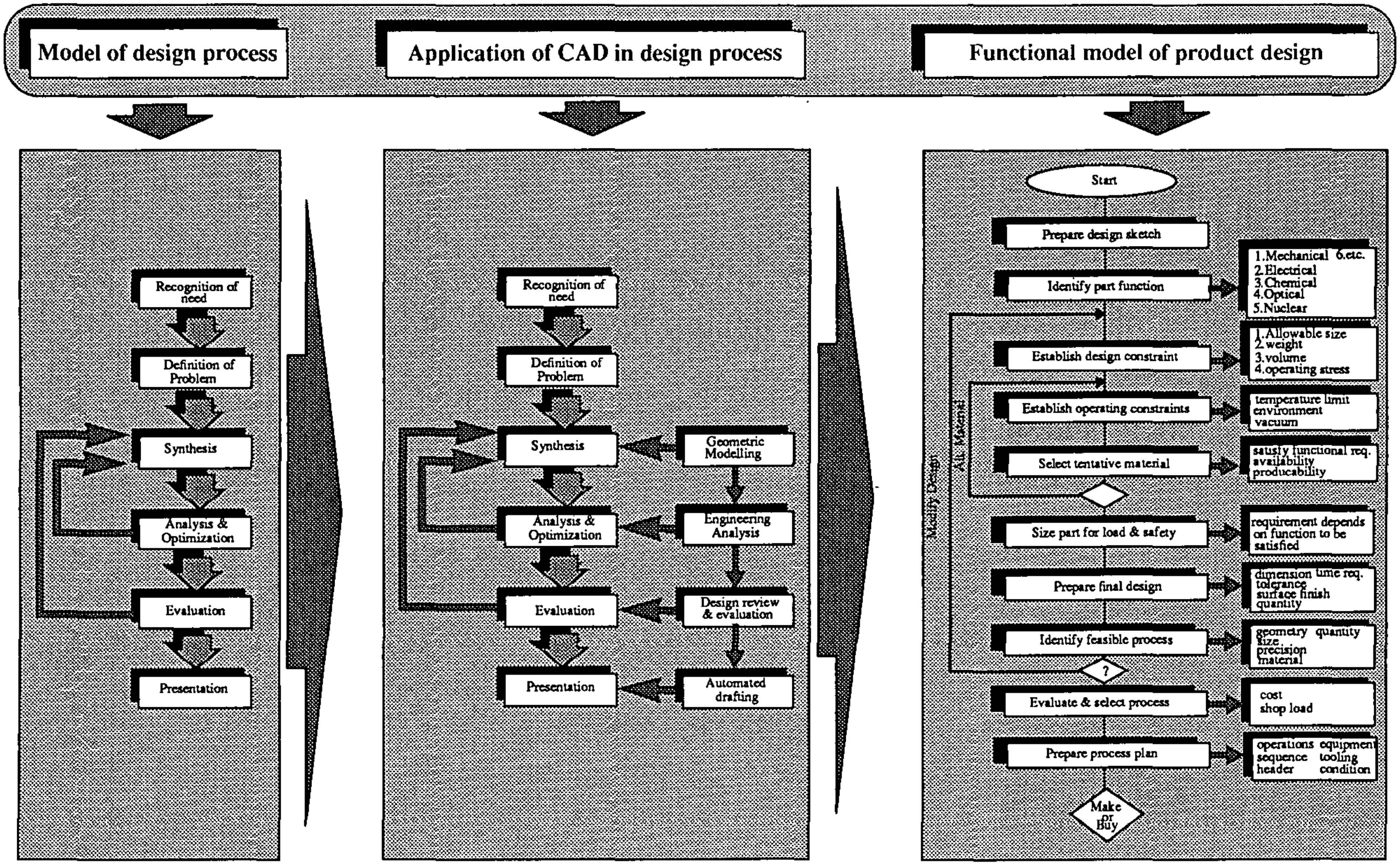
Decisions made at the product design level have a profound effect on cost *[Allen 87]*. According to a General Motors executive, 70% of the cost of manufacturing a truck transmission is determined at the design stage *[Whitney 88]*. Another study at Rolls-Royce reveals that design determines 80% of the final production cost *[Corbett 86]*. Therefore, a structured representation of the design process would be a vital tool for the designer to achieve an optimum design solution, hence maximizing profit and preventing extra cost at different levels (*product cost, assembly cost, maintenance cost, total life cycle cost*).

The design process is a complex set of activities. Because of the multifacety of the design process in the manufacturing industry, some people have come to believe that the design process cannot be rationally described. Others have taken the opposite view and have developed large and detailed decision trees explicitly defining the design process *[Suh 79][Suh 78]*. Due to the extreme nature of these views, some researchers have developed general diagrams to show the model of the design process as depicted in figure 2.1 *[Allen 87][Groover 84][Shigley 77]*.

Suh *[1979]* describes the design process as having three distinct aspects:1) Problem definition which results in the definition of functional requirements and constraints; 2) The creative process of conceptualising and devising a solution, and 3) the analytical process of determining whether the proposed solution is rational and consistent with the problem of definition *[Suh 79]*.

The steps and descriptions offered by Suh and Shigley are too general, thus are less applicable at the design product level. Others have offered a narrower but more explicit description for the process of product design as is depicted in figure 2.1 *[Allen 87]*.

The functional model of product design depicted in figure 2.1 divides the Suh *[1979]*



(a) Shigley (Groover 84) (b) Groover 84 (c)Allen 89

Figure 2.1	Design process	LUT- CAD/CAM

diagram into more specific steps so as to more accurately define the design process. Hence a more structured approach is followed so as to describe and develop the design process. The use of the computers in each area has established a better and more efficient way to design products

2.1.4 - Application of CAD in the Design Process

Due to the fast pace of high speed electronic development and the subsequent advances in software techniques, CAD has gone through a rapid transition and the word CAD no longer stands for drafting alone. Today CAD systems embody a wide range of design kits.

CAD can be defined as a discipline that provides the required know how in computer hardware and software, in systems analysis and in engineering methodology for specifying, designing, implementing, and using computer based systems for the design process *[Schlechtendahl 88]*.

The benefits gained from CAD systems are numerous. One of the main advantages of CAD in the design of products for manufacturing is the graphic representation of a component.

The eye is our most efficient data channel. Over 70% of all the information received by the brain is extracted by visual input *[Bo 89]*. Many complex problems are simplified when translated into graphic images, CAD systems provide the ability to manipulate such images easily and accurately which enormously enhances problem solving abilities, and hence raises the creative productivity of designers and engineers *[Bo 89][Schlechtendahl 88]*.

In short a CAD system enables the designer to conceptualise and apply "what if" analyses and to take advantage of the ability of the computer to display the images and retrieve or produce data fast and accurately *[Groover 84]*.

The method by which the CAD modellers hold information and the way information is structured to produce a geometric model differs for each of the corresponding models listed below *[Bedworth 91]*:

.Wireframe modeller

. Surface modeller

. Solid modeller

2.1.4.1 - Wireframe Modelling

In 1953, the first wireframe CAD system (*Sketchpad*) was developed at the Massachusetts Institute of Technology (*M.I.T*) by Sutherland and enabled designers to draw 2 D graphics *[Sutherland 63]*. Because of the limited capabilities of the Wireframe system, designers have developed more advanced systems to handle more complex components *[figure 2.2]*.

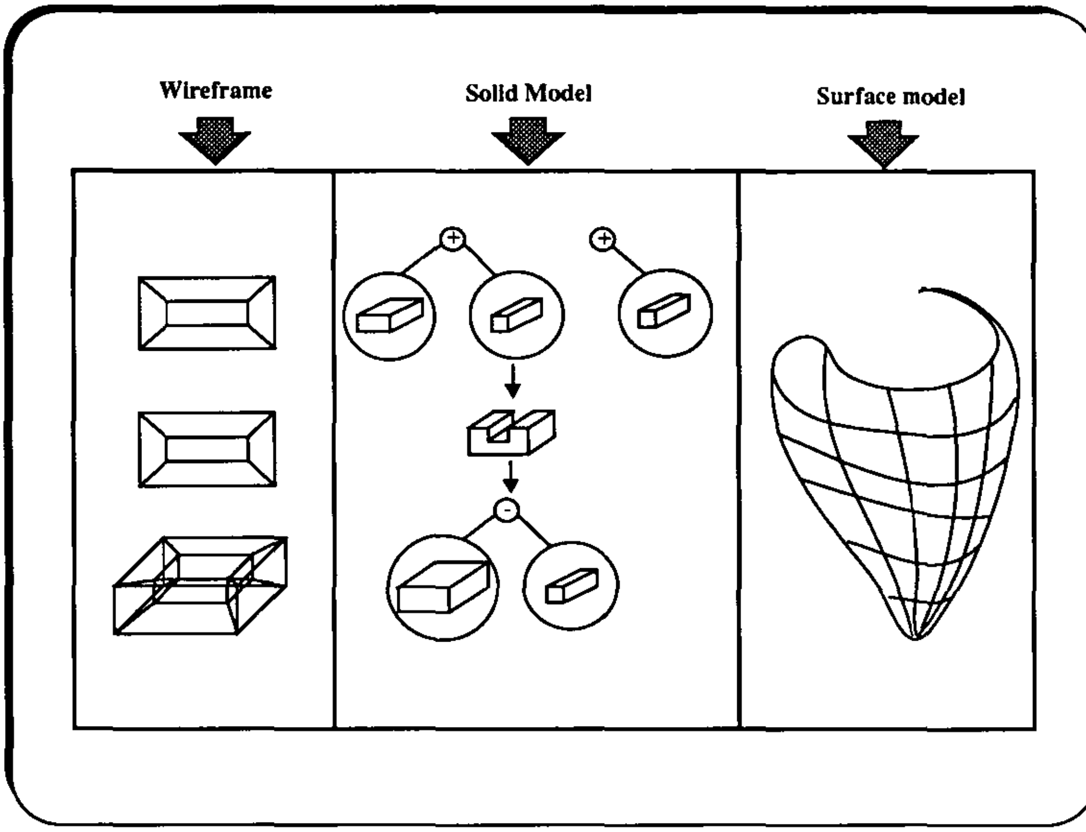
The wireframe modeller consists of lines and points; it holds information about the model in terms of edges and vertices alone *[Medland 88]*. The disadvantages of the wireframe modeller are *[Campbell 88]*:

- It does not hold and provide information on the position of faces.
- The engineering properties of the component cannot be calculated.
- The system is not able to provide information about interference or collision of surface and solid faces
- The wireframe modellers do not carry a full set of information, concerning the model, therefore they are not suitable for manufacturing and product design.

However, due to the low cost of the system, wire frame modellers are still widely used in industry today.

2.1.4.2 - Surface Modelling

Surface modelling has its roots in the mathematics of curves and surfaces. Coons *[1967]* and Bezier *[1972]* were the first pioneers who sought to replace the old methods, subsequently there has been a continuous development in devising mathemat-



1955 - 64: Interactive computer graphics invented; Homogeneous coordinate Geometry; NC programming language

	Wireframe	Polygonal	Sculptured surfaces	Solid model
1965 - 72	2D system established	Early hidden lines & visible surface algorithm for polg. faces, simulators	Aero, Auto., Marine industry; parametric polynomial rational curves coons patches bezier surfaces	
1973 - 78	3D system; more convenience for NC	Better algorithm polyhedral smoothing faster simulators 3 D animation	NC contour milling from digitized surfaces B spline curve & surfaces	Experimental Boundary CSG & sweep based systems demonstrated Theoretical found emerges.
1979 - 84	Boundary surfaces better analysis packages, color more convenience	Special computer hardware; improved displays Animation languages	Bspline subdivision algorithm	Development of industrial prototype & early production version

1985 - 95: A narrower spectrum of more powerful systems

Adopted from Requi [90]

Figure 2.2 | Computer modelling overview | LUT- CAD/CAM ical methods and comparing techniques for representing curves and surfaces *[Voelcker 80]*.

Surface modellers define the model in terms of its vertices, edges and faces. These are often the best means of providing the necessary information to generate a toolpath for all NC machining operations, including the multiaxial machining of surfaces *[Medland 88][Campbell 88][Bedworth 91]*.

2.1.4.3 - Solid Modelling

Solid modelling is distinguished by the use of complete and unambiguous representations of solids *[Voelcker 80]*. The accuracy, simplicity and efficient modelling method offered by solid modellers makes them the best option for replacing less efficient systems(*eg.wireframe*).

The two solid modelling systems most frequently used for product design are *[Besant 86]*: boundary representation (*BREP*), in which the information for the model is held in terms of boundaries and cross section and subsequently 'swept out' to produce the final component, and constructive solid geometry (*CSG*) where a set of primitives are assembled by means of Boolean operations to construct the component.

Other techniques such as, 1) spatial enumeration,2) cell decomposition, 3)sweeping and 4) primitive stancing have been used in conjunction with boundary or CSG modellers *[Voelcker 80]*. The complete conveyance of product information by solid modellers has made it one of the best tools for use in product design and manufacture.

2.2 - Computer Aided Manufacture

In 1953, the U.S airforce was confronted with an unprecedented technological requirement to machine components for high performance supersonic aircraft. The complex structural members of the new aircraft had to be machined to close dimensional tolerances and this difficult and costly process defied traditional machining procedures *[Mason 89]*. At the same time the scientific community was searching for ways to advance their knowledge about information systems and further refine the techniques of control and computation. The result was the emergence of NC technology *[Noble 86]* which constituted the first step towards computer aided manufacture.

It is quite evident that with conventional production know how, it is becoming increasingly difficult and expensive to improve the manufacturing process *[Allen 88]*. The introduction of computers provides possibilities to improve manufacturing technology in various areas; it can control production and quality control equipment directly and provide flexibility and fast response as the product and customer order alters. The advent of computers has made it possible to evaluate data instantly, assess the information flow in the plant, and immediately initiate corrective action to optimise the manufacturing processes *[Goos 83]*. But in the last decade the most important facet of the computer has been the ability to integrate entire manufacturing systems and make decisions which ultimately lead to more advanced and flexible systems capable of satisfying the market requirement efficiently by the effective use of computers *[Allen 88][Valliere 90]*.

Besant *[1986]* describes CAM as the use of a computer to assist in the planning and production of the manufacturing process *[Besant 86]*. Allen *[1988]* defines CAM as: "the effective utilisation of computer technology in the management, control, and operation of a manufacturing facility through direct or indirect computer interface with the physical and human resources of the company *[Allen 88]*".

The application of CAM falls in to two major categories:

- Direct application, in which the computer is used either to monitor or control manufacturing operations.
- Indirect application, where the computer is used in support of manufacturing activities in the plant, Hence there is no direct connection between the computer and the production process.

2.2.1 - Evolution of NC Technology

By 1800, the first steam power turning machine was invented which altered the pace of production processes. Subsequently by the 1940s the lathe was used widely in industry.

Due to the complex nature of the components designed, the traditional lathes were no longer capable of producing the desired shapes, thus the search for a more advanced and accurate system had began. By 1950 the first numerical control machine tool was designed *[Besant 86]*. This machine was capable of accepting data in terms of numerical information *[NC /CIM 87]*. Components were described in mathematical detail and subsequently the information was recorded on the tapes to produce parts.

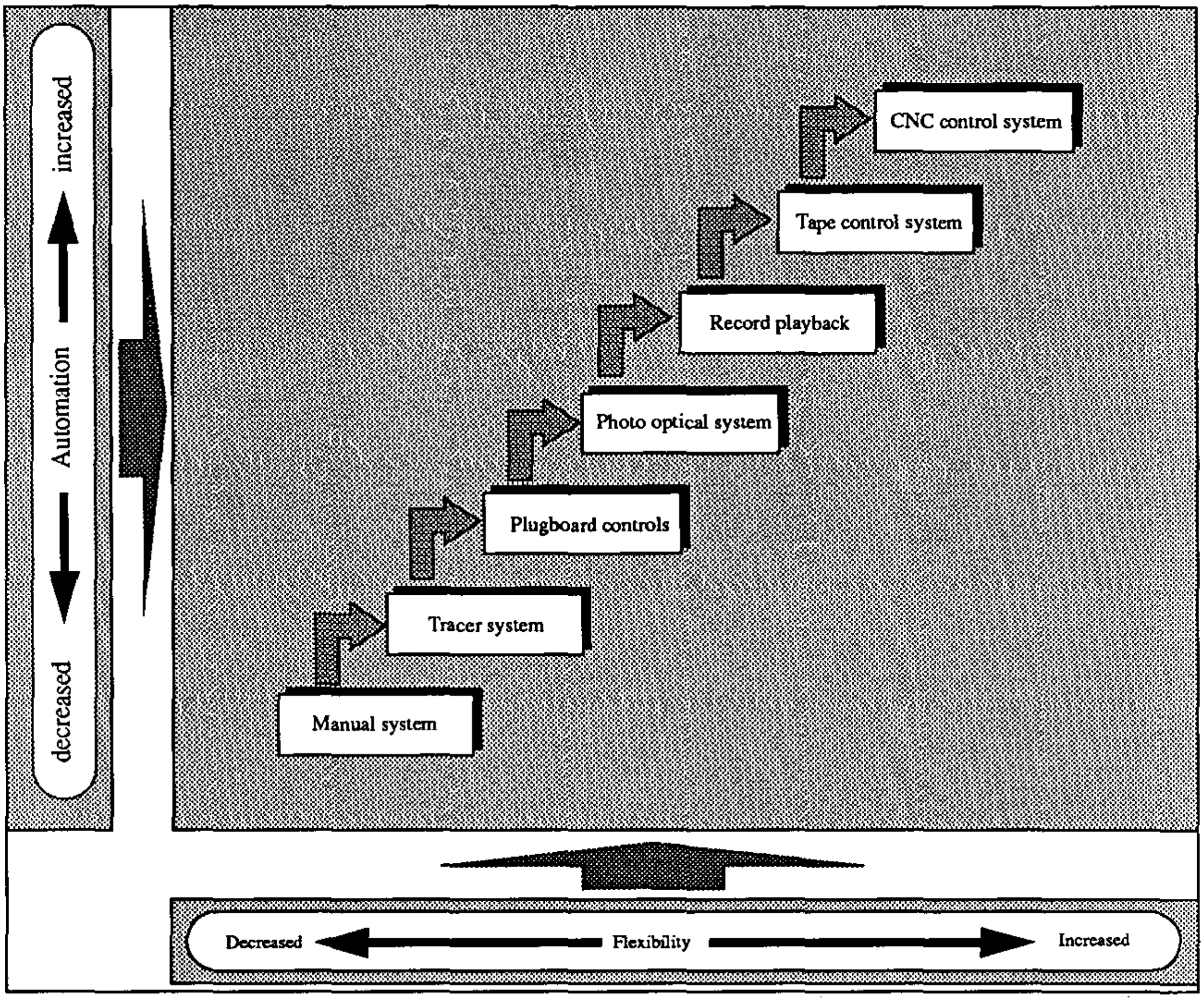
The evolutionary trends for the design and development of numerical control machine tools is shown in detail in figure 2.3. There have been many attempts both successful and unsuccessful by designers to rationalize NC technology. Some of the tactical and strategic decisions taken have been investigated by the following authors *[Rosenbrock 89] [Noble 86] [Ceruzzi 80]*.

2.2.2 - NC Program Functions

NC programming consists of planning a set of activities to produce NC code, hence NC can be defined as a detailed operation plan for the machining step to be performed on the particular machine involved *[Stocker 83]*. A more detailed diagram describing the machining steps needed to produce the code is displayed in figure 2.4.
A NC program can be designed by completing the following steps:

- Define the operation boundaries; turning,milling,drilling,punching, etc.
- Define the geometry of the part
- Determination of cutting tools- tool changes, etc.
- Auxiliary instruction for setup and operator.

This information is then converted to an NC instruction to actuate the machine tool.



Evolution of NC technology

Systems	Functionality	Advantage	Disadvantage
Manual	skilled machinist transmitted his skill, intelligence, and purpose to the machine to produce a variety of parts.	extremely versatile retained the machinist experience	time consuming & costly process limited ability
Tracer	The tracer system allowed the machinist to produce a template in order to produce many complex and identical parts	machinist retain control over program & machining produce identical part automatically	tracer were costly not suitable for small batch tracer material not reliable a higher level of dependency
Plugboard	Plugboard controls were designed for turret lathe, the machine was setup simply by changing the configuration of electrical relays.	retain control over program & machining flexible	lack of permanent storage cumbersome
Photo optical	The system had an electrical eye which followed lines drawn on paper tape corresponding to the variable pitch of the lead screw and generated motion signal for servo motor	machinist retain control over program & machining Simplified the process	a higher level of dependency not fully developed
Record playback	A recording was made of the motions of a machine tool or tracer stylus, and the recording the motion, information stored on magnetic or punch tape, the record was played back to produce automatically the identical motion.	machinist retain control over program & machining transmission of expertise	a higher level of dependency
Tape control NC	This system accepted the geometrical information in terms of numerical input by storing it on tape to actuate it the machine tool	provided a new horizon enable complex shape to be produced did not depend on machinist	removed shop-floor control remove a good measure of experience
CNC	This system combined the virtue of shop floor programming via plugboard control, with the ease of automatically reconfigure the control by means of a tape reading system.	provide the operator with full control of machine, over prog. and machine provide more flexibility for both shop-floor and operator	feature not yet fully utilized

Figure 2.3	NC technology	LUT- CAD/CAM

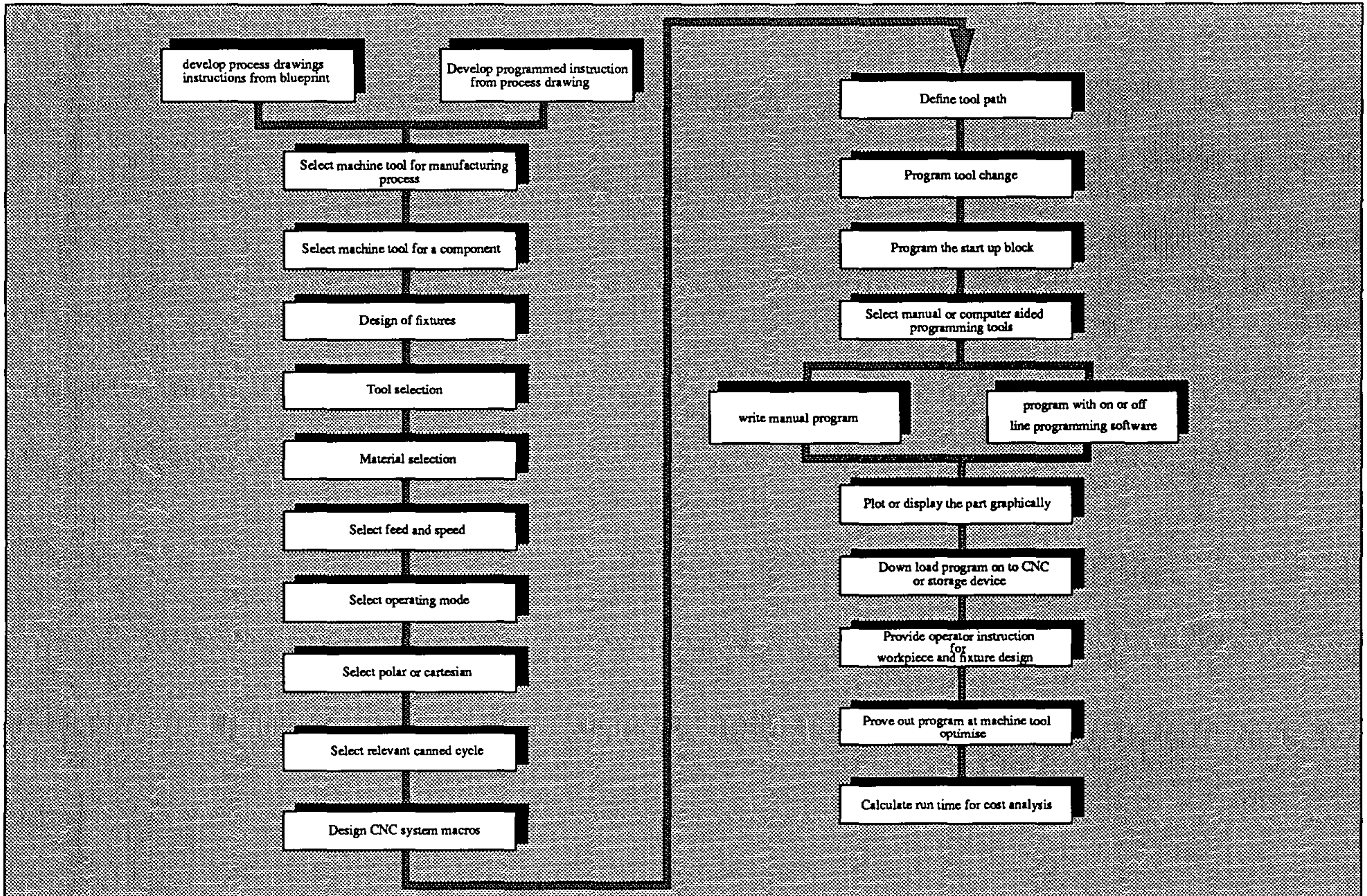


Figure 2.4	NC programming steps	LUT - CAD/CAM

2.2.3 - Evolution of NC Programming

In the last three decades NC programming has evolved significantly. The first phase of NC programming started with manual coding (*i.e. EIA*/ISO) in the fifties, which was soon followed by the design of a higher level language APT. In the 1960's other similar programs were developed (*e.g. UNIAPT, NELAPT,EXAPT,IFAPT*) *[Besant 86] [Bedworth 91]* in different countries by applying the same logic used by APT. In the early seventies the advent of computer graphic assisted NC programming rationalized the shortcomings of previous systems by providing the user with a set of tools to develop a more complex geometry which could be designed fast and accurately.

Different methods of generating manufacturing codes are discussed in the following section. They are:

- Manual NC programming
- Computer assisted NC programming
- Computer graphic assisted NC programming

2.2.3.1 - Manual Programming

Today, manual part programming is still practised in some manufacturing plants. The process of manual part programming includes the selection and suitability for subset of components to be machined. Various other tasks must be performed by the NC programmer; production of the hand written instruction (*manuscript*), preparation of tape or manual entry of data and verification and subsequent modifications *[Stocker 83] [see figure 2.5 for more detail]*.

Manual preparation of an NC program embodies two basic groups of machine control instructions; motion command controls the motion between a cutting tool and parts; auxiliary functions control machining parameters such as the feed rate, coolant, and spindle speed.

The disadvantage of handwritten manual program is: 1) it can only deal with simple parts, (*e.g. surfaces cannot be programmed*), 2) Programming is cumbersome

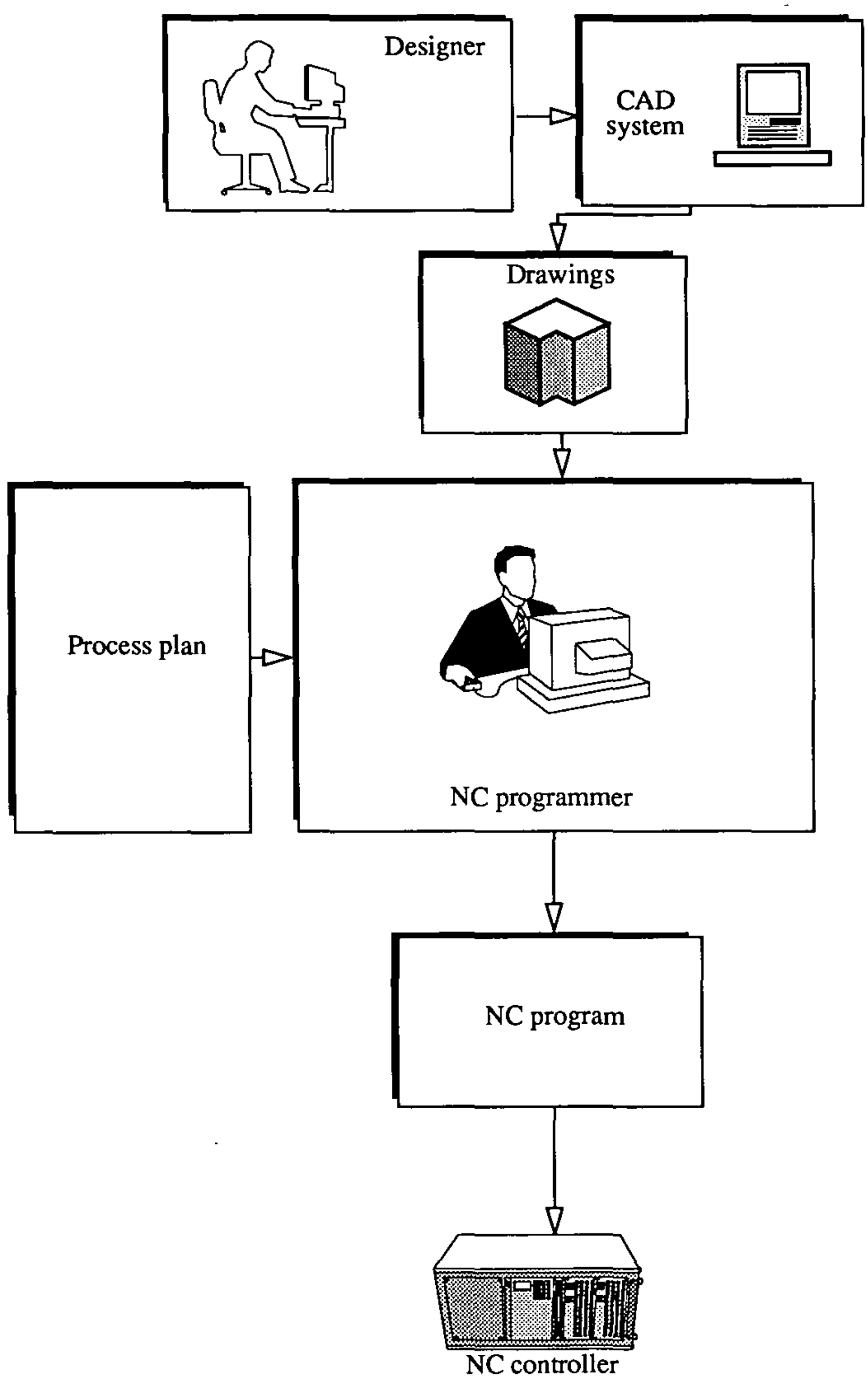


Figure 2.5	Manual NC programming	LUT - CAD/CAM

and time consuming, 3) There is a higher chance of errors, 4) The procedure is costly and, 5) verification and modification processes are time consuming and difficult.

The machine tool industry is capitalising on advances in control theory, digital computer and servomotor technology, thus machine tools are capable of handling simultaneous cutter motions in 3 to 5 axes at a high speed. While these machines are constantly improved to tackle the dynamic problems, the majority of controllers still accept primitive commands to actuate the cutting tool from point to point or in circular arcs. The calculation of theses motions is time consuming and expensive and invariably causes error.

2.2.3.2 - Computer Aided NC Programming

In the mid 1950's, the first computer aided programming tools were introduced to minimise the effort required of NC programmers. The main advantage provided was the high level standard description of the geometry which thus simplified the processes of defining the tool motion. This system only asked for the geometry to be described and the relation between the cutter and geometry(*motion*) to be specified. The output was then calculated and listed in terms of cutter location data *(CLDATA)* based on description of geometry and motion *[figure 2.6]*. The computer automated tools are typified by the automated program tools *(APT) [Rembod 83] [Well 79] [Marsland 84]*.

2.2.3.2.1 - APT

The need for a standard NC part program language prompted the researchers at MIT to develop a high level language called Automatically Programmed Tools *(APT) [Marsland 84]*. APT as described by its inventor Douglas Ross, is a method that contains the essence of the problem of moving a cutting tool through space to produce a specific curve or region, being independent of the particular surfaces and dimensions involved. The skeleton structure of APT system is depicted in figure 2.7. APT is a high level NC program that embodies four modules *[Rembod 83]*:

- Geometric definition

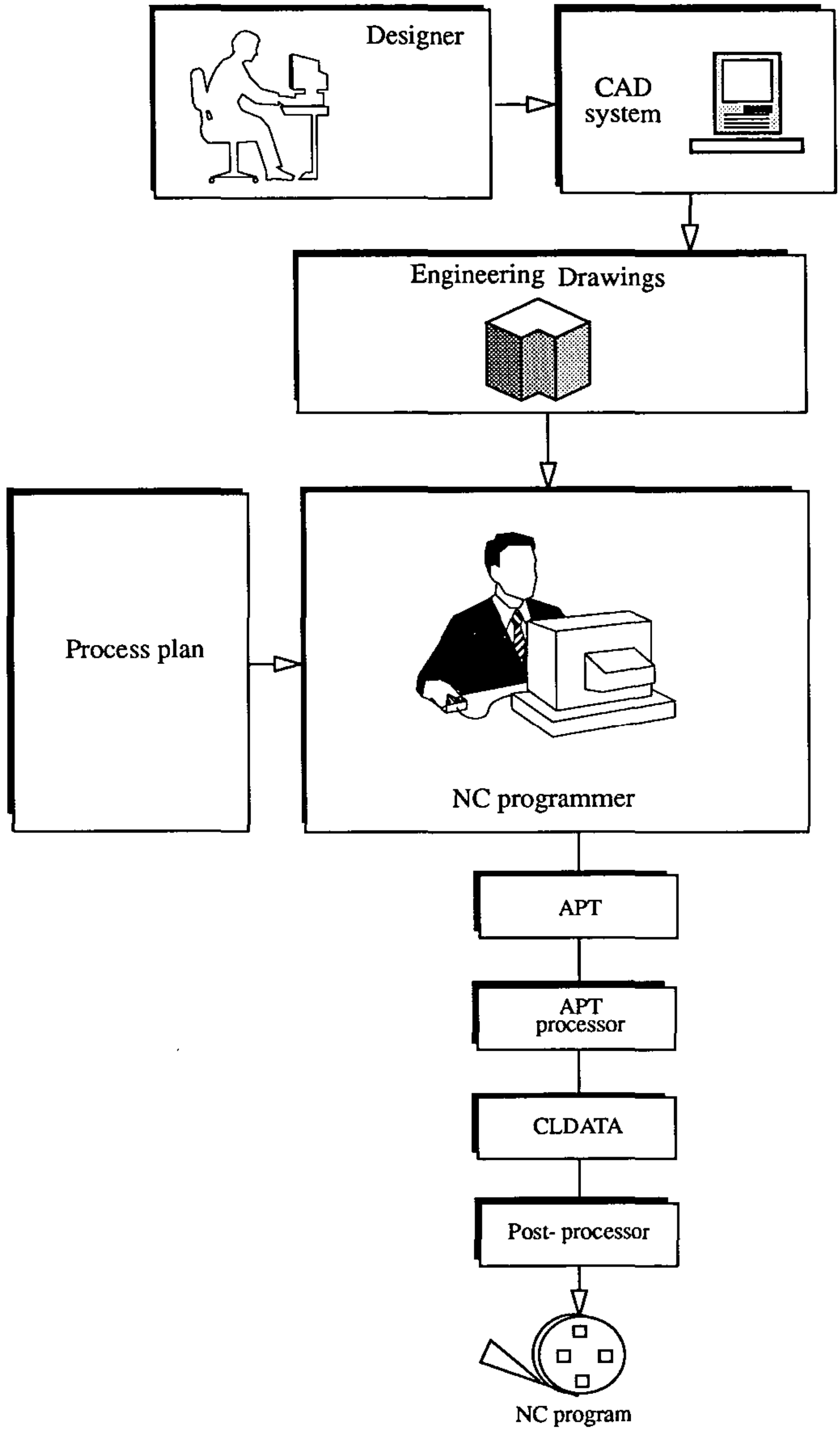


Figure 2.6	NC using APT programming	LUT - CAD/CAM

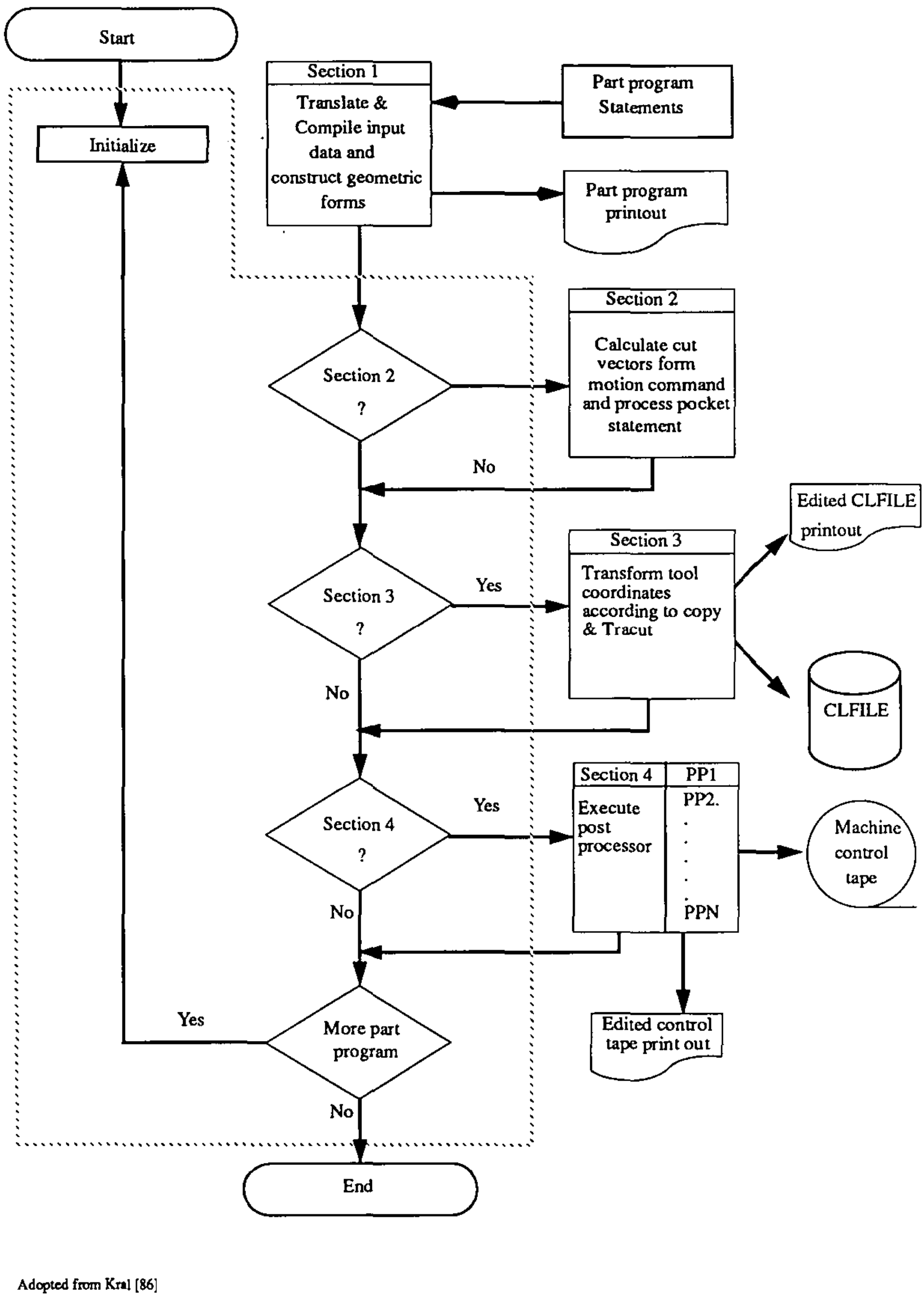


Figure 2.7	Organization of APT system	LUT- CAD/CAM

- Motion
- Post processor
- Special control

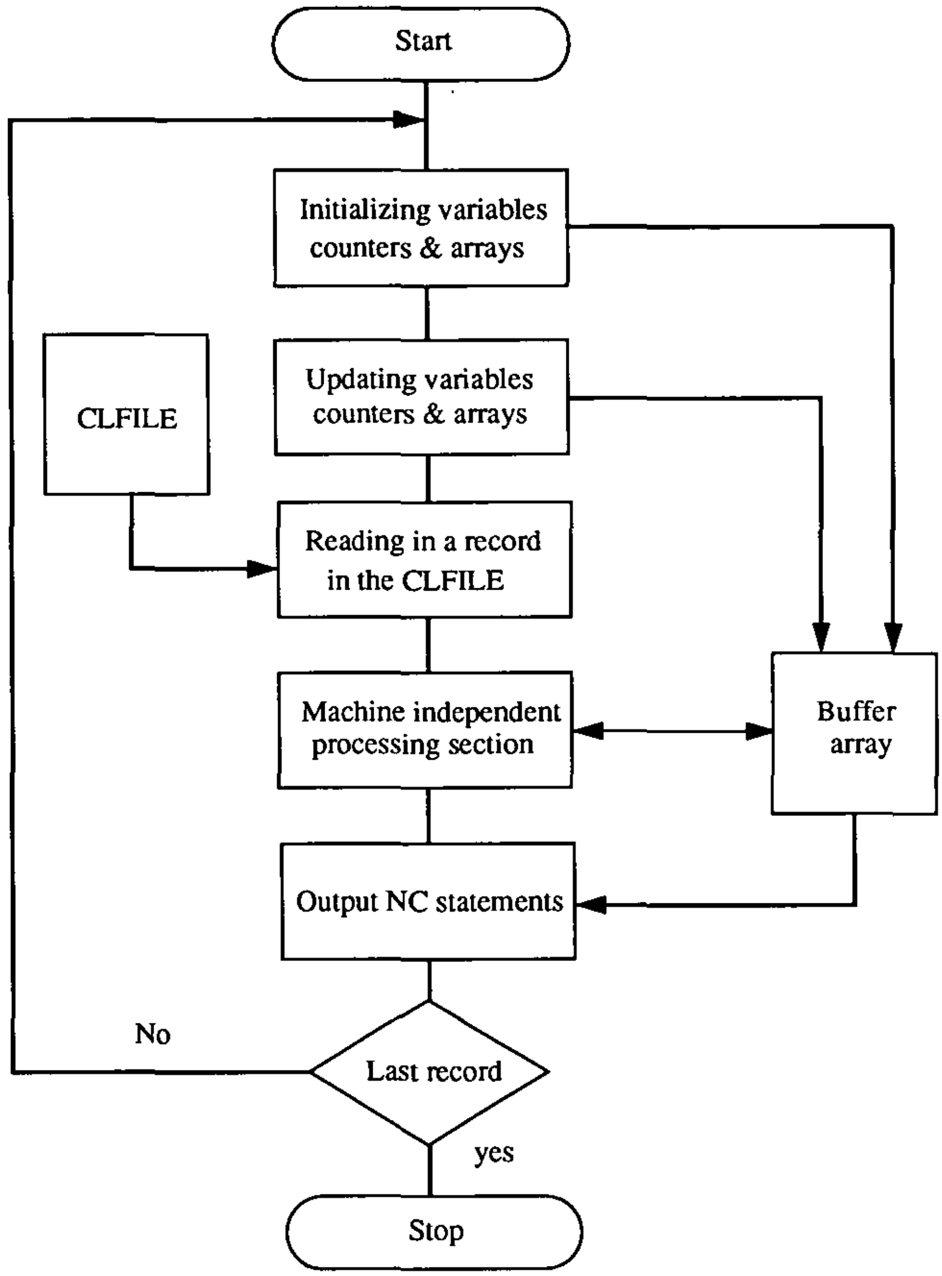
The complexity of the APT system and the limited number of technological descriptions are its main disadvantages *[Marsland 84]*. The disadvantages of APT prompted the designers to develop APT like languages with more powerful features such as EXAPT, 2CL, COMPACTII, UNIAPT, UCCAPT, MINIAPT and ADAPT *[Marsland 84][Griess 79]*.

2.2.3.2.2 - Post Processor

The first phase in the operation of any computer assisted NC part program is the processor which translates the English like statement into its own computer code for the necessary calculation and data manipulations. The second phase is called post processing. A post processor is a computer program which translates CLDATA into machine dependent format for a particular combination in a machine tool and control system for which the part program is intended *[Allen 88]*, figure 2.8 shows the structure of a post-processor.

Post processors also check feed rate, spindle speed and travelled distances and compare them with the machine limitation and capability. Some post processors also perform dynamic analysis of tool motion based upon the type of machine & servo motor used. The majority of the post processors automatically take into consideration the acceleration and deacceleration of the NC machine *[Griess 79] [Harriger 88][Allen 88]*.

Although many people in industry and research have shown interest in a standardised format for the NC machine, not much has been achieved so far. Machine tool builders have shown little interest in developing standardised format. Finally because of the wide variety of machines with different physical and functional characteristics, developers have been forced to design post processors to convert CLdata into specific machine code *[Bruce 90]*.



Adopted from CHAO etal [89]

Figure 2.8	General structure of postprocessor	LUT- CAD/CAM

The functions and structure of the post processors are classified in to five categories *[Takahashi 87]*:

- **Control**: controls the overall operation of the post processor and initially sets its data
- **Input**: feeds in CL data for formatting to permit processing by other elements.
- **Motion**: prepares interpolation data, such as linear and circular interpolation, from tool path data and sets feed rate codes.
- **Auxiliary**: processes the post process language and sets various parameters and m, s, t, codes.
- **Output**: processes the data prepared by the auxiliary and motion elements into a format which can be fed into NC equipment, and outputs.

2.2.3.3 - Computer Graphic Assisted NC Programming

The advent of computer graphic assisted NC programming in 1970 was closely linked with the advancement in computer hardware as it became available *[Harriger 88]*. Other developments such as the introduction of inexpensive and powerful mini and micro computers vastly enhanced the development of interactive computer graphic programmes. The early pioneers (*COMPACT II and UNIAPT*) upgraded their systems by adding graphic facilities to simplify the programming procedures.

Today, many CAD systems such as Computervision, CATIA and CADAM are provided with the necessary software tools to generate tool paths, by using geometric data from the design model, and they function interactively to generate the manufacturing code. Some of these systems use built in APT processors to transform the CL data into specific machine code (*e.g. SMARTCAM, ANVIL*) *[figure 2.9]*.

Computer graphic assisted NC programming has greatly enhanced the programmers capability in a number of ways *[Medland 88][Groover 84][Stocker 83]*:

- By providing calculation capability and ease of use beyond that of the machine's NC system and by avoiding burdening the programmer with the ambiguity and

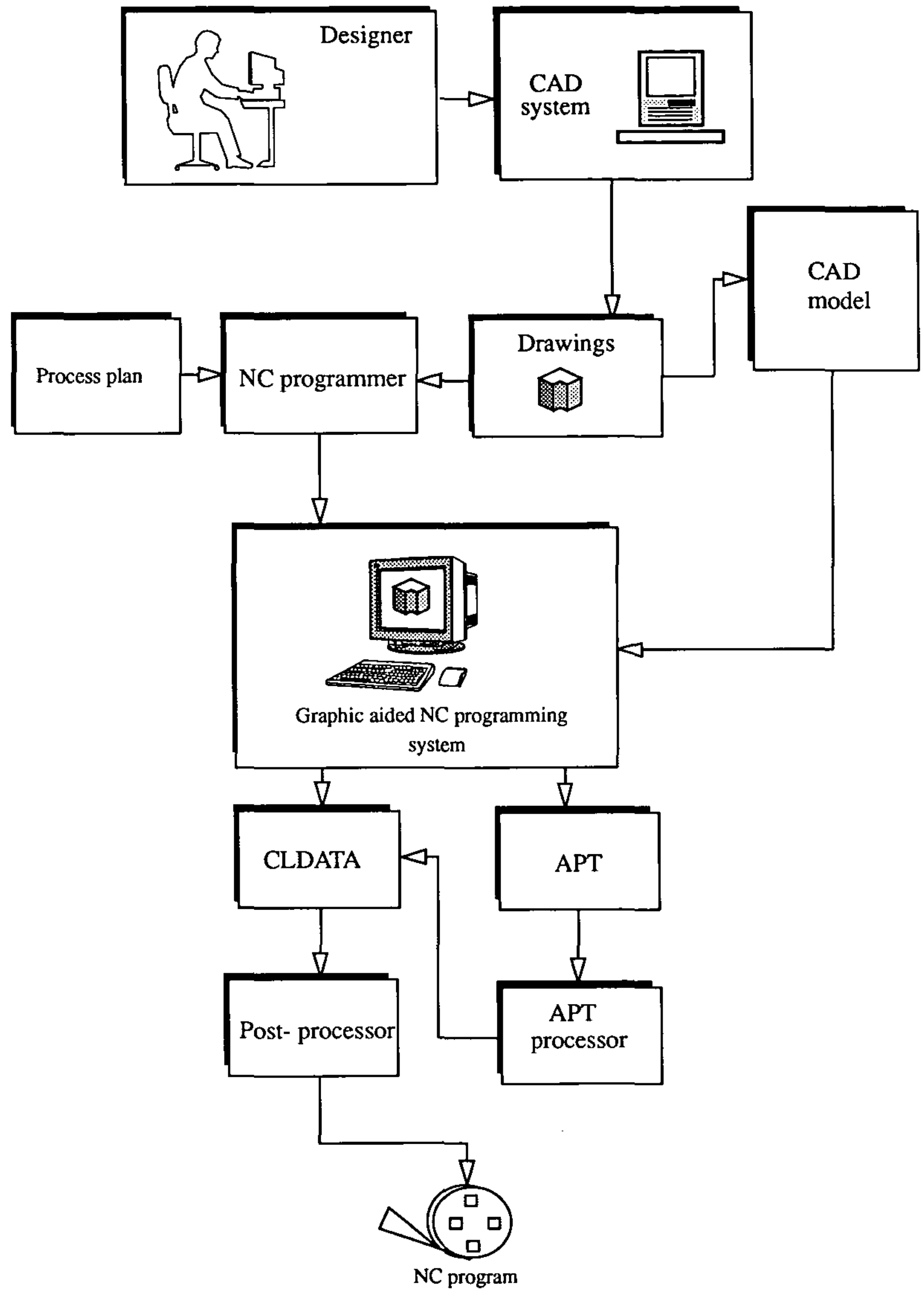


Figure 2.9	NC programming using computer aided graphic	LUT - CAD/CAM

complexity of high level NC language by providing a graphics facility for input.

- Program reliability is enhanced and the use of graphics provides the programmer with less opportunity for making errors.
- The assistance of computer graphics enables the user to check and modify the NC program graphically, and subsequently displays it in different views.
- The use of computer graphics is not only limited to generating manufacturing codes. It can also be utilised for other types of analysis.

The major draw back of most graphic assisted NC programs are the graphic modellers used by these systems. It is suggested that the majority of these systems still use wireframe modellers to represent the geometry *[Griess 79]*. The ambiguity and complexity of wireframe systems is an obstacle to the development of more complex models that are fast and more accurate *[Francis 81][Marsland 84]*.

2.2.3.4 - State of the Art

New developments in CAD/CAM have provided the designer in both the commercial and research sectors with opportunities to develop and optimise the NC code generation. It is stated *[Mills 89]* that over two billion dollars had been spent by different industrial companies in 1989 to design software that can assist in generating and verifying toolpaths, and this underlines the fact that the manufacturing industry is constantly searching for ways to rationalise NC code generation. The focus of the industry is to develop the automatic generation of NC code and improve shop-floor programming.

2.2.3.5 - Automatic NC Program Generation

As stated by Giger *[1989]* the market has taken advantage of computer graphics and artificial intelligence so as to meet some of the requirements of modern systems *[Giger 89]*.

Nathan *[1990]* believes that the long lead times, high manufacturing costs, high error rates and decreased productivity has prompted the researchers to design an automated

NC system *[Nathan 90]*. The automation of NC was pioneered by CAM-I and Grayer *[Grayer 76]* in the late 1970s. Those systems were capable of accepting the part information and the machine instructions required to produce and verify the part integrity with respect to part specification *[CAM-I 88][Nathan 90]*.

Armstrong *et al [Armstrong 79]* described automated NC code generation as a system that is provided with a complete geometrical description of the part to be produced, the stock from which it is to be machined, and the available tooling and fixtures in order to design an appropriate algorithm and representation which will automatically yields an acceptable strategy (*setup, toolpath*) to produce the part on a NC machine *[Armstrong 79][Parkinson 84][Grayer 76][Requicha 77]*.

Nathan *[1990]* and CAM -I *[1988]* underline the necessary prerequisite and key concept for an automated NC program *[Nathan 90][CAM-I 88]*:

- Form features (*by feature based or feature recognition system*)
- Solid model as the basis for designing the manufacturing (*NC*) features.
- A complete product definition data.

A major obstacle facing an automated NC program is that some of the activities within an automated NC system are difficult to automate for any general cases. In addition Nathan *[90]* states that the lack of sufficient intelligence on the part of available solid modellers, doesn't take into consideration the weight and the force interactions between the assembly components and setup rigidity for automatically planning or designing the required fixtures *[Nathan 90]*.

Early research on automated systems has provided the know how for the commercial sectors to design the commercial software for the automatic generation of NC programs *[Mills 89]*. These systems claim to generate toolpath automatically. The benefits of these systems are said *[Mills 89]* to include:

- Increased program productivity which can help to ease the shortage of skilled NC programmers.

- Reduction of lead times
- More consistent part programs
- Close the link between design and manufacturing

Some of the commercial automated NC systems currently available on the market are *[Mills 89]* claiming to fulfil the requirement of an automated NC program.

2.2.4 - Process Planning

Process planning has various synonyms; manufacturing planning, material processing, machine routing and process planning are only a few of the titles that are used for process planning. Chang *et al [1985]* describes process planning, as a function within a manufacturing facility that describes the needed machining process to convert a part from it's initial form to the final form from an engineering drawing. Chang *et al [Chang 85]* states that in a conventional production system, a process plan is created by a process planner who studies a new part and decides upon applying the appropriate method to produce it based upon previous experience, *[Chang 85]* various factors such as the geometrical shape, tolerance, surface finish, size, material type and quantity and the manufacturing system used effect process planning decisions. Hence process planning consists of operation sequencing, operation selection, tool selection and machine selection *[Chang 85]*. Figure 2.11 depicts a typical process planning system.

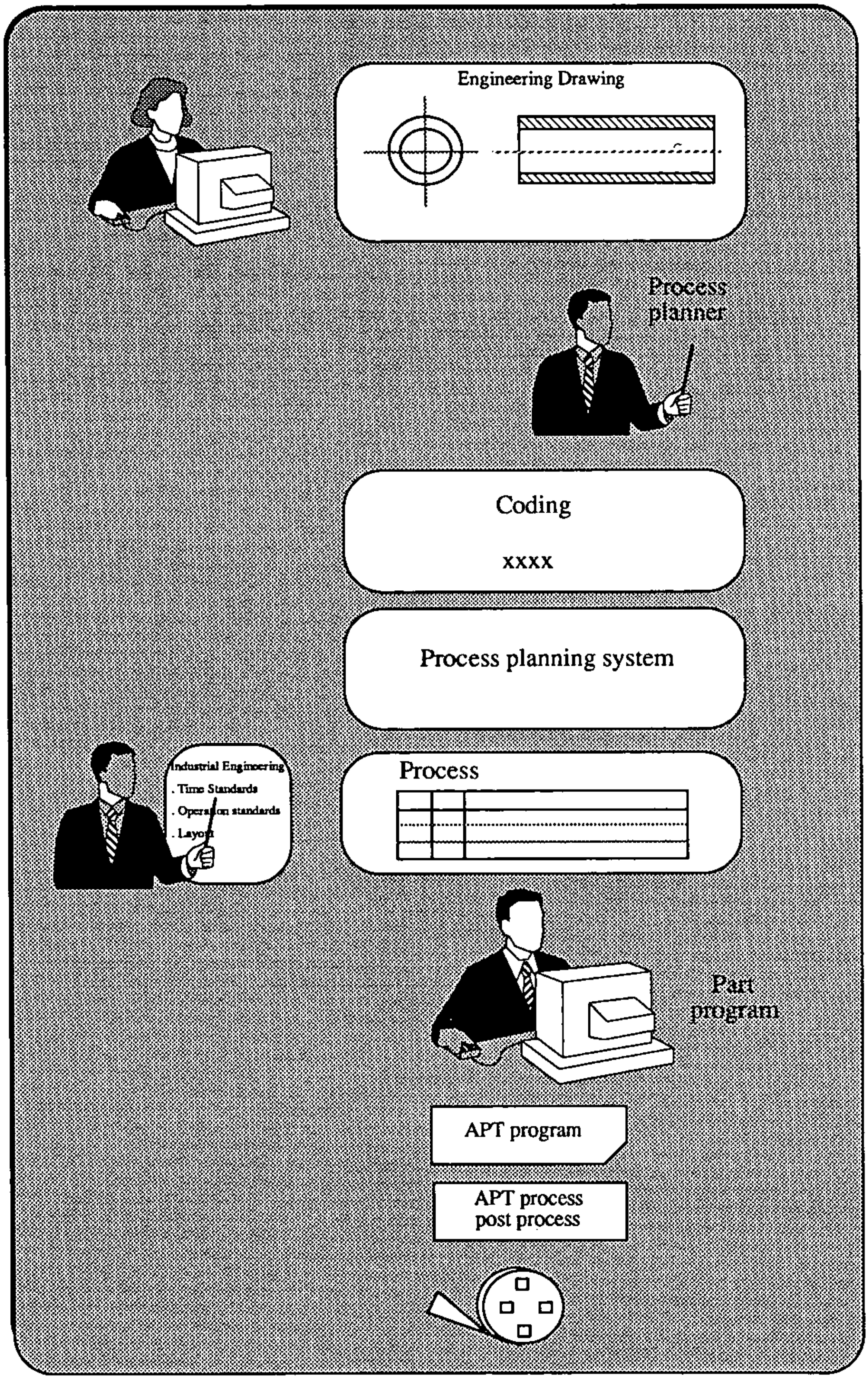
2.2.4.1 - Computer Aided Process Planning

Chang *et al [1985]* states that the number of required process planning personnel available today do not match the actual demand, hence many people in the industry began to use the aide of the computer to generate the plan. One such system is the lockhead CAP system *[Tulkoff 81]*. However Chang *et al [1985]* views the system as mainly trying to reduce the clerical work required by the process planner and not actually preforming the process planning task. CAPP is another well known system by CAM-I. The CAPP system uses group technology and stores the prepared process plan in a database. It can efficiently retrieve a similar process plan from the database for a new component and subsequently modify it to satisfy the requirements of the new part *[Link 76]*. The use of computer aided process plan has resulted in various advantages and benefits as is documented by several references *[Chang 85] [Tulkoff 81] [Link 76] [Allen 88]*. The two approaches generally used in process planning are Variant and generative *[Chang 85]*. The variant method is a library retrieval approach which finds a standard plan for similar components *[Chang 85]*. However the generative process plans are generated automatically without the need for retrieval of standard plans. Process planning is considered to be the critical bridge between design and manufacture. *[Chang 85] [figure 2.11]*.

2.2.4.2 - Variant Process Planning

The variant system relies upon the similarity among the components for the retrieval of an existing process plans *[Chang 85]* hence, as stated the variant system rationalises storage and retrieval by coding families of parts. The retrieval method and logic in the variant system is based on a grouping of parts into families. A common manufacturing method is then determined for each family and represented by standard plans *[Chang 85]*. Chang *[1985]* describes the variant system as having two operational stages: a preparatory and production stage. As depicted in figure 2.10, the preparatory stage is when the parts are coded and classified and each family and the associated standard plans are designed. The production stage is when the system is ready to search for a family of parts and retrieve the standard plan. In summary, the variant system is constructed through the following sequences: *[Chang 85]*

- Family formation
- Database structure
- Search algorithm
- Plan editing
- Process parameter selection



Adopted from Chang [85]

Figure 2.10	Typical process planning system	LUT - CAD/CAM

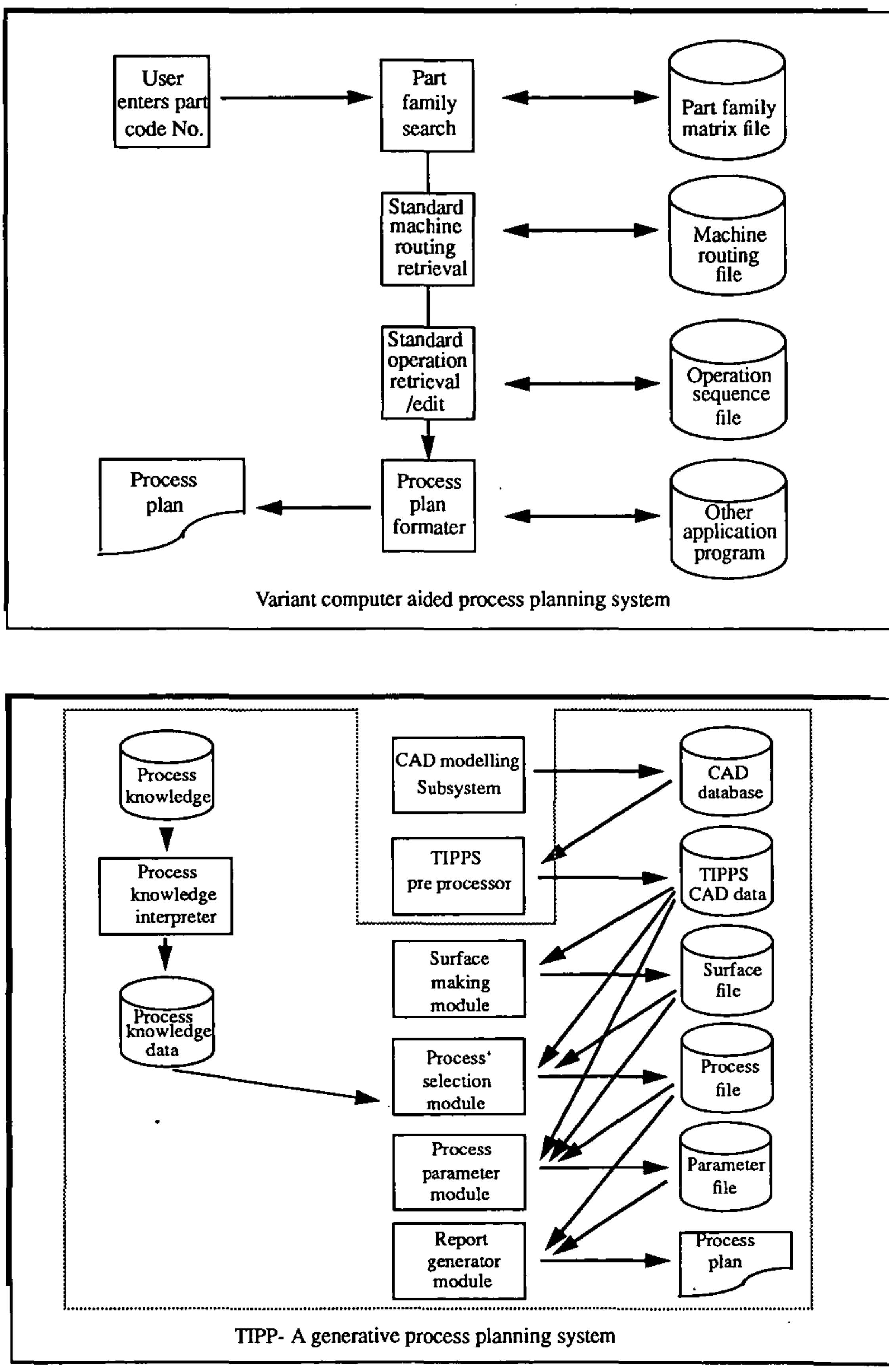
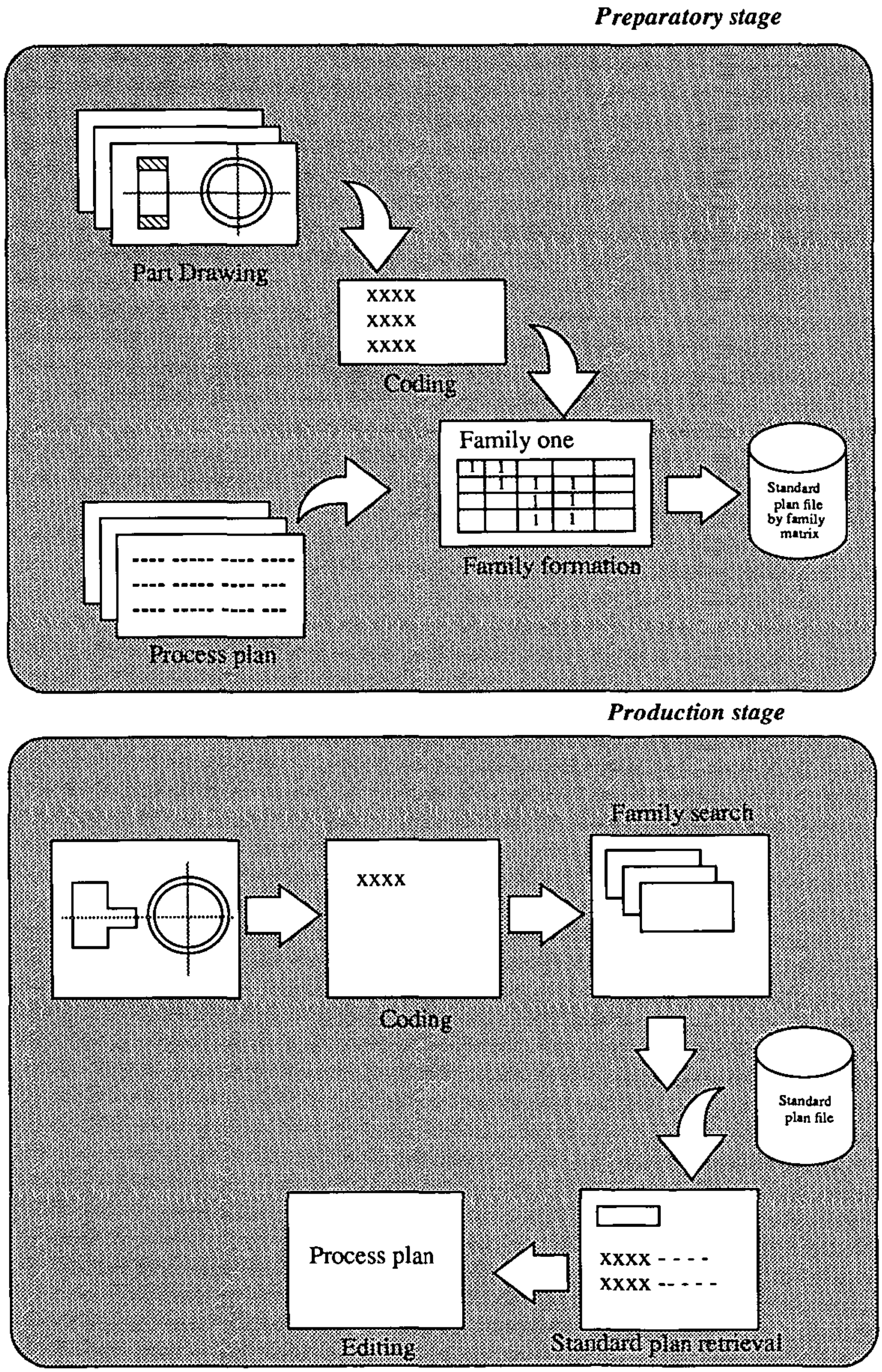


Figure 2.11	Computer aided process planning	LUT - CAD/CAM



Adopted from Chang [85]

Figure 2.12	Steps for variant process planning system	LUT - CAD/CAM

It is clear that there are great differences in the perceptions among the process planners as to what constitutes the 'optimal' method of production *[Groover 84]*.

2.2.4.3 - Generative System

Generative process planning involves the use of the computers to create process plans from scratch *[Groover 84]*. The generative CAPP system synthesises the design of the optimum process sequence, which is based upon an analysis of part geometry, material, and other factors which have an effect on manufacturing decisions *[Groover 84]*.

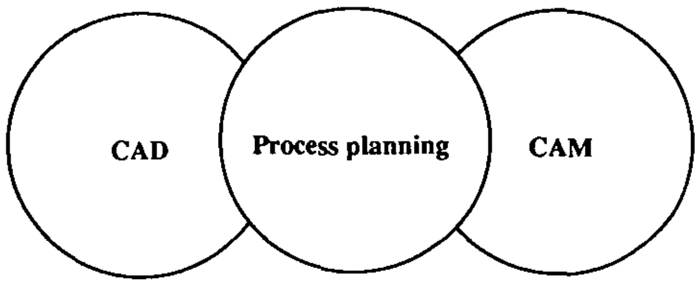
2.2.4.4 - Benefits of CAPP

The use of the computers in process planning has brought a best process rationalisation by applying and producing consistent rules and plans resulting in increased productivity, reduced turn around time and improved legibility. Finally, other application programs can be incorporated to take advantages of these benefits *[Groover 84]*. Allen *[1988]* describes the process planning problems in the following terms:

- Continuous re-education of planners
- Introduction of new processes
- Obsolete equipment
- Employee knowledge lost when they leave the organization
- No way to capture knowledge

These shortcomings have led to the following needs and expectations of a process plan *[Allen 88]*

- Use only data available in the drawings
- Eliminate all subjective, judgment choices
- Consistently produce the same plan for the same part
- Must be simple to use; requiring minimum typing skills
- Allow manual interaction for complex parts



Process Planning

Systems	Advantage	Disadvantage
Traditional	. Low cost . High flexibility	. Lack of consistency even with standard parts . Lack of common tooling . File update new process
Workbook	A few well trained planners can influence a large population of small parts	. Limited variables . Simple parts
Variant	. Increased consistency . Increased planner efficiency	. Maintaining consistency in editing . Extensive keyboard activity . Difficulty in developing good standard plans
Generative	. Consistent process plan . Rapid plan development . Plans reflects latest technology method, equipment, tooling . Reduce personnel training . Company experience captured	. Method of development not widely understood . Initial development effort . Extraction of knowledge base difficult

Figure 2.13	Process planning advan. & disadv.	LUT - CAD/CAM

- Easy to incorporate new production techniques in logic system
- System to operate on small/medium speed computers

The components and advantages and disadvantages of these system are listed in the following figure 2.13 *[Allen 88]*.

2.2.5 - Group Technology

Group technology is defined *[Chang 85]* as "the realisation that many problems are similar, and that, by grouping similar problems, a single solution can be found to a set of problems thus saving time and effort." Allen*[78]* describes GT as "A method of manufacturing piece parts by classifying these parts into groups and subsequently applying to each group similar technological operations. This obtains economics which are normally associated with large scale production in the small scale situation.

2.2.5.1 - The Principle Elements of GT

The principle elements forming GT are *[Allen 78]*:

- Composite parts
- Family of part
- Machine cell
- Classification
- Coding

These issues are explained further by the following authors *[Allen 88][Chang 85][Groover84][Hyde 81]*.

2.2.5.2 - Benefits of GT

Group technology has an impact on many areas of design and manufacturing. It is continuously used to rationalise decision making in design and manufacturing. The benefits which results in using GT are summarized below *[Allen 88]*:

Improving:

- Equipment utilisation
- Component standardisation
- Scheduling and control
- Product design rationalisation
- Job satisfaction
- Order potential
- Communication
- Cost/time estimate

Reducing:

- Planning effort
- Inventory
- Material handling
- Setup and down time
- Overall production time
- Finish parts stock
- Overall cost

Apart from the economic benefits gained by using GT, the strategic benefit of GT is of paramount importance in design and manufacturing *[Houtzeel 77]*. The strategic benefits of group technology are those that have an impact on quality, flexibility, timing and position relative to the company goals and the market's demands *[Allen 88]*. These benefits are achieved by the following activities:

- Product design
- Product flexibility
- Product quality
- Broadening employees skills
- Providing additional potential benefits

Chapter 3

The Feature Concept

3.1 - Introduction

This chapter discusses the significance of feature concept in manufacturing and set the context in which features are used in this work. A more detail study of features technology can be found in *[Shah 88]* and *[Butterfield 85]*.

Features are seen as a bridge or key to integration of design and manufacture and are applied widely in the designing and manufacturing of parts. The related areas of feature application are: design, analysis, geometric description, process planning and NC machining.

3.2 - Feature Definition

The literature provides a wide variety of definitions for features. However, these definitions are grouped into three major disciplines *[Shah 88]*:

- Features in design
- Features in processes planning and machining
- Features in geometric modelling

Shah *et al [1988]* states that features in design are used in generating, analysing and evaluating designs. The relevant definition found in the literature are as follows:

> "... A representation of shape with geometry and attributes that are recognisable to humans and programs." *[Turner 88]*
>
> "...Abstract entities that combine functionally related elements of the model" *[Shah 88]*
>
> "...The smallest grain size of information representable in mechanical design." *[Tikerpuu 88]*
>
> "...As a method of geometric creation and modification and analysis." *[Chang 85]*

...As a feature with a semantic known and used by designer' *[Bohms 90]*

Features in machining and process planning are concerned with shapes or geometric entities which are associated with technological attributes such as manufacturing operation, cutting approach and tooling. The literature provides several definitions for manufacturing features:

"...Geometry that corresponds to primary machining operation' *[Grayer 76]*

"... A chunk of surface geometry on the finished part, that is to be produced with some associated geometry by a specified machining process' *[Hummel 86]*

"...Regions of the part that have some degree of manufacturing significance." *[Hummel 86]*

Shah *[1988]* states that features in geometric modelling can be described as a grouping of geometric or topological entities that are needed to refer together. The literature provides many similar definitions:

"...Any geometric form or entity that is used in the reasoning of one or more design or manufacturing activities, feature can be geometric, topological, or attributes' *[Cunningham 88]*

"...Set of entities such as faces' *[CAMI-GM 85]*

3.3 - Features Identification

Since features are domain specific various research works have developed and identified the features into several application domains. The best example of cataloguing features is in the CAM-I report which was undertaken for John-Deereby Butterfield *[1985]*. This report has investigated and subsequently identified three feature types for process planning purposes:

i- Sheet like features

ii- Prismatic features

iii- Rotational features

Features were defined in terms of shape, parameter and technological attributes. Cunningham *[1988]* and Gindy *[89]* have also developed a set of features for injection moulding and process planning respectively.

3.4 - Feature Benefits

There are numerous benefits of using features. These benefits are described by Chung *[88]*. The design intent can be expressed by manipulating features directly, and eliminating tedious intermediate steps:

- Features databases allows a reasoning system to preform tasks such as optimization and manufacturing analysis
- Features can embody knowledge to facilitate NC machine programming, process planning and F.E analysis.
- Provide order, simplification and classification of entities to be readily used to describe geometry.

The provision of features embodying the design and manufacturing intent can greatly enhance and simplify the design and manufacturing procedures and reduce the manufacturing cost. The economic and technological advantage gained by the use of features is therefore the result of embedding knowledge and order in these entities.

3.5 - Hierarchical Representation of Features

Classification has been seen as a tool to organize the variety of features under a number of disciplines and to rationalise the numerous type of features. The classification approach resulted in a common terminology appearing which consequently resulted in the development of codes for features to simplify description and retrieval and develop data exchange standards *[Shah 88]*. Four distinct classification systems were developed. These systems are domain specific:

i- John Deere Scheme *[Butterfield 85]*

ii- Shah scheme for rotational parts *[Shah 88]*

iii-PDES classification *[PDES 88]*

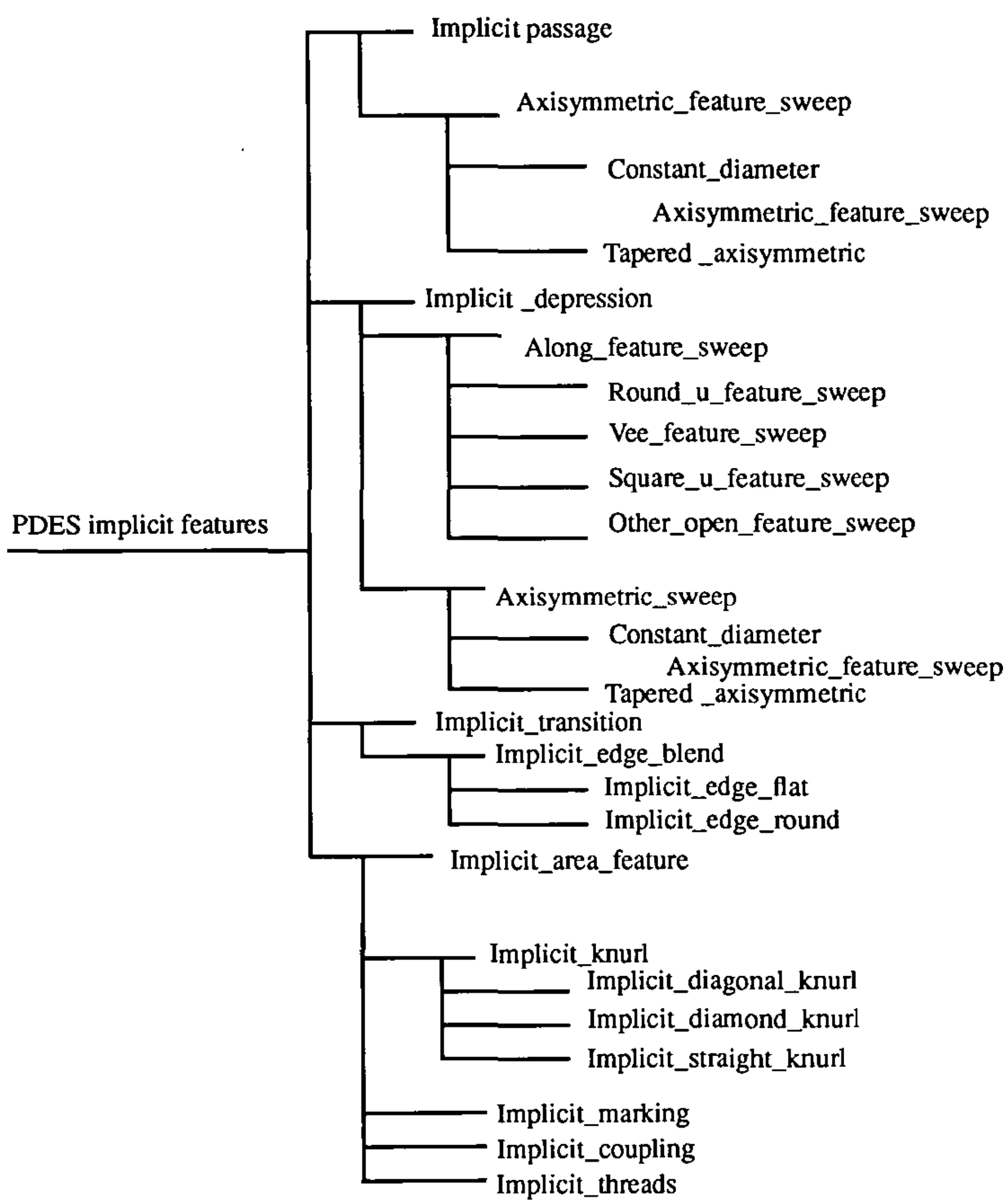
iv- Dixon & Cunninghum classification *[Cunninham 88]*

The John Deere system was proposed by Butterfield *[CAM-I 86]* in which he categorized the form features into several sets: sheet feature, prismatic feature and rotational feature. Sheet features were classified as flat or formed which in turn represents more sub-features. The prismatic features have been classified in to three categories of surfaces, depressions and protrusions, each of these were classified further. The rotational features were also classified to concentric and non-concentric, and classified further to form features and surfaces.

The Shah *[1988]* scheme divides the rotational parts into the three categories of shaft, flange and wheel type. This scheme has been the bases with which a feature based modelling system has been devised *[Asu 88]*.

PDES *[1988]* classifies the features into implicit and explicit features *[figure 3.1]*. The explicit features are the grouping of geometric models, however the implicit feature can be described by one of the following six cases:

- Passage
- Depressions
- Protrusions
- Transitions
- Area features
- Deformation



Adopted from PDES [88]

Figure 3.1	PDES based feature taxonomy for rotational parts	LUT-CAD/CAM

Dixon & Cunningham classify features into kinetic and static features. The static features are the geometric primitives and the kinetic features are classified based on the information type *[Cunningham 88] [Shah 88]*. Another method is DCLASS *[figure 3.2]* which is devised by Allen *[89]*. DCLASS introduces a complete taxonomy for process planning *[Allen 89]*.

The focus of this discussion is to state and explore a suitable method to represent features, but as yet no particular approach has fulfilled all the requirements *[Case 89]*. A brief review of some of the methods used to represent features are discussed in the subsequent sections:

3.6 - Human Assisted Feature Recognition

This method was designed primarily for process planning and NC tool path generation. The features were defined interactively by a set of geometric entities (*edges, faces*), and subsequently the relevant feature and attributes were added. This approach is also pursued by the following authors: *[Nau 87] [Hummel 86] [Brown 86]*. Shah *[1988]* states that this approach is time consuming and in addition the burden of selecting entities lies with the user.

3.7 - Automatic Feature Recognition

This method is designed to extract and locate those features which conform to a predefined geometric pattern. Three major methods are used:

- Geometric reasoning
- Volume decomposition
- CSG tree manipulation

Shah *[1988]* investigated these techniques in detail. The advantages of automatic feature recognition are:

- The use of current geometric models

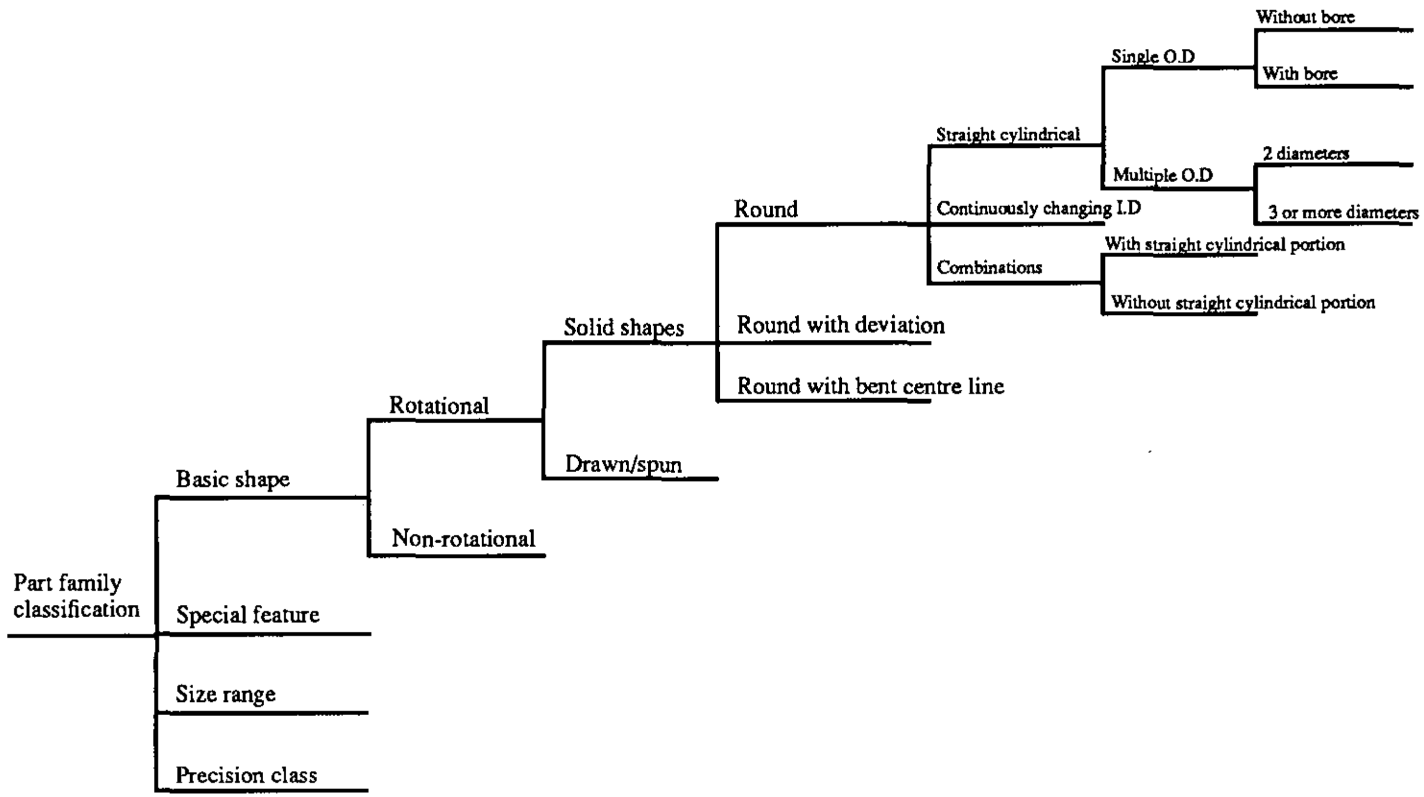


Figure 3.2	DCLASS taxonomy for rotational parts	LUT-CAD/CAM

- Adapting recognition to be application specific

The disadvantages are that the design intent is not captured at the beginning and recognition makes explicit what is implicit, furthermore the current recognition techniques constrain the functionality of this method.

3.8 - Design by Feature

In this method, the designer starts by using features to build a model. Shah *[1988]* states that several methods are used to achieve design by feature. The major advantage of this technique is that it captures the designers intent at the initial stage of design, however there are several disadvantages with this system:

- The limited range of features
- Cannot handle complex shapes
- There is a tremendous variety of data to be managed
- The design methodology is not clear

Shah *[1988]* presents four basic methods used in design by feature:

- ***Feature database unassociated with geometric model.*** This method was used by Gari *[Descott 84]* and John Deere *[Butterfield 85]*.
- ***Destructive solid geometry.*** This method is suited to simultaneous design and machine planning and is used by *[Arbab 82]* and Anderson *[Turner 88] [Cutkosky 88]*. This method is also implemented in the parametric solid modelling package (*Pro engineer*).
- ***Composition feature models.*** This system allows the designer to add, subtract and manipulate features. This method was used by Pratt & Wilson *[CAM-I Aspp 85]*
- ***Procedural feature languages.*** This approach is suited for modelling assemblies in which it allows the geometric objects to be represented

hierarchically, Rossignac *[Rossignac 88]* has developed this techniques further by developing an interactive geometric design using features.

Finally it must be noted that the method found most suitable and thus implemented by the author is the use of feature based design [*for more detail refer to chapter 7 and 8*].

Chapter 4

The Related Research Work

4.1 - Introduction

The objective of this chapter is to investigate the relevant and parallel research work being conducted and furthermore to understand the function of each work and describe the strengths and weaknesses. The research work highlighted is generally concerned with NC code generation and process planning issues for turned components. Table 1 provides a concise summary and description of some of the more reputable systems. The systems that are most relevant to this research are described at length in the subsequent sections:

Table 1: Process planning & NC systems

Author	system	Part data input	decision logic	planning function	part shape	Commercial or Experimental
Wysk	APPAS	G	Decision tree	1,4	H	E
Evershiem	AUTAP	D	Decision table	1,4	R	C
Allen	BYUPLAN	G	Decision tree	1,4	B	E
Chang	CADAM	D	Decision table	1,4	H	E
Sack	GMPP	D	Decision model	1,2,3,4	R	C
Kung	GAPPS	D	Decision model	1,4	R	E
Descotte	GARI	D	AI	1,4	N	E
Tulkoff	GENPLAN	G	Decision model	1,2,3,4	B	C
Darbyshire	EXCAP	D	AI	1,4	R	E
Logan	LOCAM	D	Decision model	1,2,3,4	B	C
MGS	OPTAPLAN	D	Decision model	1,2,3,4	R	C
Phillips	PROPLAN	D	AI	1,4	R	E
Choi	STOPP	D	Decision model	1,4	H	E
Chang	TIPPS	D	AI	1,4	N	E
Sack	XPS-I	D	Decision model	1,4	R	E

G= group technology
D= part description approach
N= non-rotational
R= rotational
B= rotational / non-rotational

1 = sequence of operation
2 = tolerance control operations
3 = reference surface selection
4 = process plan / NC output
E= experimental
C= commercial

4.2 - AIMSI

This system is designed by Wang and Wysk *[Wang 88]* at Pennsylvania state university. AIMSI is an integrated CAD/CAM system which represents an algorithm that recognises the machined surfaces. These surfaces are symmetrically rotational. The algorithm is independent of the CAD system, it's function is to perform an intelligent search so as to identify all machined surfaces. The output of the system is used to classify and code and subsequently produce a process plan and NC code. The recognition module is interfaced with a CAPP system devised by Wysk *[Wysk 87]*. This system compares the drawing file of the pre-machined blank and the designed workpiece. The decisions such as depth of cut are then made based on the differences between the two files. A separate module for acquiring the surface finish and tolerancing values is designed. These are then appended to the feature file. The algorithm used by AIMSI recognises the upper half of cross-section of the workpiece. This will undoubtedly limit the capability of this system when dealing with asymmetric features superimposed on a rotational workpiece. Since more than 70% of parts have some sort of asymmetric features, this will make AIMIS unsuitable to represent the majority of components.

4.3 - GFM

GFM is an interactive feature modeller for CAPP of rotational components. This system was devised by Desai *[Desai 91]* at the Indian Institute of Technology. GFM is an interactive graphical environment for modelling symmetric components. This system is based upon a feature taxonomy that provides concise information regarding the available features that exist in the system. These features are divided into two categories: external and internal, each representing cylinder, taper, thread, knurl, groove and form. These features are augmented by technological information. GFM is based on a modular structure and consists of a feature module which allows the features to be described and concurrently the feature validator prevents illogical information. In addition there is provision for a tolerancing module which allows the parts to be dimensioned according to standard engineering practice. The process plan generated by GFM is dedicated. The system can only represent symmetrical features and thus has no facility to represent the majority of features (*i.e. non-turning feature*). The system is easy to use and is based on some novel and yet simple conventions.

4.4 - AUTAP-NC

AUTAP-NC was developed at Aachen Technical University *[Eversheim 82]*. This system addresses rotational parts and can determine the manufacturing segments forming the geometry as well as determining cutting data, cutting tools, lathe chuck, manufacturing sequence and the generation of NC program. This system is made of different segments. The input geometry is matched against the predetermined segments and the correct segments are identified. Subsequently the relevant geometrical features, as well as the technological information is recognised for each of the segment. The chucking positions are also determined. The geometry for each segment is defined by a set of geometric elements. There are face elements and features such as threads and grooves. Once the geometry is identified, then the operations are sequenced. AUTAP is capable of primarily representing rotational features as well as representing to some extent the asymmetric features. It is important to note that this system is one of the first automatic NC systems designed which embodies a powerful and novel methodology for planning a part.

4.5 - GCAPPS

GCAPPS is a computer assisted generative process planning system for turned components. This system was designed at the Indian Institute of Technology by Panda *[Pande 88]*. GCAPPS is designed to generate a plan for three families of products, namely armature shaft, spindle and gear. This system consists of five basic modules: 1) the component representation module, 2) the operation extraction and sequencing module, 3) the machine and tool selection module 4) cost calculation module and 5) report generation module. This system uses features to represent the turned part by using a component representation scheme. It uses a feature oriented strategy and states the main rotational features as, cylinders, tapers, threads, holes, etc. These are subsequently classified and represented into axial, surface and radial features. This representation can easily handle the families of parts. The operation extraction and sequencing is dedicated and consist of rules and strategies based on the families of parts. This system provides a novel approach in representing a feature oriented approach. However, GCAPPS is designed for a limited range of families of components and so is not capable of producing process plan for the majority of rotational parts.

4.6 - EXCAP

EXCAP was developed and refined at UMIST by *[Davis 90]*. This system embodies a set of integrated modules for the automatic generation of a NC programs for turned parts using a CAD product model. Subsequently it uses a 2 1/2 D parametric Prolog model to translate it into a format suitable for process planning and NC code generation by using a menu-driven module to input the geometrical description. The system can provide an orderly representation of operations and geometric elements. This system uses features such as faces, diameters, tapers, radius, blend and chamfer to build the geometry. In addition EXCAP is capable of modelling non-turning features (*e.g. keyway*) in a limited way parametrically. This system uses a feature recognition system and rules in order to derive the machinable entities. EXCAP uses a discrimination net for sequencing rule based systems. This is a set of decision trees which form a network. The route taken through the planning has operations associated with it which form the manufacturing sequences. This system deals mainly with rotational features

4.7 - CAPP/CAM System for Turning Centre

This system was developed in Italy to produce process planning and NC codes for a turning centre. CAPP/CAM *[Boer 90]* is designed to define various machining strategies by using an expert system. The complexity of the parts as well as the machine tool complexity demands a good strategy for minimizing production time. CAPP/CAM consist of five modules: 1) A data entry module, 2) a technology module, 3) an expert system module, 4) a scheduling module and 5) a part program module. This system is designed to be utilized by non-specialists. The workpiece is described by defining the elementary operations. The rule based module assigns and allocates the relevant tools and operation to the appropriate turrets and subsequently defines the relevant machining conditions. Finally the NC module converts the information to NC instructions. This system is equipped with a man-machine interface in order to allow the user to guide the system. However, the heart of this system consists of the expert and the scheduling modules. One of the most interesting characteristics of the CAPP/CAM, is the integration of a knowledge based module with an optimization algorithm. However, the method by which the geometry is input is not clear. Nevertheless this work is unique in addressing rotational parts which are produced by a turning centre. The overall method used is similar to the workshop oriented approach implemented by TRAUB [1992].

4.8 - IPSFMS

This is an NC planning system developed by the Institute of Machine Tools and Manufacturing Technology Berlin *[Spure 91]*. This is an on-line workshop oriented system aimed at producing an optimum process plan, NC code and scheduling. IPSFMS claims that it increases system utilisation and reduces throughput time. The integrated process planing system (*IPSFMS*) is based on a features-oriented workpiece description. Alternative processes for each feature are determined using a file base. Application tools and machine details stored in an equipment knowledge base are selected and constraints for the possible sequences of operations are determined. The results is a plan consisting of all possibilities that are technologically correct so as to manufacture a workpiece. With this done in advance, an optimum plan is selected systematically and subsequently the workpiece is produced. The on-line optimization takes into consideration process planning criteria such as minimum tool changes and scheduling criteria. This system is a shop-floor oriented programming. system and is identical to

TROUB IPS. This system covers turning, milling and grinding and offers new programming techniques. The overall aim is to integrate this system into a sensible practice oriented CIM system. This part domain is mostly concerned with turning features. The non-turning features are not emphasised in this literature.

4.9 - TECHTURN

This system has been developed at UMIST by Hinduja *[1989]*. TECHTURN is designed for rotational components and generates operation plan and NC code for turned parts. TECHTURN uses features to describe the geometry of a rotational component. Given the geometry of a component OP-PIAN *[Hinduja 89]* recognises in the first instance features such as threads, grooves and recess, and then subdivides the rest of the component into volumes and subsequently determines the most suitable operation. TECHTURN consists of several technological modules, such as geometry, feature recognizer, operation planning and NC code generation. To find the optimum operation plan, cost calculation is performed based upon optimum cutting conditions. The sequencing rules for TECHTURN are based on the commonly accepted rules for turning. This system is not capable of dealing with asymmetrical features on rotational component, nonetheless TECHTURN is a complete system with all the relevant technological modules and thus can provide an efficient code and plan for turned parts.

Chapter 5

State of the Art

5.1 - Introduction

The purpose of this chapter is to introduce the state of the art advances in machine tools, in particular turning centres and list their benefits and applications.

5.2 - Machine Tools

Machine tools have primarily been improved and changed as a response to outside development which have been based initially upon the machines use, and consequently the need for constant upgrading. As a result of these influences, factors such as rigidity, horsepower and accuracy have been improved in order to obtain increased efficiency, there have also been improvements in cutting tool materials. All these factors are ultimately used to reduce product cost by focusing the attention on product quality and machine tool utilization. The increase in machine tool utilization is directly related to reducing product cost and increasing manufacturing efficiency.

5.3 - Workpiece Geometry

In order to gain perspective, table 1 figure 5.1 illustrates that about 47% of components produced are rotational and the rest are prismatic or plate like. However, it is important to note that 75% of rotational workpieces have some kind of prismatic features *[MAZAK 89]*. Therefore, it could be deduced that the majority of components are rotational with some prismatic features. It is also important to understand that about 40% *(see table 2)* of machine tools used worldwide are lathes. Traditionally, the rotational components with prismatic features have been produced on two axis lathes and the secondary operations have usually been done using a milling centre. However, current advances in machine tools have greatly simplified and enhanced the machining process.

Table 1: Workpiece geometry

Workpiece geometry	% of parts
Rotational	47
Prismatic or box like	26
Plate & beam like	27

Table 2: Machine Tool type

Machine Tool type	% of parts
Lathe	40
Drill	9
Mill	7
Boring mill	10
Cylindrical grinder	6
Surface grinder	6
Gear cutter	9
Other	13

Adopted from Carter [1971]

Figure 5.1	Workpiece & Machine Tool Information	LUT CAD/CAM

5.4 - Workpiece Time

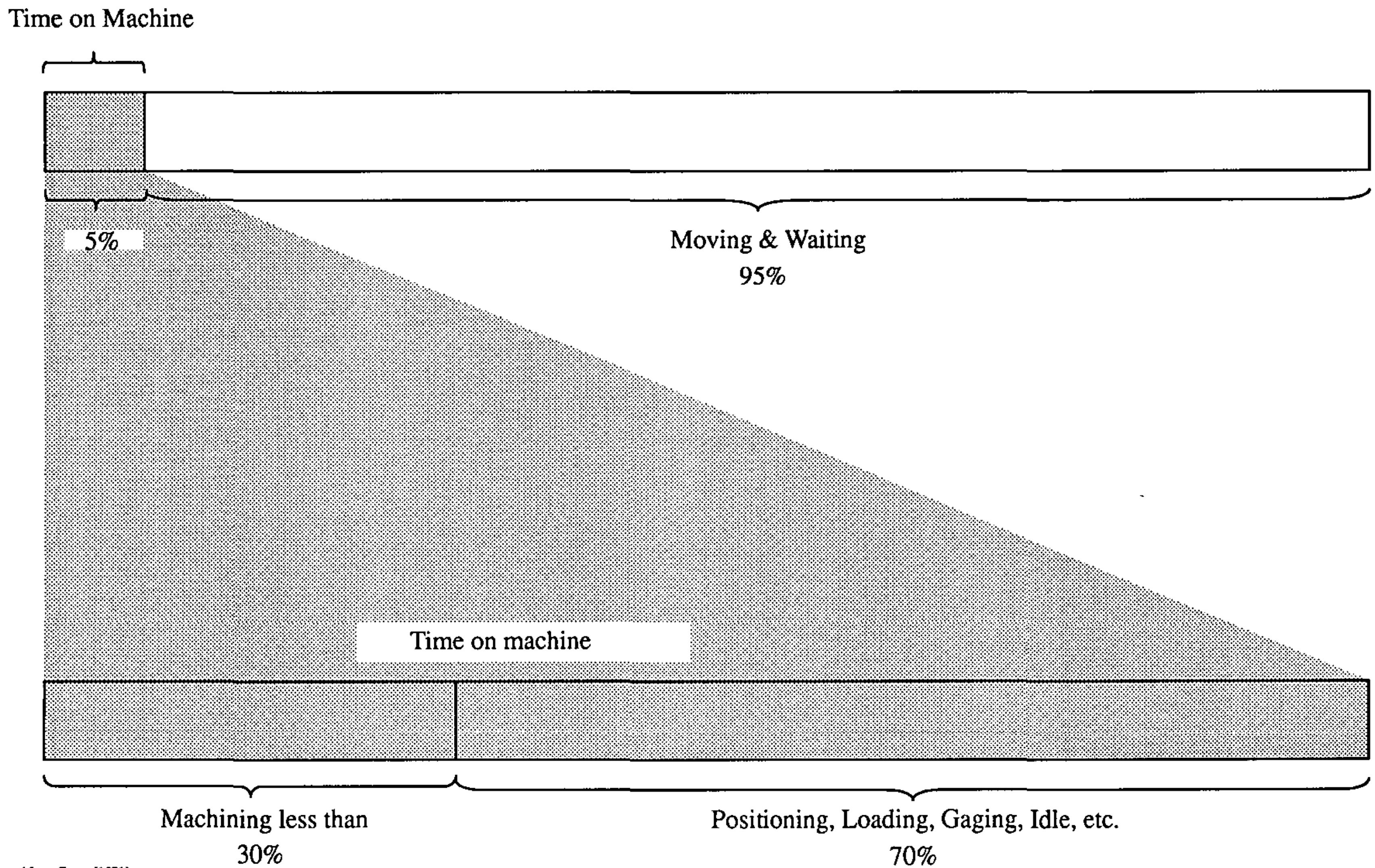
As a further insight, the study undertaken at Cincinati Milacron *[T.C 91]* clearly shows that about 5% of the life of an average workpiece is spent on the machine tool. Figure 5.2 shows that 70% of the life of an average workpiece is spent on loading, positioning and gaging. These facts clearly suggest that in order to optimise and reduce the lead time of an average workpiece, the time between each machining operation has to be reduced. This study breaks down the time utilization of a machine into such factors as cutting, setup, loading, unloading, gaging, and idle time. The machine tool producers have realized that in order to reduce the non cutting time, it is essential to combine machining processes. One such improvement is the development of the current state of the art turning centres. The combination of the turning operations with the milling operations have resulted in powerful machine tool which is capable of addressing all the rotational components.

5.5 - The NC Functions

Although methods of controlling and monitoring machines have had the most significant influence on productivity, Important developments are also occurring which are improving the productivity of individual machine tools. This has resulted in a considerable research effort being conducted in various NC functions which include: *[Okuma 91]*

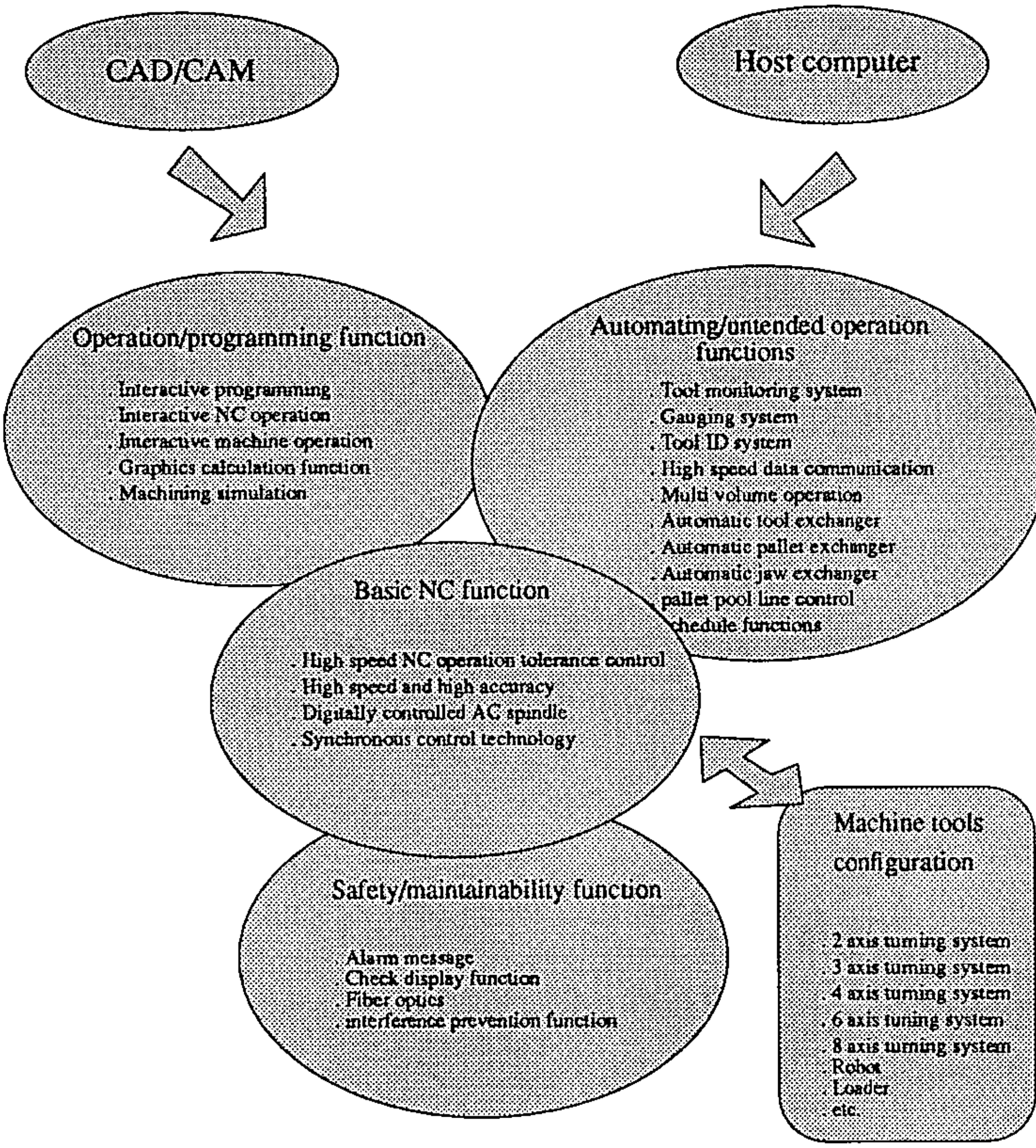
- The NC basic function that controls the machine tool accuracy at high speed.
- The interactive operation/programming function (*man-machine interface*)
- The automated/unattended operation function.
- The safety/maintainability function.

These functions are subdivided further into various activities as is shown overleaf in figure 5.3.



Adopted from Carter [1971]

Figure 5.2	Life of an average workpiece	LUT - CAD/CAM



Adopted from OKUMA [1991]

Figure 5.3	NC functions	LUT- CAD / CAM

5.6 - The Introduction of the Turning Centre

The state of the art turning centre has revolutionized the machining of rotational components and has resulted in numerous benefits and advantages. The first turning centre was initially developed by Ikegai in early 1980 *[P.T 91]*. The benefits of milling, drilling and taping with driven tools combined with CNC turning are well proven and include: *[INV. 90] [P.T 91] [T.M 88] [H.J.T 88] [TURNING 84] [TURNING 90] [T.C 91]*

- Superior surface finish quality
- Reduced cost as a result of single setting
- Flexible capability to encompass product developments
- Reduction of machine time by 65%
- Reduction of cycle time by 80%
- Less work in progress
- Reduction in lead time
- Reduction in cost
- Reduce fixtures
- Less floor space
- Greater use to be made of combination of static and live tooling
- Minimized handling
- Reduced number of operations
- Reduced frequency of setup
- Easing production scheduling & tracking
- Less machine program.
- Flexibility to respond to market demand
- Greater accuracy
- Improved geometric relationship between features
- A major contribution towards achieving zero-defect production
- Only one first off inspection stage

Due to the characteristics of rotational components and the ever increasing need to produce a rotational workpiece in a single setting, the machine tool producers have devised CNC lathes which embody the necessary facilities to perform milling, drilling and tapping. These processes are combined with turning so as to be able to produce the majority of components more efficiently and reduced cycle times. Turning centres have now achieved a level of universal acceptance and are available in many guises *[TURNING 90]*. Turning centre application with first and second operations on a single spindle with turn-round, to twin spindle, twin turret machines can accommodate complex machining in a single setting *[INV. 90]*. In short, the generally acceptable definition for a turning centre is a CNC lathe equipped with driven tooling and C axis control. Additional features extend the concept to a machine that is able to cope with quite demanding milling operations, some with spindle horsepower matching that of small machining centres *[TURNING 90]*.

A suitable workpiece for a turning centre is defined as: a finished component which is fundamentally round or has a significant proportion of material removed by turning before reaching the final form, but also has secondary machining operations to be performed before completion *[TURNING 90]*. The correct choice of a turning centre depends largely upon the balance of turning versus prismatic work and the physical size of the billet or bar.

Turning centres are generally capable of performing the following machining operations:*[P.T 91]*

- Polygon milling
- Flat milling
- Off centre holes
- Keyways without relying on cutter size
- Various milling on side face
- Direct milling of planes without axis interpolations

- Various turning operations

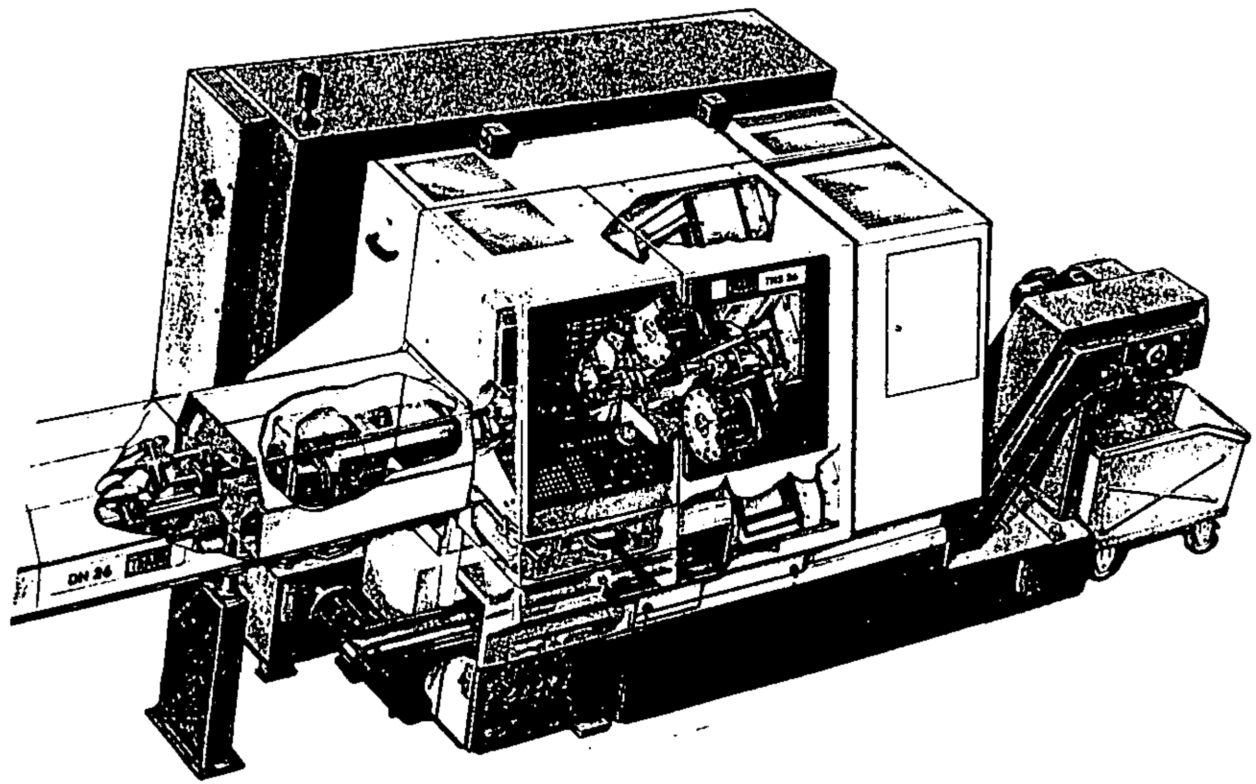
To summarize the discussion, it could be stated that a turning centre at the basic level, is a lathe with driven tooling and at its most complex, a production cell based upon turning and machining centre technology *[H.J.T 88]*. It is important to note that despite contrary hype, a turning centre is most profitably used for predominately turning applications *[H.J.T 88]*. The development making the greatest contribution to turning centre technology is the provision of power-driven turret tooling. It's essential corollary is the provision of a fourth axis of control, namely over the machine spindle. This axis allows the spindle either to be locked stationary; to be indexed angularly with accuracy; or to be rotated slowly at milling feedrate under point to point or continuous path CNC *[N.C.T 86]* (*figure 5.21 and 5.22 represent the turning centre and a typical part*).

5.7 - Control System for Turning Centres

If there is one aspect that has most influenced the uptake of turning centres, it is the control systems. The ease with which part programs can be created has brought powerful CNC to the shop-floor, and there are features that remove the mystique of programming by using conversational language and graphic icons *[P.T 91]*. In addition the introduction of 32 bit processor as well as an improvement in the internal performance of system functions has greatly enhanced the capability of current controllers. Today many machine tool builders offer off-line CAM systems to enable users to create part programs by inputting information typically found on a drawing. Some of the more reputable CAM systems are described in the subsequent section.

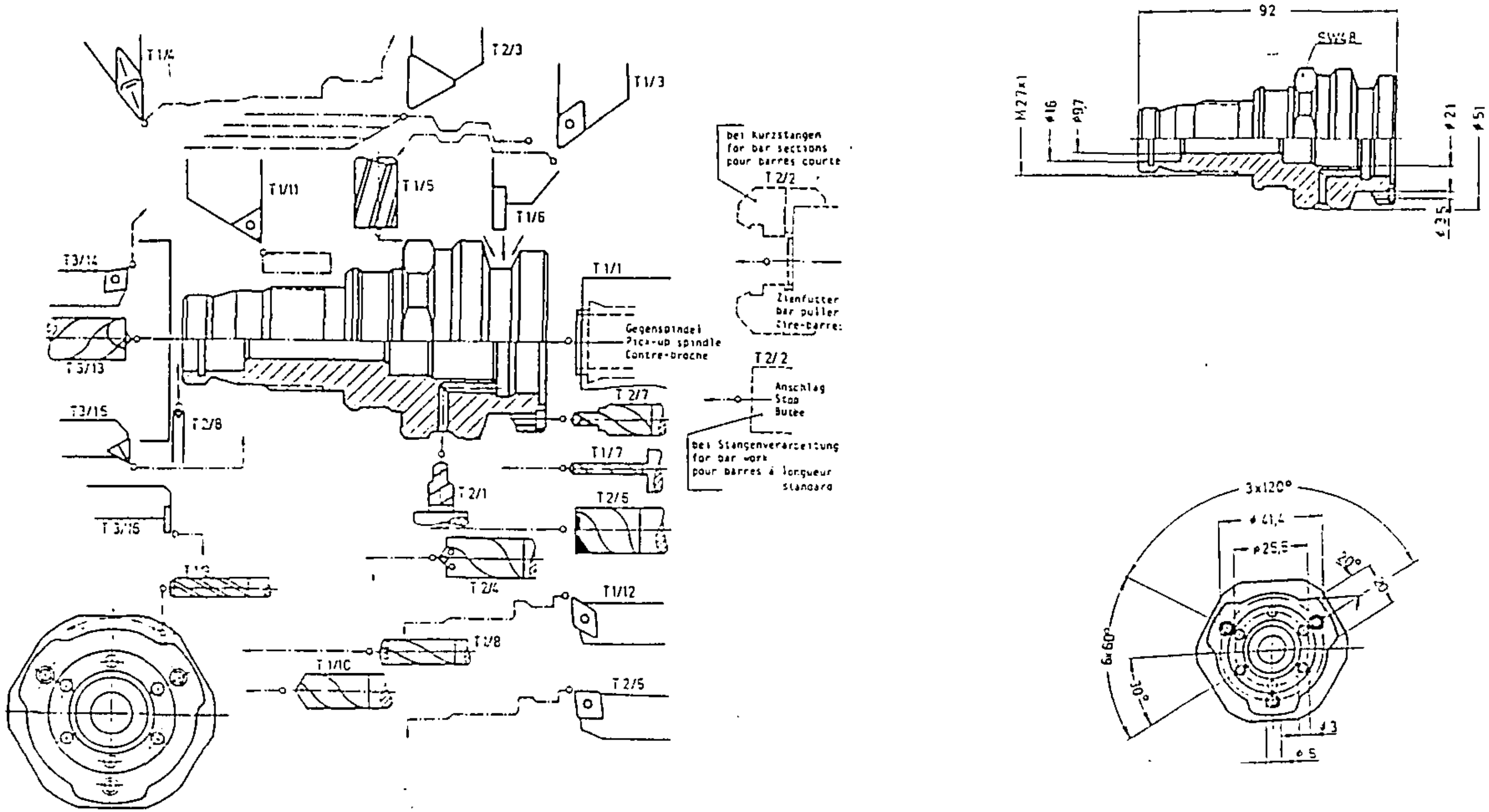
5.7.1 - TRAUB IPS

The Traub CAM system provides a graphical representation of the working environment to aid complex driven tool and three dimensional containing operations. The interactive programming system *(IPS)* allows interactive construction of programs



Adopted from TRAUB (1989)

Figure 5.21	Turning centre	LUT - CAD/CAM



Adopted from TRAUB (1989)

Figure 5.22	Workpiece examples machined by turning centre	LUT - CAD/CAM

(*parallel with program input*) incorporating geometry and cutting technology support (*i.e. calculation of cutting data*) together with extensive cutting cycle and setting up aids (*automation of tool management*) *[Traub 89]*.

5.7.2 - MAZATROL T32-2

The Mazak CAM system is a simple to use conversational CNC for multi-process machining in a single workpiece setup, containing a library of cutting data for a range of materials. The system will either default to these library routine or the user input provided. Creating a part program is simply a matter of answering the prompt, for example material, surface speed and roughing tool number. Turning features include automatic calculation of feeds and speeds, tool nose geometry, contour compensation and automatic insertion of grinding relief. For example, secondary machining (*including drilling, tapping and milling*) requires C axis interpolation using similar interactive menus *[MAZAK 89]*.

5.7.3 - BOSCH 200T

The Bosch CAM system requires only turning experience to create programs based on a simple question and answer basis. The programmer draws the workpiece by joining the geometrical element or contours, taking dimension directly from the drawing as absolute or relative dimensions. The graphic depiction of the workpiece is done parallel with the input of geometrical data.*[P.T 91]*

5.7.4 - Hitachi Seikis Multi Turning CNC

The Hitachi CAM system allows the machine tool program to be generated automatically from the input of raw material type/shape and finished component geometry. The controller automatically selects the correct tools for machining, determines their turret location and calculate cutting data i.e. checking for interference between tools and chuck jaw and determines toolpath to achieve component geometry *[P.C 87]*.

5.7.5 - Okuma APT GL

The Okuma CAM system uses simple interactive inputs that match your know how and provide auto-decision making to achieve ideal cutting conditions (*i.e. spindle speed, feed rate etc.*). It also provides automatic 4-axis synchronized programs. A full array of shape definition such as shape references, rough copy and calculation entry are provided to assist a user *[Okuma 91]*.

Chapter 6

Research Objectives

6.1 - Introduction

The purpose of this chapter is to state the objectives of the research and provide a summery of its scope. The theoretical and experimental work is outlined and references are made to the later chapters of the thesis.

6.2 - The Objectives of the Research

The overall objective of the work presented is to facilitate the rationalization and simplification of shop-floor programming, by the provision of an effective method for NC planning and applying a workshop oriented approach in computer assisted part programming. The objectives are:

1- To establish and design a workshop oriented part programming method for asym metric rotational components with non-turning features, which embodies the following:

i- The design of a novel approach for the geometric description of asymmetric rotational components using a feature based method.

ii-A technological user support system to assist the user of the system, in the efficient preparation of technological information and provision of manufacturing data.

iii-The introduction of powerful user support for multi-pass multi-tool machining sequences in order to minimize cycle times with the minimum of contribution from the user.

iv- Parametric part programming for turned components based on predetermined families of parts.

iiv-The generation of NC code for asymmetric rotational components requiring turning and milling operations.

2-To design and implement experimental application software that embodies the above objectives. The assessment of this system can be made from two distinctive perspectives. Firstly, the interaction of the user with the system and secondly, the quality of part produced.

6.3 - Workshop Oriented NC Planning

A novel and unique structure for asymmetric rotational components has been designed which is capable of generating manufacturing code for asymmetric and rotational features. Various elements, such as the descriptive methods, the technological user support system and the operation planner are designed to address the user's needs by offering a straight forward and yet effective approach which can accommodate the rapid input of part information for turning and milling operations in a clear and structured way. These issues were researched and subsequently developed for the purpose of saving time, cost and other resources. The design was established by implementing effective techniques to rationalize part planning and programming procedure. These techniques are embedded in the preparation of data to define both the geometrical and technological attributes. In addition the techniques are clearly illustrated in the design of a user support system that facilitate the design and extraction of technological data and finally the implementation of a modular approach for rationalizing the manufacturing operations.

The system architecture is configured to allow, and provide, maximum benefits to the user and consequently results in a powerful and unique environment.

The main thrust of the research is to reach and implement a work shop oriented computer numerical part programming system, specifically for turning centre with live tooling capability. live tooling is currently used extensively in the industry.The substance of this research and the general structure is reported in chapter 7.

6.4 - Part Description Using Predefined Machining regions

A major emphasis is the use of machining features and regions to describe asymmetric rotational components. The term 'feature' has been explored and used by researchers in order to rationalize a component description procedure. In addition the use of feature / region (*see sections 8.2 and 8.3*) enhances part description and allows the geometric elements to embody manufacturing knowledge for the purpose of producing and or analysing a part. However, in contrast to the application of features for an automated environment, relatively little research has been devoted to the use of features for an MDI. Various feature methods explored are used mainly for NC and process planning, see sections 3.6, 3.7 and 3.8. The approach used for developing a work shop oriented NC planning system is described in sections 7.2, 7.3, 7.4, 7.5, 7.6 and 7.65. The objectives pursued in this chapter are to reach and implement a feature oriented system that could assist the operator in describing an asymmetric rotational parts. The research areas listed below address this issue:

i- Provision of a wide range of features and regions for an efficient description of asymmetric rotational parts.

ii-Assisting the user by exploding a part geometry into recognizable regions and features.

iii-Decomposition of the shape description by interactive dialogue between the system and the user.

6.5 - Part Programming Using Parametrised Features & Components

The research emphasis is to represent rotational components in families by using a parametric description method. A parametric part programming approach uses variable inputs to produce manufacturing code for parts. The use of this technique has resulted in higher productivity and equipment utilization on the shop-floor. However, relatively little research is devoted to the use of parametric part programming for a shop-floor environment.

The provision of a user friendly MDI system has provided a new opportunity to explore and design various method of description. The research areas listed below address this issue:

i- The provision of parametrised part family database to represent a predetermined range of components so as to generate NC code.

ii- The design of a parametrised feature used to enhance and rationalize the steps for the preparation of NC data.

sections 13.4, 13.5 and 13.6 describe the parametrised part family approach. Later sections of that chapter define the methods of selection, description and definition of parametrised components. The parametrised features devised to generate NC code are presented in appendix 6.

6.6 - Technological User Support System

There is a need for the provision of an efficient technological information facility, which enables the rapid selection of the correct data for machining regions. The technological user support system is designed to be an integral part of the workshop oriented NC planning system for turning. The system contains various NC related databases. These facilities are devised to provide the relevant technological information which is paramount to an efficient generation of tool paths. The following issues must be addressed in order to achieve the technological user support:

i- To establish a novel and powerful selection procedure which provides the user with more flexibility to prepare the technological data. This approach is embedded with the necessary constraints to provide guidance to the user.

ii- To facilitate the generation of the relevant machining information based on a provision of technological data so as to perform setup (*i. e. part setup, tool set* *up and, machine set up).*

iii- The design of manufacturing databases (*i.e. material, tool, cutting data and workholding*),

These issues are described and addressed at length in sections 10.5 to 10.7, 10.4.1.2 to 10.4.4.2 and 10.4 to 10.4.4.2.

6.7 - Operation Planning

Various activities have to be performed in order to plan manufacturing operations, these activities are highlighted by *[Hinduja 89]*, *[Eversheim 82]*, and involve a series of pre-planning stages, including the definition of workholding parameters, the initiation of tooling parameters, tool selection for each cutting region and the logic designed for sequencing the operation. The regions containing the relevant geometrical features are designed in a modular structure. This highlights the importance of regions. Regions can be considered from two points of view of conveying the feature's geometrical and technological attributes and optimal selection of sequences. This structure provides an effective framework to integrate these activities. The planning is viewed and implemented considering the points listed below:

i- The importance of the pre-planning activities (*tool definition, workholding definition,* etc) which are essential steps in the generation of operation planning steps.

ii-The role and interaction of regions and features with the pre-planning activities.

iii- The establishment of multi-tool multi-pass sequencing aimed at producing manufacturable sequences and reducing the cycle time.

Tool selection issues for each region are addressed in sections 11.5.1, 11.5.2 to 11.5.5. Operation sequencing issues are also described in sections 12.9, 12.10 to 12.13.2.3.

6.8 - NC Code Generation

The objective of the designed system is to generate codes for asymmetric rotational components. In short the system must be able to generate codes for both turning and milling features. The following procedures have been designed and implemented:

i-The generation of NC code for the workshop oriented NC planning system.
ii-The generation of code for parametrised feature based system.
iii-The generation of code for parametric part family database.

Sections 15.4, 15.5, 15.6 and 15.9 describe code generation and provides an insight into the methodology and application.

6.9-The Experimental System

The major emphasis is to establish the listed objectives. The objectives are pursued and realized in the experimental system. This system was primarily designed on a Sun work station, and later transferred to a PC based system. Cost factors forced the use of a 386 system. Currently the workshop oriented system uses the Microsoft Windows environment. The software used consists of Microsoft Excel database & macros, Microsoft Visual basics and the Microsoft graphic user interface (GUI). The linkage of various packages is performed by Windows Dynamic Data Exchange (DDE) invoked from the Windows environment.

The parametric feature based system was designed on the Sun workstation, however the parametric part family approach was designed on the 386 system. The programming environment for the feature based parametric part programming system is based on the C language. The capabilities of the system were assessed and the following actions performed:

i- The implementation of the research objectives to improve code generation and increase the quality of part produced.

ii- The design of a user support system and the interaction of the user with the system.

iii-The design of interface for an efficient operator/system communication.

iv-The establishment of tests to verify the ability of the system.

The design of the experimental system is reported in chapter 17. The user interface and different elements forming it are addressed in 17.3, 17.4 to 17.5.

Chapter 7

The NC planning System architecture

7.1 - Introduction

This chapter describes the system architecture for the workshop oriented CNC planning. Each module and element is briefly described and the flow of information as well as function of each of the modules is addressed. The purpose is to identify the general task and functionality of each module and set the context in which the NC planning is performed. This work is presented under a number of headings so as to identify the tasks and modules which constitute the system.

7.2 - The System Description

The system design determines all the necessary information for the production of parts by numerically controlled machine tools. The architecture as depicted in figure 7.1 provides the necessary facility to define the geometry and extract the needed data to generate the NC code. This system is designed and configured to meet shop floor requirements. The level of detail and the domain of capabilities offered can rationally provide an appropriate methodology to solve and decompose components to a set of predefined machining entities, and thus generate manufacturing code efficiently. This system is based upon a group of pre-defined features and regions and hence provides guidance and information to the shop floor engineer in order to streamline part description and planning. The feature based method by which the asymmetric rotational component is characterised has proved to be more advantageous than other methods of description *[Eversheim 82]*.

7.3 - Functional Domain

The NC part program is a set of instructions which actuates the machine tool and requires some degree of planning. This system performs the NC planning by describ-

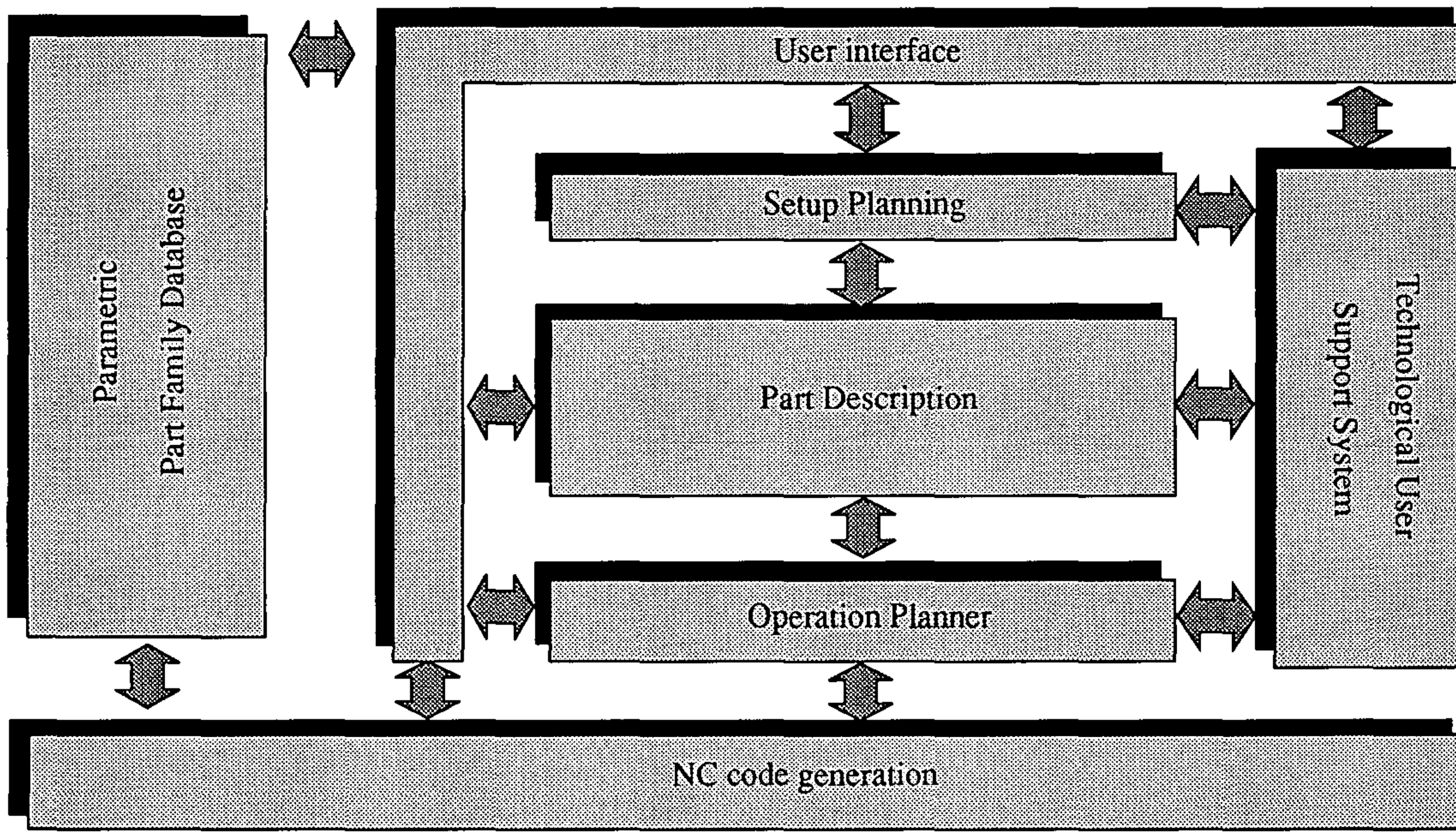


fig. 7.1	System Architecture	LUT- CAD/CAM - Lab.

ing the workpiece with predefined entities and conventions (*for further details see section 8.2 & 8.3*). The description of each machinable entity, or feature, is based on a frame of reference (*see sections 9.16.1 to 9.16.6*). The setup and operation planning is performed to ensure that the workpiece is produced according to the engineering specification as reflected in the engineering drawing. The technological user support system and the operation planner's primary purpose is to provide a series of databases so as to assist in the set up and generation of coherent sequence to machine the workpiece features (*for further details see sections 10.5 to 10.7, 11.5.1, 12.10, 12.11*).
The final activity in the system is concerned with generating NC data.

This system is designed to accommodate two methods for generating part programs. The workshop oriented planning of machining features (*this is the principle method with which the parts are usually described*) and the part family approach in which an icon based part family database is used in order to generate part programs for a predetermined component. This is an auxiliary method with which the user can store a family of workpieces which are frequently produced so as to rapidly and efficiently generate part programs.

7.4 - Process Domain

Today, there are many manufacturing processes which can be assisted by NC planning. However this research, as depicted in figure 7.2, is concerned with a specific manufacturing process which is used by the workshop oriented NC planning so as to generate the manufacturing code for a range of components. The principal process in which the part is characterised is the turn-mill process. This process is used to produce the workpiece by turning and subsequent milling operations using a single machine (*turning centre*).

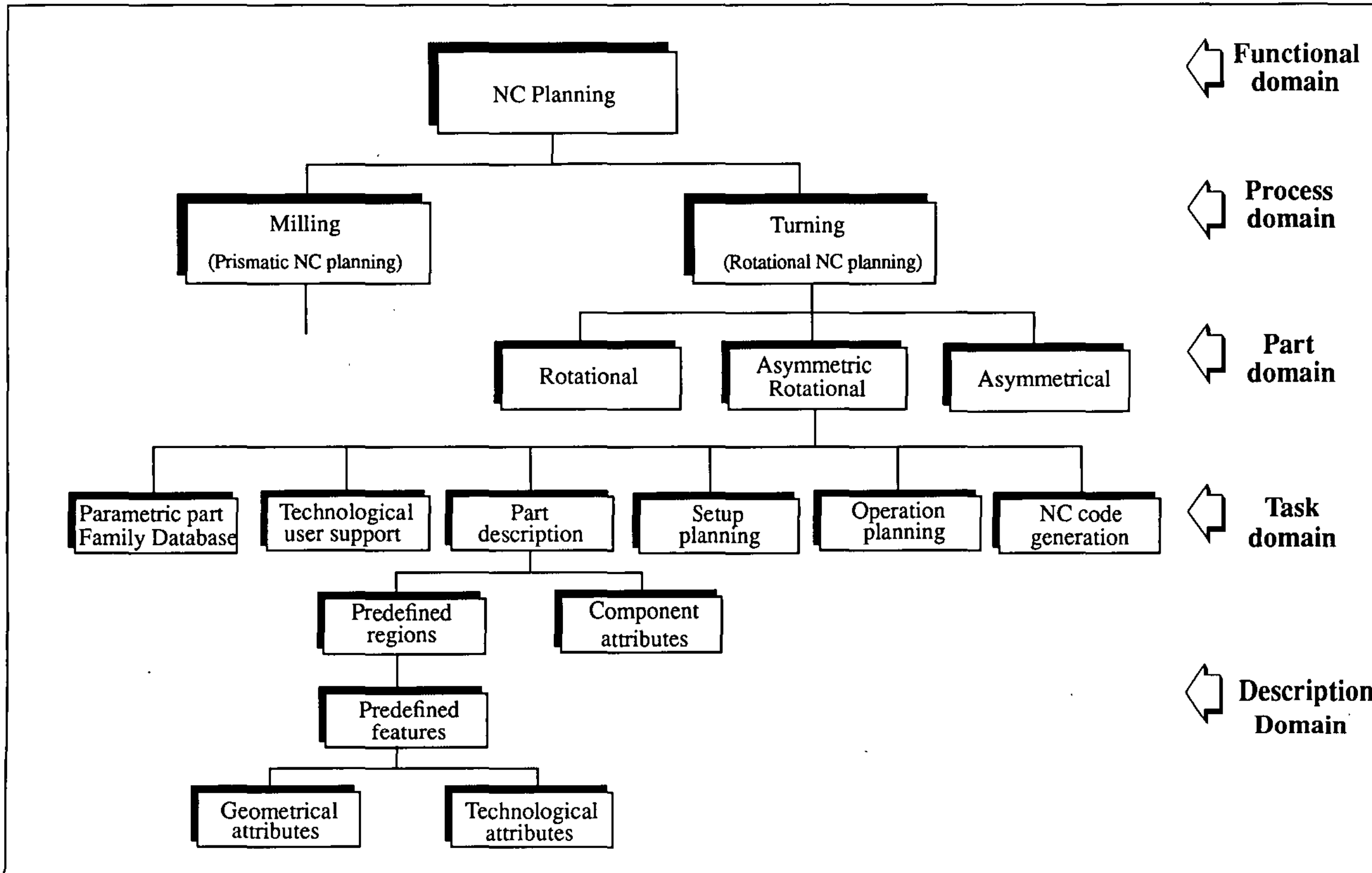


Fig. 7.2	NC planning system Configuration	LUT- CAD/CAM

7.5 - Part Domain

The part domain is concerned with the principal shape of the products for which manufacturing code is generated by using the workshop oriented NC planning system. The configuration of parts focused upon in this research are asymmetric rotational components which require a higher degree of planning. The asymmetric rotational component, as implied, is principally rotational with some prismatic features.

7.6 - Task Domain

As depicted in figure 7.2 the NC planning system embodies several important tasks which have to be performed prior to generating NC code. These activities are defined briefly in this chapter. Each task is designed to assist in the preparation of NC data. The main tasks performed by the system are listed below (*see figure 7.2 for more detail*):

i-Setup planning
ii- Part description
iii-Operation planning
iv-NC code generation

7.65 - The Description Domain

The use of predefined regions, coupled with the use of features, strengthens the geometric description of machining entities for the workshop oriented NC planning. These tools are designed to enhance, and consequently rationalize, the description process. For a full discussion of these issues refer to sections 8.2, 8.3, 8.4 and 8.5. The application of these descriptive tools are further highlighted in sections 9.10, 9.11 and 9.16.

7.7 - The System Architecture

As is depicted in figure 7.1 the architecture of the workshop oriented NC planning embodies several distinctive elements (*modules*). These modules perform a series of designated tasks. However, the objective of the modules (*system*) is to enhance and subsequently rationalise the task of data preparation. This system is highly data driven and is designed to efficiently perform the designated functions. In order to gain a broader perspective two issues are addressed for each module:

i-Activities and functions

ii-The elements of interaction

The modules that form the system architecture are depicted in figure 7.1. Each module or element is designed to perform a specific function. The system is designed to interact with the user in order to extract the necessary information. However, internally the modules are designed to interact together so as to perform the NC task. The principal modules which form the NC planning system are:

i- The part description module

ii-The parametric part family database module

iii-The technological user support module

iv- The set-up module

v - The operation planner module

vi- The NC code generator module

7.7.1 - The Part Description Module

The part is described in terms of geometric surfaces and form features (*e.g. line, arcs, hole, grooves, etc.*) represented by predefined regions. The machining features and regions devised can provide a unique and non-ambiguous geometric definition of the workpiece. Furthermore, they embody and represent the non-shape attributes. In order to understand the geometric description activity and module the following points are addressed:

i- Part description

ii- Tools for description

iii- Method of description

iv -The output

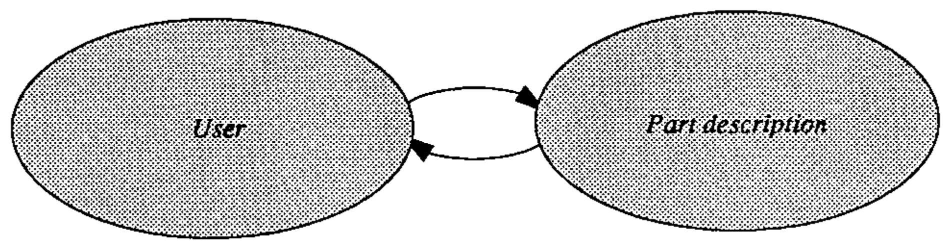
Part description requires the user to input the geometrical specifications. This module is intensely data driven and requires the user to input the geometry.

Tools for description: Predefined machining features and regions are devised to represent the different segments of an asymmetric rotational workpiece (*for further information see section 8.4 and 8.5*).

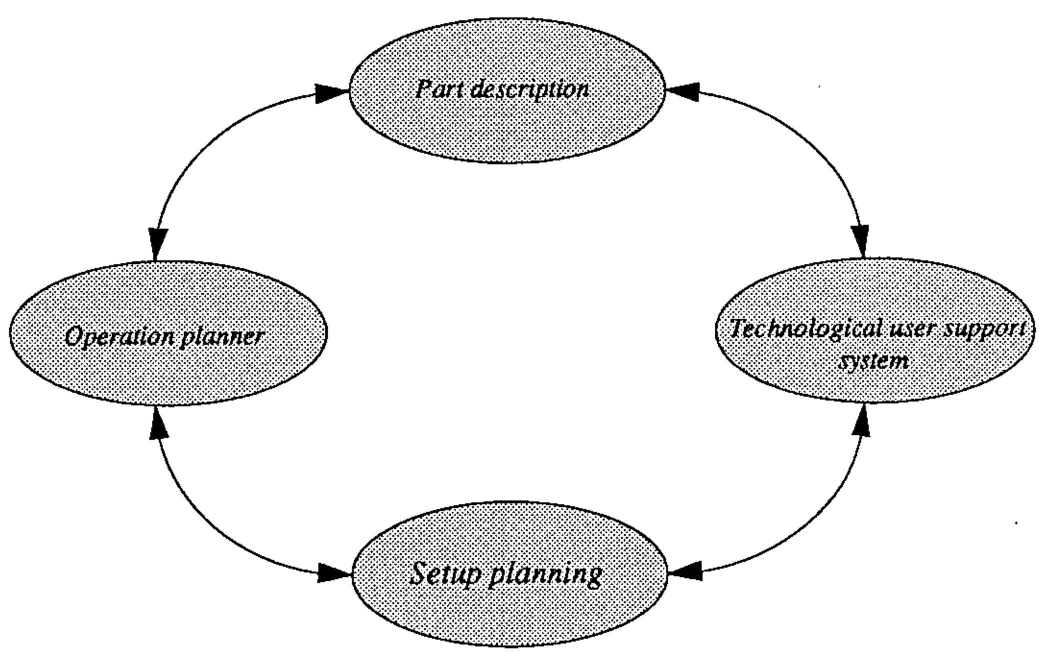
The descriptive method: As described in section 9.11, the geometrical and technological data associated with each region and feature is collected by using an information acquisition tool (*i.e. template*) (*for further detail see 9.12.1, 9.12.2. 9.12.3 and 9.12.4*).

The output generated by the part description module is used in the subsequent activities of the system (*e.g. operation planning and NC code generation*).

The elements of interaction: As depicted in figure 7.3 the external flow of information is based on the interaction of the user with the part description module. The user selects and defines the relevant regions that correspond to and represent the workpiece. However, as also depicted in figure 7.3 the internal interaction is more complex because the information conveyed by the user is used, and subsequently processed, by other modules. The operation planner module extracts the operation attributes associated with each machining region. The technological user support module interacts with the part description module in order to provide information concerning tooling and machining data. The automatic selection of tools and data for each machining region is performed within the domain of operation planning. The technological user support



External flow of information



Internal flow of information

Figure 7.3	Elements of interaction for part description	LUT - CAD/CAM

and operation planner module both interact with the setup module (*i.e. for referencing the workholding devices and datum specified in the technological user support system*).

7.7.2 - The Parametric Part Family Database Module

A parametric part family uses variable input so as to generate NC code. The parametric part family database is designed so as to store and generate NC data for similar workpieces which are frequently programmed. This module is concerned with the following:

i - Available families

ii- Part specification

iii-Method of description

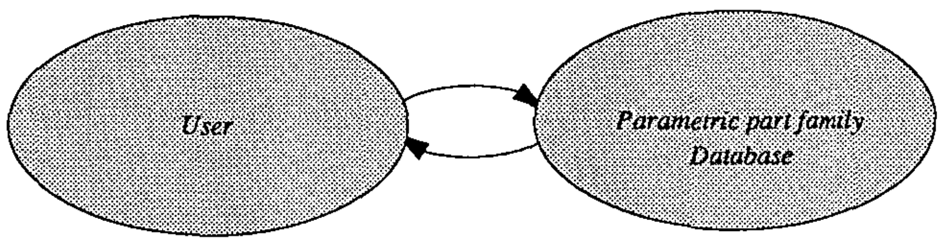
iv- The output

Available families - The contour of parts are pre-determined in the family based approach, the geometric dimensions and other attributes are initiated by variable input. Certain families are represented. Sections 13.5 and 13.6 will further address this issue.

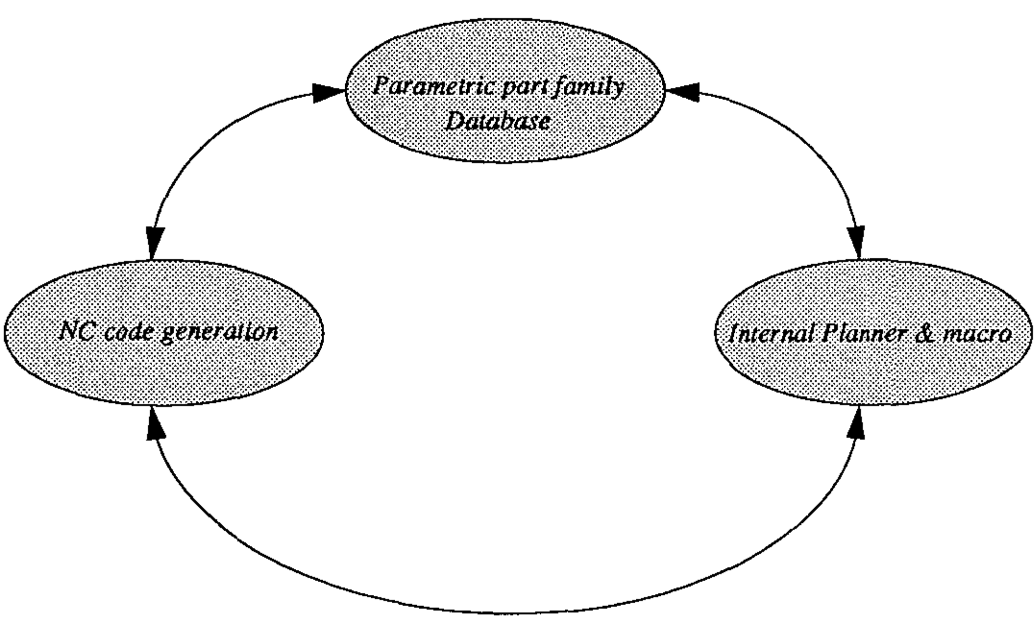
Part specifications are concerned with the part's attributes. Two type of attributes are used to describe each workpiece. The variable and fixed attributes which are used to specify the workpiece are described at length in 13.6 and 13.7.

Method of description - The selected workpiece is interactively described. The relevant families are represented by icons which may be selected by the user. The appropriate workpiece can then be described interactively. Sections 13.7 and figure 13.5 fully demonstrate this concept.

The elements interaction - This activity considers two levels of interaction to be the bases for the flow of information in the system. Externally, the system requires the user



External flow of information



Internal flow of information

Figure 7.4	Parametric part family & the flow of information	LUT - CAD/CAM

to initiate the data (*figure 7.4*). However, the internal interaction is the flow of information between the parametric part family database, planner and macro and the NC code generation module.

7.7.3 - The Technological User Support System Module

The technological user support is incorporated in the structure to supply the nucleus of the system *(part description)* with the necessary information. The technological user support embodies several databases and provides an invaluable support to other modules (*figure 7.1*). The task is to contain the required data and supply it to other elements whenever required (*figure* 7.5). The technological user support is concerned with the following activities:

i - Technological specification

ii - Technological parameters and methods

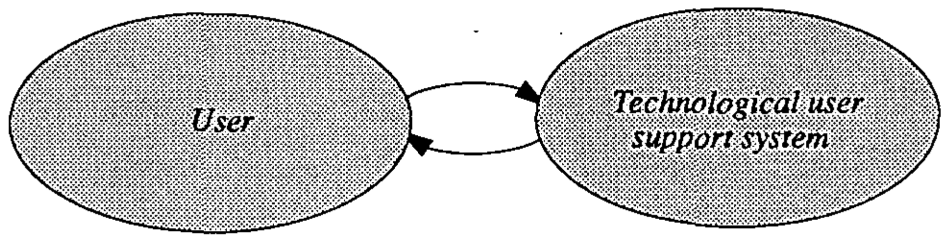
iii -Technological rules

iv - Selected resources

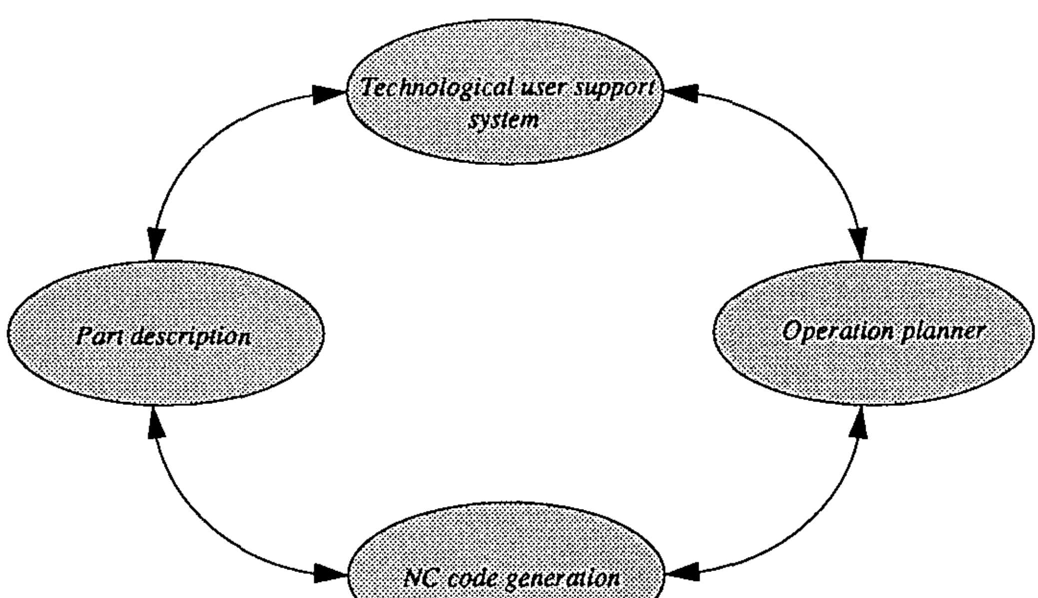
Technological specification - Component's technological specification requires a reliable source of data. The process condition model for each process provides an invaluable source of data so that the user can be provided with a general framework for technological specification. Sections 10.35 and 10.4.1 describe the available models and databases in the system.

Technological parameters and methods - The part is divided into predetermined regions. Each region is designed so as to be able to interact with the technological user support system. The parameters that are embedded in the databases can be used by the operation planner and the part description module.

Technological rules are designed so as to allow the efficient extraction of data from



External flow of information



Internal flow of information

Figure 7.5	Technological user support & the flow of information	LUT - CAD/CAM

the technological user support system. The rules are further used so as to assist in the calculation of the technological data (*i.e. surface finish, feedrate and cutting speed).*

Selected resources (output) can belong to the overall component or to a specific operation or a predefined region. This is a stage where the data assigned to different databases can be used for operation planning and setup.

Elements of interaction allows the above activities to be performed. Figure 7.5 displays the internal flow of information between the technological user support and other elements. Externally, the user interacts with various technological databases to add or modify the information. On the other hand the internal interaction is more complex. The technological user support allows the system to retrieve the relevant and required data from the databases.

7.7.4 - The Operation Planning Module

After specifying the operations and the related pre-defined regions/features, the detailed planning of each operation is carried out. This activity (*figure* 7.6) includes the following tasks *[Brooks 87]*:

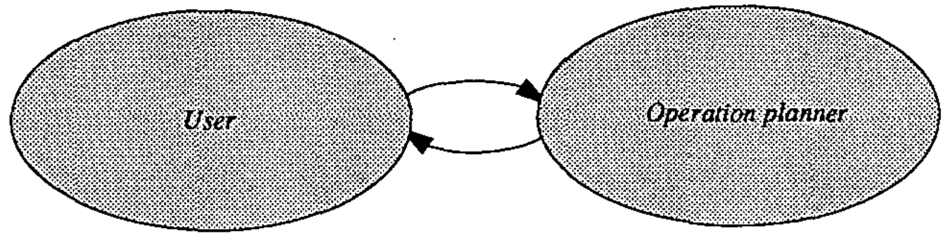
i - Specification of operation & predefined regions

ii - Operation planning tasks and methods

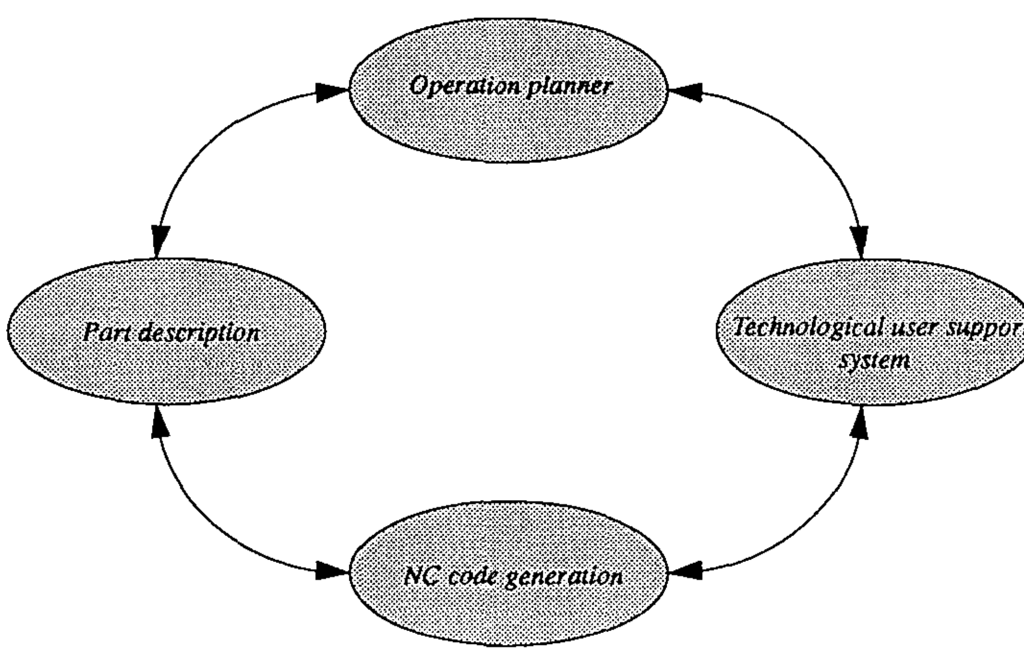
iii- Operation parameters

iv - Selected operation

Specification of operation and the selection of predefined regions. This activity requires a set of operations and predefined regions to be initiated/selected. The system represents several operations and regions. As described in 7.2.1, these regions consist of features which determine the final configuration of each region. Once these opera-



External flow of information



Internal flow of information

Figure 7.6	Operation Planner & the flow of information	LUT - CAD/CAM

tions are selected the operation sequencing can be performed.

Operation planning tasks and methods - The operation planner's task is to organize the operations in such a way so as to guarantee the physical integrity of the workpiece. There are several mechanisms which are devised to carry out the operation planning tasks. The issue of operation planning is explored further in chapters 11 and 12.

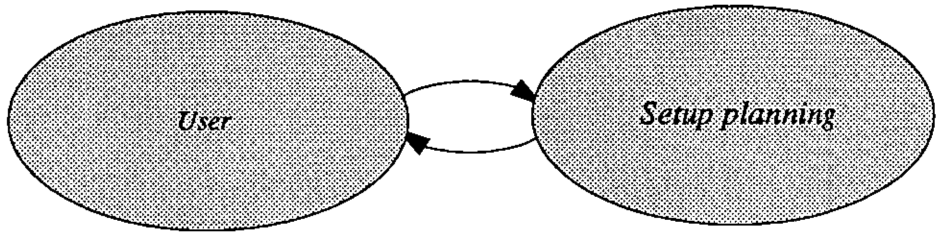
Operation parameters - A decision model is used for sequencing the operations. The parameters that are used to assist in selecting and sequencing the operations are embedded in the planner module. The decision model is addressed further in sections 12.9, 12.10, 12.12 to 12.3.2.2.

The operation output represents the actual arrangement of operations which is embedded in the operation planning file. At this stage the user is provided with a set of steps that can generate the NC output.

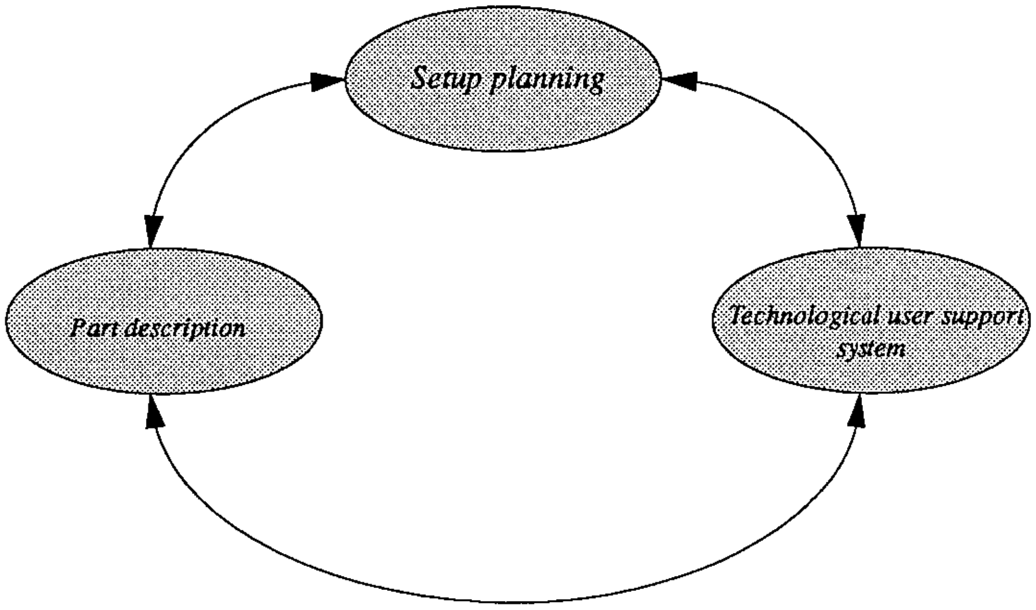
Elements of interaction-The flow of information is established between the operation planner and other modules. This flow is divided into two sets, external and internal. Externally the user can modify the sequence of operations or activate the automatic sequencing of operations. The internal interaction is the communication between the following activities; part description, machine setup, and the operation planning. The required operations are extracted from each selected region. Other operation planning activities such as tool selection and machining data selection are accommodated within each region

7.7.5 - Setup Module

This activity allows the establishment of the needed facility (*workholding, tail stock, etc.*) and the selected machine which enables the exploitation of the information regarding the motion and the physical orientation of the part. This activity includes the



External flow of information



Internal flow of information

Figure 7.8	Setup & the flow of information	LUT - CAD/CAM

following:

i - Component attributes

ii- Machine constraints

iii- Machine setup selection

iv- The selected machine & setup

Component attributes is concerned with the billet size. This information is the basis for the later operations.

Machine setup constraints/data- This is the information that can be inserted to limit and specify the setup. This includes datum setting at both Z and C axis, feed and speed parameter setting.

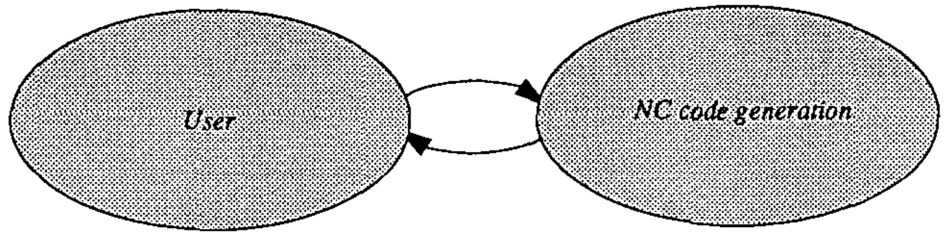
Machine setup and selection in the workshop oriented NC planning system unlike some of the automated process planning systems, requires the user to select the workholding devise.

The selected machine/setup influences and limits the cutting parameters, method of cut and tool path.

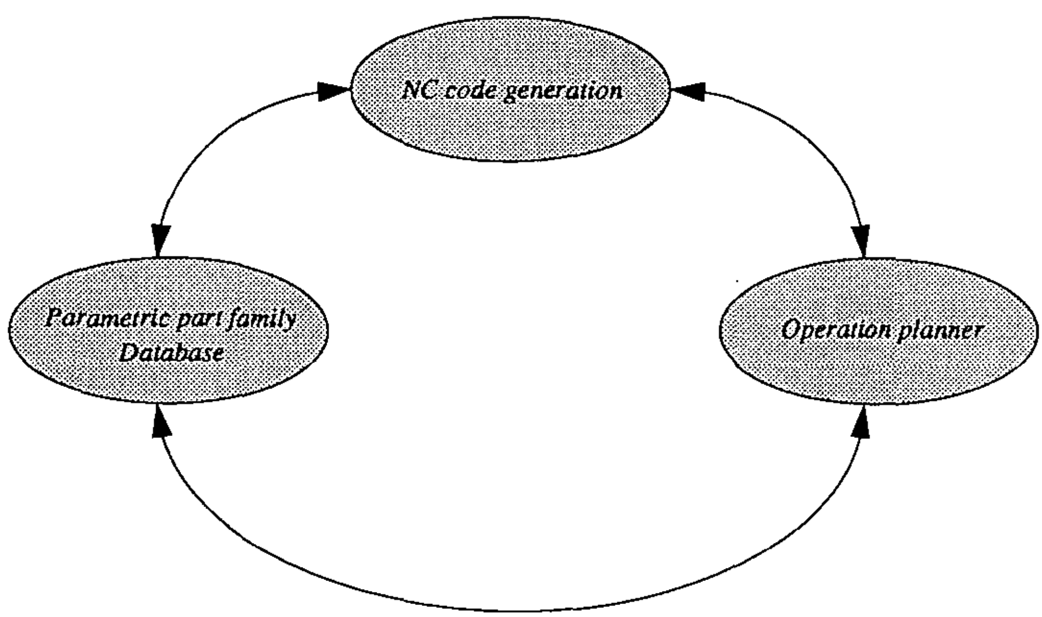
The elements of interaction include, the geometric description, the setup, and operation which need to obtain the necessary information from the geometric description to influence the operation planning of the part.

7.6 - NC Code Generation Module

NC code generation has the task of generating NC code for each predefined region and checking the geometry of each region, if an error is detected then there is a feed back to the part description module. The function of the NC macro and the final generation of NC codes are discussed further in chapter 15. This activity includes the following:



External flow of information



Internal flow of information

Figure 7.9	NC code generation& the flow of information	LUT - CAD/CAM

i - Selected sequences of operation

ii- NC macro

iii- NC format

The selected sequences form the basis with which the NC code is generated. The task of the NC code generation module is to transform the geometrical and technological specification to NC data.

The macros are used to transform the geometric and technological data to a predefined NC format, therefore certain methods are used to generate the NC data.

NC formatting, the task of templates, which function as a postprocessor, is to convert the cutter location information into a machine dependent NC format.

Elements of interaction as depicted in figure 7.9 three modules are involved in the interaction; the operation plan, setup and NC code generator. Externally the MDI system allows the user to modify the NC data.

Chapter 8

Feature & Region Scheme For NC planning

8.1 - Introduction

This chapter is concerned with the definition of a feature scheme for asymmetric rotational parts. The objective is to describe and present a hierarchical representation of features and regions in order to provide a novel framework to facilitate rational description of geometric elements. The intention is to list all the sub-elements of asymmetric rotational components. These issues are discussed under a number of headings so as to provide a clear description of the feature conventions used.

8.2 - Features

The use of feature based decomposition is seen as a major requirement for shop-floor NC planning. The ideas developed in chapters 8 and 9 draw heavily on the extensive literature on features, and in particular, on references *[Pratt 88] [Eversheim 82] [Allen 89] [Shah 88] [Butterfield 85]*. Novel ideas are put forward in this work, particularly with regard to the use of predefined regions and the hierarchical representation of features and regions. This work builds upon and extends work reported by Eversheim *[1982]* and Butterfield *[85]*.

The use of feature based decomposition gives a higher meaning for characterising components into a recognizable machining form by dissecting the part geometry into various regions, so as to allow the geometric features to be structured and organized for a specific segment (*region*). The use of features is an orderly way to transform design information into manufacturing instructions, thus allowing features to act as a medium between design and manufacture *[Butterfield 85]*.

The information incorporated in features embodies the necessary parameters which could define geometry and allow for reasoning. This information is vital for an efficient description of a part profile. A feature in this work is a region of interest on the surface of a part *[Pratt 85]*. The methodology devised in this work relates features to the manufacturing method and defines a feature as a portion of the workpiece (*region*) generalised by a certain mode of metal cutting *[choi 84]*. As is depicted in figure 8.0 the features used in this work consist of surfaces (*i.e. tapper, straight, convex, concave, chamfer and corner*) and form features such as Thread, grooves, knurl, hole, keyway and flat.

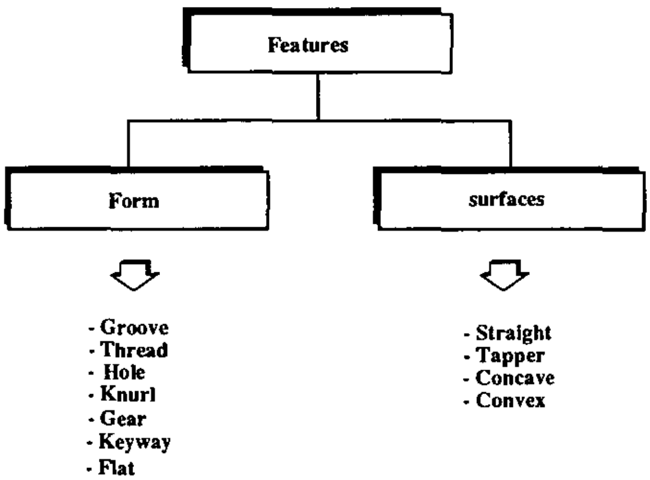


Figure 8.0 - Feature type

8.3 - Predefined Regions

Regions are designed to simplify part representation. Each region is associated with a set of relevant features. Regions consist of technological and geometrical attributes as well as features. The knowledge represented by regions consists of geometry, orientation, and operation. It is rarely the case that one particular face (*feature*) fulfils a specific manufacturing purpose. It is usually a set of faces (*features*) forming a segment (*region*) which embody a sufficient amount of manufacturing information. The regions represented in this work consist of *TURN-REGION, THREAD-REGION, GROOVE-REGION, DRILL-REGION, MILL-REGION, MILL-GROOVE-REGION [figure 8.1]*.These regions and their characteristics are addressed further in chapter 9.

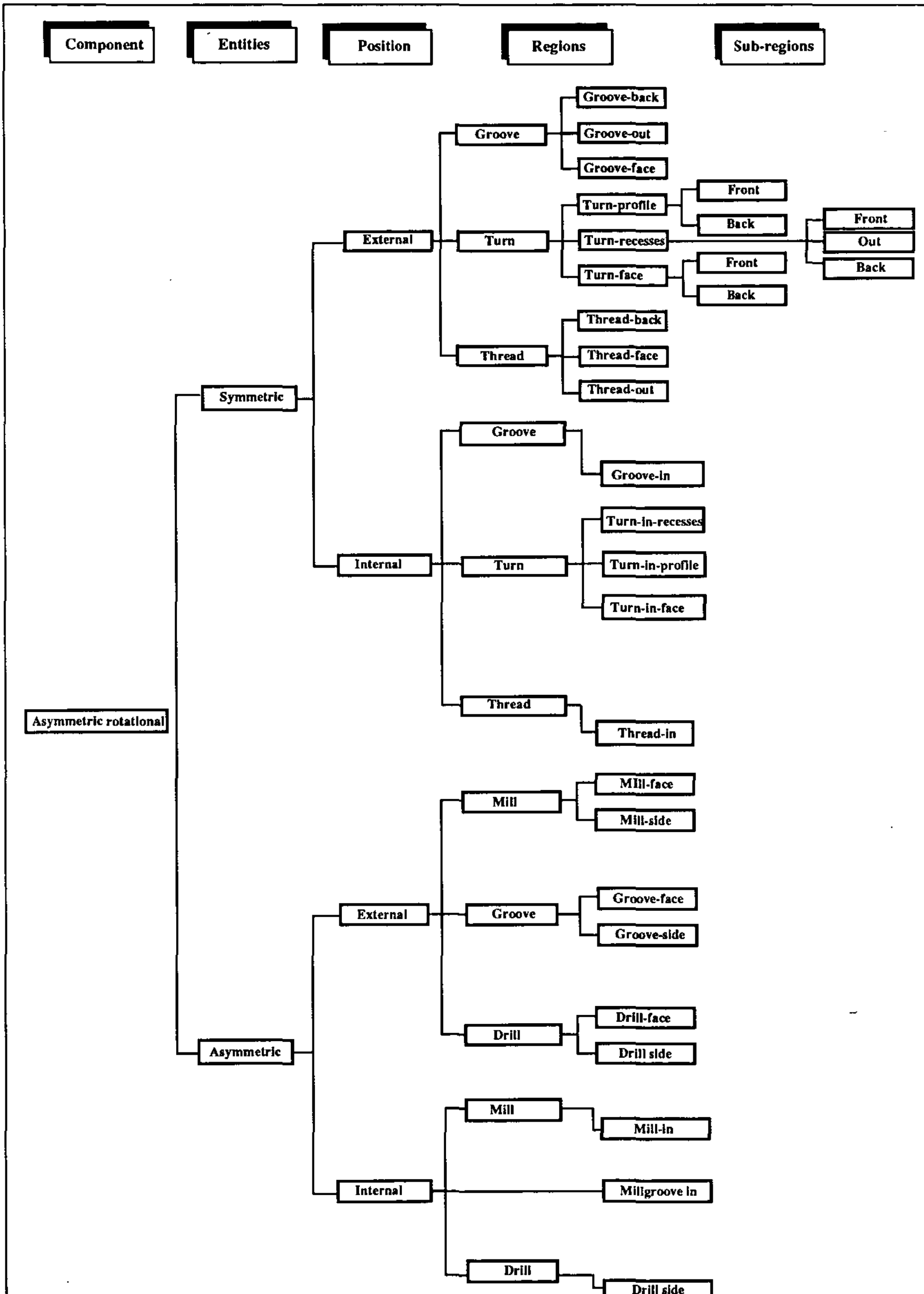


Figure - 8.1	Regions Hierarchical Representation	LUT- CAD/CAM

8.4 - Hierarchical Representation of Features

This system represents and deals with geometrical entities at two levels:

i - Representing features of part

ii- Representing regions of part

The feature scheme depicted in figure 8.2 describes the available features and displays their attributes. The hierarchy is designed to assist with the selection of required features and a subsequent definition of workpiece shape. The set of features displayed can readily describe the geometrical and technological attributes of most asymmetric rotational components. The feature representation is based on manufacturing features and thus covers the type and range of features that are grasped and understood by the user. These features as depicted in figure 8.2 are as follows:

Symmetrical:

- The main body of the part is described by a number of connected surfaces. For example a simple asymmetric rotational component can be designed by concave, taper and straight surfaces. These surfaces can be either external or internal (*i.e. the taxonomy is depicted in figure 8.2*).
- Grooves have six types: square, rounds,R.H trapezoid, L.H trapezoid, trapezoid and part off. The groove can be either external or internal.
- Threads consist of four types: ISO, BSF, ACME, and UNF. Threads can be located on external or internal diameters, the O.D thread is divided further into axial and radial.
- Knurl is divided to three major types, namely straight, diagonal and diamond.
- Centres are of two categories, standard and bell.
- Gears consist of four types, spur, bevel, helical, worm.

Asymmetric:

- The main body of an asymmetric segment is defined by the number of connecting surfaces. For example a complex cam like figure consists of tapered, concave and convex surfaces. These surfaces can be either external /internal (*i.e. the taxonomy is depicted in figure 8.2*).
- A keyway feature could be external/internal, radial/axial, straight or woodruff.
- A flat feature consist of single or multiple flat and is defined by surfaces.
- A groove features consist of helical, spiral and irregular, and these features can be either radial or axial.
- A hole feature may be drilled, reamed, bored, C'sink and tapped. Holes can be either blind or through, radial or axial. These features can be singular or multiple.

A designer can utilise the feature scheme with ease because the term conventions used are simple and can be easily recognized by the user. A designer can select the features and their related subclass to form a description of parts. This representation is complete and includes those features that are required to describe asymmetric rotational components.

8.5 - Hierarchical Representation of Regions

This section addresses a hierarchical representation of regions to assist part description *[figure 8.1]*. The hierarchical representation of regions is designed to simplify the geometric description process. The taxonomy classifies the possible regions. As is depicted in figure 8.3 each region is associated with a set of manufacturing features.

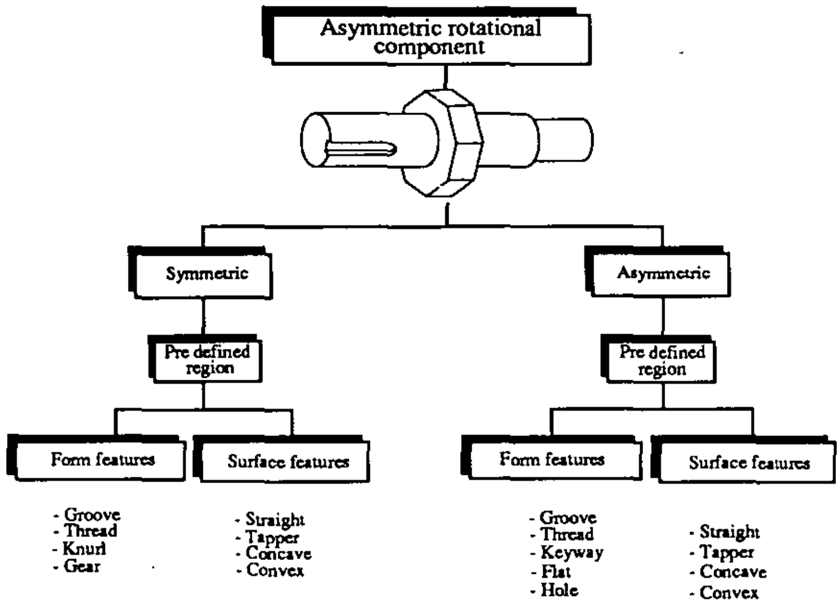


Figure 8.3 - Representation of regions & the associate features

This hierarchical representation covers a wide range of segments (*regions*) and features and since the terms used are understood by the operator or NC programmer then a part geometry can readily be described by selecting the relevant segments (*regions*) and the related features. These segments are briefly described below:

Symmetrical:

- *GROOVE-REGION* is symmetrical and can be either external or internal. This region can be described by four groove features.
- *TURN-REGION* consist of several regions and sub-regions. Each region can be defined by geometric features (*e.g straight, concave, convex, taper*).
- *THREAD-REGION* consist of several regions. Each region can be described by several thread features (*ISO, ACME, UNF, etc.*).

asymmetrical:

- *MILL-REGION* consists of several regions. These regions can be described by geometric features (*i.e. straight, concave, convex, taper*). *MILL-REGION* also includes flat features.
- *MILL- GROOVE-REGION* consists of several regions and can represent three type of groove features (*helical, spiral, irregular*). *GROOVE-REGION* also represents key way features.
- *DRILL-REGION* consists of several regions. Each region can represent several hole features (*i.e. drilled, ream, bored, tapped*)

8.6 - Component Representation

This system requires the necessary information to perform NC planning for asymmetric rotational parts. This information is provided at two levels:

i- The initial workpiece

ii- The desired geometric shape

The requirement is initially concerned with general information regarding the overall geometric size and the material specification of a workpiece. However, the desired geometric configuration needs explicit information in regard to the geometrical and technological attributes. The asymmetric rotational component consists of two major entities, symmetric and asymmetric. Symmetric entities are concerned with those geometric elements that have the following characteristics *[Opitz 70]*:

i - There is one axis of rotation.

ii- The geometrical axis and rotational axis are identical.

iii-The cross-section perpendicular to the axis of rotation is everywhere circular.

Young *[1991]* states that this definition could be extended to groove, teeth, and keyway that have deviation from a circular cross section. Nevertheless, a different approach is taken by the author in which features like keyway are categorized as being asymmetric. However, in order to simplify the description procedure, various predefined regions are designed *[figure 8.1]*. These regions represent the possible segments that can be turned/machined. These regions contain a set of geometrical elements (*features*). For example, the region *TURN-OUT-PROFILE* is represented by geometric features such as straight, tapered, convex, concave, chamfer and corner. The way in which theses features are ordered and their geometric datum determines the final configuration of region.

The asymmetric entity deviates from a circular cross section and does not rotate around the principle axis of rotation. However, due to the inherent complexity of asymmetric shapes, this entity is also defined and decomposed into various regions, subsequently each region is described by using the appropriate features. Both asymmetric and symmetric entities are needed to define an asymmetric rotational component. These entities consist of appropriate regions which are defined by form features/ geometric elements (*feature*). Form features are patterns that recur in shape *[Shah 88]* and are defined parametricaly (*e.g. groove, thread, etc*.). However, the geometric elements are those features that represent a part surface (*e.g. straight, taper, concave, convex*). A region can contain form feature/surface features. A combination of form features and surface features are needed in order to describe a part.

8.7 - Feature & Region Representation

Features are represented by two categories, explicit and implicit. These features are represented by regions *[figure 8.4 & 8.5]*. An explicit region contains a list of geometric elements. Young *[91]* defines a pocket as an example of explicit features consisting of many elements. Figure 8.5 shows a component with an explicit feature (*region*), the geometrical elements that form the profile are highlighted. The two categories of explicit features are *TURN-REGION* and *MILL- REGION* which consist of surfaces or

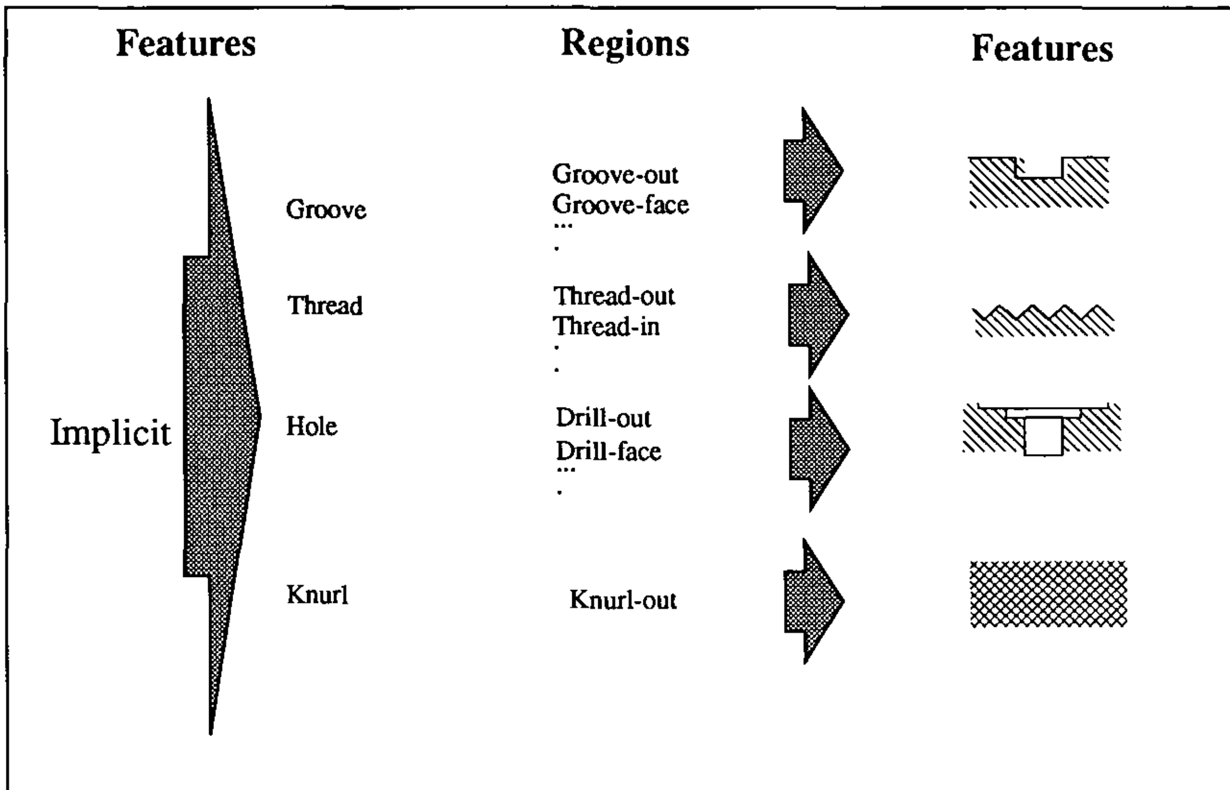


Fig 8.4 | Implicit features | LUT- CAD/CAM

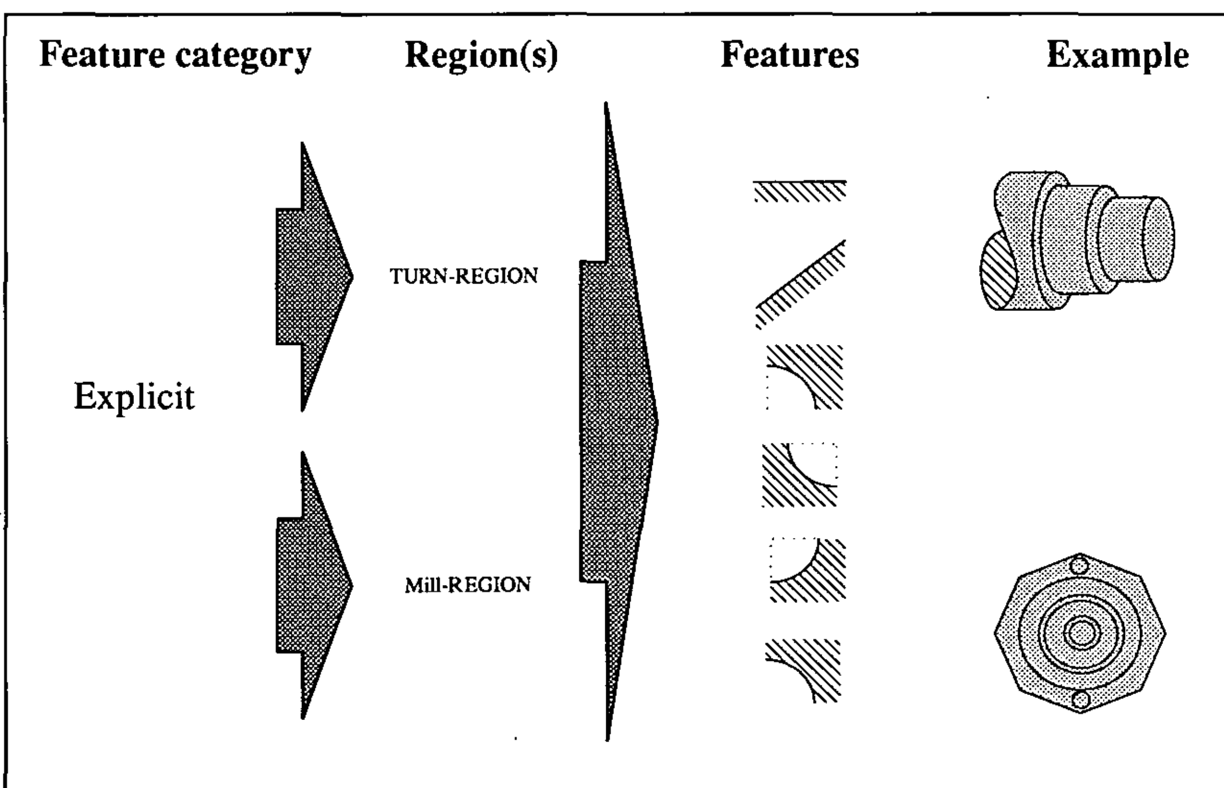


Fig 8.5 | Explicit Features | LUT- CAD/CAM

geometric elements (*i.e. straight tapper, concave, convex*). In short, the explicit features are the grouping of the geometric model *[Pratt 88]*. However as is depicted in figure 8.4, the implicit features are those features that require parametric information *[Pratt 88]*, nevertheless these features are also represented by regions, each region embracing the necessary knowledge regarding position and operation. The implicit form features can be defined by one of the following cases *[PDES 88]*:

-A feature that passes through the shape (*e.g. hole*).

-A feature that extends outward from the shape.

-A feature that extends inward from the shape.

-A feature that connects the elements.

-A feature viewed as being superimposed upon primary surfaces (*e.g. groove, thread*)

Implicit features *[figure 8.4]* are represented by three regions. *GROOVE-REGION, THREAD-REGION* and *DRILLED-REGION*. These regions embody the implicit features (*groove, thread, hole*) and provide vital information about position and operation. The NC planning system uses implicit and explicit features to define geometry and reduce the calculation time.

8.8 - Feature Classes

The features used to describe regions and the overall component characteristics consist of two classes *[Allen 89]*:

i- Primary features

ii-Secondary features

The primary features are those geometric elements that form the contour or profile of part *[figure 8.6 & 8.7]*. These elements (*features*) consist of straight, taper concave and convex surfaces. These features are used to define two regions, *TURN-REGION* and *MILL-REGION [figure 8.6]*. As is depicted in 8.7, the secondary features are a group of form features (*i.e, groove, thread, hole*) which are superimposed on the primary features and are used to define three regions (*i.e. GROOVE-REGION, THREAD-REGION*, and *DRILL-REGION*).

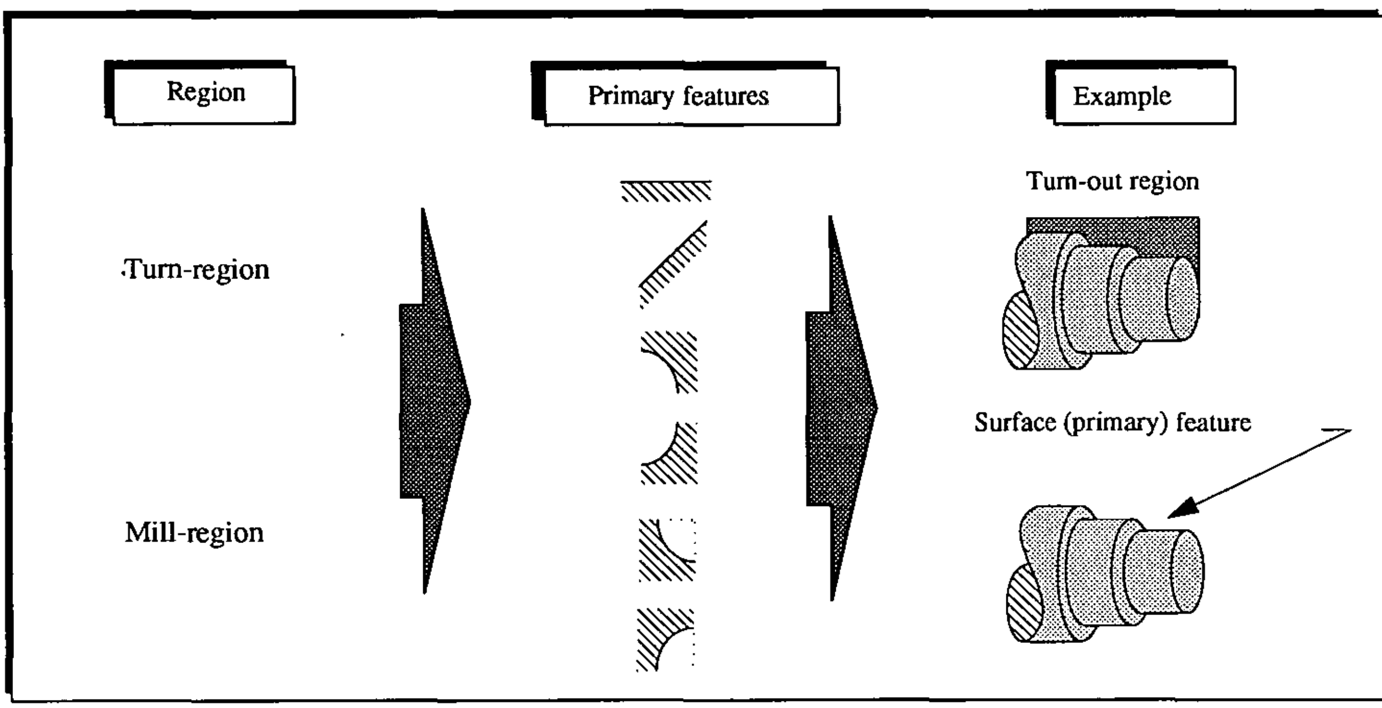


Figure 8.6 - The primary features

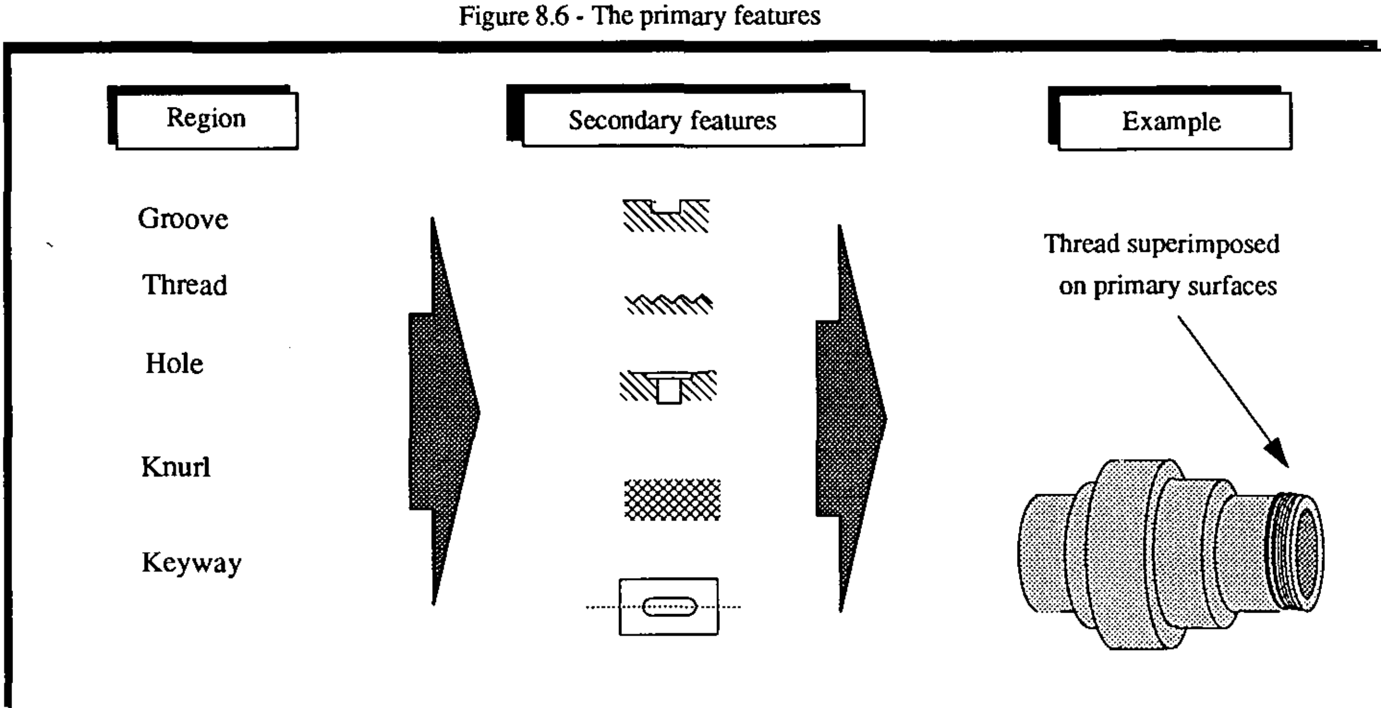


Figure 8.7 - The secondary features

Chapter 9

Part Description Using Predefined Regions & Features

9.1 - Introduction

This chapter aims to illustrate the categories of features and regions used when designing a component. These features and regions are developed in detail in order to identify the related knowledge associated with each features/region (*see section 9.5-9*). The purpose of this chapter is to underline the activity of describing a component and state the relevant factors and parameters influencing part description. These issues are discussed under a number of headings to provide a full view of the activities and tasks needed for part description. Examples to illustrate the above are given in sections 9.16.1-6.

9.2 - Scope of Part Description

The primary objective of this part of research is to enhance part description by capturing the intent of engineering drawing by devising a medium in which the recurring patterns of an asymmetric rotational component can be modelled for machining. The part description method devised consist of several building blocks. Regions are designed to systematically represent an asymmetric rotational component. Features are assigned to describe the configuration of regions. The method presented in this research decomposes a workpiece into several distinctive and predetermined regions. Each region is designed to represent a set of particular features.

The uniqueness of this approach stems from the natural way in which an asymmetric component is described. The tools for describing an asymmetric rotational component are defined at length in the following sections. A more detail representation of data for regions and features is presented in appendices *I & II*.

9.3 - IDEF0 Representation

The part description activity is concerned with providing the necessary descriptive tools (*i.e. feature/regions*) to design the workpiece. The descriptive tools are used so as to dissect a component into several predetermined regions. The information which is provided by the engineering drawing is used to define the configuration of each region. Each region is augmented by a group of geometric and technological attributes. The mechanisms and methodology for describing regions are addressed in the subsequent sections. The IDEF0 model (*see appendix III*) is used to illustrates the steps that describe an asymmetric rotational component. These steps are:

i - Design predefined regions & features

ii- Identify and select regions

iii-Define region

iv- Select & define features

The design of regions/features is influenced by the following factors: the design requirement, manufacturing need, and the available resources. These are the factors limiting the design specification. The design specification coupled with the way in which the regions would be machined determines the characteristics of the region/feature, however, these requirement are constrained by the availability of resources. The ability to add or modify regions/features significantly enhances part description.

The identification and subsequent selection of regions is based on engineering drawing information. The region boundary is determined by identifying the machining features and subsequently providing the related geometric and technological information.

Selection and subsequent definition of features is performed by examining the geometry of the region. The appropriate features are then selected to describe the region. Features are defined by geometric and technological data and subsequently input by interactive dialogue. Information regarding the geometry of regions can be verified by simulation through a controller.

The design of a region is based on the philosophy that a framework for part description had to be devised in order to tackle the complexity of manufacturing a component and thus, offering an enhanced methodology for part description.The advances in turning centres have provided the opportunity to machine complex asymmetric rotational components. However, the task of programming asymmetric rotational components still remains difficult. A close examination of a typical asymmetric rotational component reveals that without a frame of reference (*i.e feature and region scheme*) the description of the part would be an immensely difficult task. Thomas Mann *[1936]* states that, order and simplification are the first steps toward decomposing a complex problem. Allen *[89]* specifies that simplification is the road that leads to rationalization and can be achieved by classification of features. Classification provides a simple and yet effective road map for describing a component

9.4 - Data Preparation

The objective of data preparation is to assist a user to design a part program by leading them to select the appropriate regions and features for a component. Data preparation for an asymmetric rotational component consists of several tasks. These tasks are divided into two stages:

i -Blank description

ii-Part description

The activities listed above are expanded further in the following sections.

9.4.1 - Blank Description

This stage is concerned with a general description of the components. This is concerned with the material and geometry of the blank together with it's associated locations *[figure 9.1]*. These specifications are determined by design requirement and material availability. The blank diameter and length are specified and subsequently the

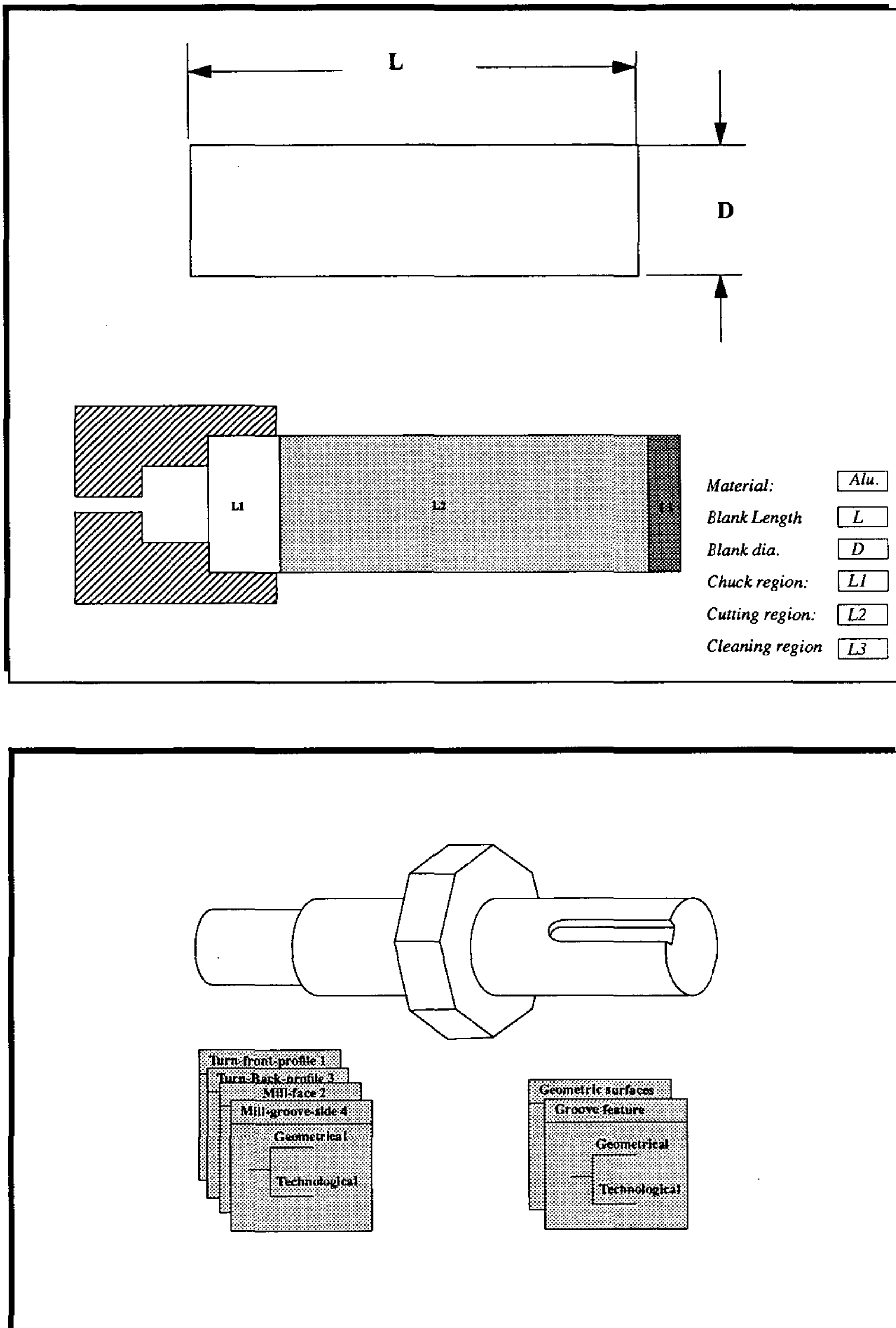


Fig 9.1	Billet & part description	L.U.T- CAD/CAM

associated regions are determined. As shown in figure *9.1* the blank or raw material is divided into three regions:

i - Chucking region

ii- Machining region

iii- Facing region

The chucking area represents a clamped region, this region is represented by value *L1*. The surface area designated for clamping must be sufficient to provide stability during the machining operation *[Boothroyd 89]*. The next area (*machining region*) is symbolized by *L2*. The machining region constitutes areas that need to be machined to produce the final part. The area *L3* represents a region that needs to be removed (*faced*) before machining the actual profile.

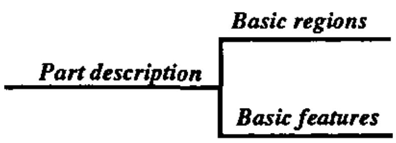
9.4.2 - Part Description

Part description is concerned with two descriptive mediums: Basic region, and basic feature. The NC planning system employs several regions so as to describe the workpiece. The relevant regions are identified, selected and defined by the user. Each region represents an area of the component requiring a specific machining operation. The next stage is to describe each region with the available and appropriate features.

After defining the regions of the component and describing the associated technological and geometrical attributes (*area L2*), the 'part off' feature (*groove*) needs to be defined. Location of this feature is defined by the user. The part off operation is explained in section 12.12.1.

9.5 - Part Decomposition

An essential aspect of the use of decomposition in the modelling of a part is to put the segments (*regions*) together in such a way that the composite regions are equivalent to the original material that needs to be removed and the composite features forming a region must be equivalent to the original piece (*region*) that was decomposed. The



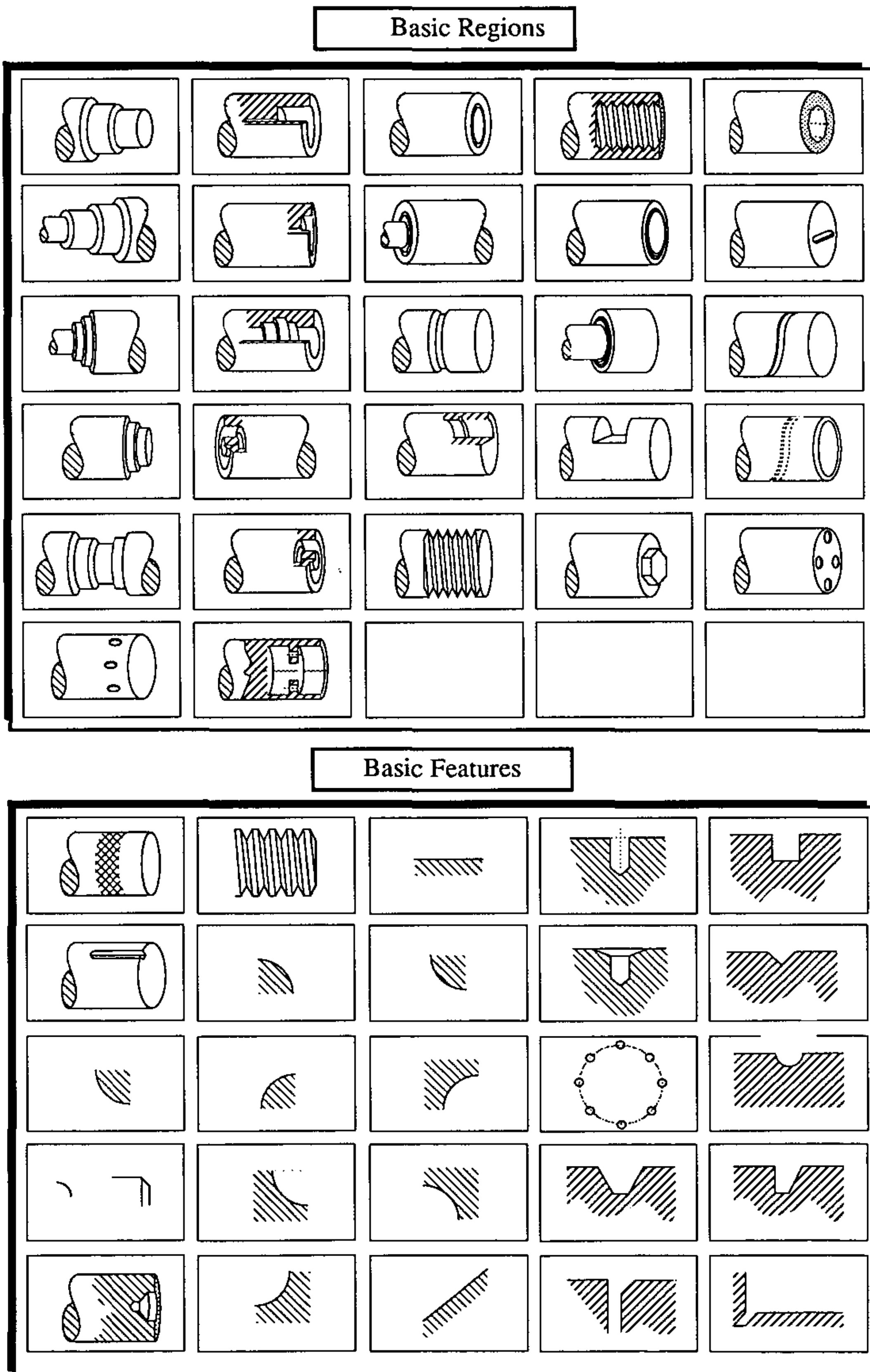


Figure 9.1a | Region & feature database | L.U.T- CAD/CAM

main effect of decomposition will be to build a model in which there are more pieces (*regions*) than in the original shape, but regions are simpler to design and are provided with the related technological and geometrical data. Therefore, the idea was to build each piece (*region*) independently by considering the necessary geometrical and technological discipline.

9.6 - Features

The strength and power of features lies in the ability to rationally design a component *[Butterfield 85]*. The hierarchies developed *[see section 8.4]* provide an invaluable road map which justifies the logic for using features. The hierarchy is developed to assist and clarify part description. The use of regions mapped with features establishes a rational basis for streamlining part description. The collection of parameters which represent a feature are devised so as to obtain information which pertain to NC machining operations. The aim is to use the parameter information so as to finally generate an efficient tool path. The two types of features used to represent the component are cited below:

i - Form features (*e.g. hole, groove, etc.*)

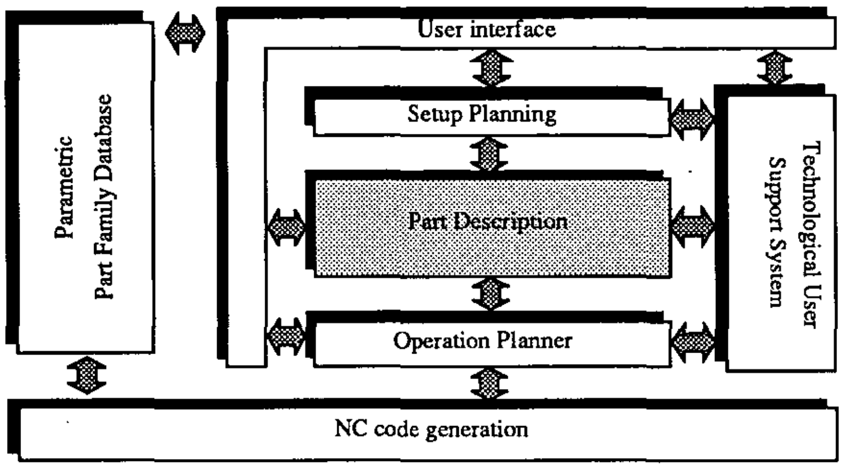
ii - Surface features (*e.g straight, taper, concave*)

The machining features employed in the NC planning system are depicted in figure *9.1a*. The regions which embrace the machining features are displayed and the appropriate parameters for each region are specified (*see appendices I & II*). These parameters are used for reasoning. The objective is to express an unambiguous description of parameters embodied by each feature. These parameters are designed to thoroughly characterize a region. Six parameters are associated with each feature *[figure 9.2]*:

i - ID

ii- Geometric data

iii-Technological data



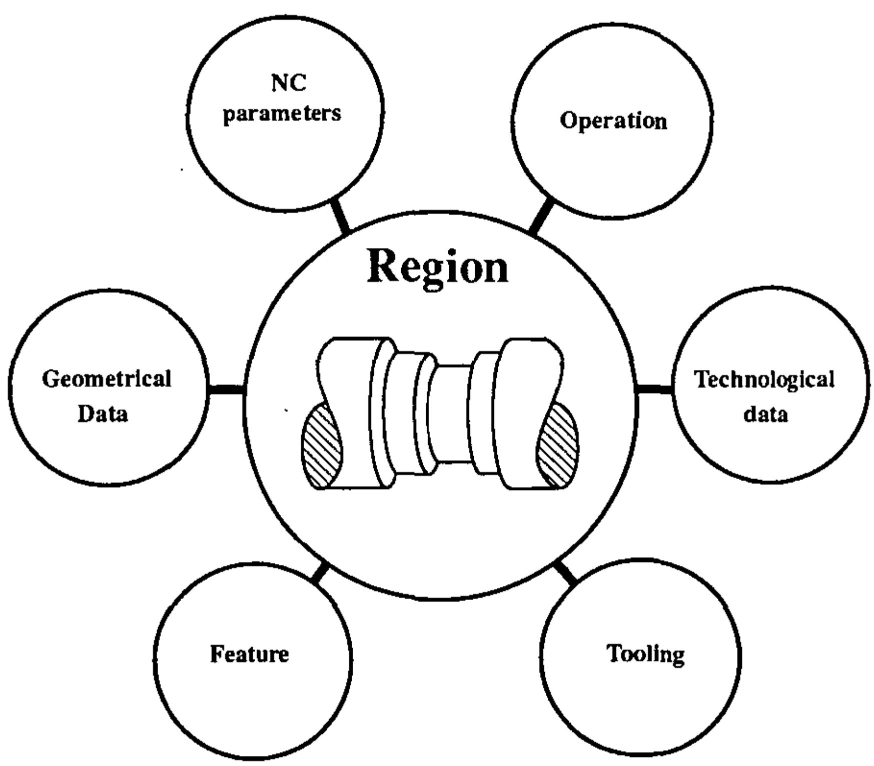


Figure 9.2	Part description	L.U.T- CAD/CAM

iv-Relationship

v-Attributes

vi-Tooling

Features are identified by their particular *ID* number. A feature *ID* is used for reasoning and manipulation of data. The most important aspect of a feature is the geometric information. Another important aspect is the embodiment of technological information. This information is represented in terms of feedrate, cutting speed and surface finish data. The relationship between features specifies the position of each feature and provides valuable information for process planning purposes *[Butterfield 85]*. Features are specified further by attributes. The surface feature's (*i.e. taper, straight, concave, and convex*) attributes include chamfer and corner. A composite feature also carries tooling information. The range of knowledge incorporated in the feature is sufficient for generating NC information.

9.7 - Region

The use of a region is a unique way of enhancing part representation. Regions are collections of features that correspond to primary machining operations *[Grayer 76]* and have some degree of manufacturing significance *[Hummel 86]*. As depicted in figure 9.3 regions are defined by a group of parameters. These parameters are divided into three sections: the first group are those parameters which are automatically selected (*i.e. operation, identification number*). The second group consists of parameters which have to be interactively collected from the user (*i.e. boundary location, geometric data, technological data and feature*). The third group is concerned with parameter information which has to be generated by the system (*i.e. NC data*). These parameters are cited below:

i- Operation

ii-Boundary location

iii-Geometric data

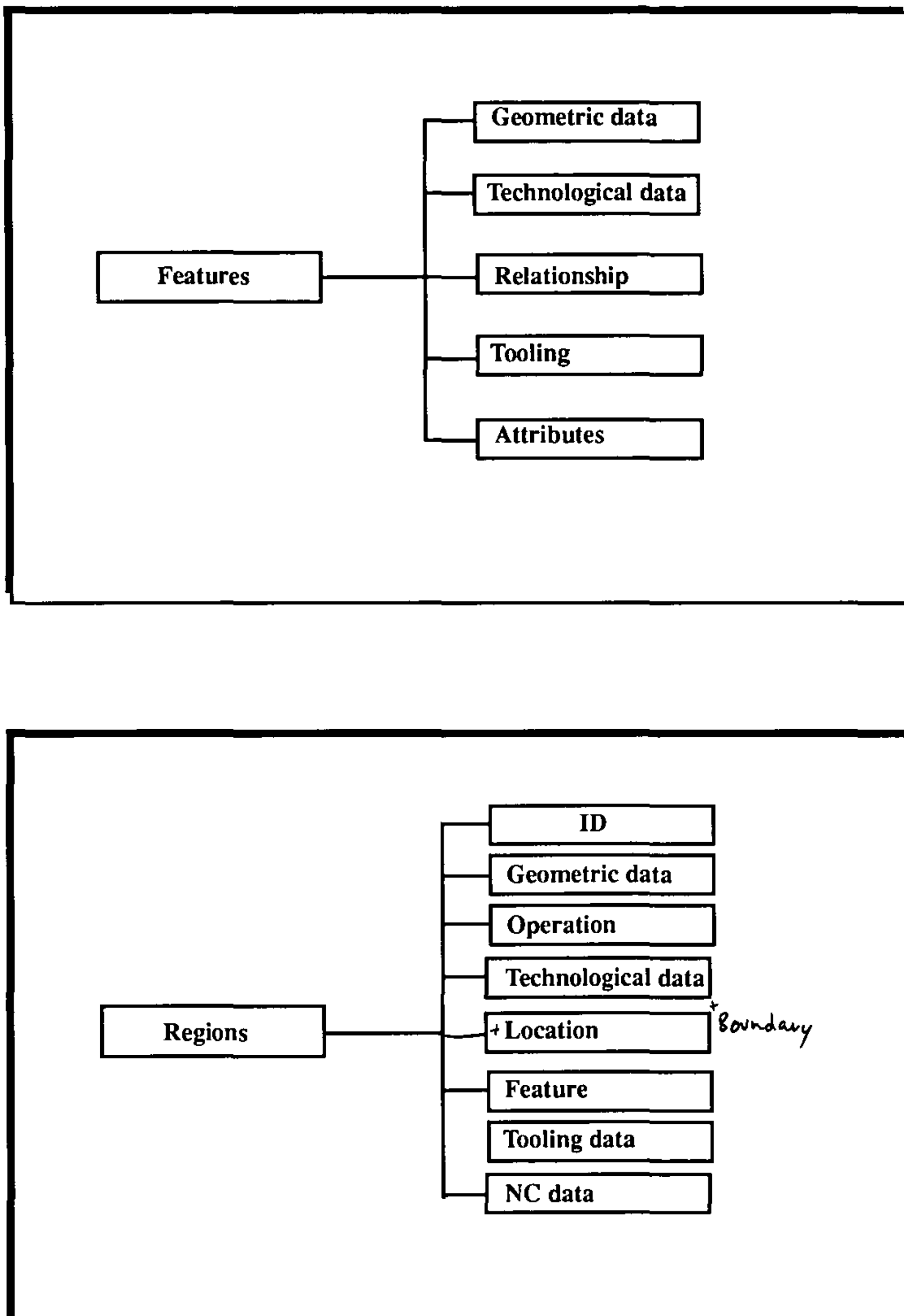


Fig 9.3	Associated parameters for region & feature	L.U.T- CAD/CAM

iv-Technological data

v- Feature

vi- NC data

For each region a specific operation is designated (*see section 12.6*). The geometric location of the region is implicitly represented. The location is explicitly defined when the features for the particular region are selected. The geometry of the region is defined further by describing the features. Each region is augmented with the relevant technological information. Regions include the necessary NC information. This data is designed and tailored for each region. The region scheme devised allows the user to navigate and systematically define a component. The following benefits and advantages highlight the importance of the use of a region:

-Requires less calculation and manipulation.

-Provides manufacturing constraints and thus guidance.

-Greatly simplifies operation planning tasks (*tool selection, machining data, etc.*).

-Provides implicit or symbolic information regarding location.

-Represents each region semantically.

-Represents the part in terms of regions, which is the way a designer programs.

-Is modular and flexible.

-Could be taken out of its surrounding and investigated independent of other regions.

-Is valuable for designing independent NC modules.

-It is also an excellent design kit for decomposition.

9.8 - Criteria for Designing Regions

The design of each region is based on the investigation of a typical asymmetric rotational workpiece. The result is the provision of library of regions which are employed to decompose a part into several machinable regions. The regions are intended for machine tools that have live tooling facilities. Another factor influencing the design of the region is the shop-floor practice and methodology. In short to design the regions, the technology, manufacturing process and machine tool limitations are the factors which are examined. The selection process is restricted by the availability of resources. *(i.e. The NC planning system is designed for three axis (X,Z,C) CNC turning centres. These machines are equipped with the necessary facility for producing a typical asymmetric rotational component).*

9.9 - Knowledge Representation at Region Level

A workpiece is represented in the form of regions. Each region consists of a name and several features. Each feature has associated attributes and values. The name of each region defines the general location and operation. It must be noted that regions may contain several features and technological parameters. In other words a region consists of a hierarchy of many layers of geometrical and technological attributes as depicted in figure 9.5.

9.10 - The Region Type

The work piece is represented by two entities. Each entity is further represented by three regions:

Symmetric:	*Asymmetric:*
i - Turn-region	*i* - Mill-region
ii- Groove-region	*ii* -Millgroove-region
iii-Thread region	*iii*-Drill-region

The six categories of regions listed above are sufficient to describe a component. For further explanation of each region refer to section 9.16:

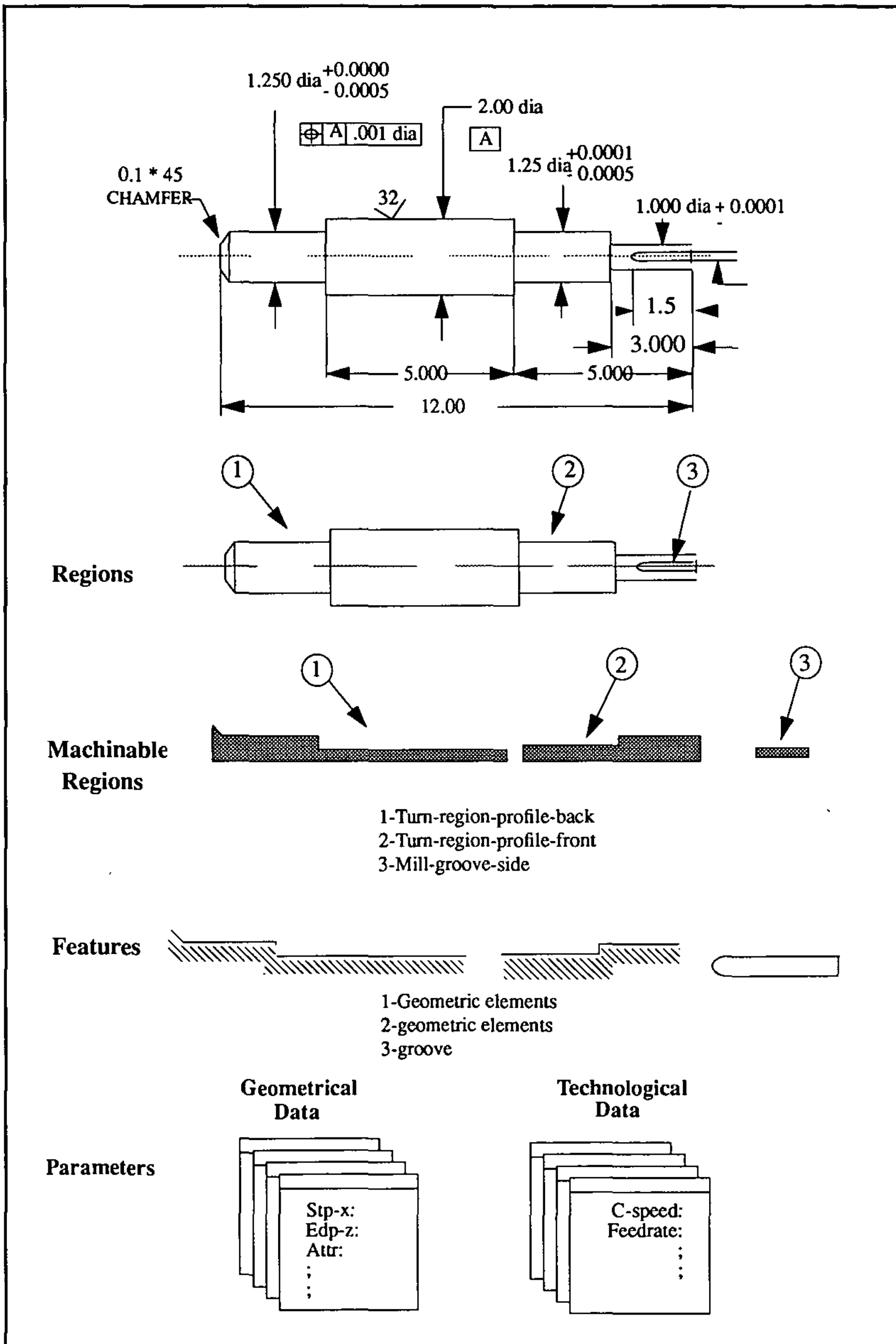


Figure 9.5	Feature based decomposition	L.U.T- CAD/CAM

9.11- Information Transaction Medium

A template is assigned for each category of information. The primary function of a template is to collect the appropriate information. Templates use a predefined format so as to provide a pattern or model for the geometric and technological data. The use of templates prevent the user entering incorrect information and thus, it provides the user with necessary guidance. The type of data collected by templates is designed to be informative and not redundant. As depicted in figure 9.6 four different templates are designed to collect information:

i - The geometric boundary template (*i.e for region*)

ii - The technological boundary template (*i.e. for region*)

iii- The geometrical template (*i.e. for feature*)

iv- The technological template (*i.e. for feature*)

The information regarding the functionality of each template is discussed in the following sections.

9.12.1 - The Geometric Boundary Template (*region*)

The function of the geometric boundary template is to provide a proper format for the user to enter the geometric knowledge related to the boundary of the region. Each category of region embodies a unique and suitable format. These formats are described at length in the description of regions, see sections 9.16 to 9.6.16.

9.12.2 - The Technological Boundary Template (*region*)

The technological boundary template acquires the technological data related to a region. This template is managed by the operation planning module. It is devised so as to assist the user to perform the operation planning tasks (*i.e tool selection, machining data selection, etc.*).

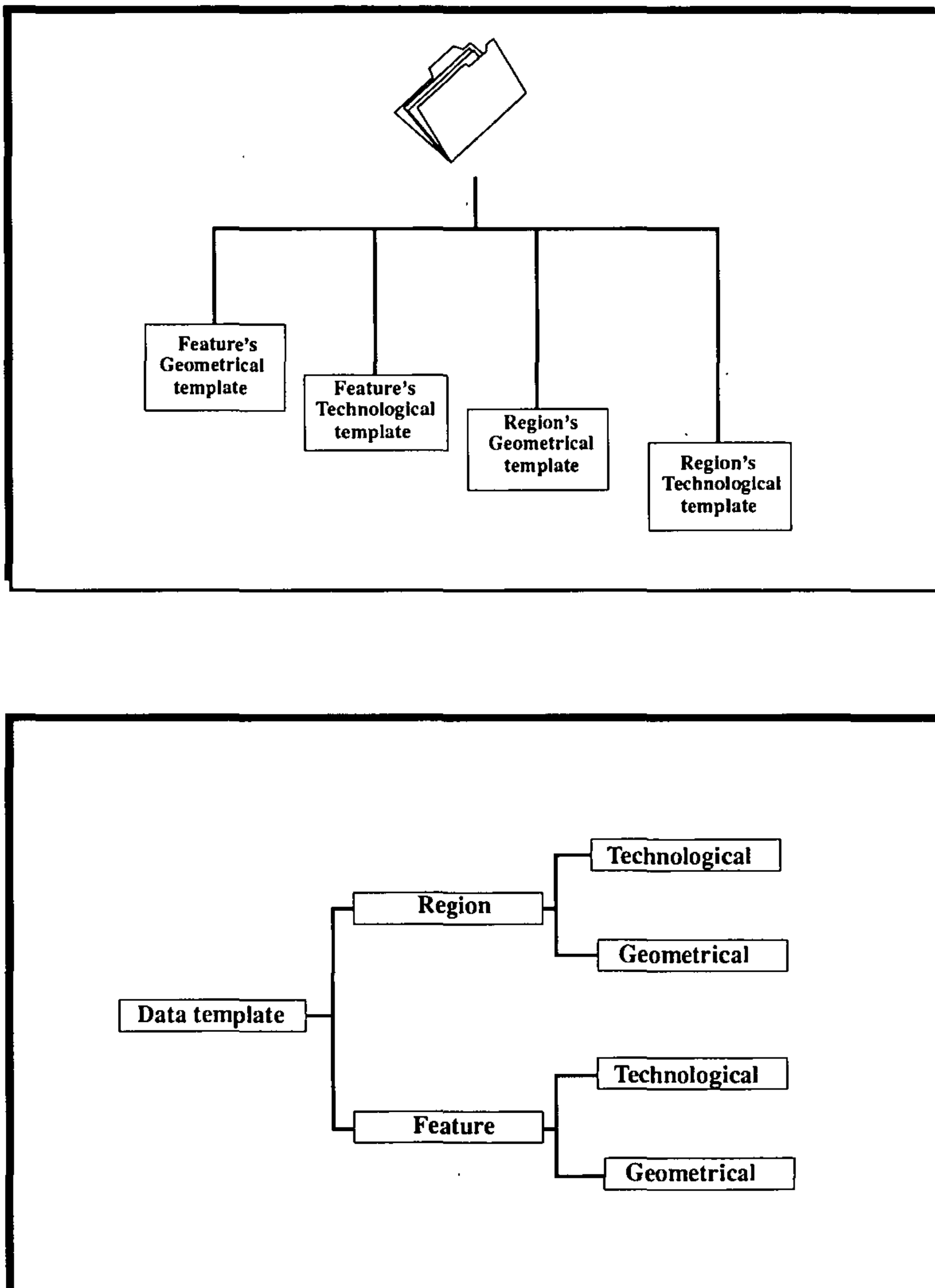


Fig 9.6	Template structure	L.U.T- CAD/CAM

9.12.3 - The Geometric Template (feature)

The role of geometric template is to acquire information pertaining to the geometry of a feature. This information is used for generating manufacturing code. The predefined format for each feature is incorporated in the template, see section 9.14.3 for the geometrical information incorporated in the template.

9.12.4 - The Technological Template (feature)

This template is designed to interrogate the user on the selected features. The information incorporated in the template is concerned with the technological attributes associated with each feature. The task of this template is to generate the relevant technological information for the predefined NC macro associated to each region. The information incorporated in a technological template is described in section 9.14.2.

9.13 - Region's Design Criteria

Design of regions for an asymmetric rotational component has been based upon the study of tool path motion during the machining operation. The investigation of possible segments (*regions*) reveals that in order to increase the effectiveness of region scheme, each category of region has to be mapped with the appropriate features and operation. The name allocated to each region reflects the operation and feature. The regions and their associated parameters and operations are described below:

Turn-regions associated with *surfaces features* and *turning operation*

Groove-region associated with symmetrical *groove features & grooving operation*

Thread-regions associated with *Thread features* and *threading operation*

Drill-regions associated with *hole features* and *drilling operation*

Mill region associated with *surfaces features* and *milling operation*

Groove-mill-region associated with special *grooves features* and *milling operation*

9.14 - The Entities Attributes

9.14.1 - The Region's Geometrical Attributes

The geometrical attributes are concerned with the information which defines the outer boundary of a region. For some regions (*e.g. Turn-region*) the region's geometrical data provides explicit information about the area of machining. Further more the geometric data is used to specify cutting tool movement.

9.14.2 - The Region's Technological Attributes

The technological data for regions is acquired so as to generate the appropriate NC parameters (*i.e tool path type, safety distances, rapid movements, etc.*). This information is essential for generating manufacturing code. Information such as tooling and operation are determined for each region by the operation planner module (*see chapter 11*).

9.14.3 - The Feature's Geometrical Attributes

Each feature is defined geometrically. The description procedure for each feature is varied. For example the surface features are described by the following parameters: starting point, ending points, and radius (*i.e. if the feature is an arc*). Surface features are defined further by the geometric attributes (*i.e chamfer and corner*). Other form features such as drilled holes, grooves, and threads are defined parametricaly. For instance, a hole is described by it's depth and diameter value.

9.14.4 - The Feature's Technological Attributes

Various set of knowledge are associated with a feature, each designed to perform or assist a certain function. Often a specific technological requirement is needed for a feature. In terms of generating manufacturing code the most important item which reflects the process planning decisions is the surface finish value. Each surface feature is associated with a roughness code value which is used in order to represent the surface specification (*see section 11.9.1*). Other form features (*e.g. groove, threads, holes etc.*) are associated with the related machining data. Features are augmented with technological information (*i.e. tolerances, surface finish information*) *[Shah 88]*. The technological and geometrical information for each region and feature typically takes the form depicted in figure 9.7.

9.15 - Identification/Selection of Regions

The identification of appropriate regions for an asymmetric rotational component takes place by examining the drawing and subsequently identifying the corresponding regions. The identification and the selection process is performed by the user. However, the difficulty faced is in deciding how to remove the negative aspects associated with human assisted identification and selection.

The human assisted approach has been used largely for inputting data for process planning and NC tool path generation *[Shah 88]*. The research discussed is in the following *[Chang 84], [Nau 87], [Hummel 86], [CAMI-GM85]*.

One difficulty with ad-hoc picking of entities is that it is the user's responsibility to select the right number and right kind of regions and features. Otherwise the NC planning system using regions and features will be unable to derive the correct NC information. To help alleviate this problem certain templates are designed to assist the user in selecting and describing the correct regions and features *[see section 9.11]*. A similar approach is used by Johnson *[CAMI-GM85]* in which templates are used to collect parameter information.

9.16 - The Description of Regions and Features

Each region is embedded with unique characteristics (*e.g. name, operation, location, etc.*). These characteristics enhance the user's ability for selecting the appropriate region. The related information is collected in the relevant template. The acquisition of data is performed by interactive dialogue. The subsequent sections describe each region and their associated parameters.

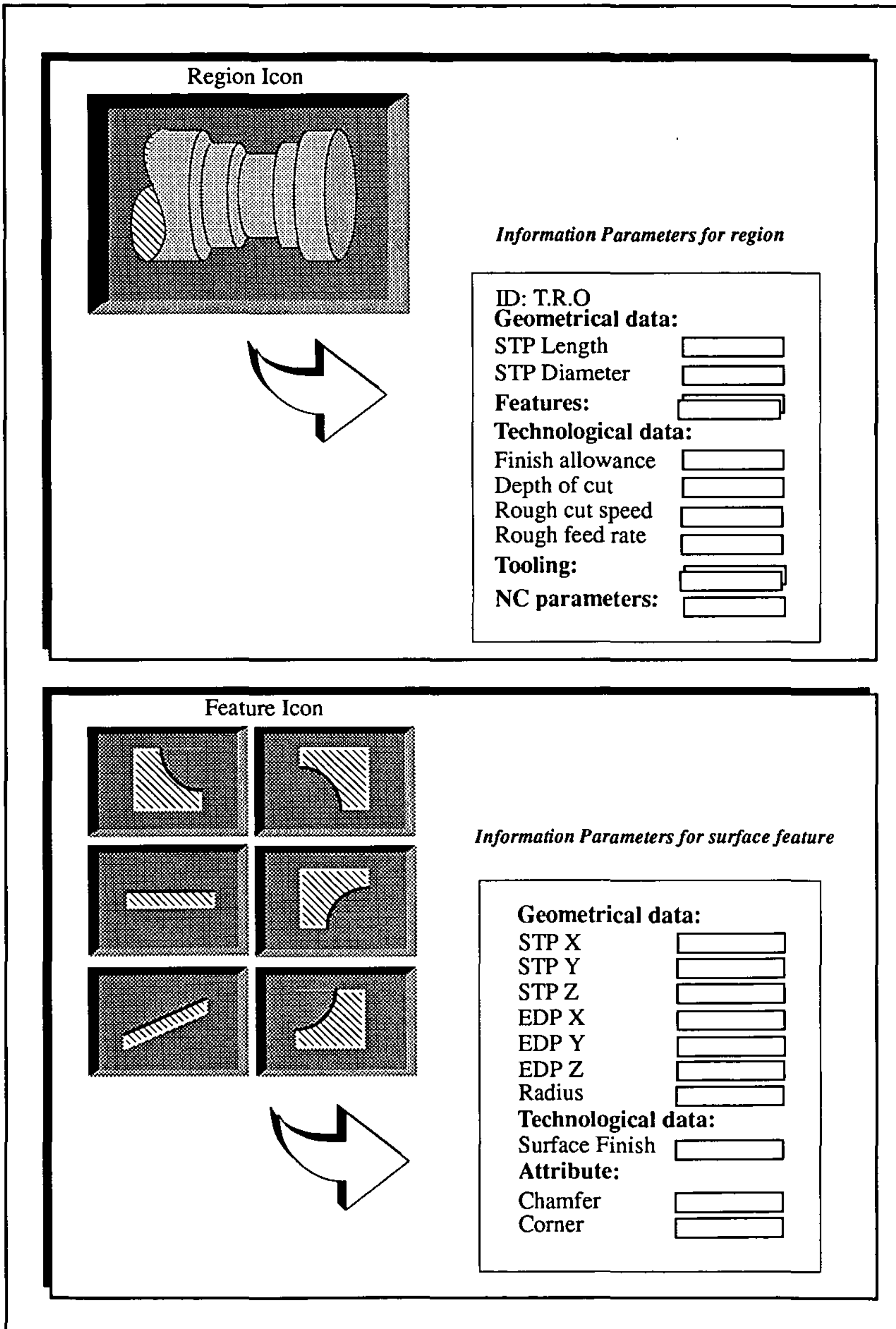


Figure 9.7	Feature & region parameter	L.U.T- CAD/CAM

9.16.1 - Turn Region

In order to describe a turn region for a component the following steps are followed:

i- Identify and select basic turn region

ii-Identify and select the associated features

Ten *turn-regions* are available. Depending on the geometry of the component the appropriate region is selected. A given component can be composed of several *turn-regions*. The variety of possible regions and their associated features are depicted in figure 9.8. After selection of a *turn-region*, the parameters listed in table 1 are used to define the regions attributes:

Table 1: Regions geometric & Technological data

P/S	CPT - X	CPT - Z	RV	FV	D/C	TR	TF
1	2	3	4	5	6	7	8

Parameter #1:Machine cycle option
Parameter #2:X coordinate of region at cut point
Parameter #3:Z coordinate of region at cut point
Parameter #4:Cutting speed for rough machining
Parameter #5:Feedrate for rough machining
Parameter #6:Depth of cut for roughing
Parameter #7:Roughing tool
Parameter #8:Finishing tool

The information concerning the configuration and shape of each region is interactively acquired by the geometrical template. The technological information regarding a *turn-region* is collected by the technological template. The parameters which best describe the geometry as well as technological data for a surface feature are defined in table 2.

Table 2: Feature's Geometric & technological data

F/N	F/T	X-STP	Z-STP	X-FTP	Z-FTP	C	R	Rd	Ctr	X-STP	Z-STP	S/F
1	2	3	4	5	6	7	8	9	10	11	12	13

Parameter #1:Surface feature number or identification

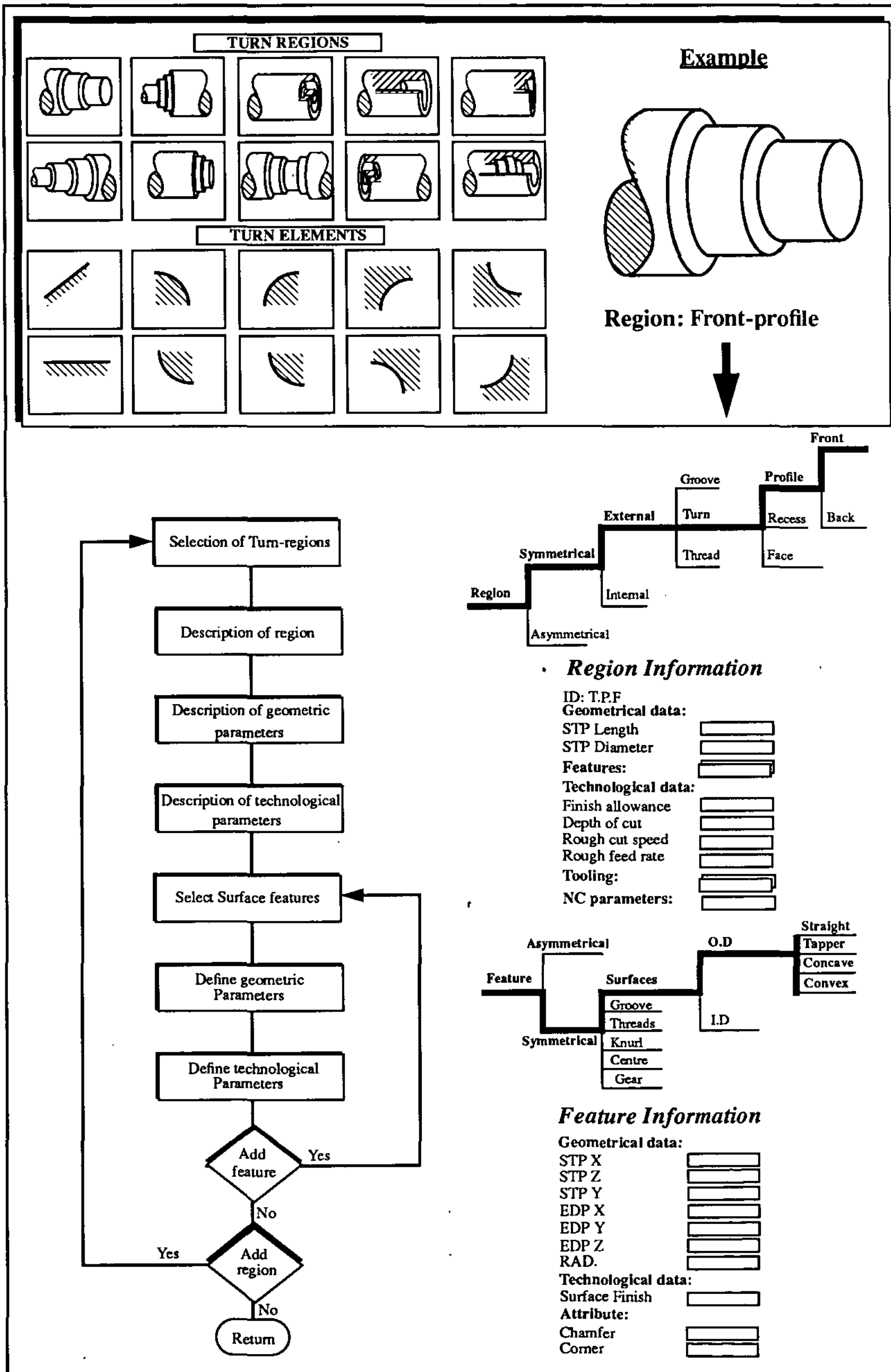


Figure 9.8	Turn region	L.U.T- CAD/CAM

Parameter #2:Surface feature type (i.e. straight, tapper, concave and convex)
Parameter #3:Initial location of surface feature at X point
Parameter #4:Initial location of surface feature at Z point
Parameter #5:Final location of surface feature at X point
Parameter #6:Final location of surface feature at Z point
Parameter #7:Chamfer status & value (surface feature attribute)
Parameter #8:Corner status & value (surface feature attribute)
Parameter #9:Radius value (used for concave & convex surface features)
Parameter #10:Centre location of arc defined by parameter 11 & 12.
Parameter #11:X location of arc (parameter #10)
Parameter #12:Y location of arc (parameter #10)
Parameter #13:Surface finish value (roughness code) for each surface feature.

A more detailed investigation of the above parameter is explored in the operation planning chapters *(13&14).*

According to the shape of the region, the proper features are selected. The *turn region* is defined by geometric surfaces and attributes *(i.e. corner, chamfer).* These surface features are depicted *[figure 9.8].* The surface features of a component are described from the start *(right)* to the end *(left)* of a region. The geometry must be specified progressively in the following directions: Z negative and X positive. The ending point of the first surface feature is the starting point of the next surface feature. The geometry of a turn region must be specified in a consecutive sequence. Otherwise an inconsistent geometry results.

Surface features are specified in terms of X and Z values. These features can be described further by feature attributes (*i.e. chamfer or corner*). The next logical step is to enter the technological information. The surface finish value is specified in terms of roughness code (*see section 11.9.1*) reflecting the engineering drawing specification. A high value roughness code for surface finish assigned for a surface feature increases the cycle time and results in higher cost *[Boothroyd 89].* However, for high tolerances and finish requirements a higher roughness code may be required. The surface finish characteristics, algorithm and roughness code are described in detail in chapter 11.

9.16.2 - Groove Region

Four *groove- regions* are available for machining. The following steps are required to describe a groove:

i - Identify and select basic groove region

ii-Identify and select groove features

The groove regions and their associated features are depicted in figure *9.9*. A component may require several grooves. After selecting the appropriate *groove-region* the geometric and technological parameters as depicted in table *3* are described.

Table 3: Regions geometric & technological data

S/N	R/D	R/L	T
1	2	3	4

Parameter #1: Region sequence & identification number.
Parameter #2: Groove region diameter
Parameter #3: Groove region tool location (Z-STP)
Parameter #4: Tool number

At this stage the appropriate groove features are selected and subsequently defined by the parameters listed in table *4*.

Table 4: Feature's geometric & technological data

G/T	G/D	N/G	G/P	F	S
1	2	3	4	5	6

Parameter #1: Groove type
Parameter #2: Groove depth
Parameter #3: Number of groove at one region
Parameter #4: Groove pitch (if parameter # 3 is more than 1)
Parameter #5: Feedrate value
Parameter #6: Cutting speed value

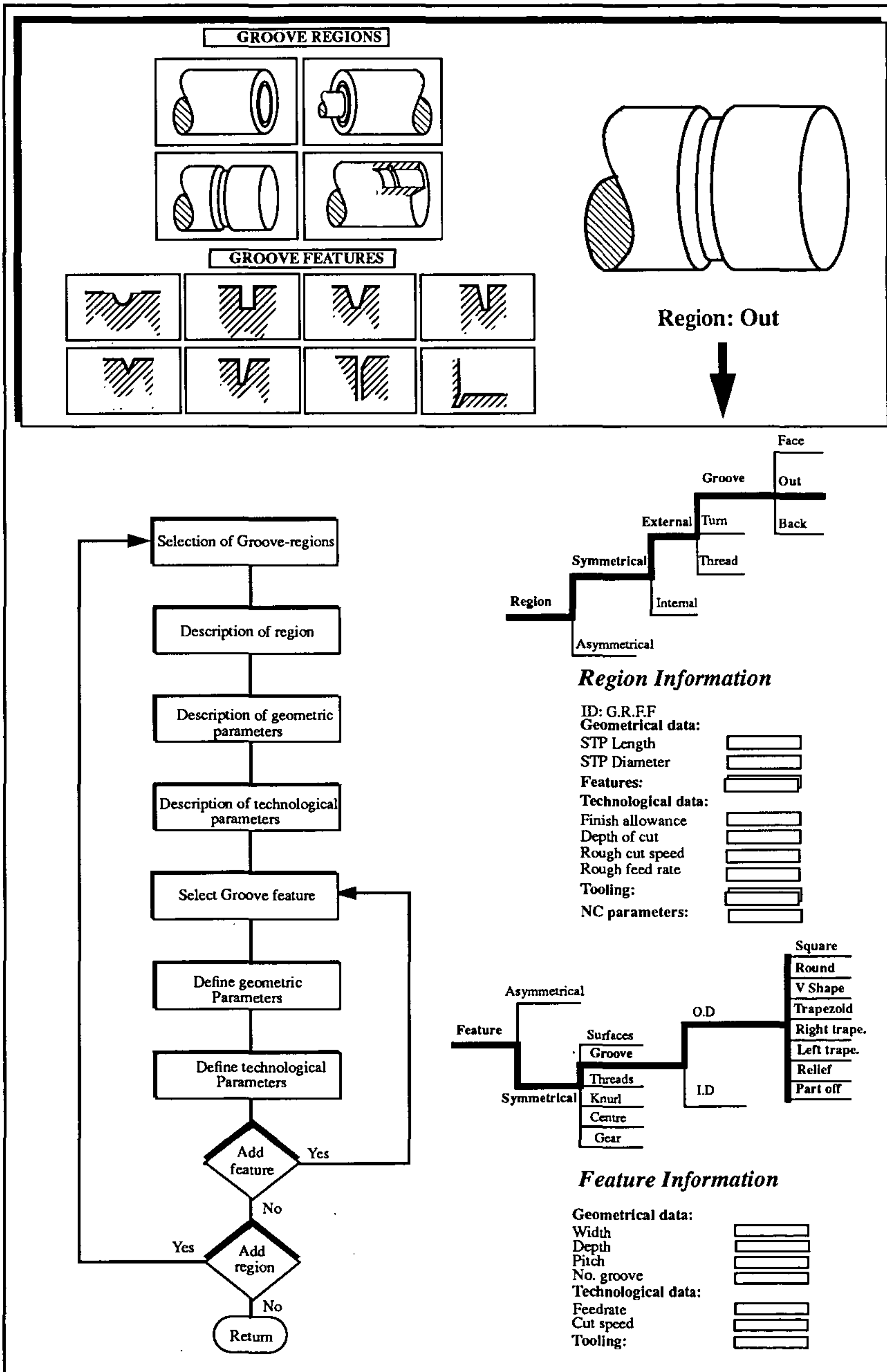


Figure 9.9	Groove region	L.U.T- CAD/CAM

9.16.3 - Thread Region

Four possible *thread-regions* are available for selection. In addition, several thread features are available for the thread region.The thread selected must satisfy the functional and geometrical specification of the component. The following steps are used to define a thread:

i- Identify and Select basic thread-region

ii- Identify & select thread features

Figure 9.10 depicts the *thread-regions* and features and list the parameters that define regions and features. The parameters which describe *thread-regions* and thread feature are cited in tables 5 &6.

Table 5: Region's geometric & technological data

S/N	R/D	R/L	T
1	2	3	4

Parameter #1:Region sequence & identification number
Parameter #2:Thread region diameter
Parameter #3:Thread region tool location (Z-STP/X-STP)
Parameter #4:Tool number

Several thread features are available. The most commonly used thread feature is metric. The parameters which describe the thread feature are listed in table 6.

Table 6: Featur's geometric & technological data

S/N	T/T	Z_STP	Z-FTP	N/P	C/V	T/A	M/D	F/A	DF/P	T/P
1	2	3	4	5	6	7	8	9	10	11

Parameter #1:Feature identification and sequence number
Parameter #2:Thread type (see the feature taxonomy in chapter 8)
Parameter #3:Initial location of thread in length (Z-STP/X-STP)
Parameter #4:Final location of thread in length (Z-FTP/X-STP)
Parameter #5:Number of passes
Parameter #6:Chamfer status & value
Parameter #7:Thread angle

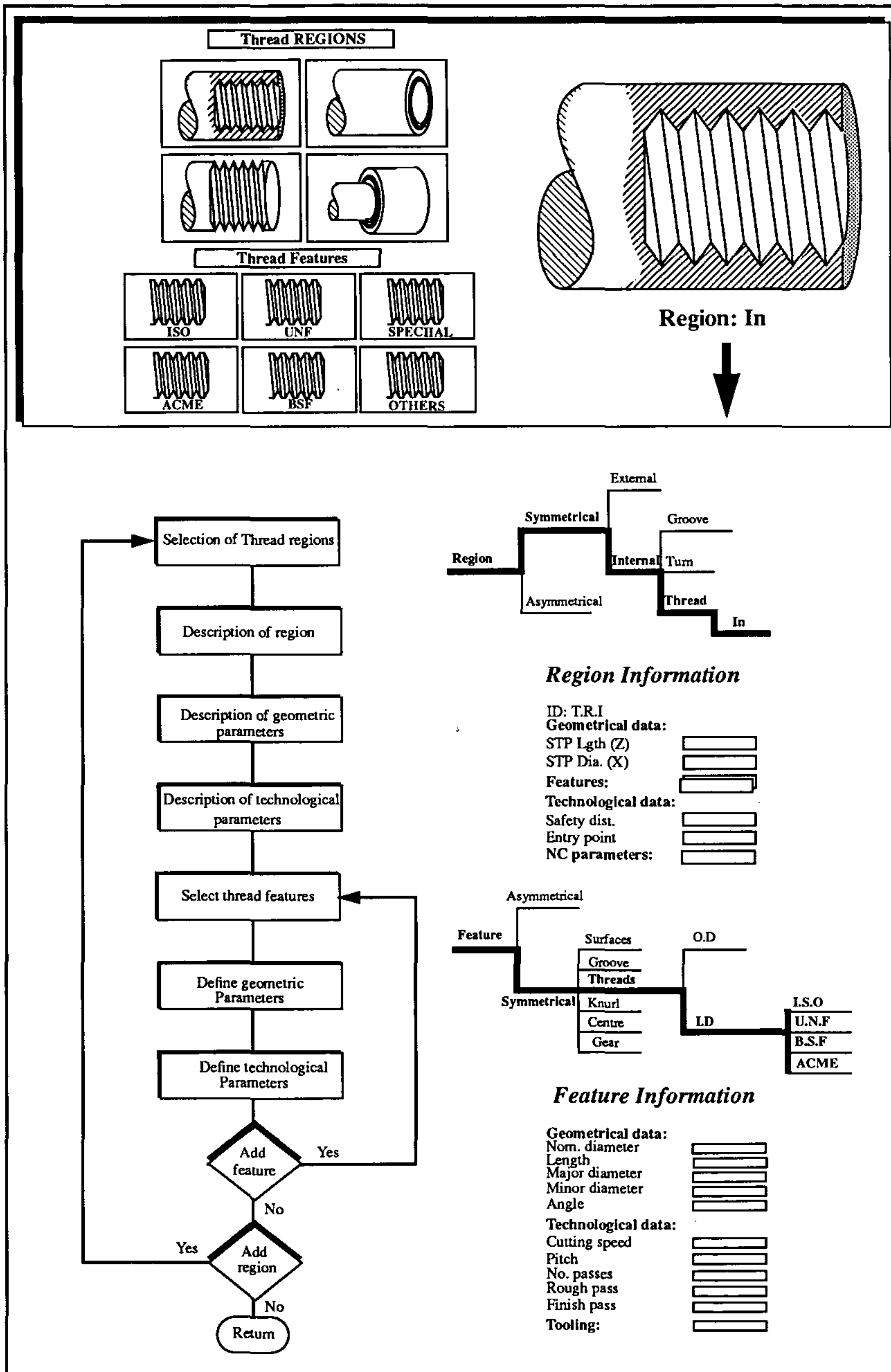


Figure 9.10	Thread region	L.U.T- CAD/CAM

Parameter #8:Minimum cutting depth
Parameter #9:Finish allowance
Parameter #10:Depth of cut for finish pass
Parameter #11:Thread pitch value

9.16.4 - The Mill-Region

The *mill-region* consists of several symbolically predetermined regions: *[figure 9.11]*

i- Face region
ii- Side region
iii-In region

In order to define a region for the workpiece which consists of mill surface features, the following steps are required:

i- Identify and select basic mill regions

ii- Identify and select features

The *mill-region* is described by the parameters listed in table 7.:

Table 7: Region's geometric & technological data

S/N	T/SD	T/L	F	S
1	2	3	4	5

Parameter #1:Region sequence & identification number
Parameter #2:Mill region tool location (Z-STP safety)
Parameter #3:Initial tool location (Z-STP/X-STP)
Parameter #4:Tool Number
Parameter #5:Feedrate
Parameter #6:Speed

The next step is to define the surface features forming the *mill-region.* The surface features are described by the parameters listed in table 8.

Table 8: Featur's geometric & technological data

F/N	F/T	X-STP	Y-STP	X-STP	X-FTP	Y-FTP	Z-FTP	Rd	S/F
1	2	3	4	5	6	7	8	9	10

Parameter #1:Feature identification & number
Parameter #2:Feature type (i.e. mill surface features: linear, concave, convex)
Parameter #3:Initial geometric location of feature at X-STP

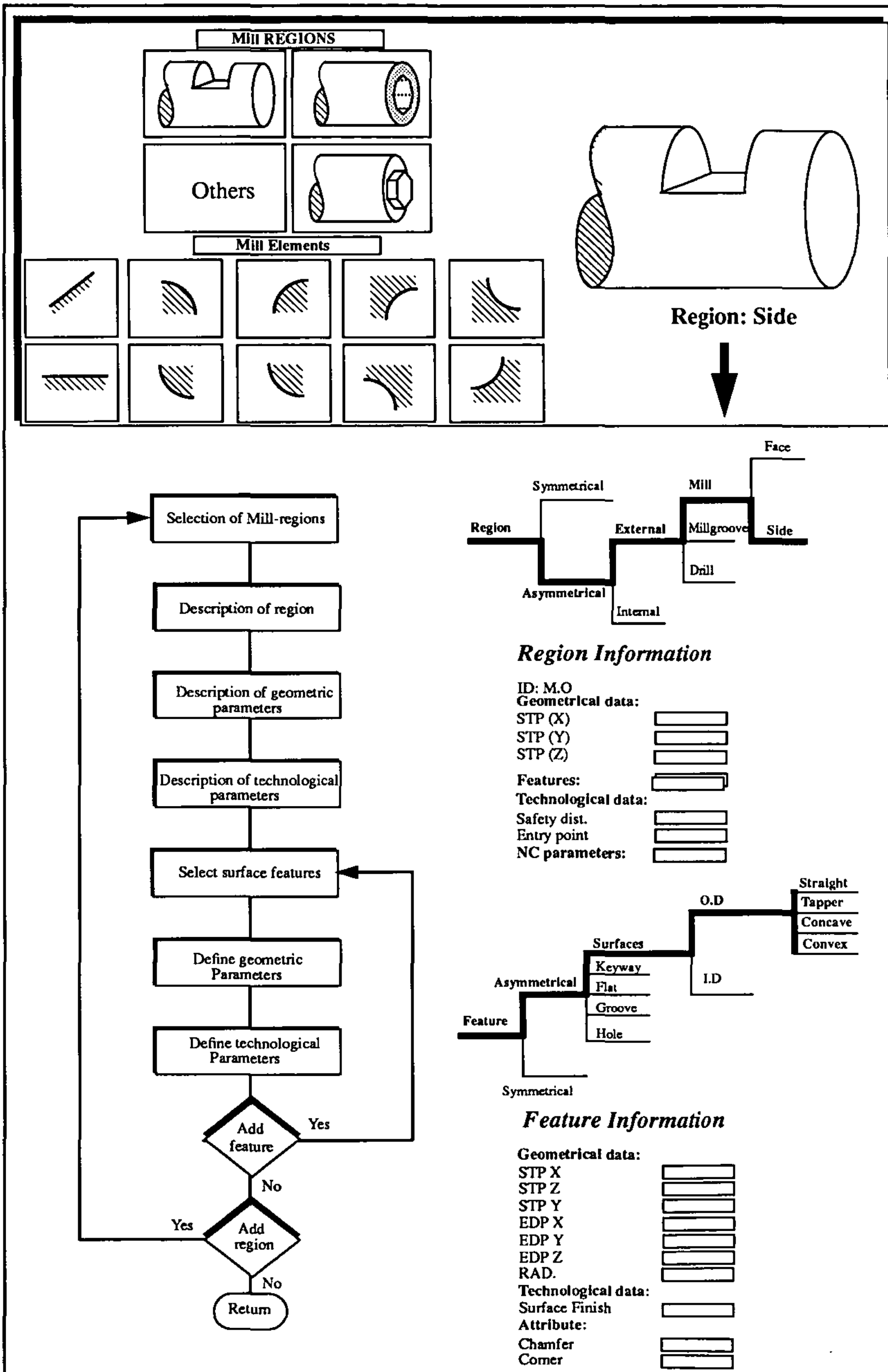


Figure 9.11	Mill region	L.U.T- CAD/CAM

Parameter #4:Initial geometric location of feature at Y-STP
Parameter #5:Initial geometric location of feature at Z-STP
Parameter #6:Final geometric location of feature at X-STP
Parameter #7:Final geometric location of feature at Y-STP
Parameter #8:Final geometric location of feature at Z-STP
Parameter #9:Radius (initiated if parameter #2 is concave or convex)
Parameter #10:Surface finish (represented by roughness code)

9.16.5 - Mill-Groove-Region

The *mill-groove* region is divided into the following regions:

i- groove face/back
ii-groove side
iii-groove in

These regions are used to describe special grooves. The features which are available in the feature library are depicted in figure 9.12. They are:

i- Helical
ii- Spiral
iii-Irregular

The *Mill-groove* region is described by the parameters depicted in table 9.

Table 9: Regions geometric & technological data

S/N	T/SD	T/L	T/N	F	S
1	2	3	4	5	6

Parameter #1:Region sequence & identification number
Parameter #2:Mill groove region tool location (Z-STP safety)
Parameter #3:Initial tool location (Z-STP/X-STP)
Parameter #4:Tool Number
Parameter #5:Feedrate
Parameter #6:Speed

The features which form a mill-groove region are described by the parameters defined in table 10.

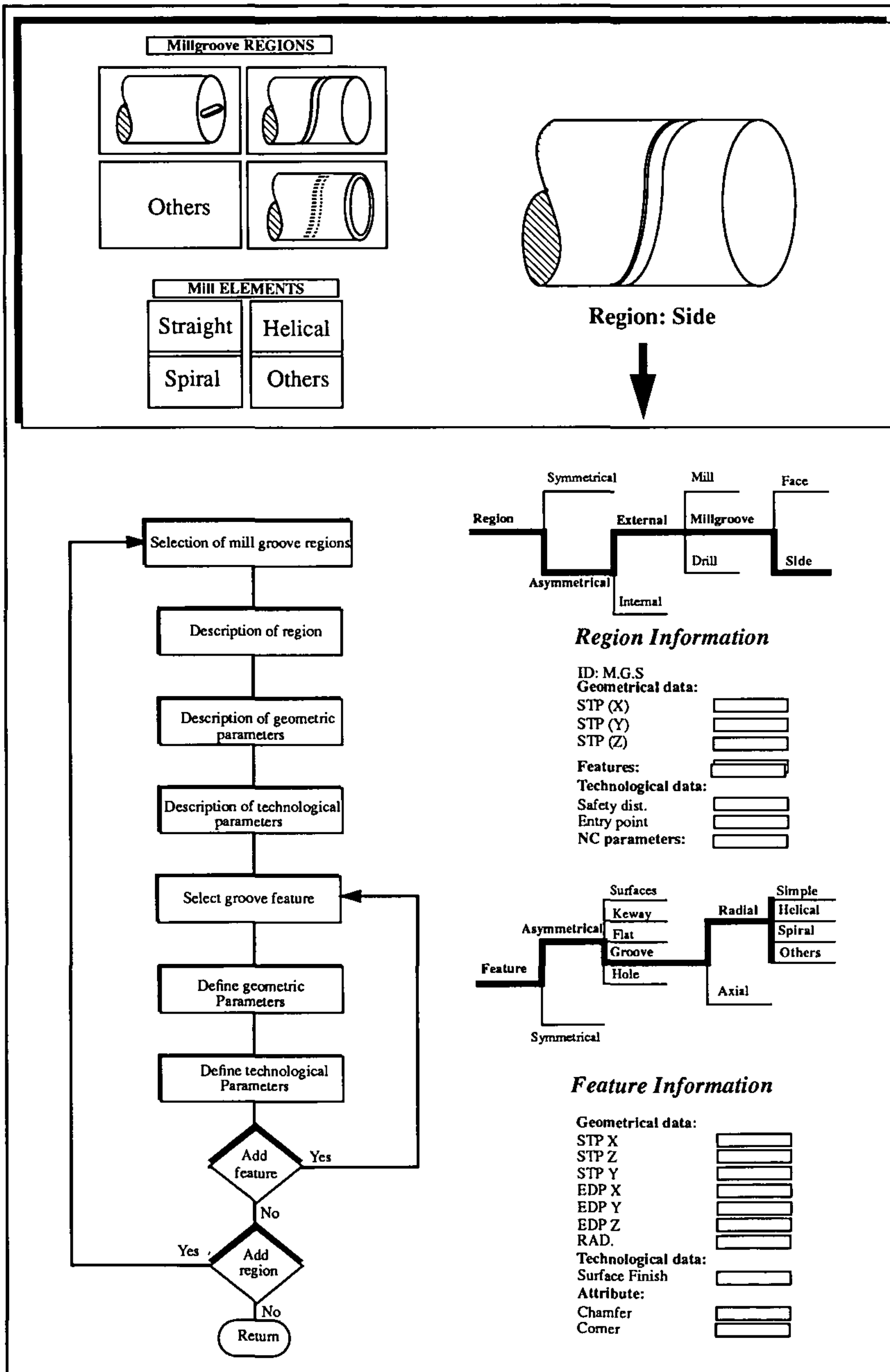


Figure 9.12	Mill-groove region	L.U.T- CAD/CAM

Table 10: Featur's geometric & technological data

F/N	F/T	STP X	STP Y	STP Z	FTP X	FTP Y	FTP Z
1	2	3	4	5	6	7	8

Parameter #1:Feature identification number
Parameter #2:Feature type (e.g helical, spiral, straight, etc.)
Parameter #3:Initial geometric location of groove (X-STP)
Parameter #4:Initial geometric location of groove (Y-STP)
Parameter #5:Initial geometric location of groove (Z-STP)
Parameter #6:Final geometric location of groove (X-FTP)
Parameter #7:Final geometric location of groove (Y-FTP)
Parameter #8:Final geometric location of groove (Z-FTP)

9.16.6 - Drill/Hole-Region

Three drill regions are identified and depicted in figure 9.13. They are:

i-Side
ii-Face
iii-In

A drill/hole region is defined by the parameters specified in table 11:

Table 11: Region's geometric & technological data

S/N	T/S	T/N	F	S
1	2	3	4	5

Parameter #1:Region identification number and sequence
Parameter #2:Tool safety distance (X-STP/Y-STP/Z-STP)
Parameter #3:Tool number
Parameter #4:Feedrate
Parameter #5:Speed

The parameters for hole feature as depicted in figure 9.13 are further listed in table 12. This information can be extended to both single hole and hole patterns for the features listed below:

i-Drill hole
ii-Reamed hole
iii-Tapped hole
iv-C'bore hole

Table 1: Feature's Geometric & technological data

F/N	F/T	O/T	H/P	P/D	N/H	A/FH	A/BH	H/D	P/V	D/W
1	2	3	4	5	6	7	8	9	10	11

Parameter #1:Feature identification number
Parameter #2:Feature type (e.taped hole, ream hole, C'bore etc.)
Parameter #3:Operation type
Parameter #4:Hole pattern/single hole
Parameter #5:Pattern diameter
Parameter #6:Number of holes
Parameter #7:Angle of first hole
Parameter #8:Angle between each hole
Parameter #9:Hole depth
Parameter #10:Peck value
Parameter #11:Dwell value

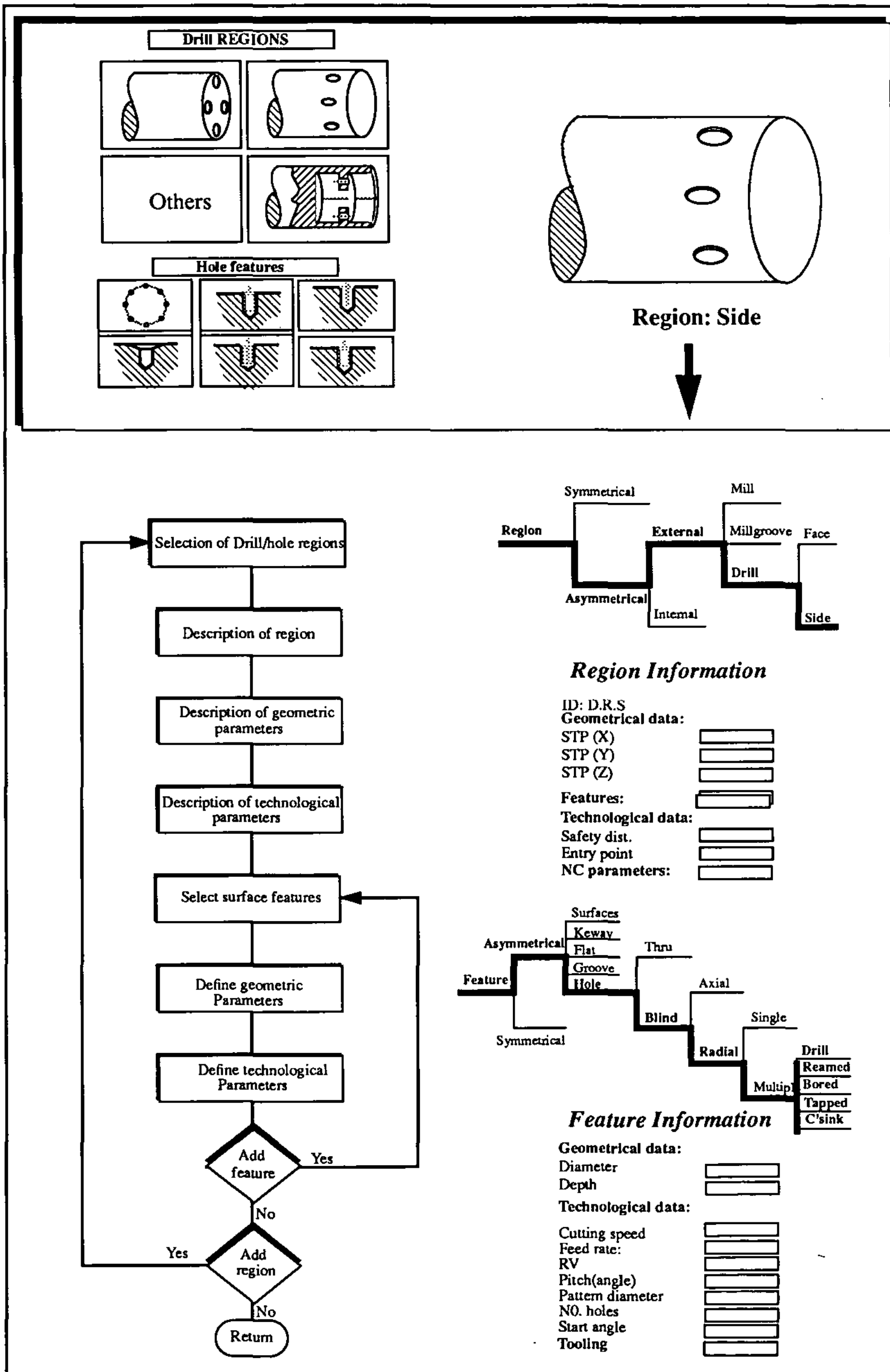


Figure 9.13	Drill/ hole region	L.U.T- CAD/CAM

Chapter 10

Technological User Support System

10.1 - Introduction

This chapter reports on the research into the design and implementation of a technological user support system. This sector of the research is described in detail so as to provide understanding and clarification of the technological activities in the workshop oriented NC planning system. It has been found helpful to use IDEF0 modelling to capture the description of technological activities *[see appendix III]*.

10.2 - Scope of Technological User Support System

The purpose of the research into the technological user support system is to devise a set of mechanisms which can assist in the preparation of technological data. This system consists of several modules *[figure 10.1]*. The sum of these modules constitutes the description of the functionality required by the user support system. The overall objective is to prepare the technological information and setup required by the NC planning system. This information is concerned with materials, cutting tools, machining data and clamping devices and each category is described at length in the following sections.

10.3 - IDEF0 Representation

An IDEF0 model is used for the purpose of decomposing, clarifying and conveying the interaction, information and activities involved in the technological user support system. It has been found that IDEF0 modelling is a positive way of getting a core representation of the interaction of all the concepts researched in this thesis. As can be seen *[appendix III]*, the technological user support is an integral part of the work shop oriented NC system. The task performed by the technological user support system is highlighted and decomposed using an IDEF0 model into the following activities:

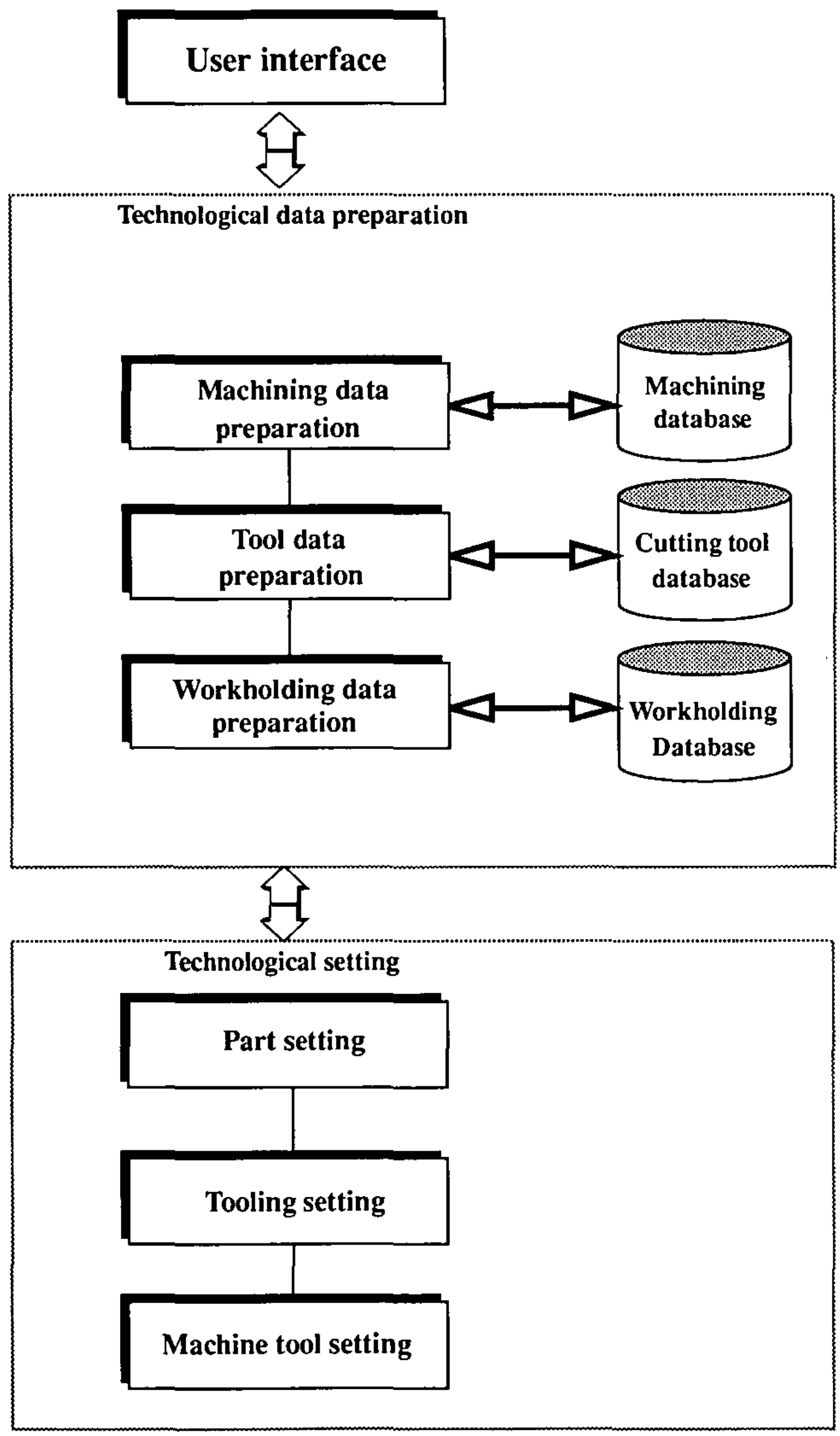


Figure 10.1	Data preparation flow	L.U.T- CAD/CAM

i- Technological data preparation

ii- Part setup

iii-Tooling setup

iv- Machine tool setup

The task of technological data preparation is to provide the necessary information regarding cutting tools, materials, inserts, machining data, and work holding devices *[figure 10.1]*. This information is held in several databases. The user is provided with the facilities to input or modify the technological information. This information is used support operation planning decisions. It is the technological requirement that dictates how and what information must be maintained or modified. These requirements will inevitably be restricted by the available resources. The appropriate information regarding machining data, tooling data and workholding information is determined at this stage.

The next activity is concerned with setting the workpiece or part. The necessary information regarding the type of material, part orientation and datum is decided based on the technological requirement derived from the technological requirements and shop-floor practice.

The tooling setup activity is concerned with specifying the cutting tools and workholding devices required for machining a given component. Information regarding the selected tooling is kept in the technological database. The selection of tools and workholding devices is based on the operation requirement. The last activity is concerned with specifying the appropriate machine tool and post processor. The machine tool selection criteria are primarily based on the operation type and geometrical requirement of a workpiece. However this activity is only considered if a range of machine tools are available to choose from.

In addition the workshop oriented NC planning system is designed as a non-dedicated system, therefore, it can be adapted (*postprocessed*) to generate manufacturing instructions for different machine tools. If a machine tool is already specified and the workshop oriented NC planning system is only required as a programming aid, then the machine tool selection highlighted will be inevitably be redundant.

10.35 - CNC Machining Knowledge

The user support system is to make available a set of facilities which can simplify data preparation and decision making. Alternatively the comprehensive range of manufacturing data designed and embedded for the turning process can be viewed as a CNC machining expert [*Bell 92*]. In this case a set of data and or knowledge regarding the turn/mill processes can be accessed for generating manufacturing instructions and also for use as a guide to assist the designer or engineer by providing sufficient insight into CNC turning processes. This approached has been utilized and emphasized by several people *[Allen 89], [Varvakis 91]*. The importance of this approach is that a set of knowledge and data can be made available from the beginning to the designer for the purpose of rationalizing and improving the decisions made at the design stage.

10.4 - Technological Data Preparation

In computer aided manufacturing, and in particular NC planning, a major source of manufacturing errors is caused by the use of outdated, inconsistent and incorrect information as the basis for generating manufacturing instructions *[Alho 89]*. The development of the advanced manufacturing system has highlighted the need for rapid access to "proven" data in the technological field *[Weill 78]*. Today in many computer aided manufacturing fields such as process planning and NC planning, there is a great need for accurate and "proven" information *[CIRP 75]*. This can be interpreted to mean that today activities in computer aided manufacture require data that is based on good manufacturing practice, and not just on laboratory results or first approximation indications *[Weill 78]*. Therefore, there is an extensive effort to build a database that includes a wider range of processes, materials, cutting tools and proven machined conditions *[Metcut 80][PERA 77]*.

In the NC planning activity various methods and techniques are used to obtain technological information. The task of technological data preparation is to utilize the designed database and provide the appropriate and proven data to determine the necessary manufacturing information. Several methods are used to calculate or retrieve the technological information, see section 10.4.4.2. Traub *[1989]* uses two different techniques for determining the manufacturing information. The first technique is to use the 'experience data file'. This data file is utilized by the operator to retrieve/input the technological information when machining familiar materials. Alternatively the machining data can be calculated by Traub's technological processor. Thus the system allows the operator to solve any likely problems independently, even when machining unfamiliar materials, cutting tools and tool tip geometries. A different technique is used by Mazak *[1989]* in which several databases are utilized. The system uses a percentage weighting to adjust and match the technological information to the user's need. The method used by the author for the NC planning system uses proven information from the Metcut *[1980]* handbook. Alternatively the potential for modifying the database to suit the operator's needs is taken into consideration. The approach pursued is in some way similar to methods used by Traub *[1989]* and Mazak *[1989]*.

10.4.1 - Technological Database

A pre-requisite of any high level NC planning system is the existence of a computer based information management system *[Ranky 83]* providing several relevant technological databases *[figure 10.2]*. The database designed for the NC planning system functions in two ways: externally and internally. External communication is concerned with the user's input of relevant data. This information is concerned with:

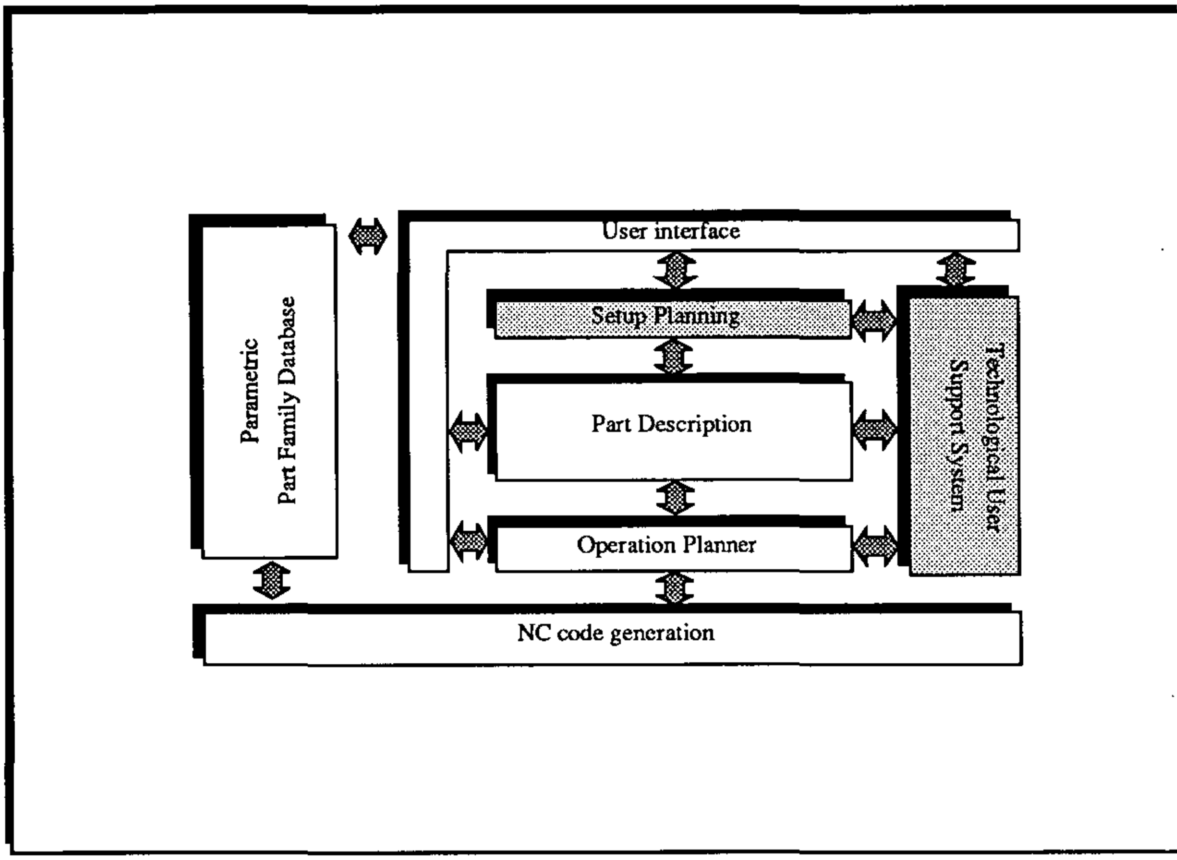
i- Tooling information needed for various cutting processes and geometry.

ii- Insert information for the determination of optimal machining data.

iii-Workholding (*clamping devices*)

iv-Machining data

v- Material data



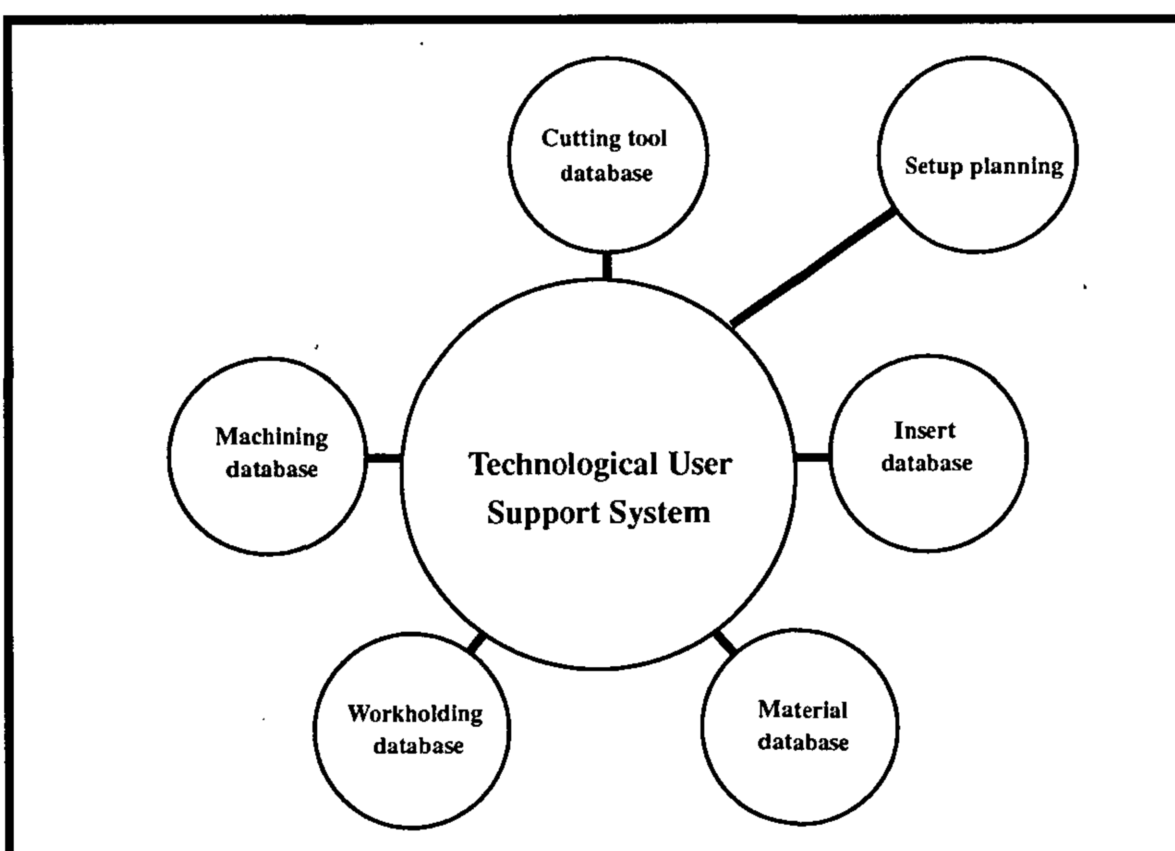


Figure 10.2	Databases & communications	L.U.T- CAD/CAM

Internally, the operation planner modules require accurate and appropriate technological information *[figure 10.2]*. This information is retrieved from the databases.

A database for a computer aided manufacturing system involves tremendous complexity. Size and information characteristics are issues, but also the appropriate structure must also provide and gather the necessary information efficiently *[Eastman 91]*. Modern database management systems *(DBMS)* are essential *[Yancey 87]* in conducting NC planning. They provide a powerful and flexible means of managing the wealth and diversity of information that needs to be held for NC purposes. A database is simply a collection of related data stored together without unnecessary redundancy *[Yancey 87]*. The data for an NC planning system is stored so that it is independent of programs that use the data. A structured and common approach is used in adding new data and in modifying, deleting, or retrieving existing data within the database. In order to take full advantage of a database, the DBMS was designed to be closely coupled with the NC planning system *[figure 10.2]*. The technological database is integrated to support various activities in this system.

10.4.1.1 - User Interface

An effective and user friendly mechanism is devised for manipulating and inputting information. The user interface consist of multiple Windows, pull down menus, and graphic icons. These facilities are activated by Mouse. The task of the user interface is to allow a simple and yet effective interaction between the user, NC system and the databases *[figure 10.21]*.

10.4.1.2 - Material Database

Material property forms the nucleus of technological derivation. Several factors such as feed rate, cutting speed, tool type and horse power are dependent on the type of material selected *[Allen 89]*. There are literally hundreds of different properties of materials. The most important to consider when selecting a material for a given part are those that are essential to the function of the part.*[Budinski 89]*. The study of

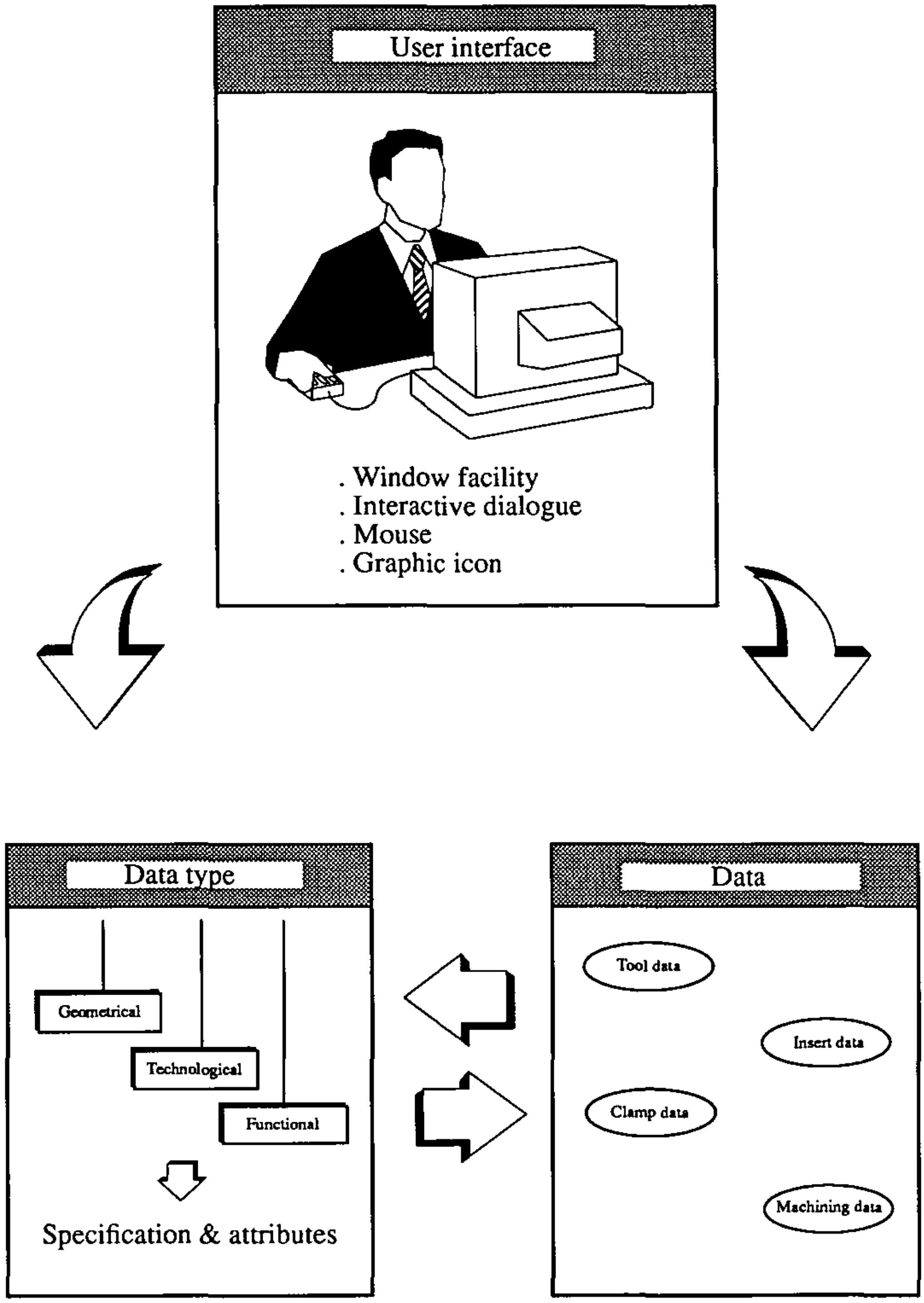


Figure 10.21	The database user interface	L.U.T- CAD/CAM

parameters involved for material selection is beyond the scope of this research. What is important is the characteristics of the selected material which influence the technological data derived for machining operations. The material characteristics used for this system are listed and their machineability ratings are specified: aluminium, brass, and plastics have good to excellent machineability rating, while cast iron and mild steel only have good machineability characteristics. Stainless steel has a poor to fair rating because of its toughness and its tendency to work harden when machined *[Drozda 83]*. The selection of material is based on the technological requirement. The material database is equipped to accommodate a limited range of materials. Materials are defined when describing the workpiece. Five basic categories of material are considered:

i- Steel

ii- Cast iron

iii-Aluminium

iv-Plastic

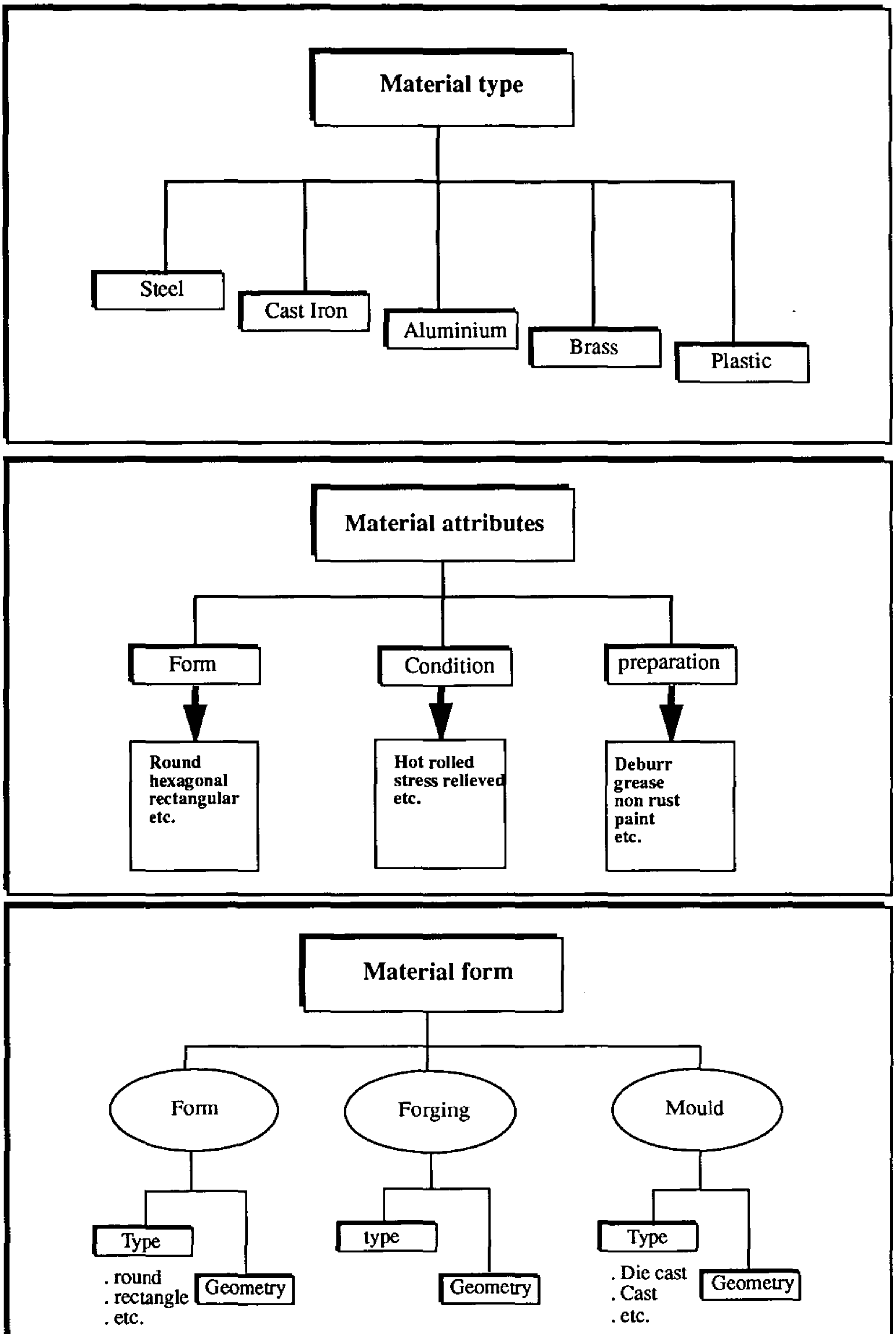
v- Brass

10.4.1.3 - Material Attributes

Material attributes *[figure 10.3]* are concerned with the material form, condition and surface preparation *[Butterfield 85]*. Material form is important from the NC planning aspect. The shape *(form)* of a given workpiece *(blank)* has an impact on NC code generation. *[Allen 89]*. Other attributes of material as depicted *[figure 10.3]* are used mainly for process planning purposes. These attributes are concerned with material condition and surface finish preparation. They fall outside the domain of this system and thus are not taken into consideration.

10.4.1.4 - Material Form

The initial material may take a number of forms *[Figure 10.4]*. The most common of which are bar-stock, plate, forging and moulding *[Chang 85] [Butterfield 85]*. With these raw materials, the necessary steps must be observed to establish an appropriate



Adopted from Butterfield 85

Figure 10.3	Workpiece material characteristics	L.U.T- CAD/CAM

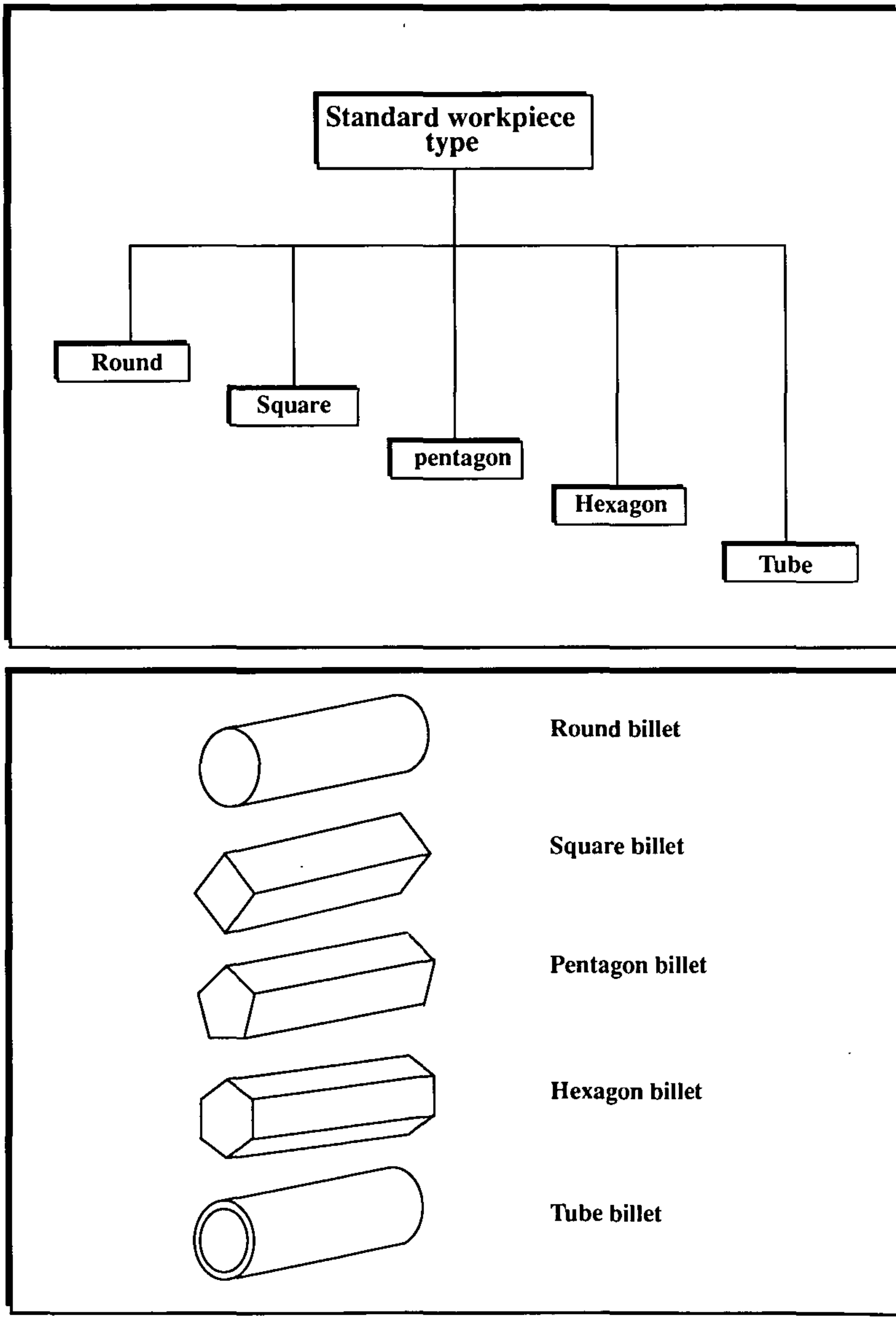


Figure 10.4	Workpiece shape	L.U.T- CAD/CAM

setup. As depicted *[Figure 10.4]* only barstock and principally symmetrical components are considered. The shape of the workpiece has an influence on the workholding method selected.

10.4.2.1 - Insert Database

Another piece of important information in the technological preparation is concerned with the cutting tool insert data. The selection of an appropriate insert is vital in producing a quality product. Variables that influence insert selection are *[Drozda 83]*:

i- Workpiece material and condition

ii- Tolerance, surface finish

iii- Cutting speed, feed rates and depth of cut

iv- Setup and rigidity

vi- Operation type

vii-Insert holder type

The insert information serves several purposes. Information pertaining to inserts can be grouped and held in the insert database *[figure 10.5]*. This data could be queried by the user, or the system, and can be subsequently used to retrieve or calculate the necessary machining information. This data will be useful in determining the suitable range of inserts. The user can add or modify insert attributes. The tooling and machining data are based on the insert characteristics *[Boothroyd 89]*. These characteristics are essential in determining the correct machining data. As shown *[figure 10.5]* the inserts embody five major characteristics:

i- Shape

ii-Application

iii-Operation

iiv-Material

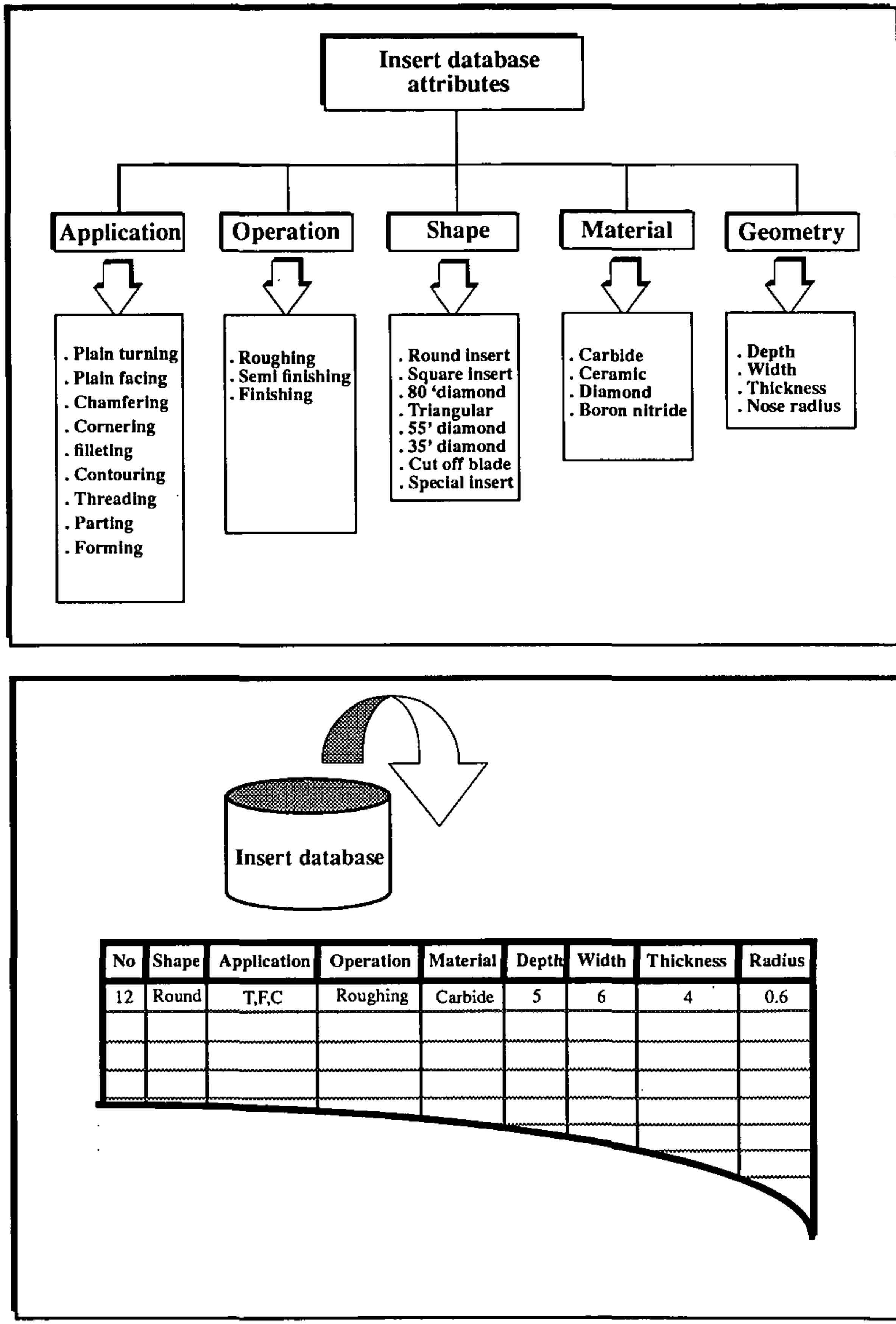


Figure 10.5	Insert database and attributes	L.U.T- CAD/CAM

v-Geometry

10.4.2.2 - Insert Shape

The most suitable insert shape that the configuration of a given workpiece demands should be selected. Each region can accommodate certain shapes, see chapter 11. As depicted *[figure 10.6]*, the system uses standard inserts. Each category of insert is representative of a particular shape and set of characteristics. *[Drozda 83] [Allen 89]*.

10.4.2.3 - Insert Application

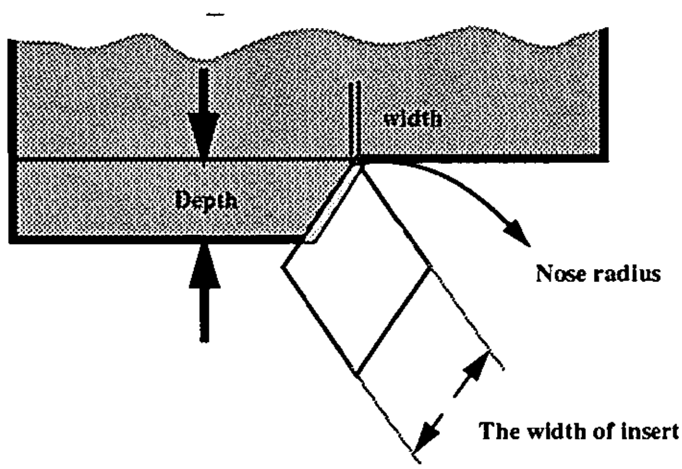
As can be seen, each shape is designed to perform a particular operation. The geometry of a given workpiece as well as operational requirement are the main factors used for insert selection. It is important to select the correct insert for the relevant operation. As depicted in figure *[10.6]* the larger the angle of the included corners the stronger the insert. Inserts with larger included angles (*round insert, square insert, 80 degree diamond*) are used for roughing operations. These inserts are used for turning, facing and contouring. Inserts with smaller included angles (*triangular insert, 55 and 35 degree diamond*) are assigned for finishing operations. These inserts are used for turning, facing, and contouring operations. *[Drozda 83]*

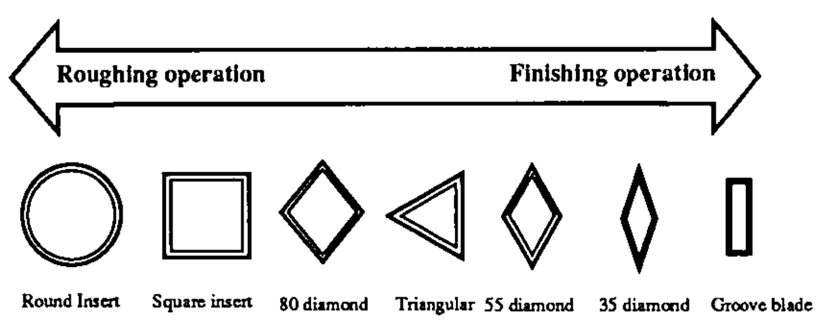
10.4.2.4 - Insert Material Characteristics

The material characteristics of the insert are directly related to the type of cut, workpiece material and surface finish specification *[Amstead 87]*. Four major materials are offered. But in order to reduce CPU time, and data storage, only coated carbide inserts are considered in the experimental system. There is however the potential to add inserts with different material characteristics.

10.4.2.5 - Insert Geometrical Characteristics

The geometrical characteristics of the insert determine whether a particular region can be machined with a certain insert geometry. It is potentially the task of the operation planner module to compare and select the correct insert geometry for a given work-





Material	Insert shape	Operation	Application
Car, Cer,Dia,Bn	Round Insert	Roughing	Turning, recessing, Contouring
Car, Cer,Dia,Bn	Square insert	Roughing	Turning,Facing
Car, Cer,Dia,Bn	80 diamond	Roughing	Turning, Facing
Car, Cer,Dia,Bn	Triangular	Finishing	Turning, Facing,Contouring
Car, Cer,Dia,Bn	55 diamond	Finishing	Turning,facing,contouring
Car, Cer,Dia,Bn	35 diamond	Finishing	Turning,facing,contouring
Car, Cer,Dia,Bn	Groove blade	Rough & finish	Parting,grooving,recessing

Figure 10.6	Insert characteristics	L.U.T- CAD/CAM

piece. For further discussion see chapter 11. The geometrical attributes are entered into the insert database for further utilization by user.

10.4.3.1 - Cutting Tool Database

When developing NC code, one of the planning stages is tool selection. Proper selection of cutting tools is important to any NC planning operation which involves up to date knowledge of cutting tools. One of the problems associated with the use of numerically controlled machine tools is the provision and control of cutting tools. The efficient control and utilization of cutting tools demands an effective cataloguing of their usage *[Crossely 87]*. The cutting tool database is based on a series of numbers by which each individual cutting tool is identified and referenced, and to which the geometrical and technological characteristics for each tool are specified. The cutting tool data held in the database can be readily updated and modified by interactive dialogue. The data stored in the database can be easily accessed by the system *(internally)* or the user (*externally*).

Tools are classified into several categories based on machining operation. The classification is related to variation in shape and application *[Eversheim 87]*. The classified tools are *[figure 10.7]*:

i - Turn-out tools

ii- Turn-in tools

iii- Groove-out tools

iv- Groove-in tools

v- Thread-out tools

vi-Thread-in tools

vii-Drill-tools

viii-Mill-tools

The turn out tools are those tools that perform turning, facing and contouring on the outside diameter of a workpiece. The turn-in tools are assigned to perform the inside

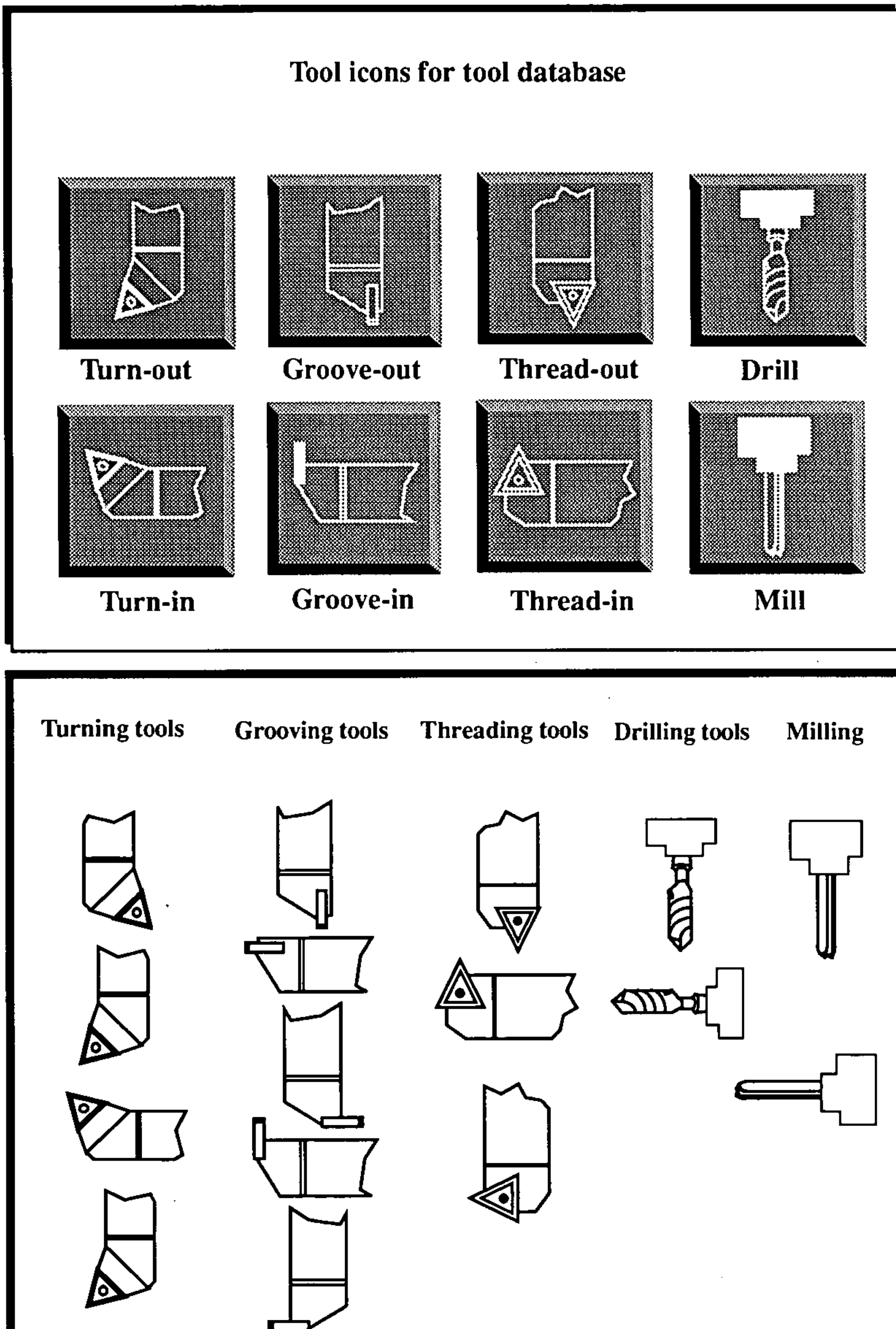


Figure 10.7	Cutting tool database	L.U.T- CAD/CAM

diameter operations. The groove-out tools are used for external grooving operations, the groove-in tools are assigned to perform inside diameter grooving. The threading tools are classified similarly. The thread-out tool is used for any outside diameter threads and the thread-in tools are used to perform the inside threading operation. The last category is drilling and milling tools. These are live tools which perform milling and drilling operations on a turning centre.

10.4.3.2 - Cutting Tool Parameters

The tool classification scheme imposes requirements on the tool database *[Eversheim 87]*. The tool data is classified *[figure 10.8]* based on the following parameters: *[Mazak 89][Traub 89][Hinduja 86]*

i - Tool identification data

ii- Tool function

iii-Tool position

iv -Technological data

v - Geometrical data(insert)

vi -Tool holder position

vii-Tool holder geometry

viii-Tool graphic icon

10.4.3.3 - Cutting Tool Identification

Tool identification data is a unique number which is associated with each tool, and is used to identify and reference it. This data is used to modify or add and manipulate the tooling information.

10.4.3.4 - Cutting Tool Position

Several tool positions are needed to produce a workpiece. Geometry and direction of cut are the primary parameters that influence tool position. As depicted *[figure 10.9]* three major categories of turn tools are specified:

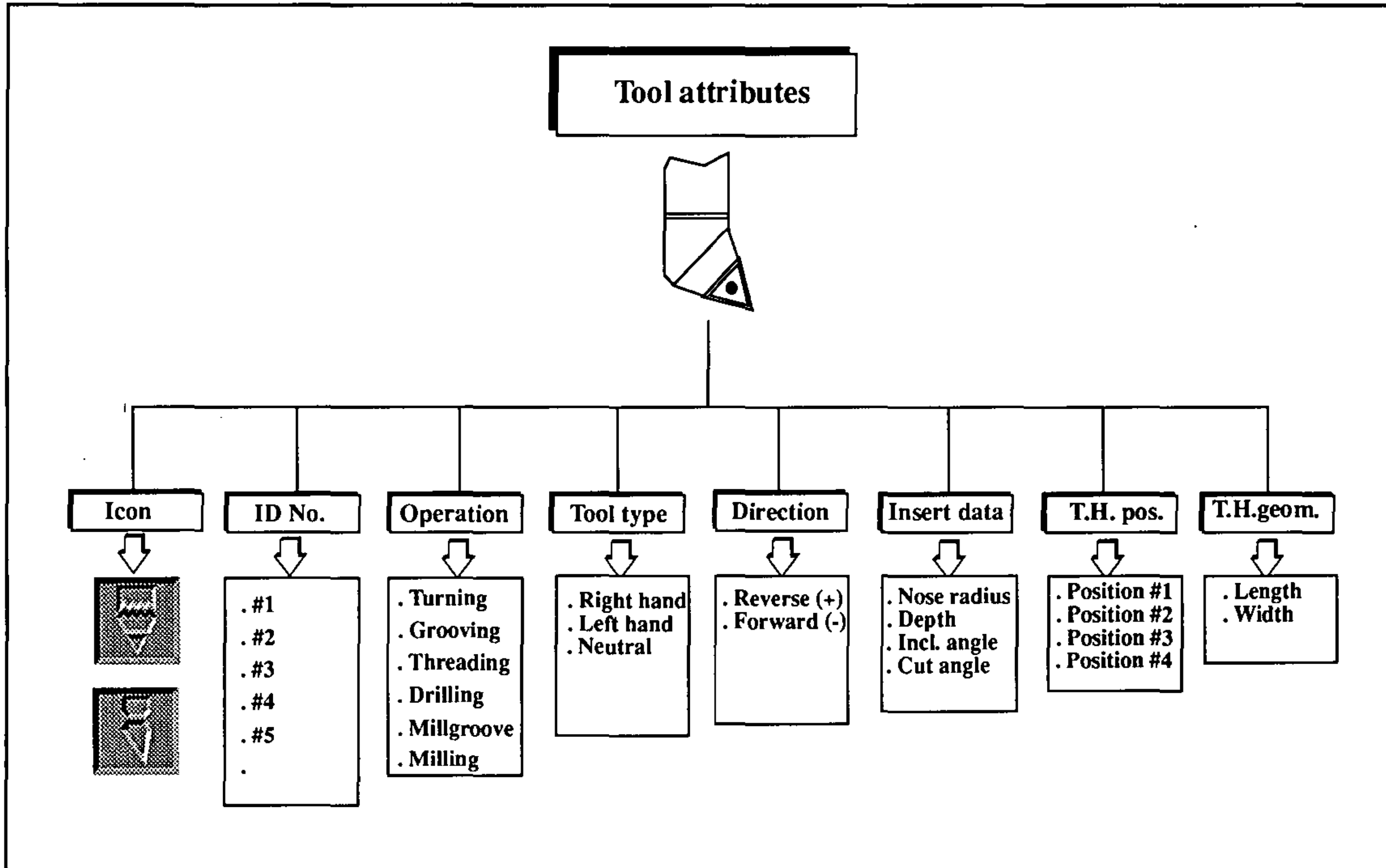


Figure 10.8	Cutting tool information for asymmetric rotational characteristics	L.U.T- CAD/CAM

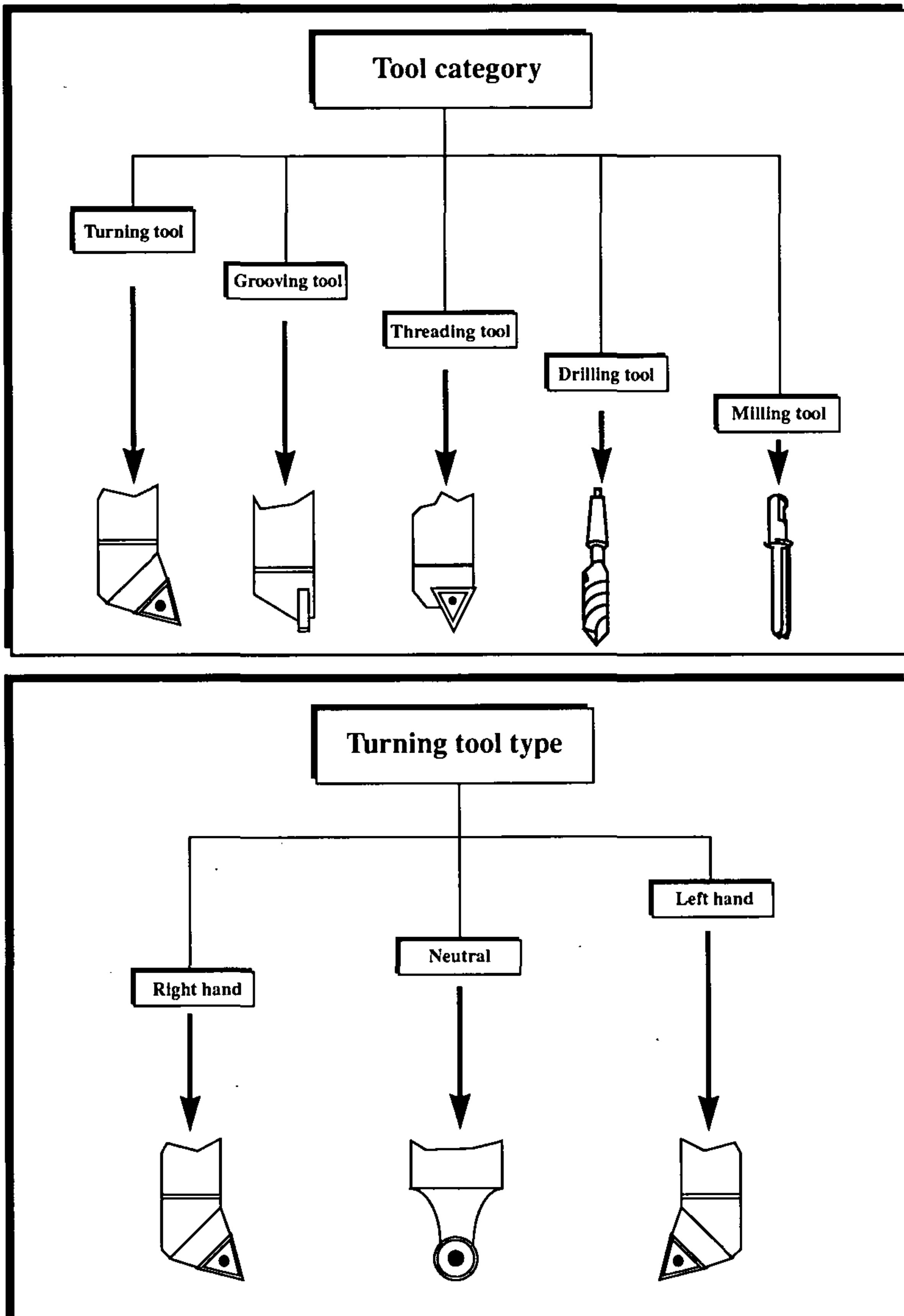


Figure 10.9	Cutting tool position & operation	L.U.T- CAD/CAM

i- Left handed cutting tools

ii- Right handed cutting tools

iii-Neutral cutting tools

A left hand, right hand, or neutral cutting tool can be used to machine a particular region. The most commonly used tools are the right and left handed cutting tools. However, it is the direction of cut as well as the geometrical configuration of a given region which determines the tool position. The left and right handed cutting tools are restricted and cannot be used for all geometrical possibilities. In the cases where a left or right handed tool can not be utilized the neutral cutting tools can be used to machine that region. It is important to point out that a neutral tool exerts more force and, therefore, imposes more demands on the machine tool *[Hinduja 86]*

10.4.3.5 - Cutting Tool's Technological Data

This information is concerned with the workpiece rotational direction *[fig 10.10 a]*. This is the next logical sequence in setting tool information. After specifying the required tool position. the correct direction needs to be specified. A correct direction is that when the workpiece is rotated toward the cutting tools it results in cutting. The incorrect direction moves the workpiece away from the cutting tool which results in rubbing against the tool. The directions are displayed by negative *(-)* and positive *(+)* signs. The next piece of information is concerned with the cutting tool's attributes. Information such as nose radius, entrance angle, allowable depth of cut, and included angle is of paramount importance in determining the correct cutting tool for a particular region *[fig 10.10 b]*.

10.4.3.6 - Cutting Tool Holder Position

The tool holder position is used to determine the orientation of the shank with respect to a given workpiece *[fig 10.11]*. This information is used to detect any possible collision. The correct tool holder must be specified to handle the assigned operation.

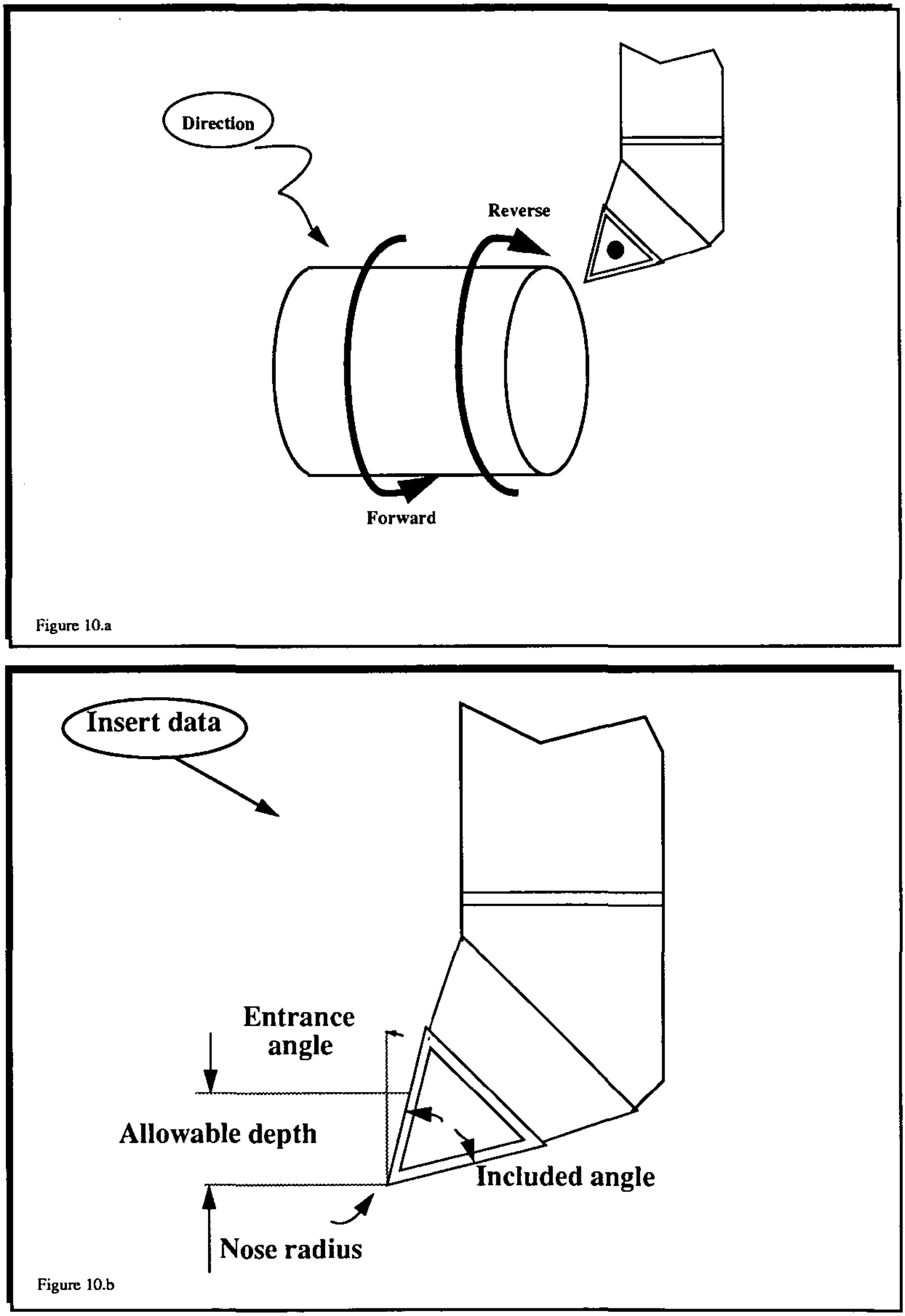
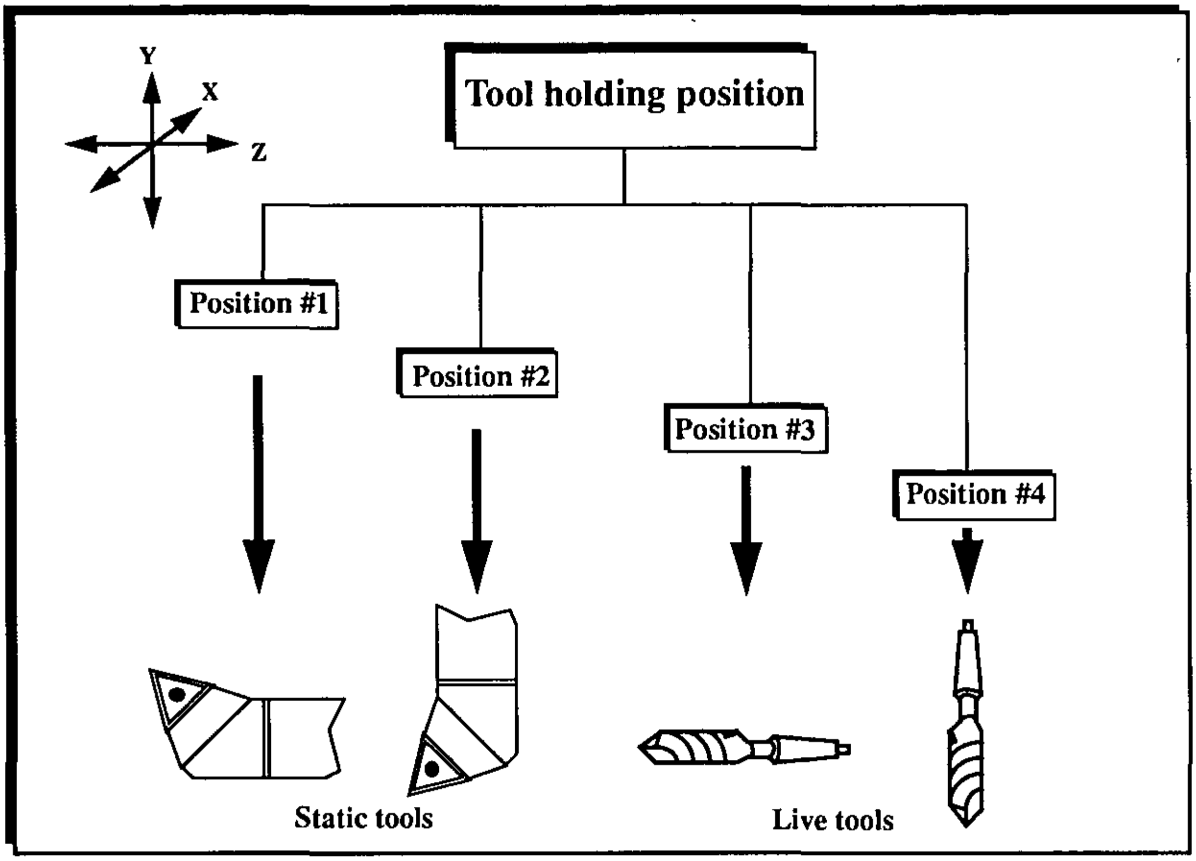


Figure 10.10 | Cutting tool technological information | L.U.T- CAD/CAM



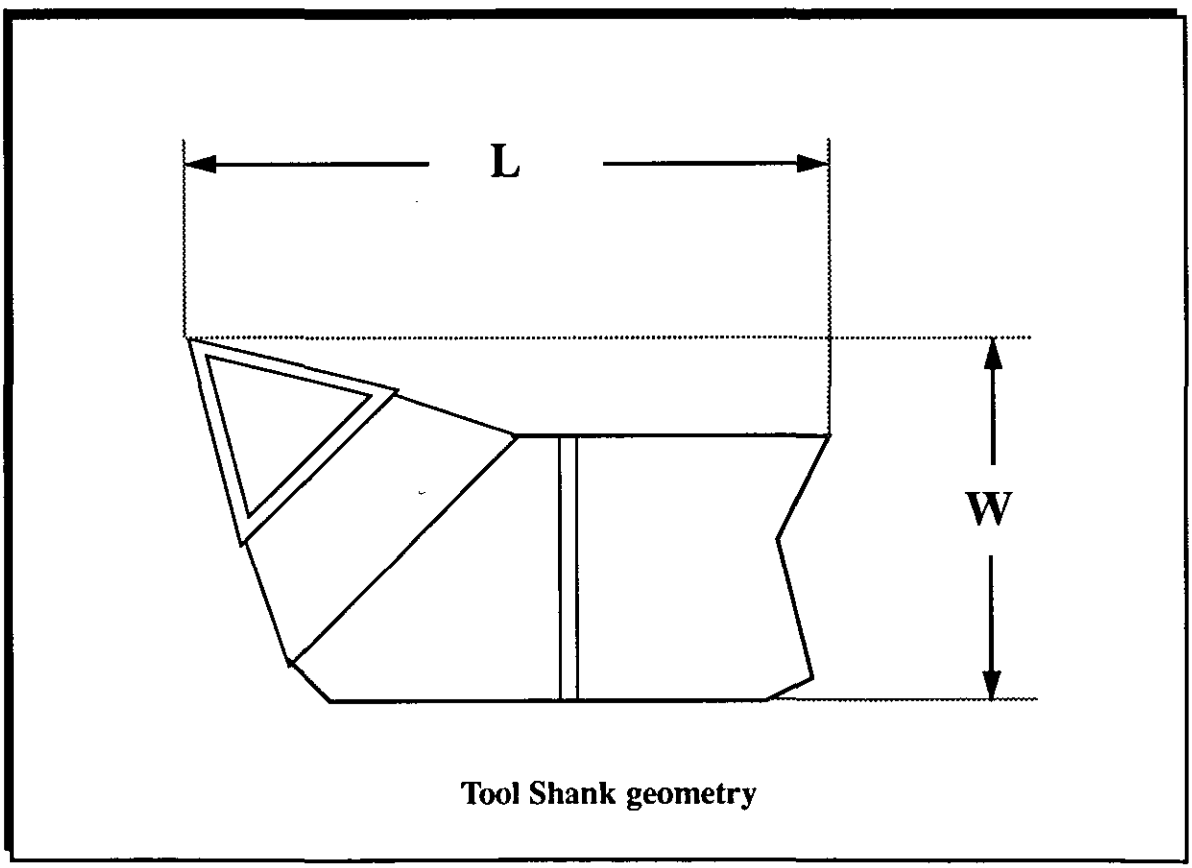


Figure 10.11	Tool holder geometry and position	L.U.T- CAD/CAM

[Traub 89] [Mazak 89]. Each tool holder position is designed for a certain category of operation. The four major tool holder positions are described below:

i - Position #1 is a horizontal position (*static tools*)

ii- Position #2 is a vertical position (*static tools*)

iii-Position #3 is a horizontal position (*live tooling*)

iv- Position #4 is a vertical position *(live tooling*)

Position one consists of those tools that are perpendicular to the face of the workpiece and parallel with the Z axis, these tools are classified as static tools and are used for turning, grooving and threading. These tools are mainly used for internal operations. Position two consists of those tools that are parallel to the X axis and perpendicular to the outside diameter of the work piece. These tools are static and are used mainly for external operations. The next major category represents live tooling. Position 3 is concerned with those parts that are perpendicular to the face of the workpiece. These tools are used for milling, drilling and millgrooving operations. The next and final category is position 4 which represents live tools used for external operations performed on the outside diameter of the workpiece. The tool holder position is perpendicular to the Z axis. This position is used for turning, drilling, and millgrooving operations.

10.4.3.7 - Cutting Tool Holder Geometry

This information is concerned with the geometry of the shank. The geometry of the shank provides vital information about cutting tools and correctly shows any possible collision between the part geometry and chuck. The geometry specified in terms of length and width must be the reflection of the actual geometry on the turret. This information provides a clear view of possible problems in CNC operations.

10.4.3.8 - The DBMS for Cutting Tools

The cutting tool database is designed to assist the user to plan the cutting tools that are required during the machining operations. A user friendly interface assists the user in generating the search instruction. The menu guides the user through the database. The selection process is facilitated by graphical icons. By selecting each tool icon the appropriate questions are asked and relevant information is entered and or modified. The user can input all the tool information required for a component. The full range of questions or specifications related to the cutting tool are interactively prompted by the database management system. These parameters are specified in 10.4.3.2. In addition, the questions are designed to suit the category of tools available in the system. The DBMS interface is designed to provide guidance semantically (*see section 10.4.3.1*) for selecting the relevant tool for a particular operation and geometry.

10.4.3.9 - The Tool Database Task

The most essential task of this database is to contain data and provide access for input and modification of the data both by the user and the system. Users are allowed to input/modify tooling information. The purpose of inputting tool information can be viewed from two aspects. The first aspect considers those tools which are needed for a particular component. This information will enable the user to realize the limitations and further more allows the user to know the range of standard tools that are available in the manufacturing plant. Alternatively, the cutting tool database can accommodate a range of cutting tools for several components.

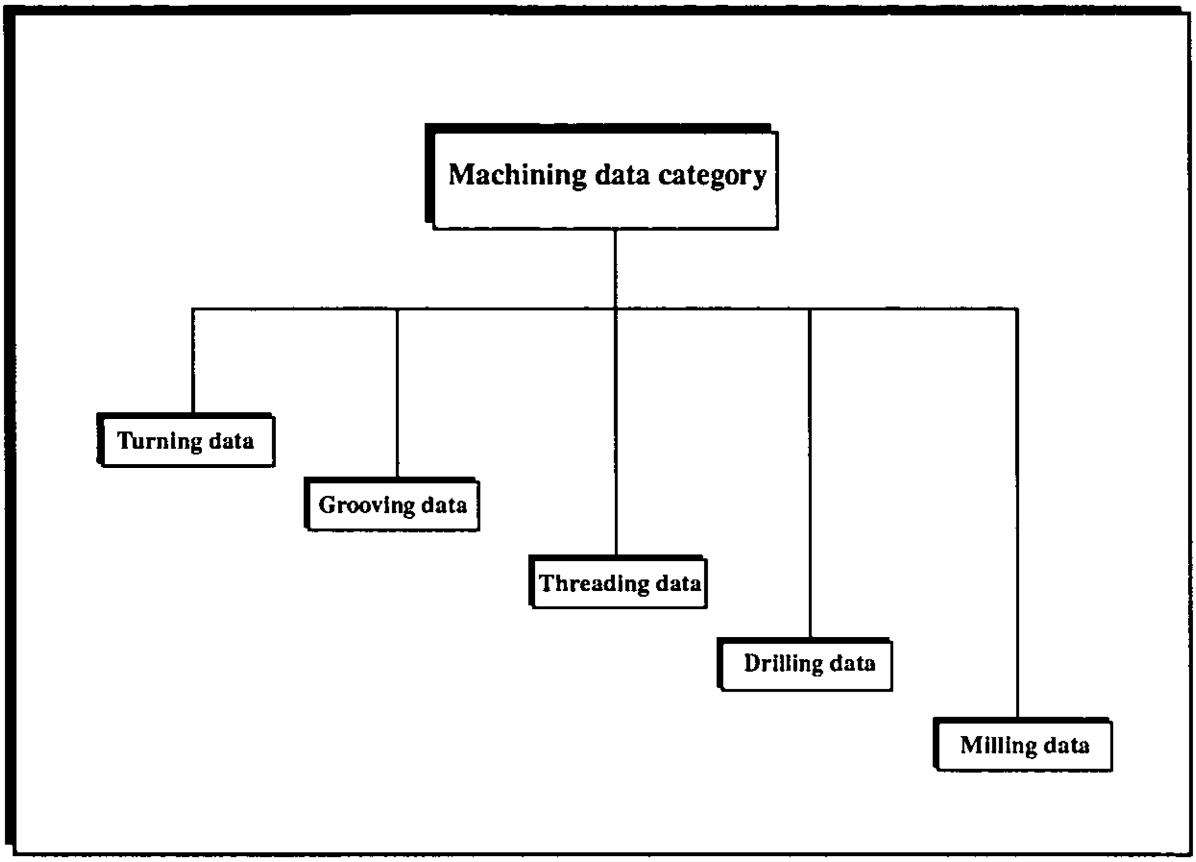
10.4.3.10 - Internal Integration

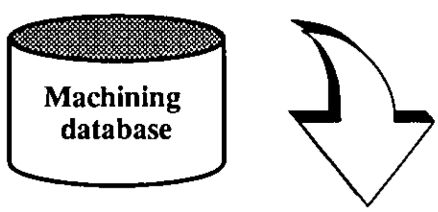
The database is an independent entity. The user can access information and subsequently modify data. The database is designed to be linked with the NC planning system. Therefore the data contained in the database can be used by the NC planning system.

10.4.4.1 - Machining Database

Several categories of machining data are represented in the database *[figure 10.12]*:

i - Machining data for turning





Material	Insert	Operation	Depth of cut	Spindle speed	Feedrate
Alum.	Carbide	Turning	x mm	X R.P.M	mm/m.

Figure 10.12 | Machining data & database | L.U.T- CAD/CAM

ii- Machining data for grooving

iii-Machining data for threading

iv-Machining data for drilling

v- Machining data for milling

For each appropriate operation the relevant machining category is invoked and utilized. For more information see chapter 11. The cutting data information has been extracted from the METCUT *[1980]* machining data handbook.

The machining database contains the necessary machining information. This information can be input and or modified by the user. The type of data assigned is from the Metcut machining handbook, nevertheless this information can be replaced by the user's data which can be based on machining experiences. A similar approach is used by Traub *[1989]*. The information held in the database is generally designed for coated carbide tools. This constraint is imposed by the experimented system in order to reduce CPU time. However, machining data pertaining to other cutting tools can also be added.

10.4.4.2 - Machining Data Selection

The assignment and selection of "optimal" machining data (parameters) is an essential and yet difficult task. A significant amount of work has been conducted in this area *[Wang 85] [Tipnis 75][METCUT 80]*. The desired and or optimal solution has not yet been found.Three selection methods are practised and found to be effective *[Wang 86]*:

i - Mathematical optimization

ii- Heuristic equation

iii-Data retrieval method

10.4.4.3 - Machining Data

The workshop oriented NC planning system can automatically calculate the machining information *[TRAUB 89][MAZAK 89]*. Once the cutting tools are selected (*tool data-*

base) and the tools for the region are determined (*see chapter 11*) the machining data can be retrieved *[Tranub 89]* or calculated *[MAZAK 89]*.

10.4.4.4 - Database Management System for Machining Data

The database provides a user friendly access to machining information. Relevant data can be looked up or retrieved. In addition, machining information can be added or deleted. The user interface uses Windows and a Mouse facility. A form or template is provided for accessing the database information.

10.4.4.5 - Internal Integration

The machining database can be accessed by a user to add or modify information. This information can be used independently of the NC planning system. However, the machining database is integrated with the NC planning system, and allows the operation planner to access and manipulate machining data information. This facility provides a greater flexibility to the user and, therefore, allows the user to add necessary and sufficient information for NC planning purposes.

10.4.5.1 - Workholding for Turning

The power required at the cutting tool is transmitted through the work holding device to the workpiece and thus a safe, fast and rigid means of holding a workpiece on a CNC turning centre is an essential requirement. This is specially important when higher speed and closer tolerance and smoother finishes are required.

The force requirement for a rigid and safe workholding depends on the following parameters:

i- Geometric configuration of workpiece

ii- Overhang of the workpiece

iii-Workpiece materials and properties

iv- Cutting tools

v - Machining data (*speed, feedrate*)

Speed for workholders used for turning depends on the following factors:

i - Workpiece size

ii- Workpiece shape

iii-Workpiece finish

iv- Rigidity of the setup

v- The gripping force

vi-Operation

vii-Tools used

Several workholding techniques used for turning *[Hinduja 89][Allen 89]* are:

i - A chuck for clamping component

ii - Clamping using centre and chuck (*one end chuck & one end centre*)

iii- Clamping Between centres (*Two centre used to hold component*)

iv -Clamping using collets

v - Others

10.4.5.2 - Work holding Selection Method

Three distinctive systems or procedures for clamping the rotational workpiece exist:

i- Manual procedure

ii-Semi automated procedures

iii-Automated procedures

10.4.5.2.1 - Manual Procedures

Traditionally, the human operator or process planner has planned the workholding configuration. With these procedures every parameter for clamping is calculated and determined by the user.

10.4.5.2.2 - Semi-automated Procedures

In this method the user or operator is assisted to provide a limited range of information about clamp specification, position, and attributes *[TRAUB 89] [MAZAK 89]*.

However some factors such as best possible clamping position are not provided. Nonetheless, this limited information is sufficient to assist in setting the correct information for the workholding devices.The work shop oriented NC system uses a semi automated method for clamp selection, in which the user with the aid of the system provides the appropriate workholding parameters.

10.4.5.2.3 - Automated System

The main characteristic of the fully automated work holding systems are the Automatic decisions about clamping, numbers and succession of set-ups, positioning, selection of clamping devices and the necessary calculation.*[Noe 91] [Hinduja 89] [Tuffentsammer 81]*.

10.4.5.3 - Workholding Database

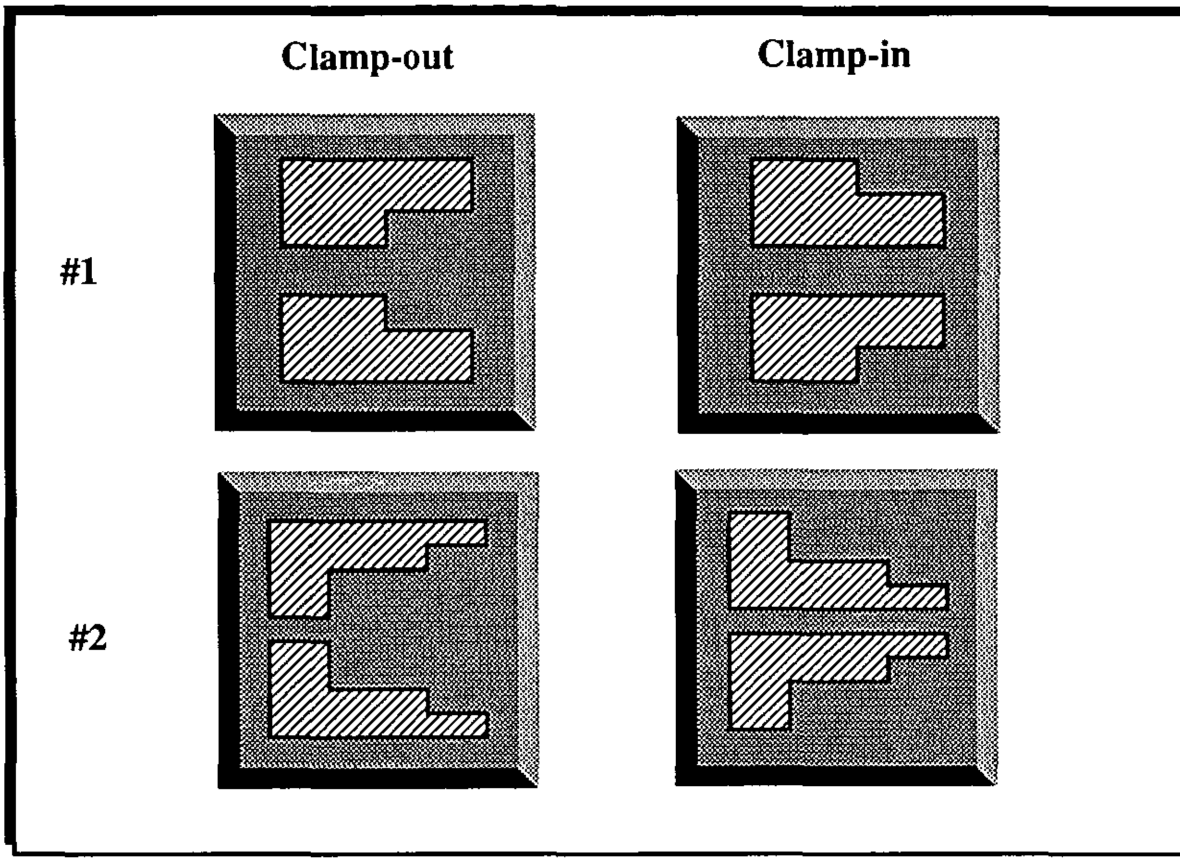
The workholding database contains the necessary information about the workholding device, type of workholding, the geometrical attribute of clamp, the geometrical attribute of part and clamp *[figure 10.13]*. The selection of workholding type and the clamp's geometrical attributes are specified by the user. This information is kept in the workholding database. Data regarding the common information between clamp and workpiece is described in section 10.7.

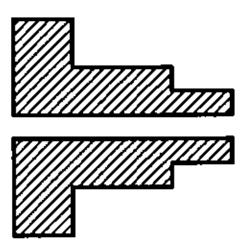
10.4.5.4 - Workholding DBMS System

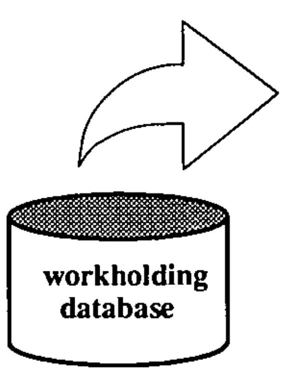
The workholding database is embedded with a user friendly interface for a general access to workholder information. The database allows an easy and interactive dialogue for modification and input of information. The user interface uses a Window and Mouse facilities that can ease the input of information.

10.4.5.5 - Internal Integration

The workholding database is integrated with other facilities and modules within the NC planning system. The information regarding a selected workholder is transmitted through an ASCCI file to the controller for the purpose of illustration and or simula-







No	Type	Out/in	A	B	C	D
# 1	1	out				

Figure 10.13 | Workholding database | L.U.T- CAD/CAM

tion.

10.4.5.7 - Constraints & Available Resources

The technological preparation is an essential aspect of manufacturing code generation. However the range of data and attributes used are limited. This constraint is imposed because of several factors. These factors primarily originate from the lack of proven and useful data as well as hardware and software limitations, therefore it could be summarized that the user is not only limited as far as quantity of information is concerned but a greater constraint imposed is the quality of data derived or provided, thus the quality of data will inevitably constrain data preparation and consequently will have an impact on the NC code generation.

10.4.5.8 - Data Preparation

It is undoubtedly the task of the user to provide the initial data. Even though the system uses clear prompts and messages to limit the number of user mistakes but that cannot prevent the user copying the wrong data into the system. The term *'garbage in garbage out'* can be used to demonstrate the danger of having inconsistent and incorrect information. In short, it must be pointed that the system is intensely data driven, therefore it relies upon the sound judgment of the user to provide the relevant and correct information. The data required from the user is:

i - The cutting tool data

ii-The machining data

iii-The workholding data

iv-The material data

v- The insert data

The specified information is utilized by the relevant modules in the system.

10.5 - Setup planning

10.5.1 - Part Setting

Part setup is an important sub-task of the technological user support system. The way in which a component is positioned in the chuck and relative distances are essential for generation of a correct tool path. The information that is required for part setup definition is specified in section 10.5.1.

10.5.2 - Part Setting Information

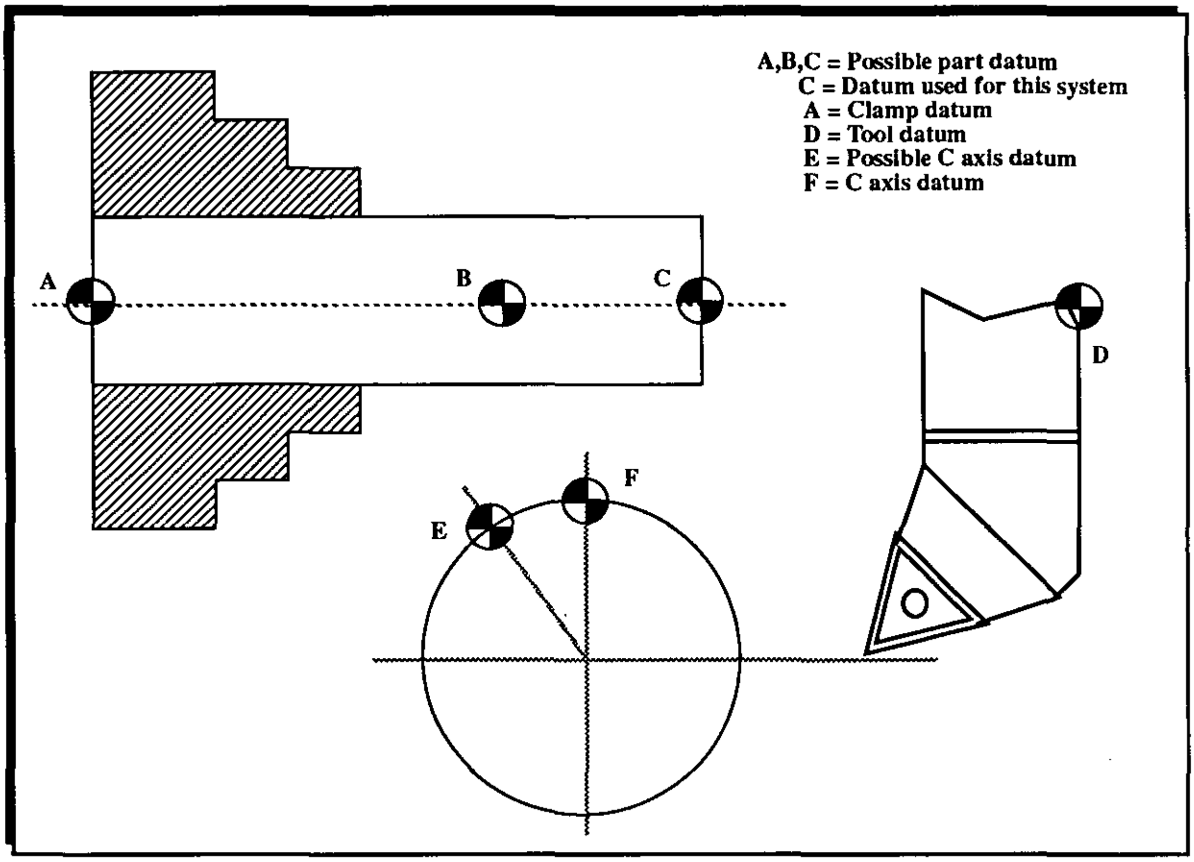
Part setup information is concerned with the material selection, Billet *(workpiece)* type, part orientation and the starting datum. In this module the material of the workpiece is specified and the billet type (*e.g. round, square, hollow*) is determined by the user. The next activity is to set the orientation of workpiece. The orientation with regard to the rotational workpiece can be set for the C axis. This datum provides a new reference for the workpiece in the radial position. The final activity is concerned with setting the part datum for the Z axis. Various methods are used for setting datum in the Z axis *[MAZAK 89] [TRAUB 89]*. In the work shop oriented NC system the datum is set at the face of the workpiece. Nevertheless the datum could be specified anywhere along the Z axis *[figure 10.14]*.

10.5.3 - Part Setting Procedure

The part setting information is used internally by the NC planning system. The setting requirement is based on the blueprint (*engineering drawing*) information and other technological requirements.

10.5.4 - Tooling Setting

In addition to inputting information into the technological database (*material, data, machining database, insert database etc.*) one needs to select the supplementary tooling for a given workpiece (*e.g. clamping devices and cutting tools*). This module embodies a list of available tooling to support the machining operations *[figure 10.15]*



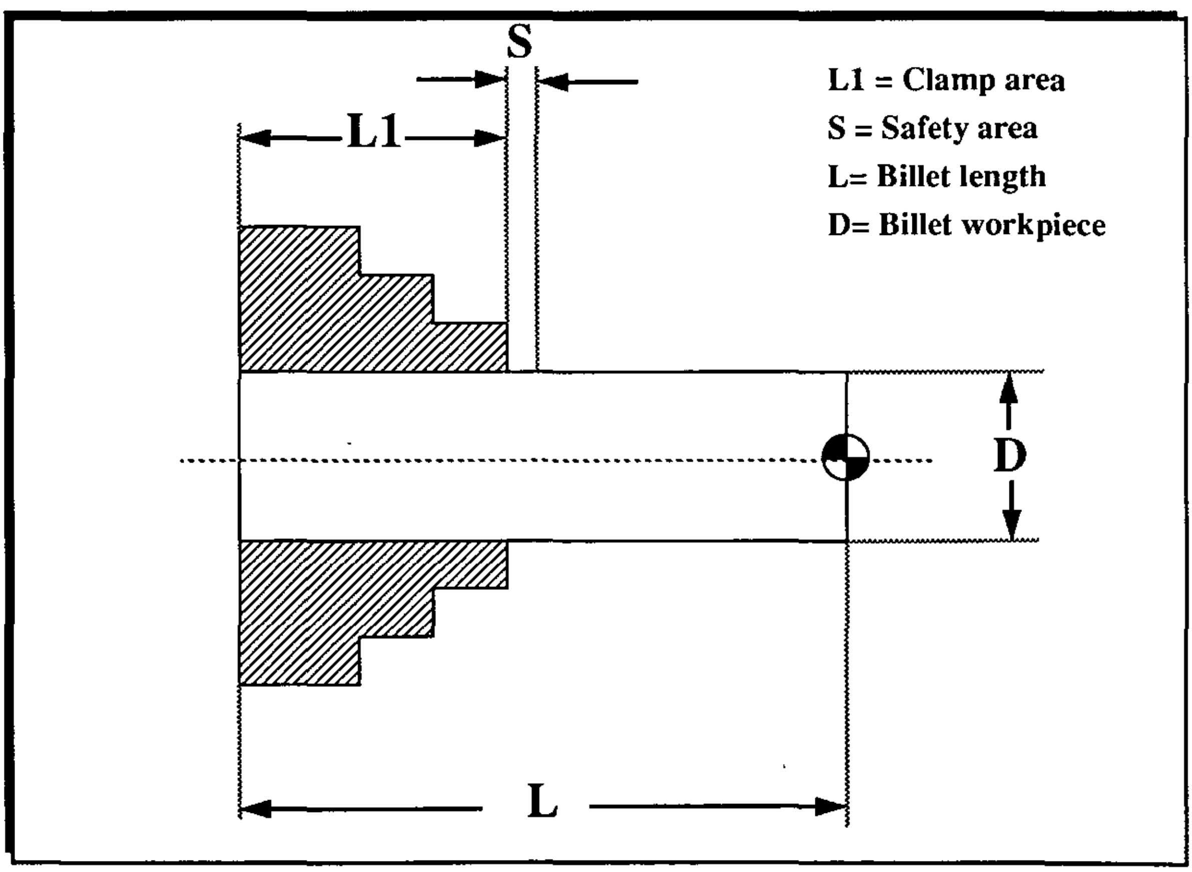
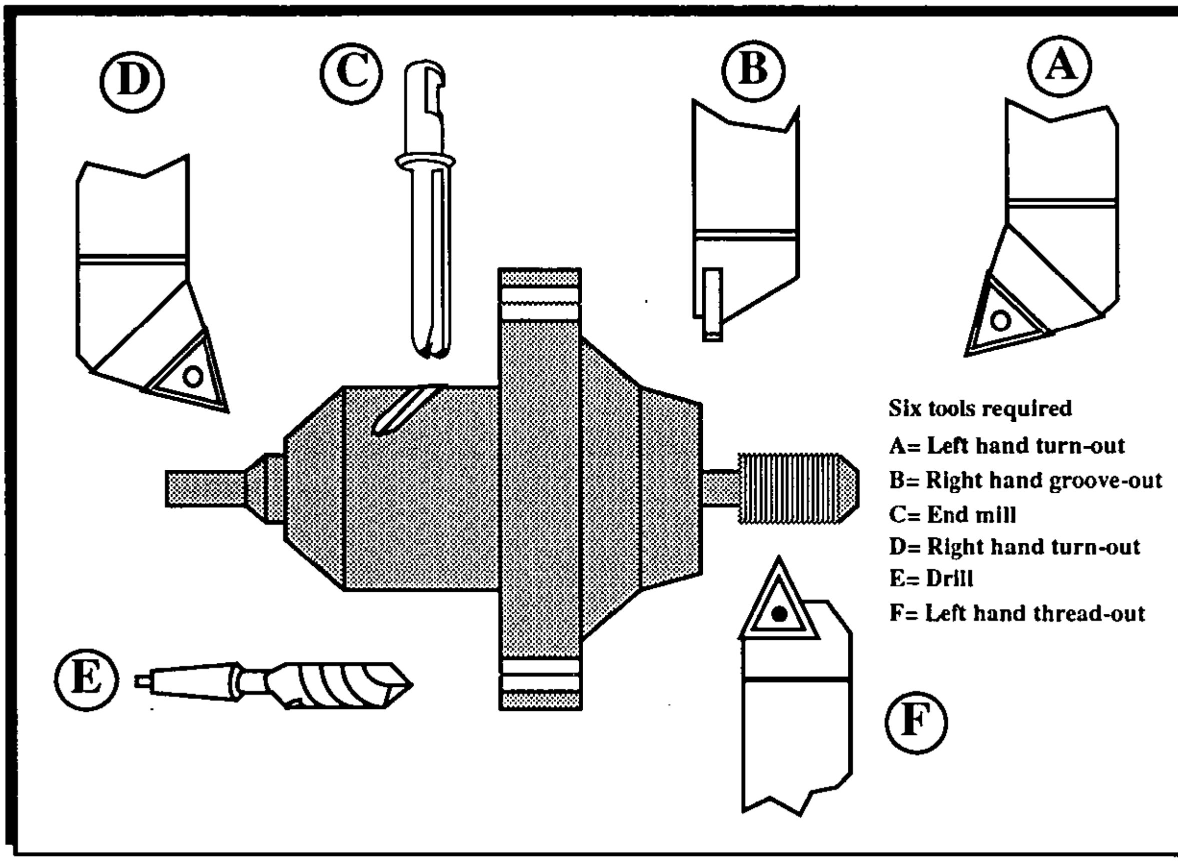


Figure 10.14	Part setting definition	L.U.T- CAD/CAM



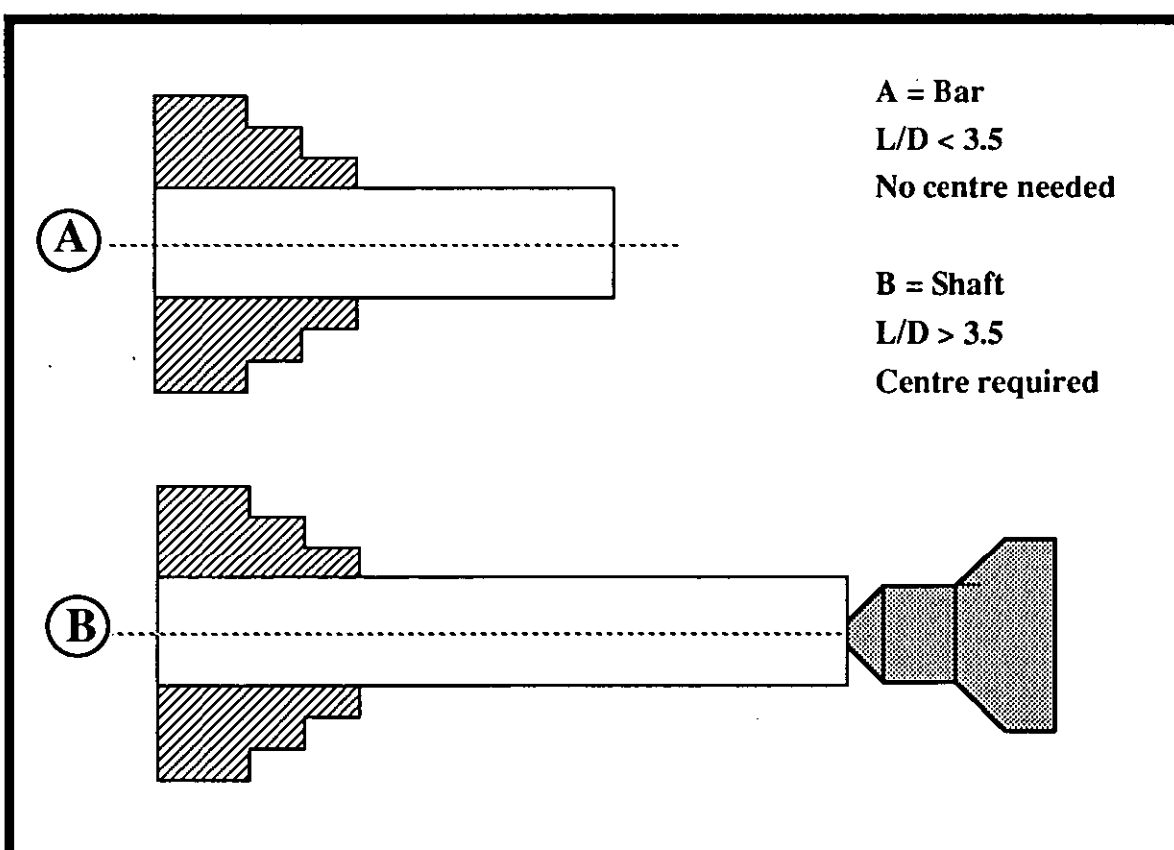


Figure 10.15	Tool & clamp setting	L.U.T- CAD/CAM

10.5.5 - Tooling Strategy

Each and every component requires a set of cutting tools. The appropriate cutting tools required to machine a part must be described with the parameter listed in section 10.4.3.2. This description ensures that the proper tools are available on the turret and, therefore, the tool selection procedure is ensured. Subsequently the operation planning module can select the relevant cutting tools for each region.

10.5.6 - Clamp Setting Strategy

The decision of how the blank is to be clamped is made at this point. The correct work holding parameters for the particular machining operation is selected from the workholding database.

The Workshop oriented NC planning system considers two methods for clamping *[figure 10.15]*:

i - Clamp the workpiece by chuck

ii- Clamp between chuck and centre (chuck & tailstock)

Regardless of the work holding device used the blank should be gripped on the largest diameter practical *[Hinduja 89]*. This ensures a favourable relationship between the gripping and cutting diameter to accommodate torque more easily *[Drozda 83]*. Workpiece or blank is griped as close to the face of the chucks as possible. As can be seen, *[figure 10.14]* two parameters are taken in to consideration:

i - Distance (*L1*)

ii- Distance (*S*)

The (*L1*) distance is designated to be the clamping region of the workpiece. This area is marked from the start of the chuck face to the edge of the clamped jaw *[figure 10.14]*. The distance (*S*) is assigned to be 5 millimetres *[Jackson 90]*. Region (S) is designated as a safe distance to prevent any possible collision between cutting tools and the chuck.

To determine the clamping method, it is necessary to classify components based on their length (*L*) and diameter (*D*) *[Hinduja 89][DCLASS 79][MICLASS 79]*. Two major classifications are considered: short workpiece (*bar*), long workpiece (*shaft*). The long workpiece has a ratio L/D of 3.5 or larger. However the short workpiece has a ratio of equal or less than 3.5. Both short parts that require chuck, and long parts that require chuck and centre can be machined in this system. Another important factor which influence clamping method is the number of setups. This number is closely related to the geometry of component. In the work shop oriented system only those parts that require a single setup are considered, this consists of parts that can be turned, grooved, threaded, drilled and milled in a single setting. However if more than one setup is required it must be manually arranged.

10.5.7 - Workholding Setup Information

The diameter of workpiece and the chuck number selected from the database are specified. If the workpiece is a shaft then the tail stock is assigned to support the workpiece.

10.5.8 - Machine Tool Selection

Once the geometry of the component is determined and possible machining operation are considered, then the task of the user is to select a machine tool that can perform the machining operations *[figure 10.16]*. There are two factors that influence machine tool selection. The primary factor is concerned with the basic and fundamental requirement of this system. Certain pre-requisites are required when employing the workshop oriented NC planning system. These pre-requisites are mainly concerned with two characteristics. A machine tool used must have a live tool facility and a minimum of three axes (x, c, z). However the second factor is concerned with more detailed information regarding the operational capability of machine tool. These requirements are depicted *[figure 10.16]*.

In usual circumstances the proper machine tool is provided and the workshop oriented NC planning system is used as a programming aide. However if there is a need to select a machine tool the parameters provided *[figure 10.16]* can be used to satisfy the selection requirements. It is also important to note that in the majority of cases where a control is dedicated to a particular machine tool, it serves to maximize the effectiveness of the use of the machine. It is possible to imagine in the number of other cases that this software would be useful as a aid in selecting the proper machine or, as referred to in the beginning of the chapter, as a machine tool expert in optimizing the design to manufacture of a component.

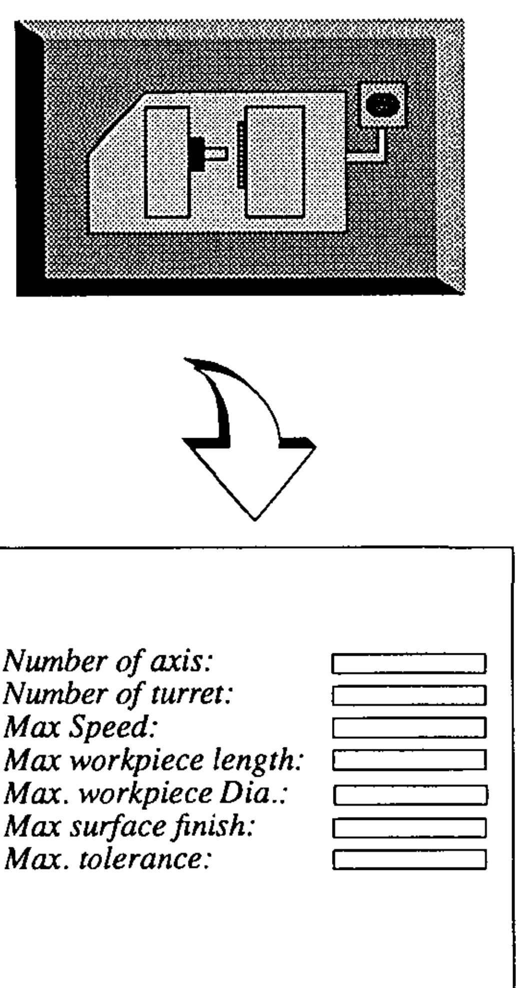


Figure 10.16 | Machine tool information | L.U.T- CAD/CAM

Chapter 11

Operation Planning

(Determination of Technological data)

11.1 - Introduction

This chapter reports on the design and implementation of the operation planner. The purpose is to provide a unique and yet effective and novel approach for planning of operations for work shop oriented NC planning. The objectives are explicitly defined in section 11.3 of this chapter. IDEF0 is used to model the activities which are concerned with operation planning (*See Appendix iii*). The IDEF0 model is designed to assist and clarify the operation planning activities. The following sections are each designed to describe the methods used in designing the operation planner.

11.2 - Scope of Operation Planning

The operation planning activity is designed and tailored to perform the planning tasks for the workshop oriented NC system. The methodology devised allows the regions to be selected on an ad-hoc basis. It is the task of the operation planner to determine the technological information (*i.e this data is determined at each region*) and the appropriate sequences necessary to produce a component. Unlike some work shop oriented systems *[Traub 89] [Fanuc 89]*, the sequence of operation can be modified to suit the user's requirements. Tool and machining data selection are also considered in this research. However tool selection as a major issue in operation planning is not the primary focus of this research. The approach put forward for tool selection is implemented to a limited extent so as to demonstrate the concept. However the derivation of an optimised solution for tool selection exceeds the scope of this research. The dilemma posed is whether to emphasis the optimization of tool selection or to devise and develop a framework with which the tool selection issues can be addressed. The emphasis in this research has been on the latter approach. The use of a region and feature scheme provides an effective methodology for tool selection (*see sections 11.5.1 to 11.5.5*)

11.3 - Operation Planning

Operation planning is primarily based on the relationship between operations and the geometric definition of regions. As described in section 9.13 each region is associated with a set of operations. Region descriptions not only embody geometrical and technological information but also the operational characteristics that are associated with each region. The next activity is concerned with the detailed planning of operations for each region. In the specific context of machining the general tasks embedded in operation planning include the following *[Brooks 87] [CAM-I 88]*:

i. Determination of cutting tools

ii. Number of cuts for roughing, semi-finishing and finishing

*iii.*Distribution of cut (*i.e. rough, finish, semi-finish*)

iv. Machining parameters for each cut

v. Operation order

*vi.*Operation instruction

*vii.*CLDATA

The following tasks summarises the principal activities that need to be achieved by operation planner. The primary activities that are performed by operation planner are: *[Herman 89]*

i. Cutting tool selection and cut distribution at each region

ii. Cutting parameters and operation condition selection at each region

*iii.*Operation sequencing

iv. CLDATA

It is important to note that within the context of operation planning novel approaches are put forward which are specifically designed for the workshop oriented NC planning system. These methods are used to automatically retrieve the technological data required for each region. These methods are extensively discussed in the subsequent sections of this chapter. The first phase of operation planning (*the determination of technological parameters*) is addressed in this chapter (*see chapter 12 for operation sequencing and CL data generation*).

11.4 - IDEF0 Representation

An IDEF0 model is used to clarify the tasks involved in planning the operations. It decomposes the operation planning activities into two principal sets: (*see A1.3.1 Appendix iii*)

i- Determination of technological parameters

ii- Operation sequencing

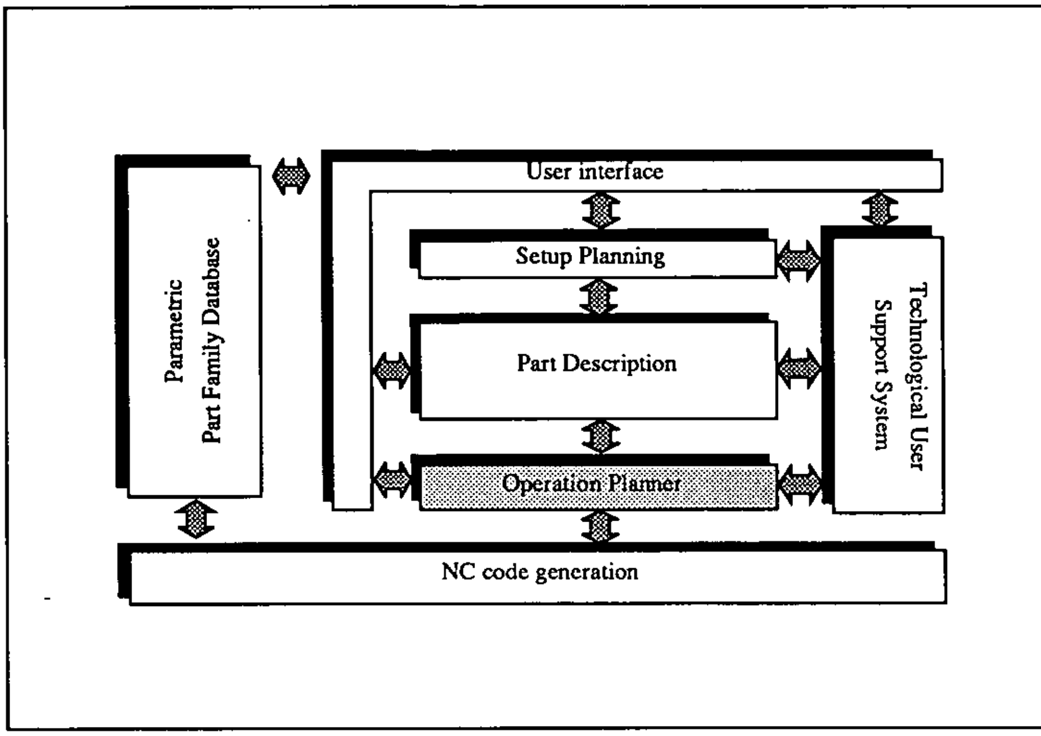
This chapter addresses the tasks involved in designing or determining the technological parameters for asymmetric rotational workpieces. Due to the complexities of the NC planning systems various activities, rules and mechanisms culminate in the IDEF0 model (*see A1.3.1 Appendix iii*). The IDEF0 representation is used to model the fundamental activities that determine the technological parameters *[figure 11.1]*:

i- Cutting tool selection for each region

ii-Determination of cut distribution parameters for each region

iii-Determination of cutting parameters for each region

The initial task of operation planning commences with cutting tool selection *[Hinduja 86][Wirtsch 80]*. This is an activity which is performed during the description of the technological parameters *(see section 9.14.2)* for each region. Traditionally, this activ-



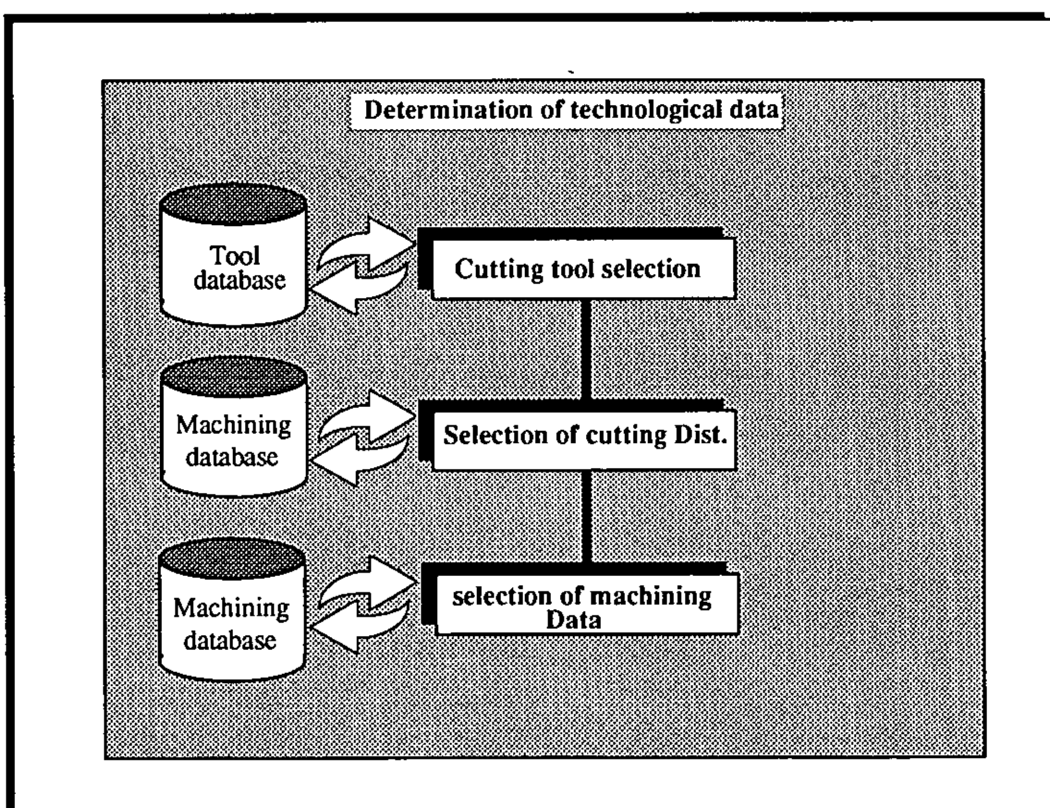


Figure 11.1	Operation planning	L.U.T - CAD/CAM

ity has been performed manually *[Allen 87]*, however, with the advancement in software and hardware, and the demand created by advanced automated manufacture, the computer based provision of tools has become an essential requirement *[Syan 91]*.

The implementation of automatic tool selection will undoubtedly enhance and simplify part programming procedures. The methods used for selecting the proper cutting tools are constrained by factors such as the availability of standard tools, inserts and their associated cost which will inevitably influence automatic tool selection. However, in the context of work shop oriented NC planning, some of the parameters such as cost are not considered.

Certain information is required in order to select the correct tools for each region. The geometry and the operational characteristics associated with the region must be considered before selecting the relevant cutting tools. The associated descriptive data for each cutting tool is defined in section 10.4.3.2.

The cutting tool for a given region can be interactively selected by referencing the relevant tool in the cutting tool database. The next logical activity following tool selection, is to define the relevant machining parameter which can determine the correct cut distribution (*i.e depth of cut, number of cuts*). Several factors which influence cut distribution are:

i-Shop-floor practice & methodology

ii-Available tools in the database

iii-Available tools on the turret

iv-The range of cutting data

These factors should be considered when selecting a depth of cut for each region. The provision of the appropriate processing knowledge or condition for each category of operation is essential (*a sample of process conditions for some operations is provided in the experimental application software*). The presence of this knowledge would assist the user and may be used as the basis with which the cut distribution parameters are determined. The process condition information can be retrieved from the machining database (*see section 10.4.4.1*). The provision of such knowledge can be used as a limit so as to guide the user. This knowledge provides general information with regard to the acceptability of a particular range of machining data for a given process. Certain information is required to determine the optimum distribution cut:

i-The characteristics of a given region

ii-The characteristics of a given tool

iii-Material specification

iv-Type of operation

The next step in the determination of technological parameters is the selection of cutting parameters for each region. The presence of correct cutting data is of paramount importance which and consequently influence the way in which the final product is machined. Several parameters and rules are used in order to retrieve the appropriate cutting data. The selection decision is based on two major pre-requisites, namely the tool characteristics and depth of cut. The sequence of activities which represent operation planning are modelled by IDEF0 (*see A.1.3.1 Appendix iii*).

11.5 - Cutting Tool Selection

One of the vital pre-requisites for NC code generation is the selection of the correct cutting tools *[Eversheim 87] [Van 86]*. In workshop oriented NC planning, two major categories of information are devised so as to enhance and control tool selection. The first category is concerned with the basic tool data (*see section 10.4.3.2*) which describes the cutting tool in considerable detail. This information is used as the basis for the decision making process and the selection of the appropriate, and feasible, tools for the machining operations. The second category is concerned with the appropriate tool information for each region (*see sections 11.53 & 11.5.4*). The importance of this information is due to the fact that each region embodies distinct characteristics (*i.e.*

features and operations). These diverse characteristics form the basis for designing different tool models which can advise the user to select the appropriate cutting tools. Regions must be selected before the relevant cutting tools can be listed (*i.e. interactively or automatically*).

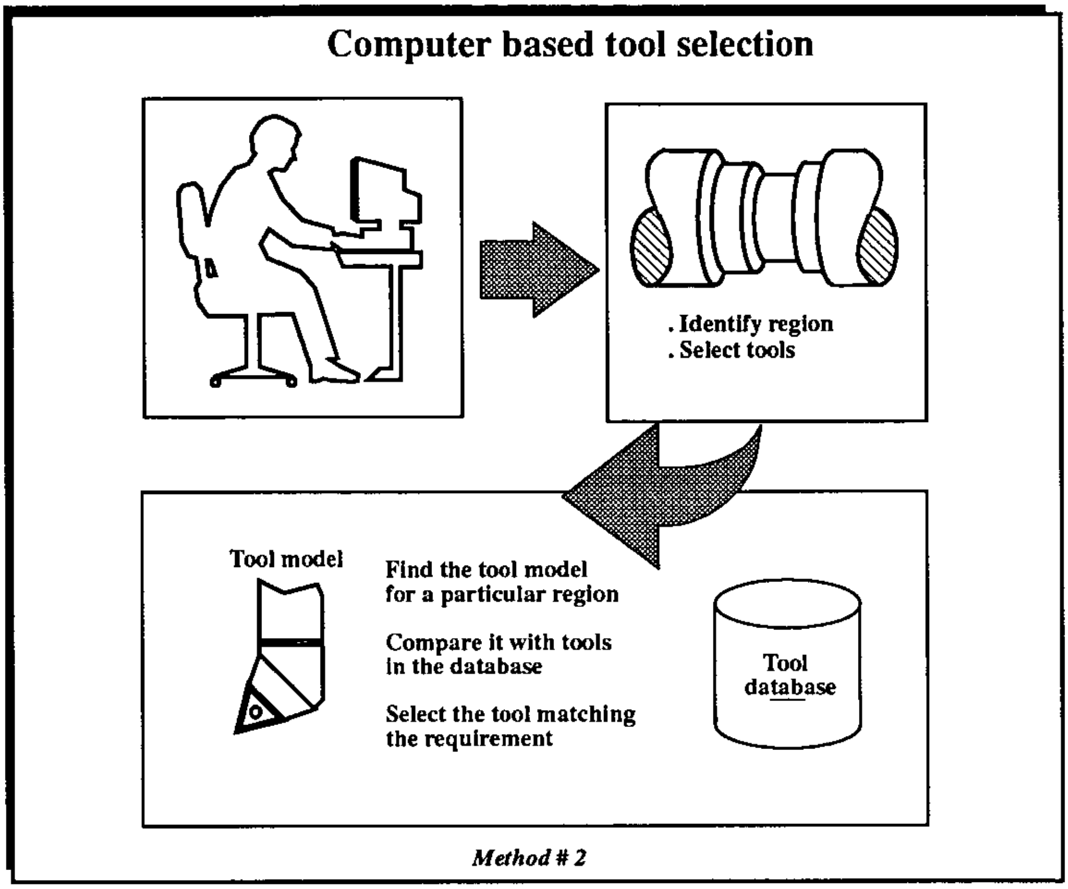
11.5.1 - Tool Selection Methodology

Tool selection is an essential and yet critical task in NC planning. The automatic tool selection is implemented for turn-region (*i.e in the experimental application system*) so as to demonstrate the applicability of computer based tool selection. Traditionally, the majority of the workshop oriented NC systems have used a manual procedure for selecting the cutting tools *[Fanuc 89]*. With the advancement in computer aided manufacture, some of the pioneers of the workshop approach *[Traub 89] [Mazak 89]* have developed more effective ways to select the appropriate cutting tools.

For instance, Traub *[1989]* provides a series of tool information for the machining entities. This information is designed in order to guide the user and to select the appropriate cutting tools. In general, some systems *[Traub 89][Syan 91]* have employed two methods for tool selection *[figure 11.2]*. The first method uses the manual selection of tools augmented with the pertinent tool information. In this case, the burden of responsibility for selecting the correct tools lies with the user. Alternatively, the second method uses an automated approach in which each geometric or machining entity is linked with the appropriate tool information. This information is compared with the available data in the tool database and hence, the appropriate cutting tool can be selected. Inevitably the biggest obstacle faced is the availability of the relevant tools in the cutting tool database.

11.5.2 - Tool Information Criteria

Tool information can be either general, encompassing a wide range of data, or it can be specific. The information embedded in the tool model consists of an acceptable range



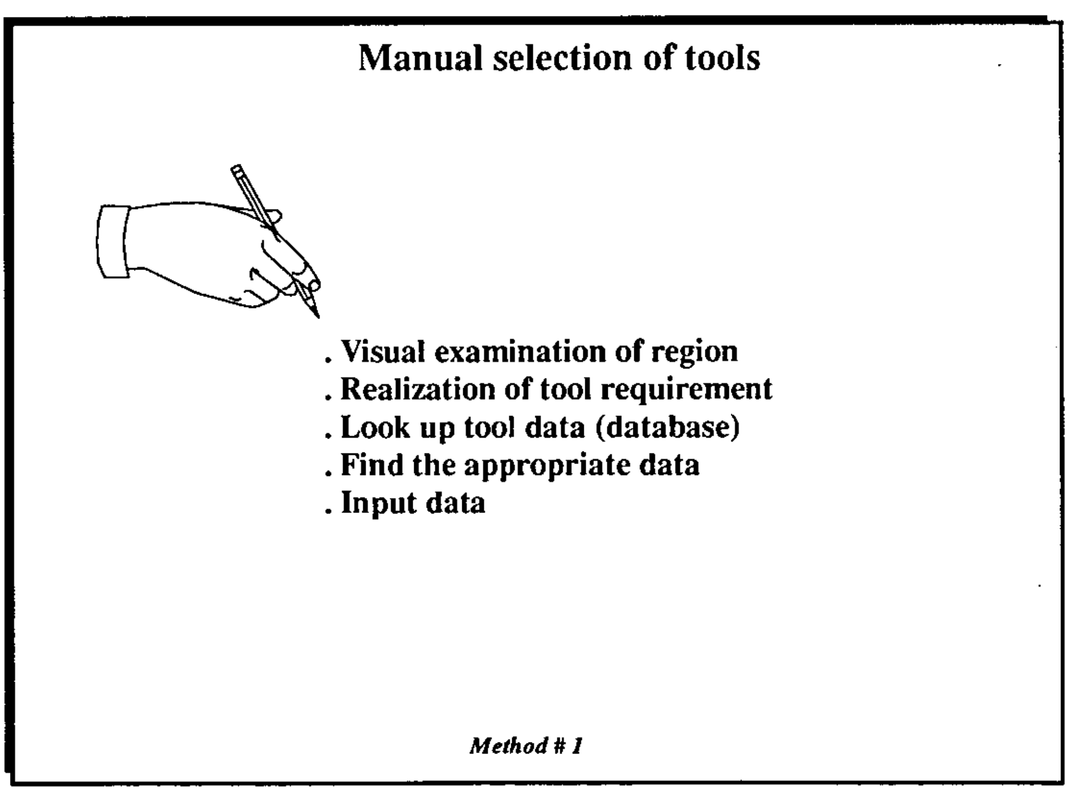


Figure 11.2 | Tool selection methods | L.U.T - CAD/CAM

of data for each region. This is intended to limit the data search and offer a greater flexibility which will inevitably simplify tool selection. Traditionally, several factors have influenced selection decisions *[Syan 91]*:

i- Cutting tool specification

ii- Shop-floor methodology

iii-Range of available cutting tools

iv-Cost consideration

v- Machine tool capability

The cutting tool specification, see section 10.4.3.2, generally provides a framework which is based on the machining and functional requirement of a particular manufacturing process (*i.e turning, milling*) and thus enables each region to be supplied with the appropriate cutting tools. Methods and rules are principally designed for the predefined regions. However tool selection is primarily based on two major elements *[Allen 89]*: Technological requirement and economical criteria. The technological requirement is used as the basis on which the appropriate tools are selected, however, these requirements are further refined by economical factors *[Hinduja 89]*. In addition, the use of standard tooling reduces cost and results in standardization. These factors should determine the suitable cutting tools. It is important to note that apart from using standard tools no economical models or factors are considered in this research. The tool data which is input into the database must be representative of the tools that are mounted on the turret and the tools specified must be available in the manufacturing plant.

11.5.3 - Tool knowledge

The tool knowledge that is incorporated in each model is concerned with providing the acceptable range of data for each region taking into consideration the following factors:

i- Operational requirement

ii- Application requirement

iii-Geometrical requirement

iv-Technological requirement

Each tool is designed for a specific operation. For instance the *Turn-out* tool is designed specifically for the external turning regions. Hence, the relevant application and operation for each tool is predetermined (*i.e Turn-out tool can be used for turning and facing operation*). The geometrical factors are primarily concerned with the size of the cutter, nevertheless, the technological data is more concerned with the entrance and cutting angles. The range of data on cutting and included angles will inevitably determine the suitability of a particular tool for roughing or finishing operations *[Allen 89]*. In addition it will assist in preventing any possible collision *[Anderson 78]*. The technological factors also deal with the position of the tool with respect to the region and the tool orientation (*i.e.left handed, right handed, etc.*) *[Hinduja 89]*. The most appropriate range of tool information for each region is predetermined and incorporated in the tool model (*see section 11.5.4*).

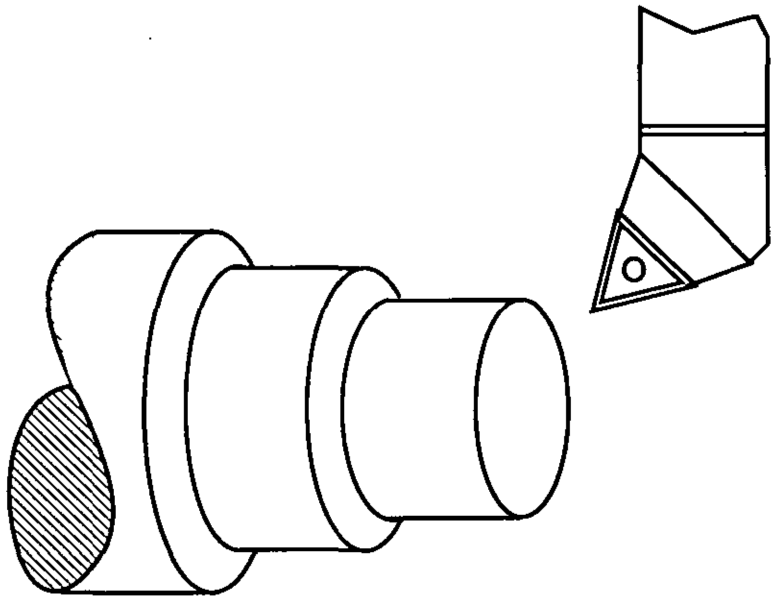
11.5.4 - Tool Model

There are basically two principle classes of information used for the selection process. The first set represents the acceptable range of geometry for a given region. The purpose is the provision of cutting tools which can perform the required operation and therefore, it considers the application and functionality of a given cutting tool. The second set of information is based on technological parameters. For instance, it is important to select a roughing tool for turning operations with the widest possible angle (*included angle*), see section 10.4.2. 3. The acceptable range of data for each region is incorporated in the tool model. Several tool models are designed for various regions.

Tool models for regions can be queried and therefore can aid the user when inputting the cutting tool values into the cutting tool database. Tool models can be represented in different ways. For instance, Traub *[1989]* displays a list of tool data externally so as to guide the user. In contrast, the approach pursued by Mazak *[1989]* aids by the provision of automatic tool selection. The method used by the author provides the user with several tool models in order to simplify and enhance tool selection. In addition, the facility for automatically selecting the tools is demonstrated to a limited extent in the experimental application software (*see section 11.5.5*). The tool models embody several parameters *[figure 11.3]*. The operations which are associated with each cutting tool form the basis for selecting the suitable cutting tool. The tool model information is concerned with the tool name, type and direction. The range of parameters and data appropriate for each region is predetermined. The included angle, the entry (*cutting*) angle, tool holder position, and tool holder geometry are also incorporated in the model. The tool models for the available regions are depicted in figures 11.11 to 11.17.

11.5.5 - Automatic Tool Selection

The *autotool* icon is devised to demonstrate the ability to select cutting tools for each region automatically. The provision of an optimised method for tool selection exceeds the scope of this research and requires a closer examination of factors such as tool insert material, depth of cut, length of cut and workpiece material. However, the method employed in this research allows the application of automatic tool selection to be demonstrated. The aim is aid the selection of an appropriate tool that may be available in the cutting tool database. It is not the intention of this research to find or select an optimised cutting tool for an operation but merely to provide a framework where the more appropriate cutting tools can be selected. As depicted in figure 11.4, once the tool icon is activated then the first step is to identify the region which will be the basis for automatic tool selection. The tool model information can be the basis with which the appropriate cutting tool is selected *(figure 11.5)*. The search for the appropriate tool commences with the tool name, as described in section 10.4.3.1 each category of tool



Tool parameter:	**Tool data:**
Operation:	Turning, facing
Tool name:	External
Tool type:	Left handed
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	MAX. 2/3 D
Included angle	85 rough/35 finish
Entry angle	R[90<E<92.5] F[90<E<152.5]
Tool hld. pos.	Pos. #2 vertical
Tool hld. geom.	x,y

Figure 11.3	Tool model for turn-out region	L.U.T - CAD/CAM

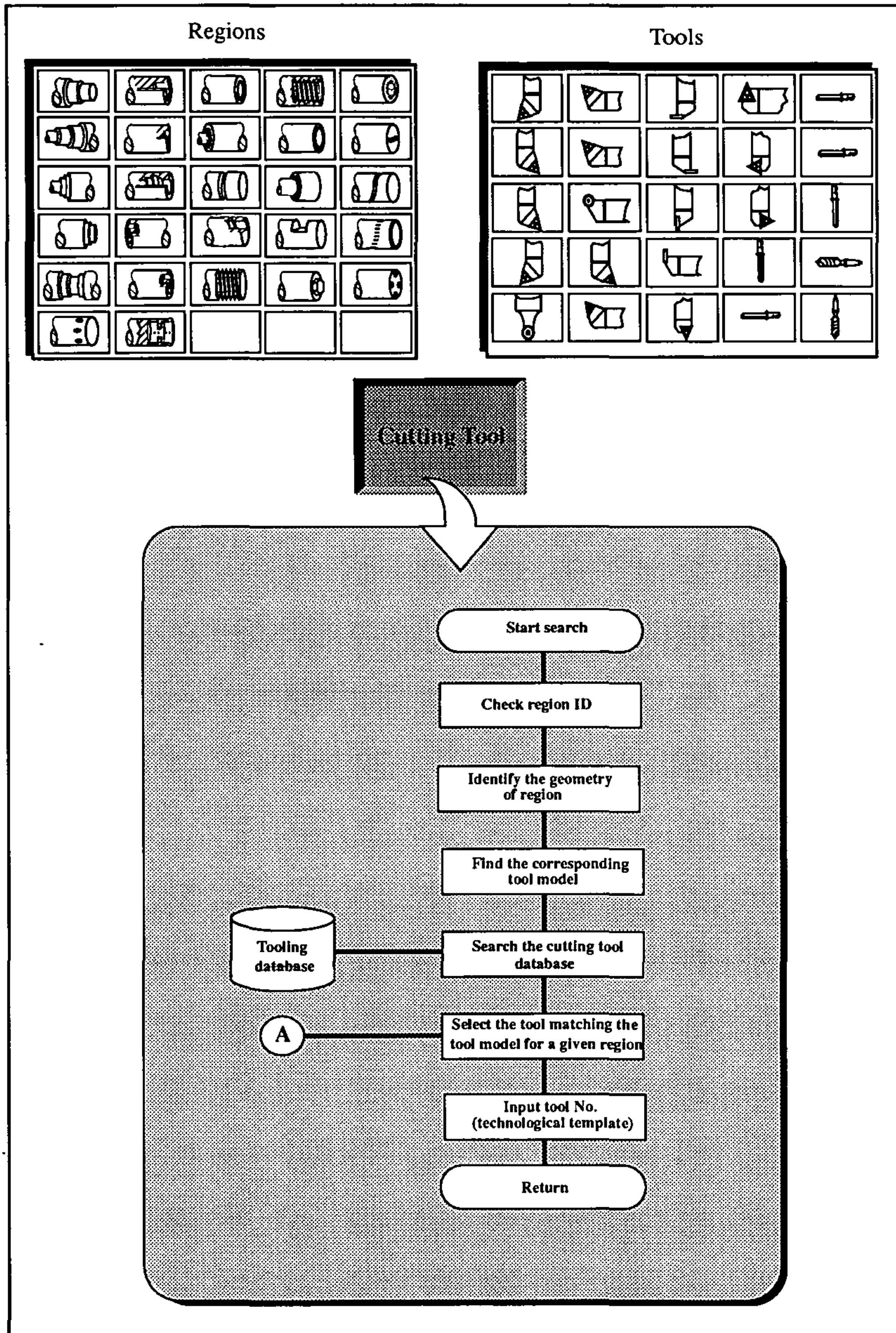


Figure 11.4	Tool selection	L.U.T - CAD/CAM

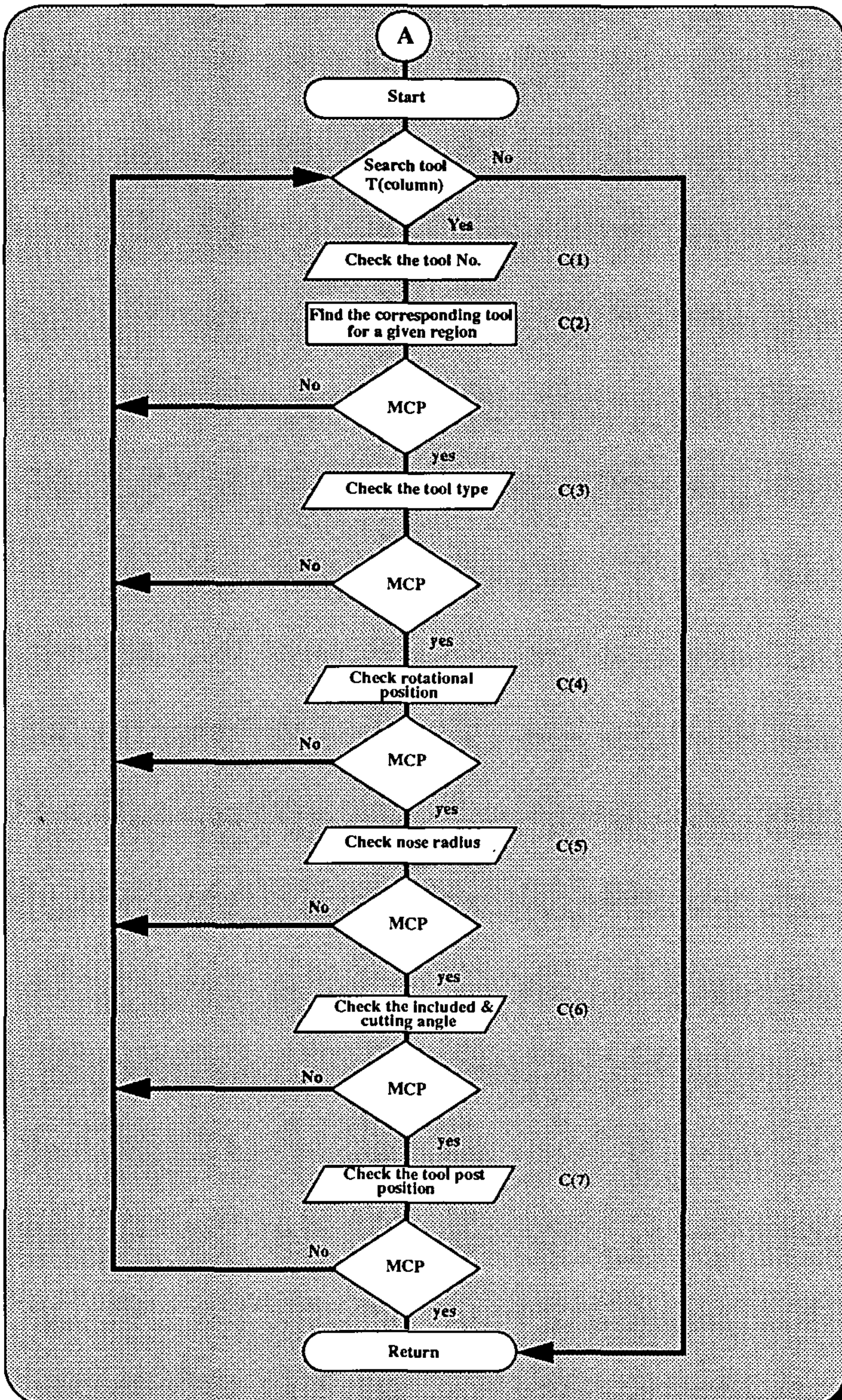


Figure 11.5	Steps for checking tool data	L.U.T - CAD/CAM

is represented in terms of it's basic operation and position. For instance the *turn out* tool represents a cutting tool which is suitable for external turning operations, therefore, the tool name which can machine the appropriate region must be retrieved. The next data represents the movement of the workpiece. This data is determined based on the configuration of the machine tool, the turret, and the cutting tool position and is represented in terms of the reverse or forward position. The next data represents the nose radius of the cutter. A larger nose radius is usually used for finishing operations. The next information is concerned with the cutting and included angles of the cutting tool. For roughing operation a wider included angle is desirable. The next piece of information is concerned with the cutting tool position. Selection of the wrong tool position will result in collision. As described in section 10.4.3.6, four primary positions are available in the turret. Position one represents a static tool parallel with the Z axis and the second position represents a static tool that is parallel with the X axis. Position three and four represent horizontal and vertical driven tools respectively. The predetermined tool model associated to each region specifies the appropriate tool position for each region. The tool models can be used as the basis for selecting the appropriate values. If any of the data represented for each tool does not correspond with the relevant information in the tool model then the following tool information item can be indexed and queried until the appropriate tool is retrieved and copied into the technological template. Alternatively if the relevant data is not available in the cutting tool database then the word *N/A* is displayed to inform the user that the required cutting tool for that region is not available.

11.6 - Selection of Machining Parameters

In a manufacturing environment, the design and selection of machining parameters is performed on a frequent basis. The advancement in new machine tools and cutting tools technology has increased the complexity of determining the appropriate machining condition. Traditionally, the determination of the machining condition has been carried out by a machinist based largely on experience gained during the machining operation. With the ever increasing complexity of cutting tools and machines and the vast array of data, materials, and tools, the task of determining the machining data manually has become inefficient. Simultaneously with the emergence of NC a generation of good machinists and planners have been replaced by less experienced operators, which has consequently shifted the responsibility of assigning machining data from the machinist to the planner or engineer who usually performs this function in an office, receiving little or no feedback from the shop floor to optimise or correct the machining data. In short, the evolution and complexity of technology and the lack of experienced planners has provided the incentive to establish the necessary machining knowledge to assist and guide the operator. In addition, the strong emergence of computer integrated manufacturing (*CIM*) and just in time (*JIT*) approach demands a more effective method for determining the machining data *[Allen 89]*. The purpose is to increase the quality of information and rationalize the methods with which this information is determined. The quality and methodology for obtaining machining data has been addressed by both the industrial and academic worlds *[Eversheim 81] [Zdeblick 80]*. These methods are discussed extensively in the subsequent sections. Several methods can be used to determine the machining data. These methodologies are analysed in section 11.6.1-11.63 and the methods implemented in the NC planning are highlighted.

11.6.1 - Data Retrieval Approach

This approach is based on the retrieval of machining data from a database. The machining database is designed to be integrated with the workshop oriented NC planning system. Machining data for various combinations of operation, material and tools is incorporated in the database *[Metcut 80]*. The disadvantages of using the data retrieval approach must be recognised and considered before utilization. They include:

i-Large amount of space is required

ii-More CPU time is required for searching *iii*-The data supplied is conservative and not optimal

iv-They are expensive to design and maintain

There are strong advantages of using the data retrieval approach. The strengths and benefits associated with this technique are that it has encouraged many users to utilize it. The advantages are:

i- It is user friendly (no complex calculation is required)

ii- It can store a variety of information

iii-It is independent from the system which uses it

iv-It can store and modify data

v- It can be designed to receive self update or feedback from an operation

11.6.2 - Mathematical Optimization

One way of producing machining data has been the use of a mathematical approach for calculating the necessary data. The literature *[Boothroyd 76] [Drozda 83] [Jhe 88]* points to several factors that can be used to optimise the operations. Six cost factors can be taken into consideration to achieve the optimization. These are: (1) material cost, (2) machining cost, (3) tool changing cost, (4) over head cost, (5) tool cost, (6) and set-up cost *[Drozda 83]*. The overall objective is to minimize production cost and time and consequently increase the profit margin *[Boothroyd 76]*. The total cost per part under minimum cost conditions is presented *[Drozda 83]*:

$$Ctmin = KTs + KTm + KTc\left(\frac{Tm(min)}{Tmin}\right) + Ct\left(\frac{Tm(min)}{Tmin}\right)$$

$$Tm(min) = \frac{pdl}{12VminF}$$

$$K = costfactor$$
$$Tm = machiningtime$$
$$Ts = setuptime$$
$$Tc = toolchangetime$$
$$Tmin = toollifeformincost$$
$$Ct = costofacuttingedge$$
$$d = diameterofworkpiece$$
$$L = lengthofcut$$
$$F = feed((mm)/(min))$$

This technique has an staggering array of variables and coefficients which will inevitably demand high CPU time and a consistent provision of data. Because of small variation in maximum and minimum machining cost (*less than 10%*), the suitability of this method for the majority of cases (*small to midsize lots*) is in doubt. *[Peters 71]*. It is important to note that this technique has not been used in this system.

11.6.3 - Empirical Equation

Empirical methods are primarily based on the Taylor tool-life equation to determine the cutting parameters *[Boothroyd 89]*. A number of equations and procedures are designed to satisfy different machining operations. For instance, certain equations can be used for turning, boring, drilling and reaming operations *[Malov 79]*:

$$V = (\frac{C1}{TmDxFy}(\frac{BHN}{200})n)$$

$$V = (\frac{C(DIA)(BHN)n}{TmDxFy})$$

$$V = (\frac{C1(DIA)}{TmDxFy(BHN)n})$$

$$V = cuttingspeed$$
$$T = toollife$$
$$F = feedrate$$
$$BHN = materialhardness$$
$$D = depthofcut$$
$$DIA = drilldiameter$$

For further detail refer to Malov *[1979] [Van 86][Chang 85]*.

11.6.4 - Methods Used by the Experimental System

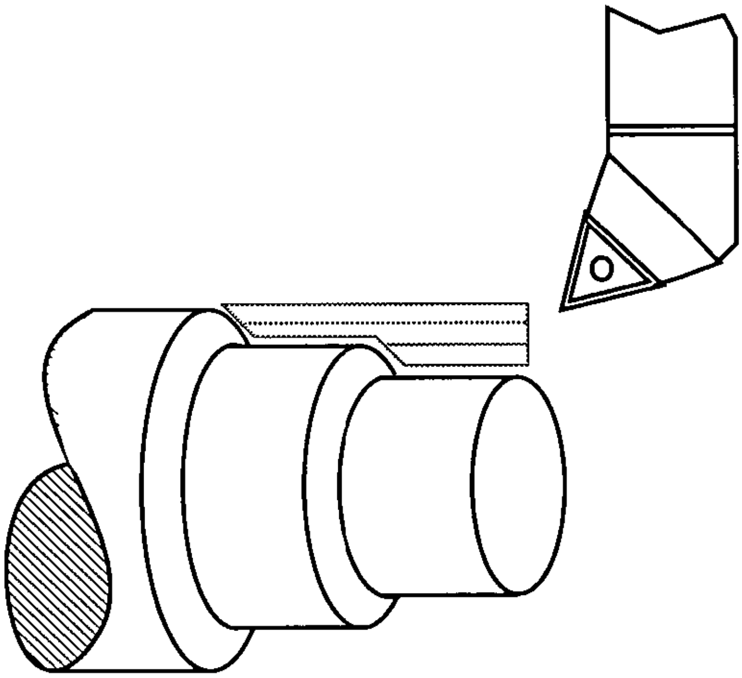
The vast combinations of materials, tools, operations and other data has forced the author to use more than one method to prepare the technological data. Data retrieval is used as the primary method to determine the majority of machining data. However, in some cases (*i.e the determination of surface finish parameters*) a set of tables and empirical equations are used to calculate the appropriate feedrate and cutting speed (*see section 11.9.1*).

11.7 - Cut Distribution Parameters

Cut distribution for a machining operation is primarily concerned with the maximum allowable depth of cut. The maximum permissible depth of cut is used to reduce machining time and consequently maximize the utilization of resources. Deciding the correct depth of cut is based on the following factors *[figure 11.6]*:

i- Area of cut (*i.e. for each region*)
ii-Tool parameters
iii-Material
iv-Operation type

The area of cut is the basis with which the appropriate depth of cut is determined. In short, three rules are used to determine the depth: (1) The depth of cut must not exceed the width of region (*area of cut*), (2) The depth of cut must be within the acceptable limit of a chosen process, (3) the depth of cut must not exceed the permissible cutting depth of insert (*2/3 of insert depth*). Two major types of operation are planned within the workshop oriented NC system: (1) roughing and (2) finishing. The roughing operation constitutes several passes. In contrast, a finishing operation is made with a single pass. Thus the maximum permissible depth is assigned for a roughing operation. It must be noted that the geometry of a given region, as well as the tool required, must be determined before the appropriate depth of cut can be retrieved from the machining



Cut distribution parameters:

Area of region:	*X-cpt, Z-cpt / step*
Tool characteristics:	*Allowable depth*
Operation:	*Rough/finish*

Depth of cut:	
Length of cut:	
Number of cut:	
Cutting time:	

Figure 11.6	Cut distribution parameters	L.U.T - CAD/CAM

database. It is also important to note that the workholding device, machine rigidity and horse power must be within the acceptable range to perform the operation. For instance, if an optimum depth of cut is configured for a particular roughing operation without considering the necessary horse power, the operation may run into difficulty. The horse power required is strongly dependent upon the type of machine tool selected, nevertheless, if the workshop oriented NC system is used only as a programming aid then it can be assumed that the appropriate horsepower and rigidity is provided.

Cut distribution information for several materials is incorporated in the machining database (*see section 10.4.4.1*). The model is designed to provide the applicable depth of cuts for a chosen process. This information is based on the Metcut handbook *[Metcut 80]*. The possible depth of cut for a given tool type and material, within a chosen process, and the associated parameters such as feed rate are provided.

11.7.1 - Cut Distribution Methodology

Three methods can be used to select this data: (1) Interactively enter the information, (2) Look up the tables in the machining database as a guide to manually enter information, (3) Invoke the automatic selection of data to retrieve the relevant information. This information is determined at each region. The algorithm for retrieving the relevant depth of cut is depicted (*See figure 11.7*). This algorithm was initially applied for the work presented in chapter 14 (*it calculates the depth of cut*). It has also been used to a limited extent for the workshop oriented approach. It is however important to note that modifications are made in order to apply it in the experimental application software (*i.e for the workshop oriented system a retrieval approach is used*).

11.7.2 - Automatic Selection of Cut Distribution Data

The algorithm assigned for automatic selection of cut distribution data is designed in a way so as to retrieve the correct depth of cut for a given region. The first step is to recognize the region by analysing the features that shape a given region. Thus, the smallest diameter surface feature is checked against the stock diameter and if there is enough material in between for machining then the appropriate depth of cut is determined. Two methods can be used to assign the appropriate depth of cut. The first approach is based on calculating the depth of cut by retrieving the insert attributes such as the effective depth of an insert. The framework for calculation is available, nevertheless it is not used in the experimental application system. The method used is to retrieve the appropriate depth of cut from the cutting feed and speed database. The next step is to check to see if the permissible depth retrieved is less than the difference between the stock diameter and the smallest feature diameter. If the value is not within the limit assigned then a smaller depth of cut is looked for and retrieved. If the depth of cut for roughing is within the process condition limit then the value is automatically assigned to the technological template. The permissible depth for each material and cutting tool is available in the database.

11.8 - Determination of Machining Parameters

Two pre-requisites are essentially required in order to determine the appropriate machining data: 1) Depth of cut and 2) the selected cutting tool. This data is used as reference for retrieving the machining information listed below:

i- Feed rate for roughing

ii-Feed rate for finishing

iii-Cutting speed for roughing

iv-Cutting speed for finishing

It is the task of this module to determine the parameters listed above. The machining data for a selected region is retrieved from the machining database. The range and quality of data available in the machining database will inevitably constrain the selection of optimum data. As depicted *[figure 11.8]* a range of information regarding several processes can be used to guide the user. This information acts in two ways. As

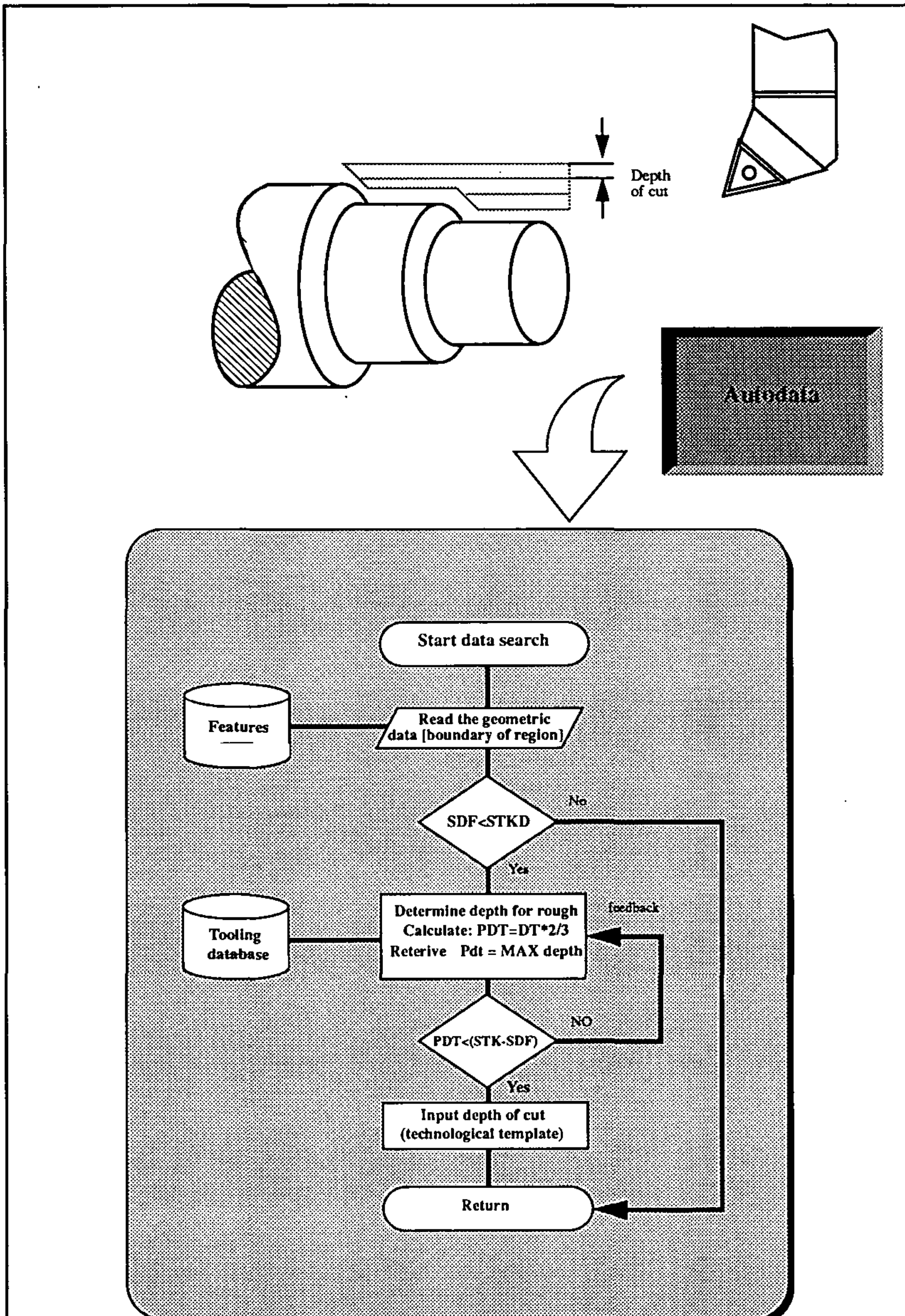


Figure 11.7	Steps for defining the number of cut & depth	L.U.T - CAD/CAM

mentioned in chapter 10, it could be viewed as CNC machining knowledge to assist the decision making process during the design of a component or it can be used to assist the user or the system, to retrieve the information for a particular operation. This information is intended to represent the acceptable range of machining data that can be used for a particular process.

11.8.1 - Automatic Selection of Machining Data

Based on the selected tool and depth of cut, the relevant machining information such as feed rate and cutting speed is selected from the machining database and subsequently assigned to the technological template of a given region *[figure 11.9]*. The selection of machining data can be done manually by inputting the appropriate values. In addition to the MDI facility provided, the *autodata icon* can be used to select the appropriate machining information automatically. The first step is to look up the technological template of a selected region and subsequently read the given depth of cut. Based on that value the machining database is searched to retrieve the appropriate values for feedrate and cutting speed. Finally these values are automatically input into the technological template.

11.9 - Surface Finish Information

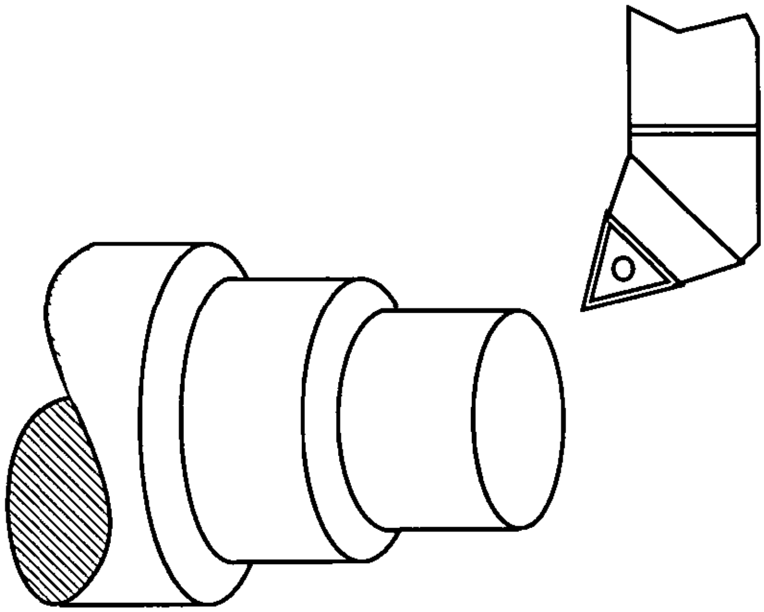
Surface texture is effected by many variables in the cutting process, including the machine tool, cutting tool, cutting conditions, cutting fluids and the workpiece (*Drozda 83*]. The purposes of using a particular surface finish are listed:

i- Dimensional tolerance

ii-Surface to be painted

iii-Surface appearance

iv-Specific heat or light reflectivity



Roughing feedrate:
Roughing speed:
Finish feedrate:
Finish speed:

Table 1: The acceptable range of technological parameters

Technological parameter	Rough	Finish
Depth of Cut (m)	2.4 TO 4.75	0.38 TO 2.4
Feedrate (MPR)	0.38 TO 0.77	0.13 TO 0.38

Table 2: The acceptable range of cutting speed for turning operation

Material	Rough	Finish
Aluminium	111 To 166	166 To 259
Brass	185 To 222	222 To 259
Cast Iron	92 To 129	129 To 166
Mild Steel	148 To 203	203 To 259
Stainless Steel	92 To 111	111 To 148
Plastics	92 To 148	148 To 240

* Data adopted from METCUT & SME machining data handbook

Figure 11.8	Guide for machining data	L.U.T - CAD/CAM

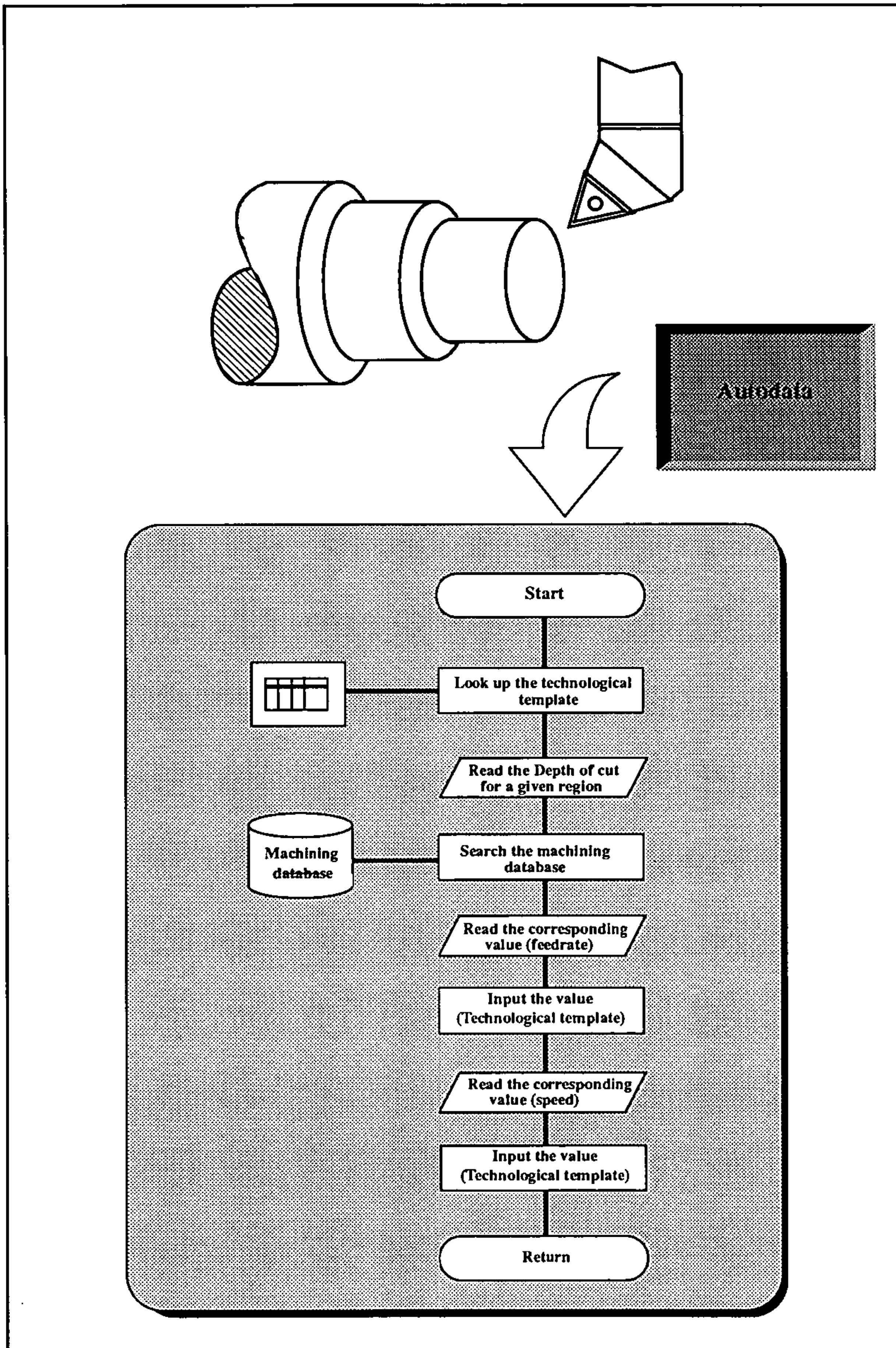


Figure 11.9	Machining parameters (feed & speed)	L.U.T - CAD/CAM

Nose radius and feed rate are the cutting variables which exhibit the greatest impact on average roughness height in a machining process *[Drozda 83]*.The two equations listed below are general formulas that can be used to determine the theoretical surface finish based on the nose radius and feed rate:

$$AA = \left(\frac{2\,(\sqrt{B - HG}) \times 10 \times 10^{-3}}{F} \right)$$

$$AA = \left(\frac{(r - (\sqrt{\frac{F1}{2}}))^{2} \times 10 \times 10^{3}}{2} \right)$$

$AA = surfaceroughnes\,(mm)$
$r = noseradius$
$F = feedrate$
$G = prepedicular distance to mean line$
$B = angle between normal centreline$
$F1 = feedperinsert$

Surface finishes of 0.51 - 1.27 *um* are the practical limit that can be generally expected for turning operations, however smoother surfaces can be produced (0.025 *um* or less) which requires the use of precision machines and diamond cutting tools. The higher surface finish value results in more cost *[Drozda 83]*. The quality of the machined surface is one of the important criteria by which the success of a machining operation is judged.

11.9.1 - Surface Finish Selection and Methodology

Each feature within a given region can carry a different surface finish value. The values designed are represented in terms of a roughness code of 1 to 9 *[Mazak 89]*. The higher the roughness code the finer would be the surface finish. The method used starts by reading the tool number and subsequently identifies the associated nose radius. The next stage is to compare the nose radius value with the parameters in the surface finish table. The corresponding value for the selected roughness code is identified and subsequently used in the formula to calculate the finish feedrate for a give feature. This information is produced in terms of cutting feedrate which consequently can produce the desire surface for each feature (*see figure 11.10*).

$$Feedrate F = \sqrt{\frac{8R\mu}{1000}}$$

Table 1: Surface finish For axial cut

Roughness code	1	2	3	4	5	6	7	8	9
Surface Finish	100	50	25	12.5	6.3	3.2	1.6	0.8	0.4

Table 2: Surface finish for radial cut

SRF	1	2	3	4	5	6	7	8	9
Kf	$\frac{Ko}{0.8^3}$	$\frac{Ko}{0.8^2}$	$\frac{Ko}{0.8}$	Ko	$Ko \times 0.8$	$Ko \times 0.8^2$	$Ko \times 0.8^3$	$Ko \times 0.8^4$	$Ko \times 0.8^5$

* Data adopted from Mazak [89]

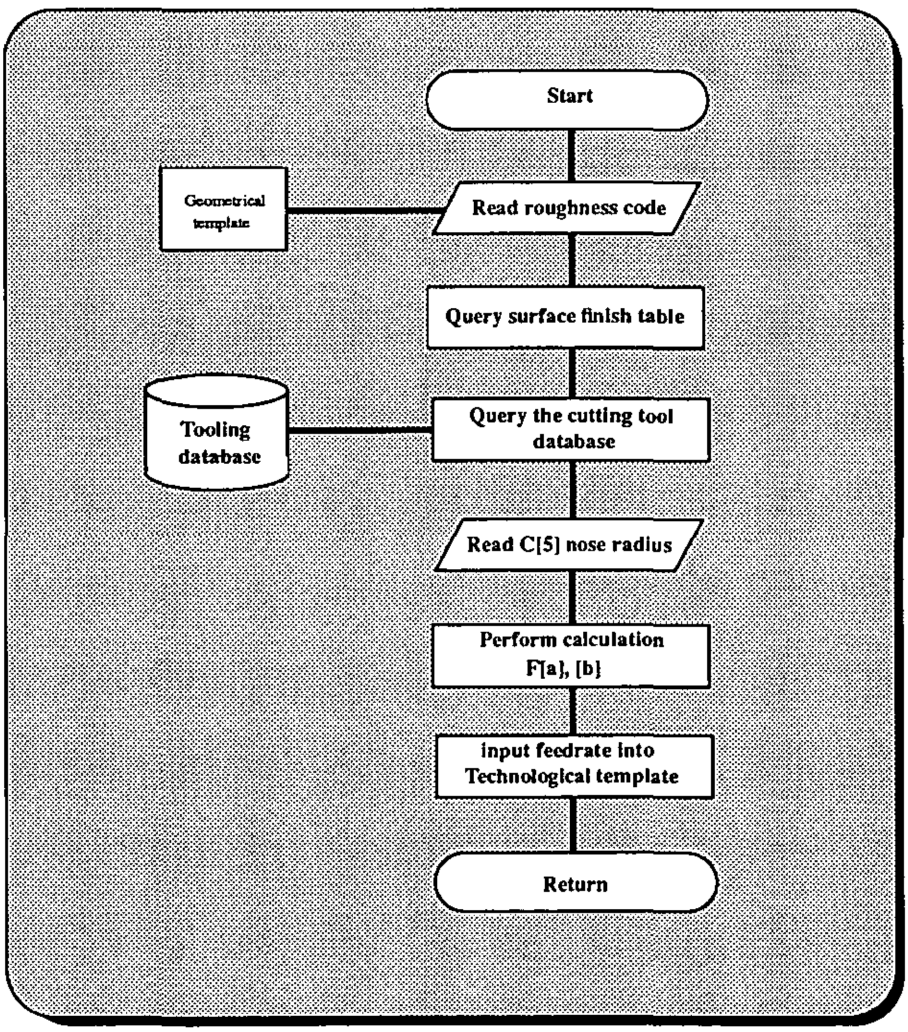


Figure 11.10	The surface finish algorithm	L.U.T - CAD/CAM

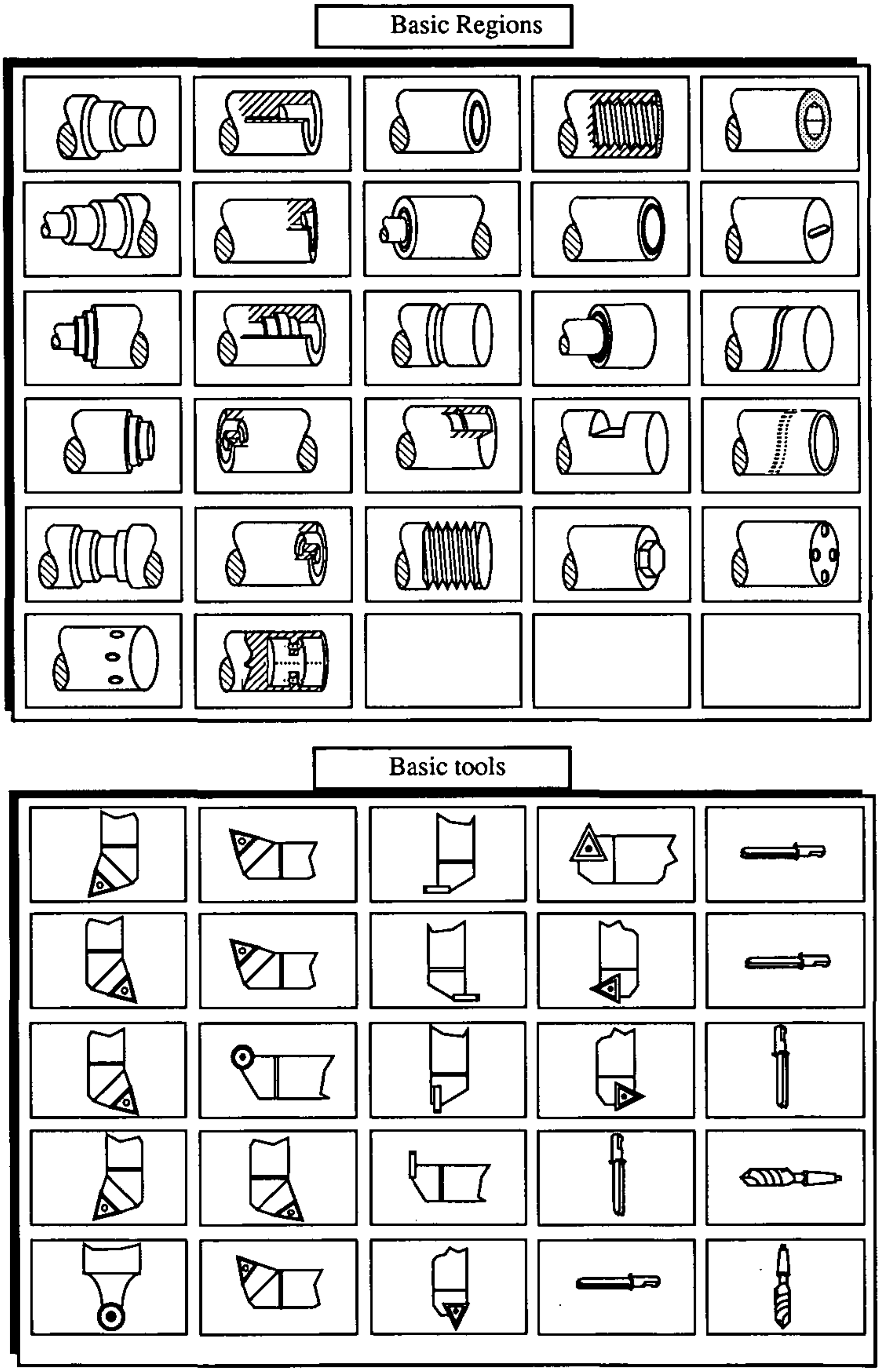
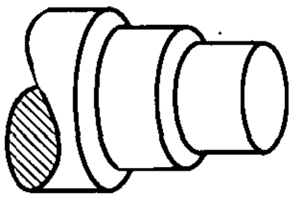


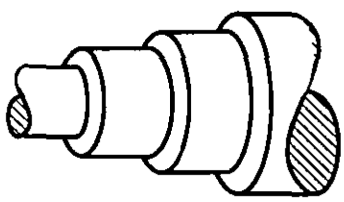
Figure 11.11	Regions and the associated cutting tools	L.U.T - CAD/CAM

Region | **cutting tool** | **Tool model**



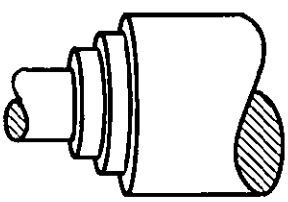
Region: profile-front

Tool parameter:	Tool data:
Operation:	Turning, facing
Tool name:	External
Tool type:	Left handed
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	MAX. 2/3 D
Included angle	85 rough/35 finish
Entry angle	R[90<E<92.5] F[90<E<152.5]
Tool hld. pos.	Pos. #2
Tool Hld. geom.	x,y



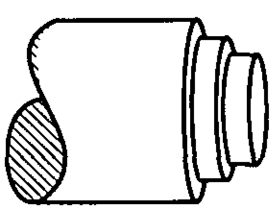
Region: profile-back

Tool parameter:	Tool data:
Operation:	Turning
Tool name:	External
Tool type:	Right handed
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	MAX. 2/3 D
Included angle	85 rough/35 finish
Entry angle	R[90<E<92.5] F[90<E<152.5]
Tool hld. pos.	Pos. #2
Tool Hld. geom.	x,y



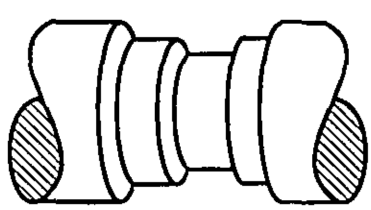
Region: face-back

Tool parameter:	Tool data:
Operation:	Facing
Tool name:	External
Tool type:	Right handed
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	MAX. 2/3 D
Included angle	85 rough/35 finish
Entry angle	R[90<E<92.5] F[90<E<152.5]
Tool hld. pos.	Pos. #2
Tool Hld. geom.	x,y

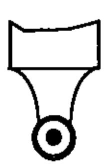


Region: face-front

Tool parameter:	Tool data:
Operation:	Facing
Tool name:	External
Tool type:	Left handed
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	MAX. 2/3 D
Included angle	85 rough/35 finish
Entry angle	R[90<E<92.5] F[90<E<152.5]
Tool hld. pos.	Pos. #2
Tool Hld. geom.	x,y



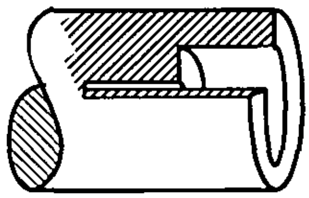
Region:recess-out



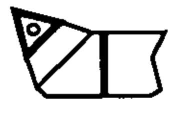
Tool parameter:	Tool data:
Operation:	Turning
Tool name:	External
Tool type:	Neutral
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	MAX. 2/3 D
Included angle	85 rough/35 finish
Entry angle	R[90<E<92.5] F[90<E<152.5]
Tool hld. pos.	Pos. #2
Tool Hld. geom.	x,y

Figure 11.12	Tool models for turn regions	L.U.T - CAD/CAM

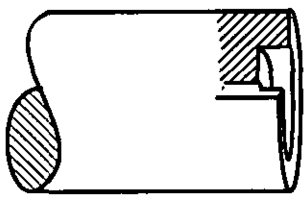
Region	cutting tool	Tool model



Region: profile-in

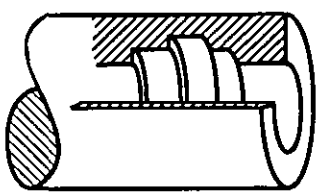


Tool parameter:	Tool data:
Operation:	Turning
Tool name:	Internal
Tool type:	Left handed
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	MAX. 2/3 D
Included angle	85 rough/35 finish
Entry angle	R[90<E<92.5] F[90<E<152.5]
Tool hld. pos.	Pos. #1
Tool Hld. geom.	x,y



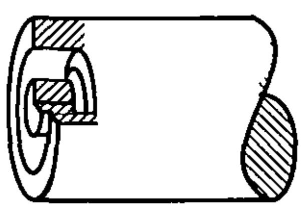
Region: face-in

Tool parameter:	Tool data:
Operation:	Facing
Tool name:	Internal
Tool type:	Left handed
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	MAX. 2/3 D
Included angle	85 rough/35 finish
Entry angle	R[90<E<92.5] F[90<E<152.5]
Tool hld. pos.	Pos. #1
Tool Hld. geom.	x,y



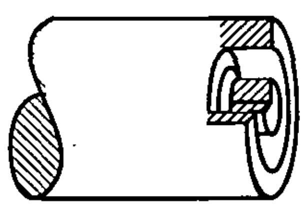
Region: recess-in

Tool parameter:	Tool data:
Operation:	Turning
Tool name:	Internal
Tool type:	Left handed
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	MAX. 2/3 D
Included angle	85 rough/35 finish
Entry angle	R[90<E<92.5] F[90<E<152.5]
Tool hld. pos.	Pos. #1
Tool Hld. geom.	x,y



Region: recess-face-back

Tool parameter:	Tool data:
Operation:	Facing
Tool name:	External
Tool type:	Right handed
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	MAX. 2/3 D
Included angle	85 rough/35 finish
Entry angle	R[90<E<92.5] F[90<E<152.5]
Tool hld. pos.	Pos. #2
Tool Hld. geom.	x,y

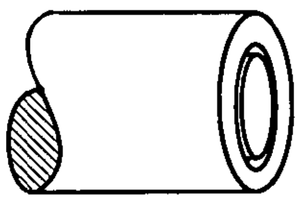


Region:recess-face-front

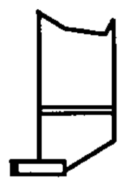
Tool parameter:	Tool data:
Operation:	Facing
Tool name:	External
Tool type:	Left handed
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	MAX. 2/3 D
Included angle	85 rough/35 finish
Entry angle	R[90<E<92.5] F[90<E<152.5]
Tool hld. pos.	Pos. #2
Tool Hld. geom.	x,y

Figure 11.13	Tool model for turn regions	L.U.T - CAD/CAM

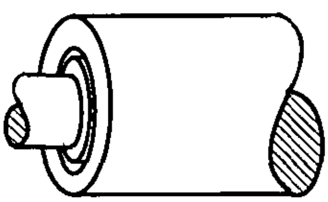
Region	cutting tool	Tool model



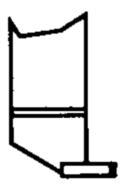
Region:face-front



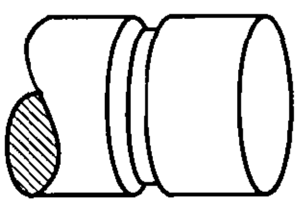
Tool parameter:	Tool data:
Operation:	Grooving
Tool name:	External
Tool type:	Left handed
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	Effective L
Width	W
Tool hld. pos.	Pos. #2
Tool Hld. geom.	x,y



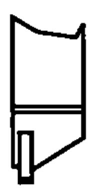
Region:face-back



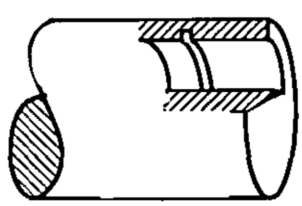
Tool parameter:	Tool data:
Operation:	Grooving
Tool name:	External
Tool type:	Right handed
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	Effective L
Width	W
Tool hld. pos.	Pos. #2
Tool Hld. geom.	x,y



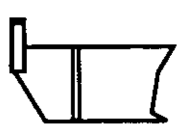
Region:out



Tool parameter:	Tool data:
Operation:	Grooving
Tool name:	External
Tool type:	right handed, neutral
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	Effective L
Width	W
Tool hld. pos.	Pos. #2
Tool Hld. geom.	x,y



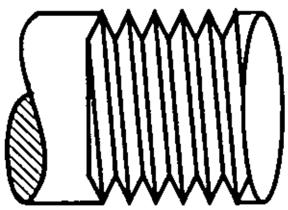
Region:in



Tool parameter:	Tool data:
Operation:	Grooving
Tool name:	Internal
Tool type:	Left handed
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	Effective L
Width	W
Tool hld. pos.	Pos. #1
Tool Hld. geom.	x,y

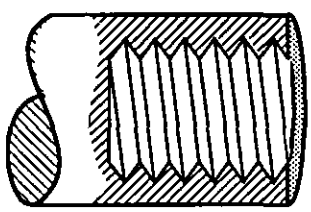
Figure 11.14	Tool model for groove regions	L.U.T - CAD/CAM

Region | **cutting tool** | **Tool model**



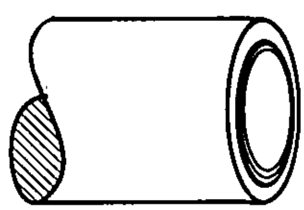
Region:out

Tool parameter:	Tool data:
Operation:	Threading
Tool name:	External
Tool type:	Left handed, neutral
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	MAX. 2/3 D
Included angle	35,55,60,80
Tool hld. pos.	Pos. #2
Tool Hld. geom.	x,y

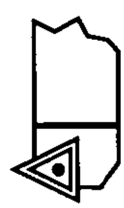


Region:in

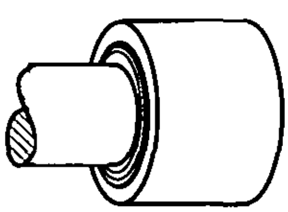
Tool parameter:	Tool data:
Operation:	Threading
Tool name:	Internal
Tool type:	Left handed
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	MAX. 2/3 D
Included angle	35,55,60,80
Tool hld. pos.	Pos. #1
Tool Hld. geom.	x,y



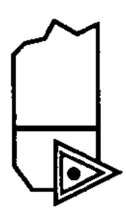
Region:face-front



Tool parameter:	Tool data:
Operation:	Threading
Tool name:	External
Tool type:	Left handed
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	MAX. 2/3 D
Included angle	35,55,60,80
Tool hld. pos.	Pos. #2
Tool Hld. geom.	x,y



Region:face-back



Tool parameter:	Tool data:
Operation:	Threading
Tool name:	External
Tool type:	Right handed
Tool dir.	forward'
Nose Rd.	0.1-0.9
Allowable dpth.	MAX. 2/3 D
Included angle	35,55,60,80
Tool hld. pos.	Pos. #2
Tool Hld. geom.	x,y

Figure 11.15 | Tool model for thread regions | L.U.T - CAD/CAM

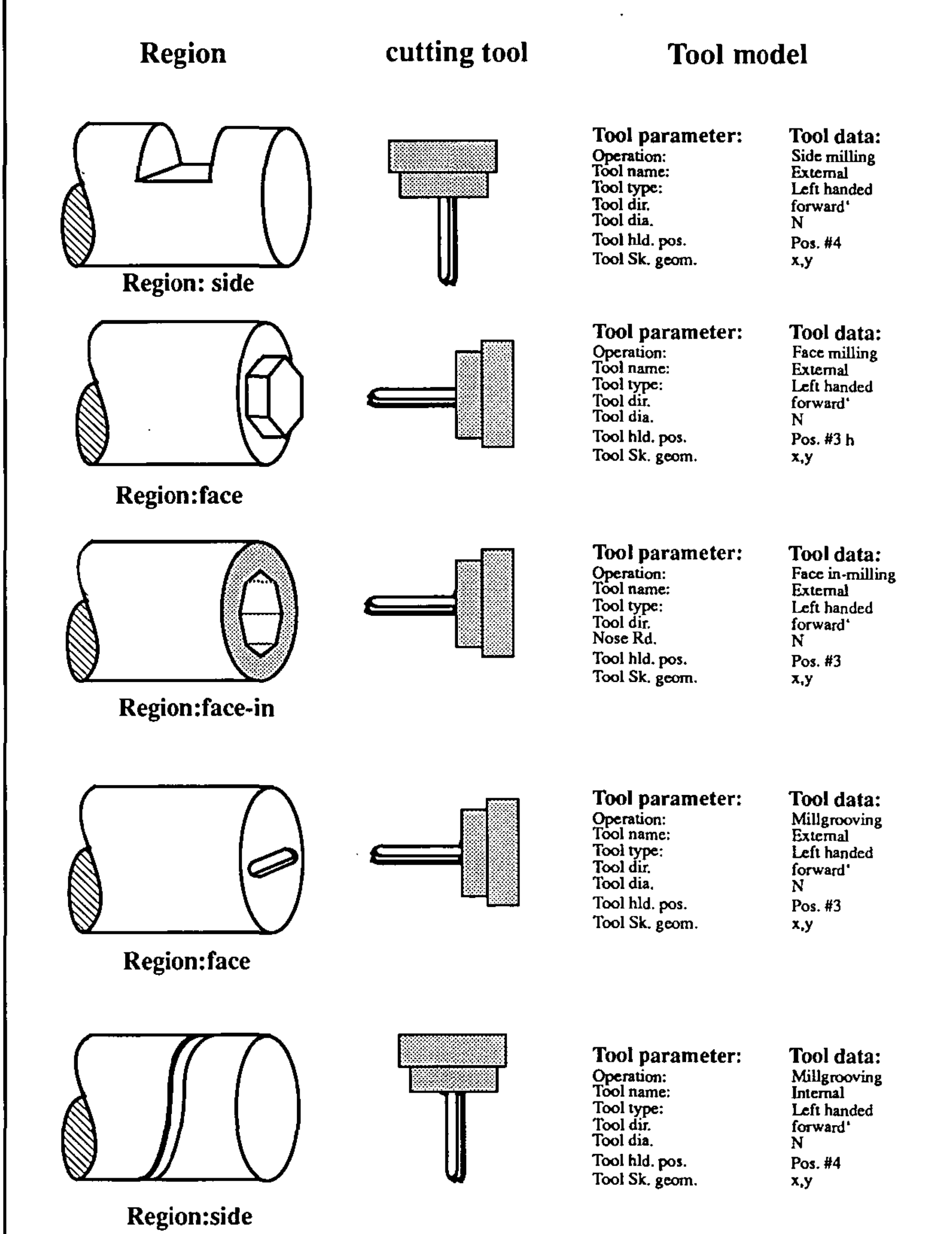


Figure 11.16	Tool model for mill region	L.U.T - CAD/CAM

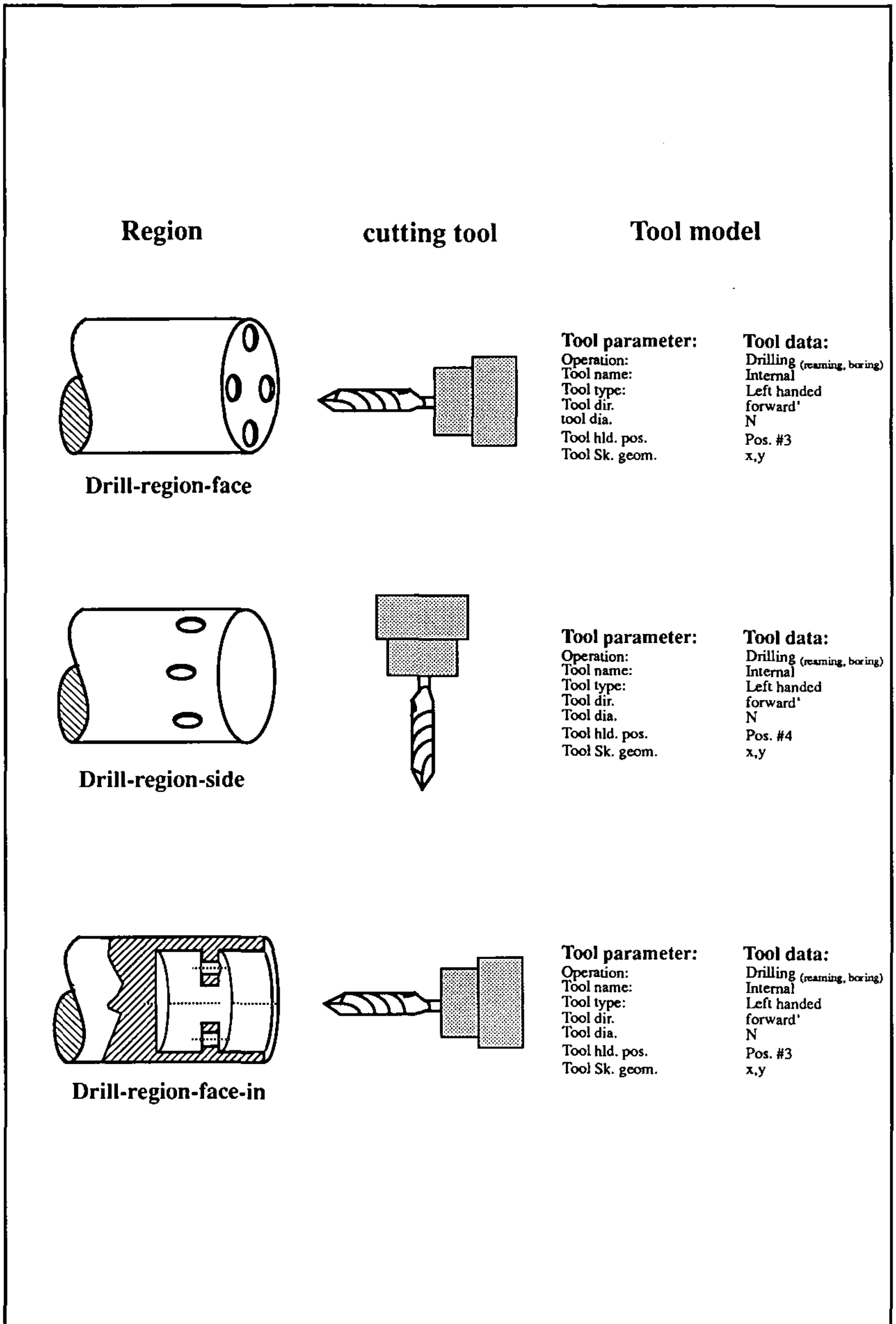


Figure 11.17	Tool model for drill region	L.U.T - CAD/CAM

Chapter 12

Operation Sequencing

12.1 - Introduction

This chapter is concerned with research on the design and implementation of operation sequencing for workshop oriented NC planning. The scope of the necessary information, and it's structure for the generation of an acceptable plan for machining, is explored and the methodology for operation sequencing is addressed.

Many reputable experts and authors *[Allen 89] [Chang 84][Chang 85] [Evershiem 83] [Hinduja 89][Hummel 89]* have described the basis for operation planning decisions. A comparison of these works shows (*see table 1 chapter 4*) the basic common factors used for generating process plans and manufacturing code:

i- The size and the geometry of part

ii- The tolerance and / or finish requirement

iii-The material used

The geometry of the workpiece determines the parameters required for shape description. It also will define the domain in which planning has to be performed (*i.e. turning operation, milling operation etc.*). The geometry of the workpiece also influences set-up decisions (*workholding, machine tool, etc.*). Technologically, the tolerance and finish required for a given surface is a factor which controls and limits the cutting speed and feedrate. Lower cutting speed and higher feed rate are required for roughing where no close finish or tolerance is needed, however, if a high tolerance or surface finish is required this necessities higher cutting speeds and lower feed rates. The maximum and minimum permissible feed and speed for a given surface, material and tool are addressed in chapter 10 & 11. In general, the majority of process planning and NC systems consider the factors mentioned above. However, where they differ most is the methodology and level of application.

12.2 - Scope of Operation Planning

The focus of this research has not been to address the optimal solution for operation sequencing but to devise the means by which the sequence of operations can be planned (*i.e. automatically or manually*) so as to machine the workpiece efficiently. The method devised can plan the sequence of operations in order to achieve the correct technological and geometrical specification. The operation planning module employs two methods to plan the machining sequence. The first method manually sequences the operations. In this case, the user decides the best possible plan. Alternatively, the second method can be used to determine the machining sequence automatically. In this approach the sequence of operations is determined by using a decision model (*see section 12.9.1*).

12.3 - The Purpose of Operation Sequencing

Operation planning is an essential function for NC planning. The main objective of the operation planning module is to generate an acceptable plan for machining the regions. The overall task of the system is to provide the necessary facility and assist the user in selecting the pertinent regions, features, cutting tools and sequence. The fundamental aim of the operation planner is to guarantee the dimensional integrity of the workpiece through every operation *[Johnson 62]* and set the operational environment in a way so that the inherent variation in the workpiece and the various manufacturing processes are closely monitored and controlled.

12.4 - IDEF0 Representation

The IDEF0 methodology has been used to model the operation planning activity by decomposing the planning phases into two sets (*see appendix iii, A132*):

i- Operation sequencing

ii-Determination of CLdata

The operation planning method used in this research establishes a systematic approach for selecting the appropriate machining sequence for the metal cutting operations. Operation sequencing is considered a vital part of operation planning and is principally concerned with offering a set of steps that produce a component *[Sundaram 86]*. Traditionally, the sequencing of operations for workshop oriented NC systems *[Fanuc 89]* *[Traub 89]* have been performed manually. New advances in technology have provided the opportunity for the machine tool industry (*i.e Mazak & Traub*) to develop and automate the operation planning activities and in particular operation sequencing. Nevertheless, the majority of MDI part programming systems still require the user to generate the correct sequence of operations. The method which is used in this research provides the necessary means to sequence the operations automatically. The pre-requisites for sequencing the operations are:

i- The relevant regions and features have to be selected and described.

ii- The appropriate workholding device has to be specified.

iii-The cutting and machining data must be specified for the selected regions

By describing the selected regions, and their associated features, accurate information is conveyed which is used for generating the machining steps in order to produce the workpiece. Each region is designed to embody the relevant information (*i.e. regarding location, geometry, operation type, tooling and machining data*). This information is used to determine an efficient and logical manufacturing sequence for producing the component. In addition, the setup information provides an invaluable assistance to the operation sequencing.

The next activity is designed in a way to provide sufficient support for generating cutter location data. The design for operation sequencing is modular and independent. Each region is associated with cutter location parameters. These parameters are used for generating NC macros. Each macros is designed to fulfil the requirement of a particular region. The information used for generating cutter location data is presented below:

i- The geometrical boundary of region

ii- The geometry of features

iii-Tool information

iv-Clamp information

v- Machining parameters

vii-Operation

The geometry of each region is used as a reference in order to identify the associated macro. Regions are associated with predefined macros. The geometry of region and the associated technological information (*depth of cut, number of cut, operation, etc.*) are used so as to generate CLDATA. The generated CLDATA forms the basis for generating the NC code.

12.5 - The Role of Regions

The concept of regions substantially enhances operation planning decisions. It provides a model with which the operation planning tasks can be accomplished. Consequently, it simplifies the operation planning decisions by decomposing each task into several sub-tasks. Some operation planning tasks are performed at regional level (*i.e. machining data selection, tool selection*). The operation sequencing is performed at component level. The advantage of using regions is that it provides an effective methodology for planning the operations. The knowledge embedded in the regions is used for operation sequencing decisions. The concept of region has been the basis for designing the decision model. Without any frame of reference (*i.e. region and feature scheme*) the logic for establishing the operation precedence would be difficult to accomplish (*Chapter 8 and 9 discuss at length the way regions are described*).

12.6 - Operation Selection

In the concept advanced in this part of research, the user is supported by an automatic selection process which assists the process of selecting the appropriate operations for a particular region *[figure 12.1]*. The logic for this supporting selection process is depicted in figure 12. A set of rules are required for each region which would typically take the form cited below:

If:
(region is profile front)
Then:
(The operation is (rough turn the front profile)
The operation is (finish turn the front profile))

In this research several regions have been identified and specified in chapter 9. The rule sets for these regions are listed in appendix IV.

12.7 - Operation Type

Two basic operations are used for machining the workpiece: 1) roughing operation and 2) finishing operation. These operation types are chiefly used for turning, facing and milling operations *[see figure 12.2]*:

Roughing operation, this is a rapid multiple cut removal of excess volume of material. Roughing tools are used to perform this operation. Maximum permissible depth of cut and feedrates are used to speed up the process.

Finishing operation, this is a single cut operation which is performed along a predetermined profile of a given region which embodies the appropriate roughness code so as to achieve the desired surface finish for each feature.

12.8 - Operation Sequencing

The literature points to several methods that have been used to generate operation sequencing, namely the use of AI by Wang & Wysk *[1988]*, decision tables by XPS-I and the decision tree used by Allen *[1987]* (*see table 1 in chapter 4*). The approach used by the author uses a decision model to sequence the NC operations.

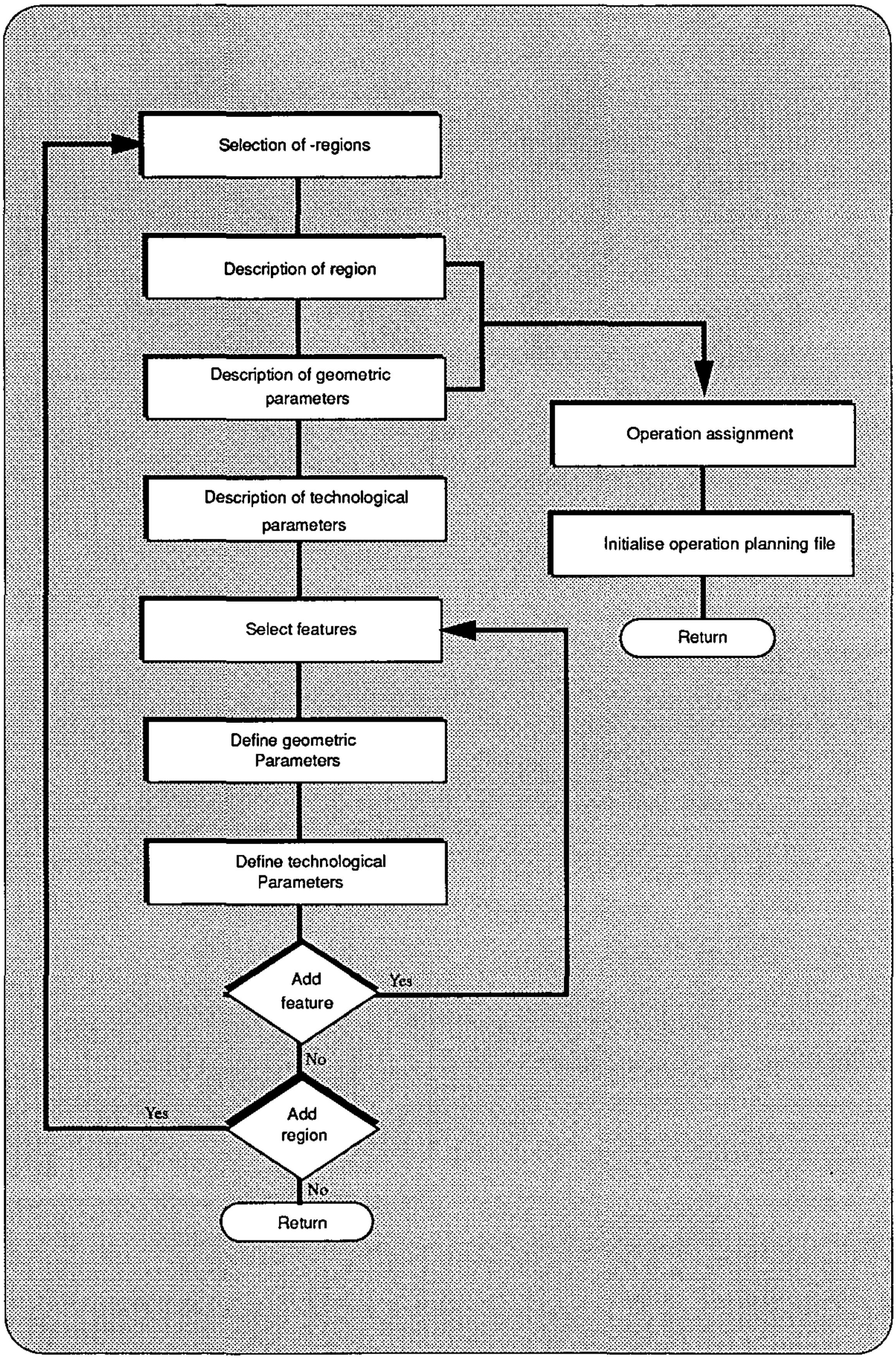


Figure 12	Operation selection	L.U.T CAD/CAM

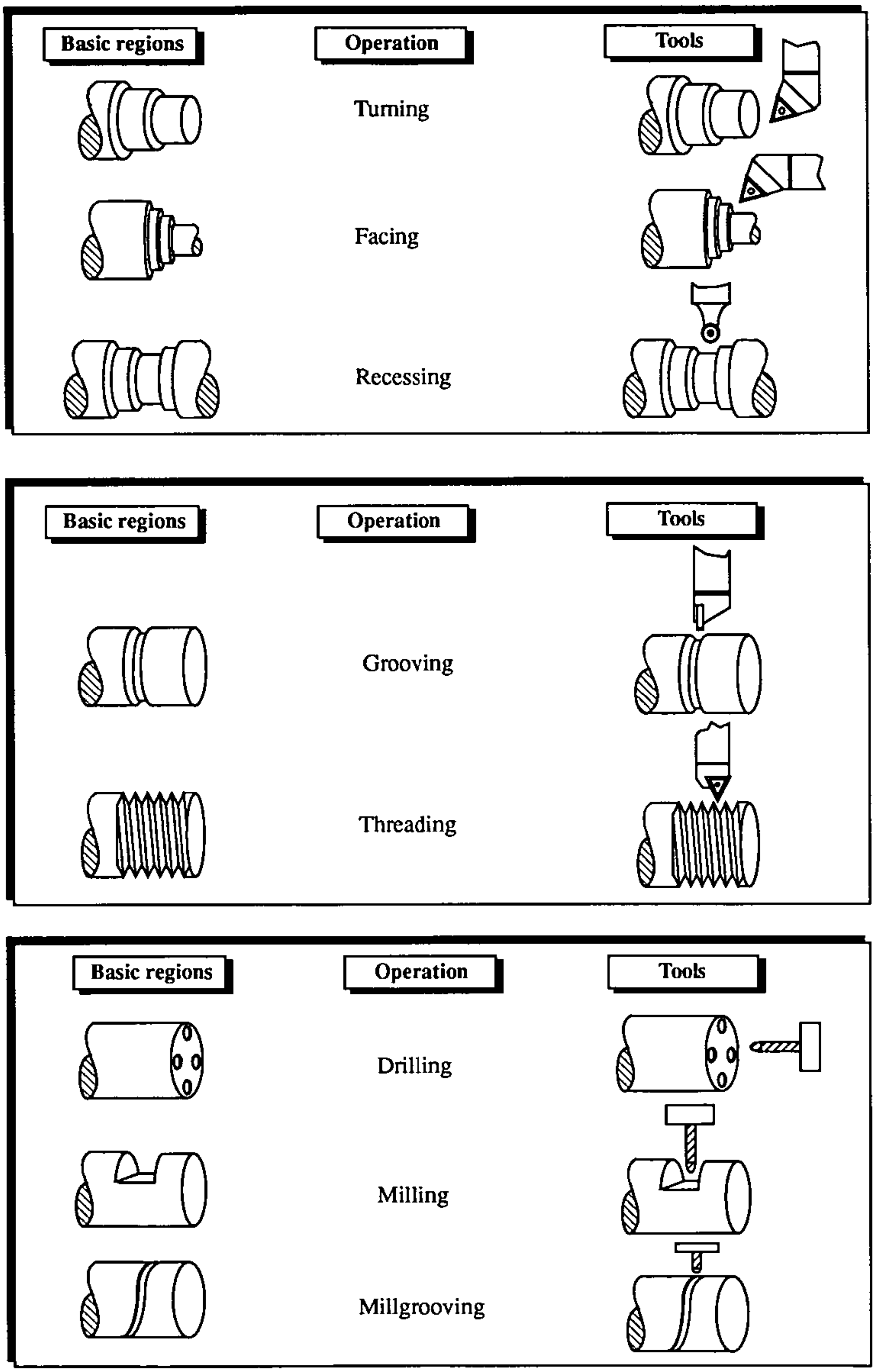
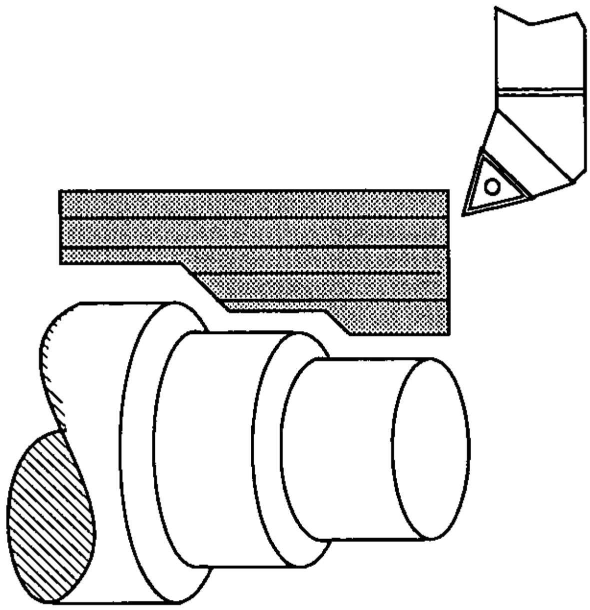
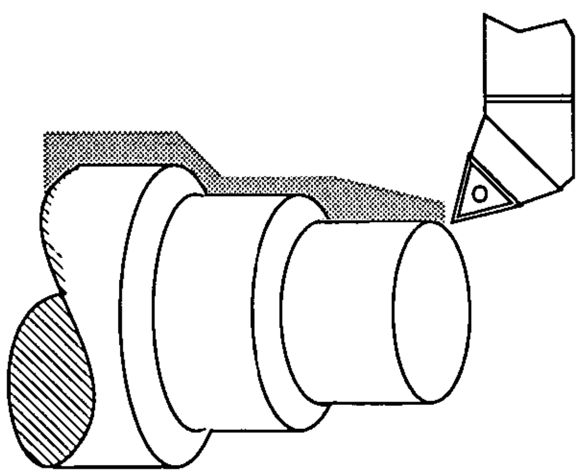


Figure 12.1	Machining operations	L.U.T CAD/CAM



Roughing operation



Finishing operation

Figure 12.2	Operation type	L.U.T CAD/CAM

During the design of the decision model it was found that the process of extracting and formalizing rules for operation sequencing is much more complicated than that of operation selection. The logic to associate the appropriate operations to a geometric region is easily understood. However, the knowledge required to allocate priority to operations, considering the requirements and specification, is subject to localized rules and regulations *[Wang 88]*. The purpose of sequencing the available and or selected operation is to produce a manufacturable sequence by considering the relevant constraints (*i.e. the geometrical and technological specification*) *[Bell 89]*.

A process is associated to a set of regions and or features which generally specifies how a region is transformed from an original (*raw stock*) state to a final shape. In this research regions are defined by their associated operations. The purpose is to organize and plan the knowledge around regions and features in order to rationalize operation sequencing. The relevant literatures points to the different methods which can be used to control and produce an effective and correct operation sequence *[Peklenik 89] [Bell 89] [Wang 88] [Dong 91][Barkocy 84]*.

12.8.1 - Sequencing Method Adopted

The operation sequencing method used in this research is called sequential operation planning and is primarily based on the idea that each region of a component is considered with a unit operation *[Choie 84]*. However, some regions are produced by more than one operation. The operation type and attributes are predetermined for each region. For example, *turn-regions* are machined with two operations: (1) rough turning and (2) finish turning operation. Operation sequencing is seen by some *[Shyu 87]* as a bottleneck in operation planning. The primary objective is to consider the bottleneck and subsequently generate the best possible sequence of operations by considering the economical and technological requirements. The operation planning function commences with tool selection and subsequently the operation planner, using the pre designed decision model, applies the appropriate cutting sequences to divide the machining of regions and features into entry, roughing, and finishing operations

[Barkocy 84]. The operations associated with the selected regions and features have to be put in such an order such that the precedence relationships are ensured *[Eversheim 82]*. This is determined by the following considerations *[Wang 88]*:

i. Precedence in operation

ii. Precedence in tooling

iii.Precedence in geometry

Precedence in operation is considered at component level. The task of the operation sequencing module is to sequence the operation so as to ensure and control the integrity of the workpiece. Precedence in tooling is usually used in order to organise and group the cutting tools so as to eliminate redundant tool changes. The use of regions and features enhance tool selection and to some degree reduce the number of tool changes. However, the author believes that the application of tool precedence, which is not given a priority in this research, should totally eliminate redundant tool change time. The geometrical precedence basically addresses turning and milling in which the geometric sequence of surface features for defining a region must follow a fixed pattern and therefore the precedence in geometry must be observed so as to eliminate error, see section 12.9.5.

12.8.2 - Constraints (*Precedence & setup*)

The order in which the regions are machined dramatically effects the production of a component. For a component several distinct and equally plausible machining sequences can be planned. As described in previous sections only a single setting is considered, in which a series of operations such as turning, grooving, threading, milling and drilling may be performed on the workpiece without any re-clamping. The machine tool used can perform all the operations in a single setup. The increase in the number of operations is directly proportional to the number of re-clamping steps. As the number of re-clamping operations increases so does the number of plausible and viable machining plans *[Giusti 89]*. Thus the choice for selecting the best possible sequence can become extremely complex and tedious, which consequently requires a great deal of analysis and CPU time in order to produce the best possible sequence. The limitations imposed in this research will undoubtedly limit the possible choices. The experimental system is devised for the state of the art turning centres. Many of the complex operations such as drilling, turning, milling, etc. can be performed on the workpiece in a single setting, thus providing many benefits (*see chapter 5*) as well as saving time and other resources.

12.8.3 - The Sequencing Criteria

The best possible sequence for machining operations is mainly determined by the level of control which is applied through the operations. This is dependent upon the following criteria *[Johnson 62]*:

i - Design specification
- The workpiece geometry
- The workpiece technological specification

ii - Operation specification
- Operation constraint
- Operation variation or alternatives

The general pre-requisite for operation sequencing is highlighted above. In this research, the geometric, technological and operational specifications are determined for each region. Thus, three constraints are considered which are in essence based on the above criteria (*refer to section 12.8.3*). The subsequent constraints were used as a basis to determine and formalize the decision model *[Wang 88]*:

i - The geometric constraints

ii - The operational constrains

iii -The tooling constraints

12.9 - Operation Sequencing Steps

In general (*i.e. process planning*) the sequence of operations usually begins with obtaining a forged or casted raw material, then the necessary machining operations required to generate a component are performed in a logical sequence. Finally the operations are terminated by the packaging and subsequent shipping operation. In the context of this research the initial and final operations are only concerned with machining. The principle sequence of operations are (*see the examples in figure 12.2a &12.b*):

i- The initial and qualifying operations

ii- The Principal operations

iii-The final operations

12.9.1 - Decision Models

The decision model developed for this research is straight forward and logical. This model is designed for general cases, therefore in exceptional cases the MDI facility can be used to plan the sequence. The decision model applied is based on the sequence which is commonly accepted for turning *[Hinduja 89]* and milling *[Mazak 89]* operations. The principle of a decision model is based on two steps: vertical sequencing and horizontal sequencing. The objective is to subdivide the sequencing task so as to simplify the sequencing process and thus provide a frame of references, with which the operations can be subdivided into smaller segments and subsequently sequenced by matching the selected operations with the relevant decision model. As depicted in figure 12.3 two sequencing phases are embedded in the decision model. The first phase is called horizontal sequencing in which each category of operation (*i.e. Qualifying, prin-*

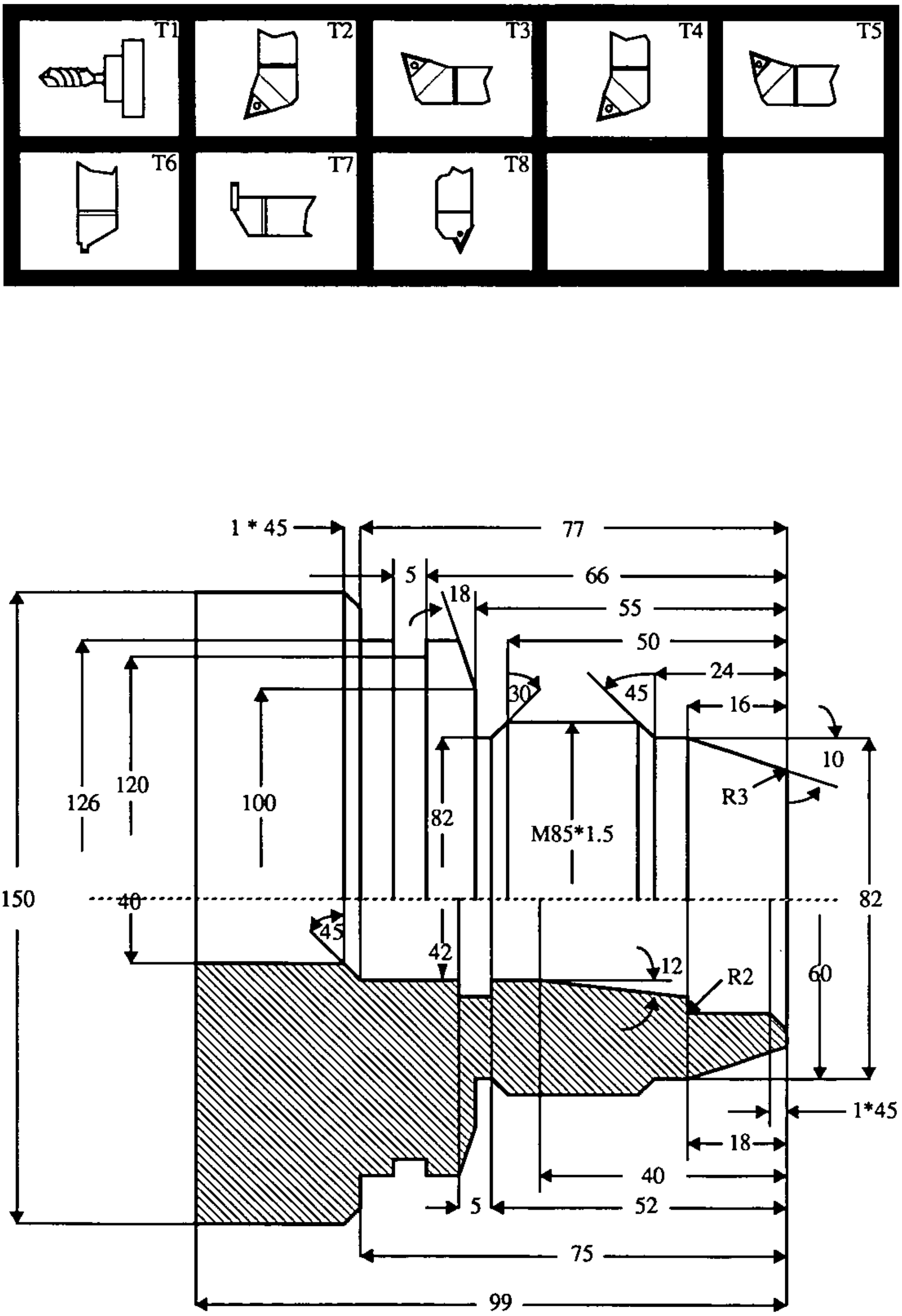


Figure 12.2 a	Example - Rotational workpiece	L.U.T CAD/CAM

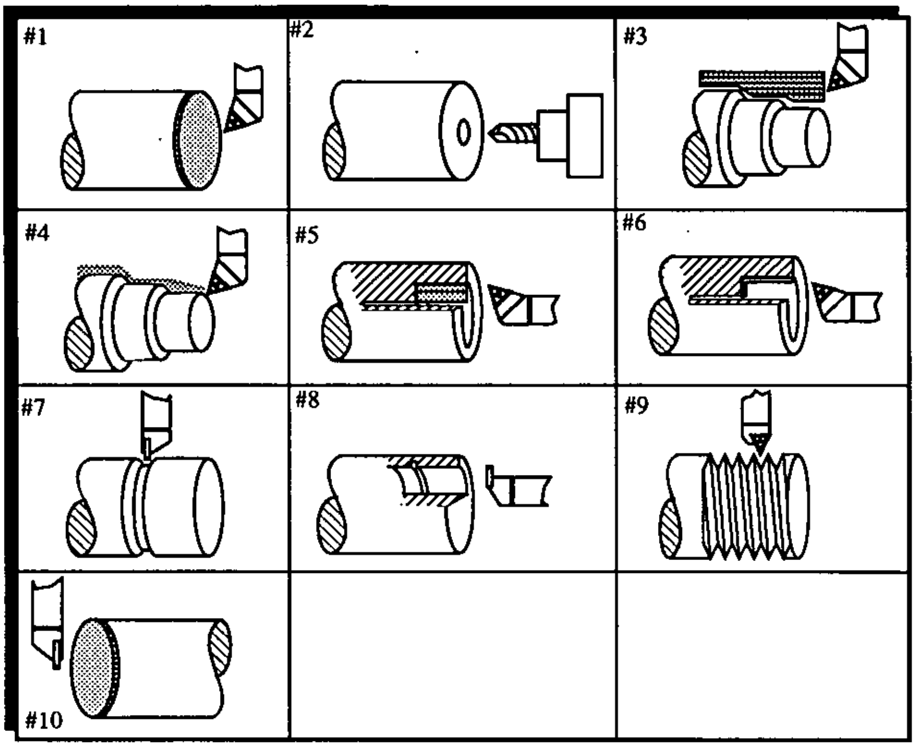


Table 1: Operation Planning header

Program No	Operation Plan	Name: Date:
Machine Tool:	Material:	Drawing No:

Table 2: Operation Plan

No	Op. Type	Operation Description	Tool No.	Tool Description	Feed	Speed
1	Q	Face the billet	T1	Facing tool		
2	Q	Drill Face	T2	Drilling tool		
3	P	Rough the External profile [front]	T3	Roughing tool		
4	P	Finish the external profile [front]	T4	Finishing tool		
5	P	Rough the internal profile	T5	Roughing tool		
6	P	Finish the internal profile	T6	Finishing tool		
7	P	Machine the external groove	T7	Grooving tool		
8	P	Machine the internal groove	T8	Grooving tool		
9	p	Thread the external diameter	T9	Threading tool		
10	F	Part off	T10	Parting tool		

* Q = Initial & qualifying operation
P = Intermidiate or primary operation
F = Final operation

Figure 12.2 b	Operation sequence	L.U.T CAD/CAM

cipal and final) are associated with a decision model so as to sequence the sub-operations. The vertical sequencing is concerned with the precedence for the major operations (*i.e the sequence between the qualifying operation, Principal operations and the final operations is planned*). Vertical sequencing is performed for the major operations. The horizontal sequencing is performed by the three designated decision models. The primary rule for operation sequencing is listed below:

Principle rule:

The roughing operation is performed prior to the finishing operation.

12.9.2 - The Qualifying Operations

The characteristics of the raw material may require that certain operations be performed on the billet prior to accomplishing the main operations that generate the shape of a component. The qualifying operations are divided into two parts. The first part mainly deals with those operations which are required to prepare the surfaces for clamping. As mentioned in section 12.11 since a single setting is used to produce asymmetric rotational components, there would be no need for any qualifying operation of this sort (*the assumption is that surfaces are already prepared prior to clamping*). The second set of operations are mainly concerned with those surfaces that need to be machined prior to major operations to produce a component. Three distinct operations may by required as a qualifier before other regions can be machined:

i- Plain turning
ii-Facing
iii-Drilling

Plain turning may be required in some cases to remove a large volume of excess material before the major operations which form the actual shape of the workpiece are performed. Facing is usually used to face the surface of the billet and establish the zero

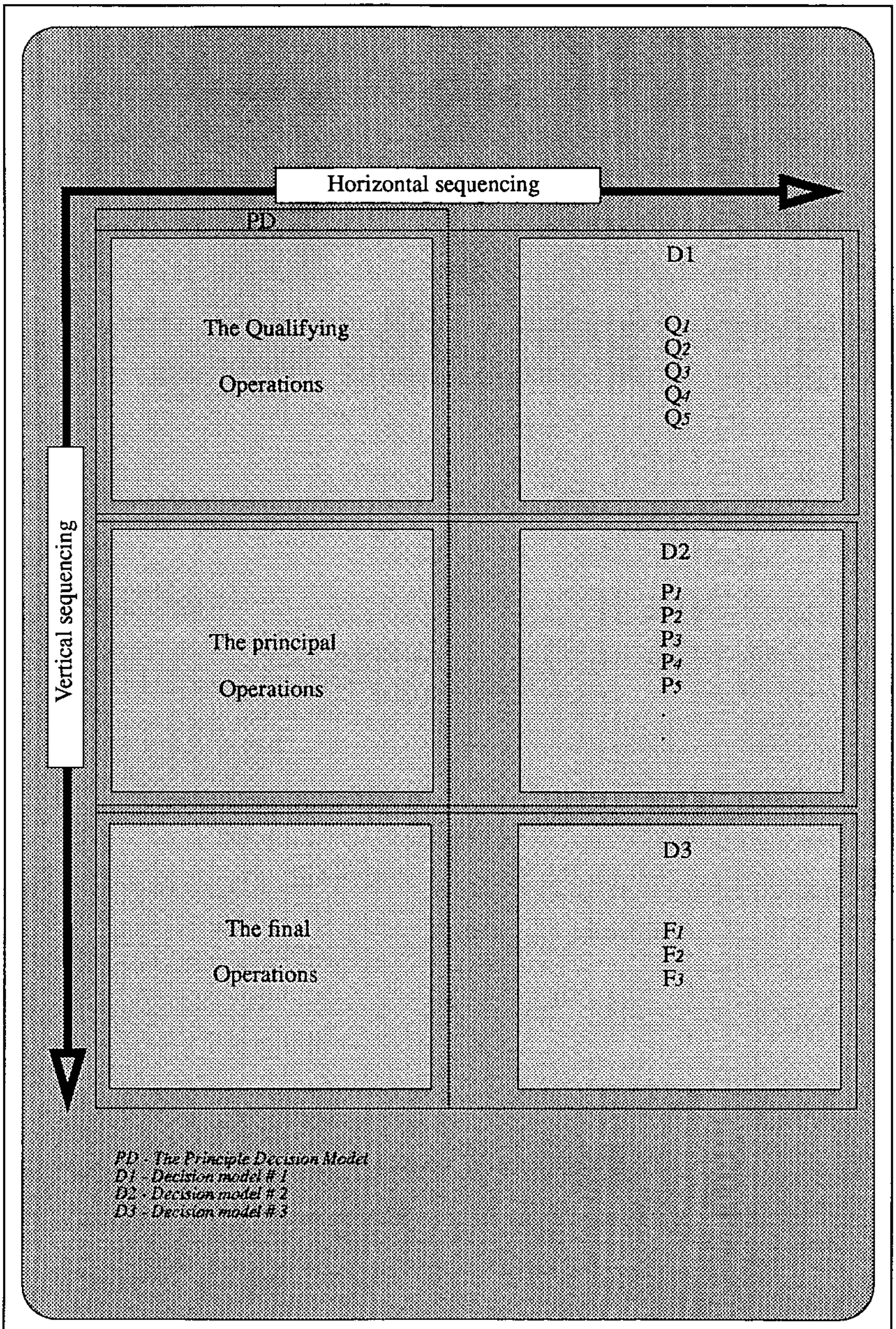
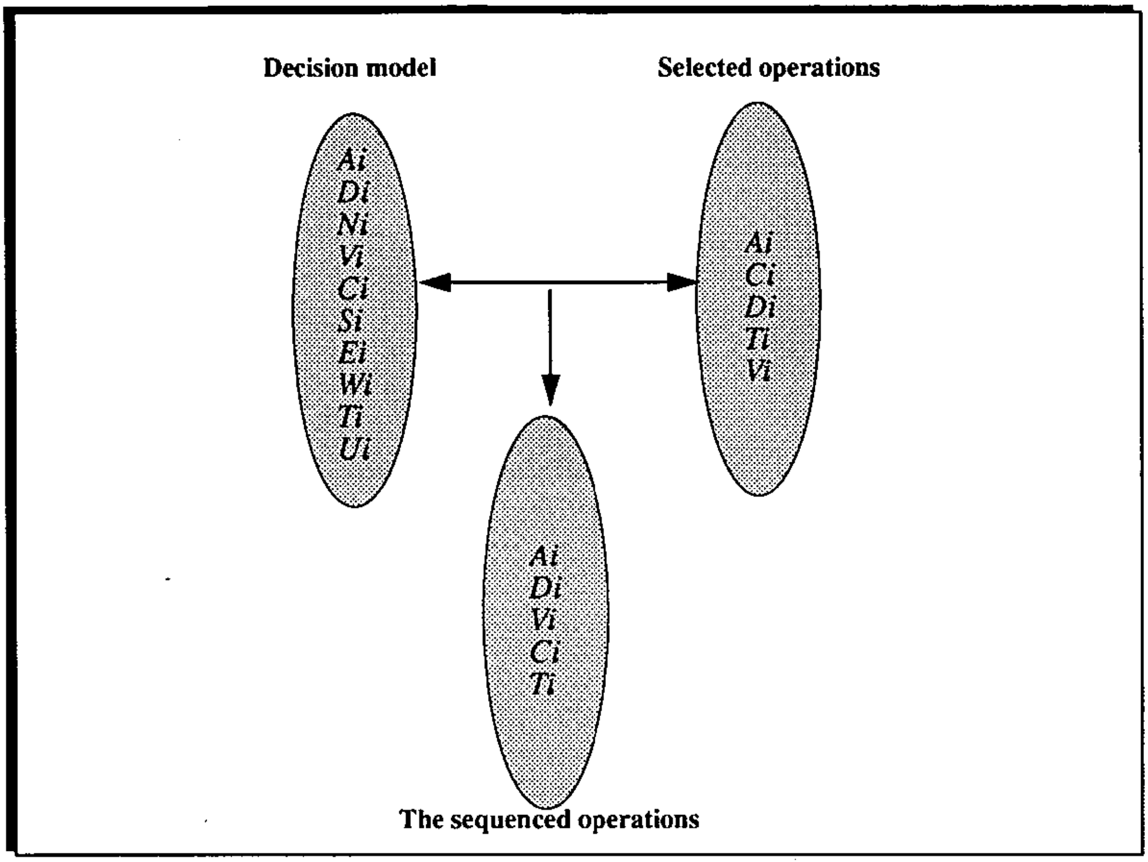


Figure 12.3	The decision model architecture	LUT - CAD/CAM



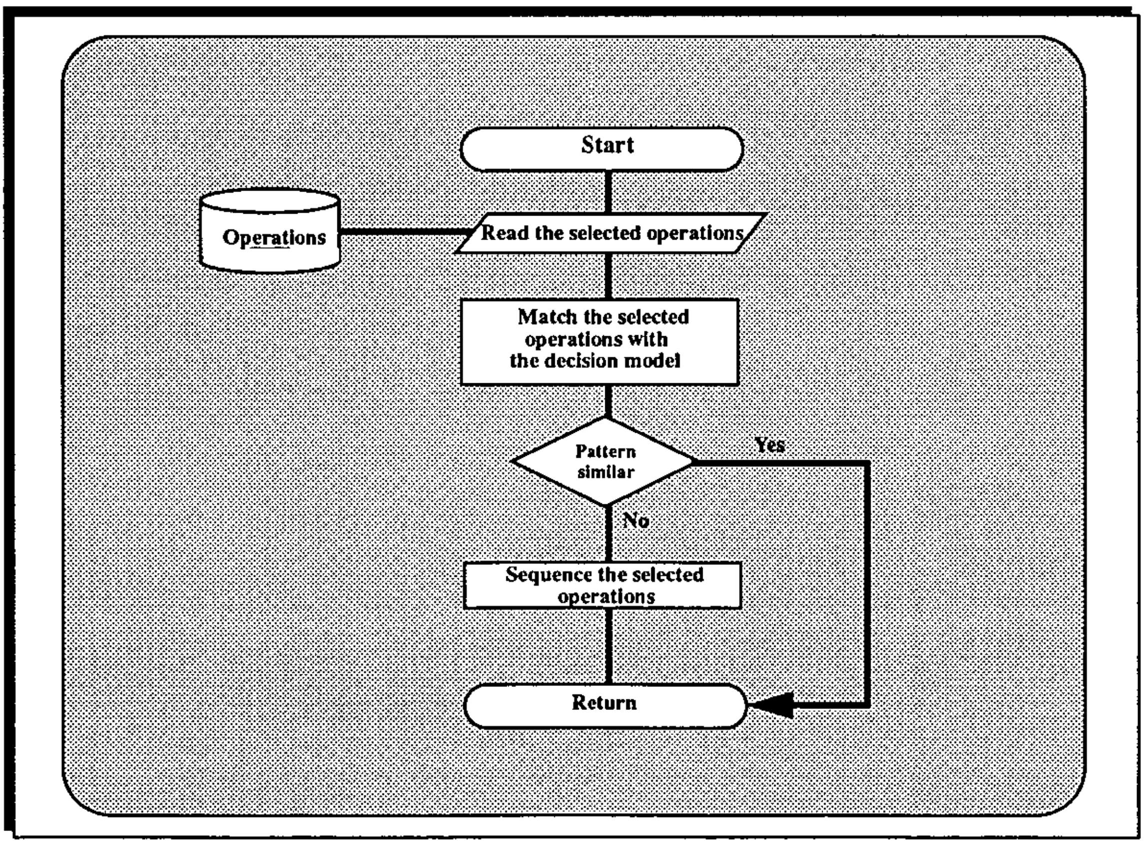


Figure 12.4	The decision model function	LUT - CAD/CAM

point (*part datum*). This is a qualifying operation which is essentially required before any other operation can be carried. Drilling operations are used mainly to prepare the billet for the auxiliary operations (*i.e. centre drilling to support the workpiece with tailstock*). The drilling operation is also performed to remove excess material and prepare the inner profile of the workpiece (*i.e. for any subsequent internal operations such as internal turning, inside grooving and / or inside threading*).

12.9.2.1 - Decision Model for the Qualifying Operations

Qualifying operations are performed prior to any other operations. Horizontal sequencing is embedded in the decision model to prirotize the sequence of qualifying operations.The sequence with which these operations are organized are:

Step #1 *Facing*

step #2 *Drilling*

step #3 *Plain turning*

The facing operation is performed prior to other operations to prepare the surface of the billet and set the datum for subsequent machining operations. The next operation can be drilling. A static or live tool can be used to remove the excess material. Plain rough turning can be used to decrease the diameter of the billet prior to any major operation.

12.9.3 - The Principal Operations

The Principal operations are primarily concerned with regions that describe the geometry of a given component. As described in chapter 9 each region is associated with a metal cutting operations *[Choi 84] [Lewis 82]*. By selecting the required regions, the appropriate operations are automatically selected and subsequently stored in the operation planner file. The operation planner is used to sequence the operations. Two distinct methods are considered for sequencing the machining operations. The first method allows the user to examine the selected operations by studying the given sequence (*i.e. the sequence in which the regions are selected and described by the user*). In many cases the given sequence needs modification, unless the user has selected regions/ features in a specific order. If necessary the system provides the user with an MDI facility to modify the sequence. The second method supports the user by automatically sequencing the operations. The automatic sequencing of operations is based on several decision models.

12.9.3.1 - The Decision Model for The Principal Operations

As depicted in figure 12.4 for the principle operations, the sequence of operations are determined by matching the selected operations (*i.e. the operations which are in the operation planner file*) with the predetermined sequence in the decision model. Consequently the sequence for the principal operations is determined. The first operations are concerned with turning. This is simply designed so as to generate the principle shape of the component. As shown in step one, turning operations are divided into many sub-operations. Those operations are also prirotized to ensure the best sequence for machining. The next operation is threading. Threading can be performed either before or after the grooving operations. Both grooves and the threads are considered as secondary features (*see section 8.8*) and therefore machined after the component is turned. The next operation in the list is a milling operation in which those segments of the component that require milling operations are machined. This operation is followed by the millgrooving operation. Basically, keyways or slots can be machined either on the basic profile of the workpiece (*i.e on the turned profile*) or on the milled profile. The final operation is drilling. The different segments of the workpiece can then be accessed for drilling. The model for the Principal operations is depicted overleaf.

Step#1 Turning:

step # 1.1 *Turn the front profile (region: profile front)*
step # 1.2 *Turn the back profile (region: profile back)*
step # 1.3 *Turn the front face (region: face front)*
step # 1.4 *Turn the back face (region: face back)*
step # 1.5 *Turn the front recess (region: recess front/face)*
step # 1.6 *Turn the outside recess (region: recess profile)*
step # 1.7 *Turn the back recess (region: recess back)*
step # 1.8 *Turn the inside profile (region: in profile)*
step # 1.9 *Turn the inside face (region: in face)*
step # 1.10 *Turn the inside recess (region: in recess)*

Step #2 Threading:

Step # 2.1 *Thread the O.D (region: out)*
Step # 2.2 *Thread the face (region: face)*
Step # 2.3 *Thread the back (region: back)*
Step # 2.4 *Thread the inside (region: in)*

Step #3 Grooving:

Step # 3.1 *Groove the O.D (region: out)*
Step # 3.2 *Groove the back face (region: back)*
Step # 3.3 *Groove the front face (region: front)*
Step # 3.4 *Groove the inside (region: in)*

Step #4 Milling:

Step # 4.1 *Mill the face (region: face)*
Step # 4.2 *Mill the side (region: side)*
Step # 4.3 *Mill the inside face (region: in)*

Step #5 Millgrooving:

Step # 5.1 *Mill groove the face (region: face)*
Step # 5.2 *Mill groove the side (region: side)*
Step # 5.3 *mill groove the inside (region: in)*

Step #6 Drilling:

Step # 6.1 *Drill the face (region: face)*
Step # 6.2 *Drill the side (region: side)*
Step # 6.3 *Drill the inside (region: in)*

The decision model is used in order to sequence the principal operations which are chiefly concerned with the operations that are required to machine a component.

12.9.4 - The Final Operations

In the context of this research the last machining operation is concerned with a parting off operation which is used so as to dissect the workpiece from the billet. Prior to the parting off operation, the workpiece can be measured. The measurement schema is not considered in this research. However, it is considered as a substantial activity in which the workpiece may be inspected so as to evaluate the validity of the machining process and the feature.

12.9.4.1 - The Decision Model for the Final Operations

The decision model presented below embodies the appropriate sequence for the final operations.

step #1 Measurement

Step #2 parting off

Step #3 Part catching

Step one is not considered in this research. Therefore the final operation is concerned with dissecting the machined workpiece from the billet and subsequently catching the workpiece.

12.9.5 - Geometrical Constraints

The surfaces selected for location impose a constraint on how the workpiece and the operations are controlled. In this case since a single setting is assumed, the constraint imposed is predetermined *[figure 12.5]*. The sequence of geometrically defining the turned surfaces is constrained. The turned and milled regions have to be defined in a particular sequence. For instance, the surface features for defining the *turn front profile* region have to be described from right to left. Any deviation from this sequence will result in error. Therefore, the geometric precedence is implemented by enforcing mandatory rules for surface feature description.

The workpiece can only be machined on those surfaces which are not being clamped, however those areas that are clamped are therefore geometrically constrained. The advantages are that since all the machining operations have to be performed in a single setting the areas or regions which cannot be machined are fixed and easy to recognize. In short the areas for clamping cannot be geometrically assigned to any machining operation. The geometrical constraint doesn't allow certain regions to be defined. The following regions and features cannot be machined in a single setting unless a fifth axis is considered *(double chuck)*:

i- Hole (*Drill, ream, bor, taping*) on the left face region

ii-Threads on the left face region

iii-Grooves on the left face region

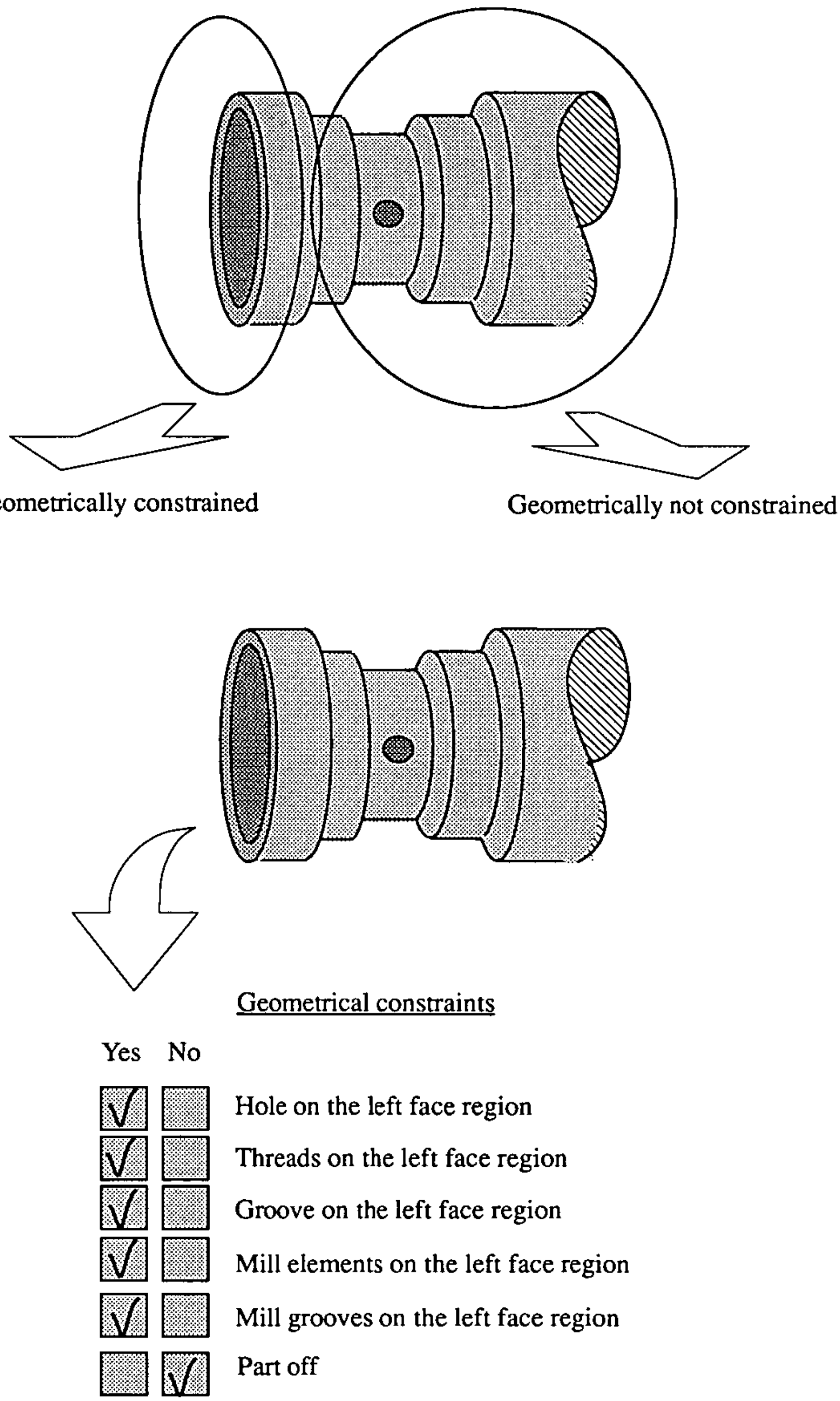
iv-Mill elements on the left face region

v-Mill grooves on the left face region

These regions are pictorially shown overleaf *[figure 12.5]*. In general the surface located for clamping will enable the determination of the logical sequence and the number of operations required to machine the workpiece.

12.9.6 - Operational Constraints

Operational constraints are considered when planning the operation sequence. Therefore, some operations have to be performed before other operations can proceed *(see figure 12.6)*. The operation planner module classifies the operational constraints into two groups. The first group are represented by operations such as internal and external turning and facing where roughing operations have to proceed before the finishing operations. The second groups are operations such as tapping and reaming which must



√ * The geomtrical constraint is based on a four axes turning centre

Figure 12.5	Geometrical constraints	L.U.T CAD/CAM

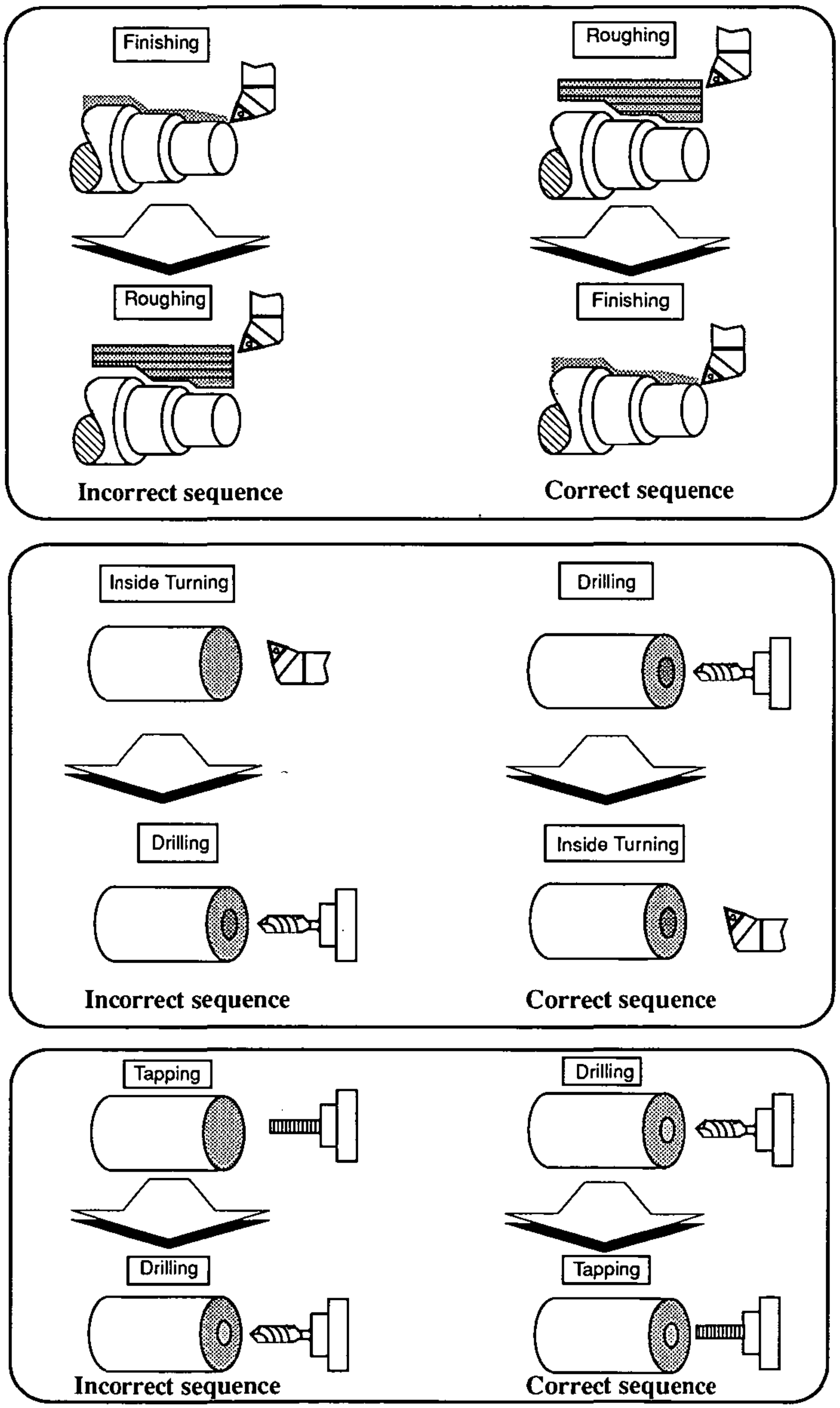


Figure 12.6	Operational constraints	L.U.T - CAD/CAM

follow a logical sequence. For example a hole cannot be tapped before being drilled, therefore the necessary constrains must be considered during the selection so as to prevent an incorrect sequence of operations. The operation sequence is generated by using a decision model *[Wysk 77] [Chang 85]*

12.9.7 - Tooling Constraint

As described in chapter 11, some regions can only be produced by a particular type of cutting tool (*see figure 12.7*). As can be seen region *[A]* can be machined with a left or a neutral cutting tools, however, region *[B]* can only be machined with a right hand or a neutral cutting tool, nevertheless region *[C]* can only be machined with a neutral cutting tool or a combination of left and right hand cutting tools. The use of an incorrect cutting tool may deform the region or lead to incomplete machining operations. Furthermore, grouping regions based on usage of common cutting tools may result in the reduction of tool changing time *[Hinduja 89] [Wang 88] [Eversheim 82].* When selecting tools for each region the tool model and database can be invoked in order to guide and assist the selection of the relevant cutting tools for a particular region. For more detail discussion see chapter 11.

12.10 - The Cutter Location Data

The generation of cutter data only takes place when the specified regions are described and the pertaining operations associated with each region are sequenced. Each operation is designed to be linked with a particular region. Thus each operation is embedded with a set of geometrical and technological information required to generate CLDATA. As depicted *[figure 12.8]* in the flow diagram, the specified region is recognized and the specified features are listed. Each feature provides the relevant geometrical and technological data which is subsequently used to generate CLDATA. The flow chart for generating the cutter data would typically take the form sighted in figure 12.8.

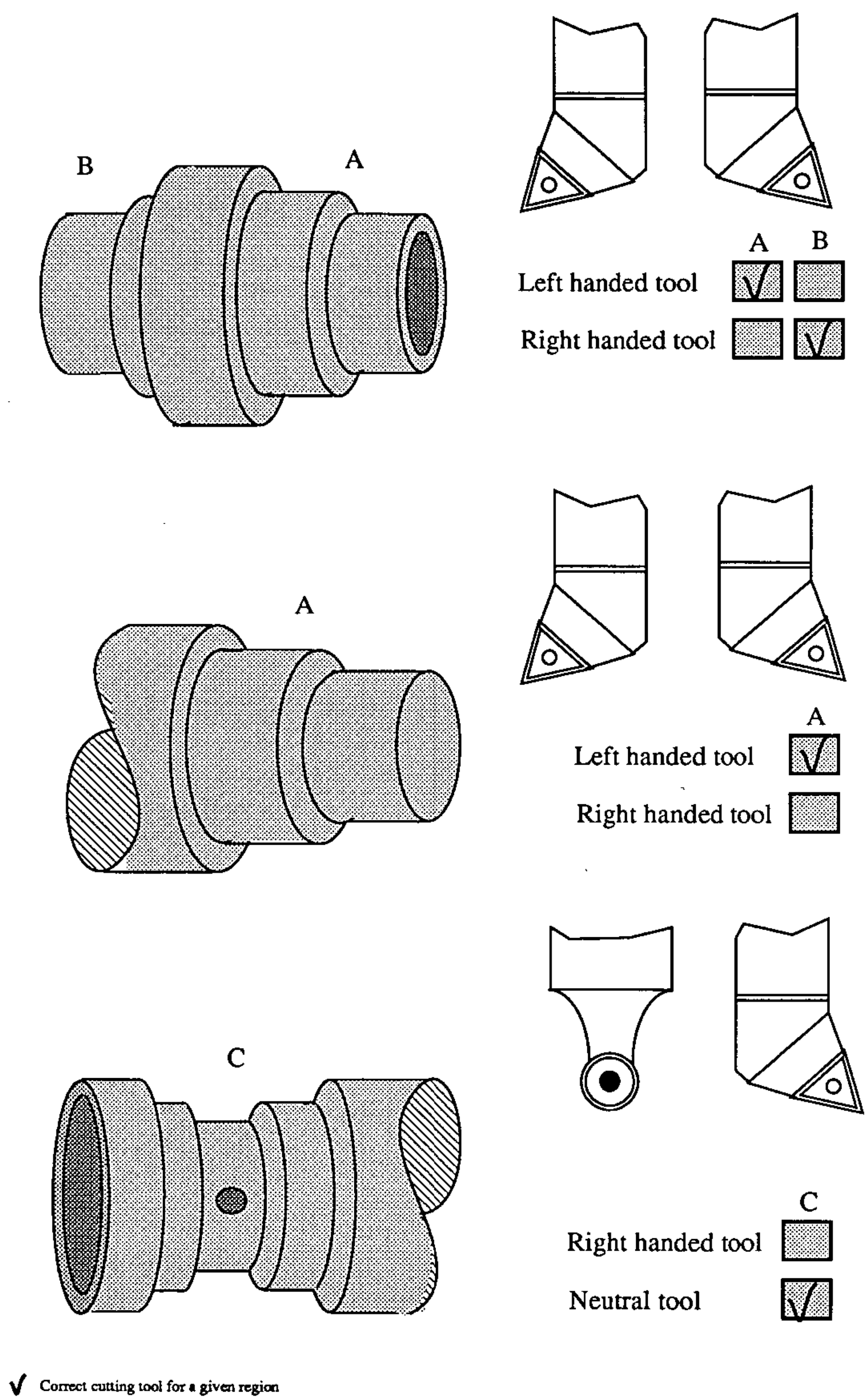


Figure 12.7	Tool constraints	L.U.T - CAD/CAM

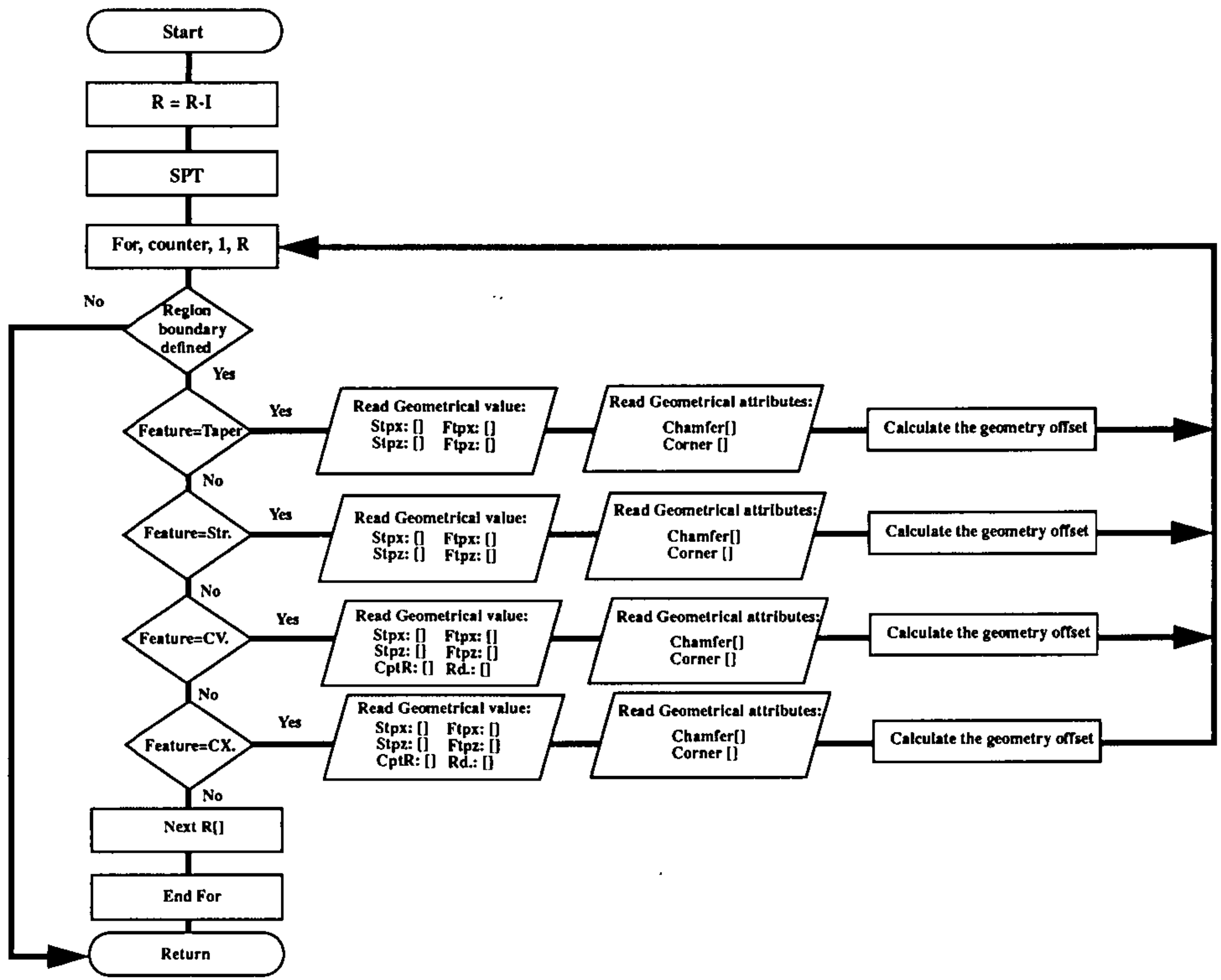


Figure 12.8	CLDATA generation for turn and mill region	L.U.T - CAD/CAM

12.10.1 - CLDATA for Turned and Milled Regions

The turn and mill regions consist of several (*see chapter 9*) predetermined regions each representing a portion of a component. The surface features used for defining the turn and mill regions are transformed into cutter location data. The steps for generating the cutter tool data for the surface features are depicted. The major prerequisite for generating the cutter location data would be to have the selected operations (*i.e. the list of operations which are available in the operation planner file*)

Chapter 13

Part Programming Using Parametrised Components

13.1 - Introduction

The purpose of this chapter is to report on the implementation of parametric part family programming and introduce the concepts used in designing and developing the parametric system. The chapter therefore describes the necessary interactions required to produce the part families and parametric representation. The aim is to describe the essential elements in the implementation of this concept. The differential advantages which are inherently embedded within the parametric representation are also addressed. A general description of parametric part family programming is represented using IDEF0 which is designed to provide the basic framework in which all the activities that are interacting are shown. The representation of this system by IDEF0 provides a brief and useful insight into the architecture which models and illustrates the parametric approach (*see appendix III*).

13.2 - Scope of Parametric Part Family Programming System

The discussions in the previous chapters (*chapter 8,9,10,11,12*) were intended to describe a unique approach for the representation of components and generation of part programs. The aim was to concentrate on increasing the quality of data, and provide a highly structured environment which can efficiently address and excel the representation of part geometry for machining. In summery, the novel approach used in those arguments concentrates on the method which can best rationalise part description (*i.e regions & features*). However it is felt that in order to move beyond the thinking established by the pioneers of the workshop approach *[Fanuc 89] [Traub 89] [Mazak 89]*, a combined and cohesive approach is required which would provide the synergic result demanded by the industry. The design of a parametric part family database as an extension of the workshop oriented NC planning system is a step in a right direction which can be designed to fulfil the practical needs of many companies. The provision of a part family database offers numerous advantages and simplifies the process of workpiece description by eliminating the repetitive and cumbersome task of creating a part program from scratch for every component. This approach is applied by developing a range of part families which would be representative of parts produced in a manufacturing plant. Each part is represented parametrically, the variables or arguments required for geometry are designed by the combined participation of all the relevant functions (*management, design and manufacturing*).

13.3 - IDEF0 Representation

Several activities are highlighted by IDEF0 which functions as the primary pillar to represent the parametric approach (*see appendix III A1.2.2.1*). The initial activity is concerned with the design of families, at this point several elements are required which must be present in the design function; the role of management, the manufacturing need, the participation of several functions (*i.e design, manufacturing*) and the specification of design and manufacture. Subsequently, based on the design and manufacturing needs of similar components, a family can be designed. This activity identifies the family needed by the use of interactive dialogue with the user. Information such as family attributes can be designed into the system so as to distinguish one family from the other, and based on the available families a relevant family can be selected. The final activity is concerned with the general description of a particular component in a family. As implied, each part is represented by several parameters:

i-Family type & shape
ii-Geometrical dimension
iii-Geometrical attributes
iv-Technological data

Each parameter is designed to describes a particular aspect of a component, nonetheless the geometry of a component is represented by a fixed parameter, therefore the attributes which can vary are the dimensions of features and the technological data. A more detail description of the parametric part family representation is provided in the subsequent sections.

13.4 - Definition of Parametric Program

Several synonymous terms have been used to define the parametric method. The term symbol, shape, and macros are often used to convey a similar message and simplify the programming process *[Harrison 86]*. The first parametric concept began in 1950 when APT was developed at M.I.T and with in APT the word macro was used to define several functions and the repetition of a motion sequence several times. As a result the redundancy of data in APT was significantly reduced. Similarly, the concept of symbol or shape was first used in CAD systems and thus enabled the designer to create standard parts (*i.e pins and bolts*). Furthermore it allowed the designer to use a symbol or shape in several common aspects of a drawing in order to eliminate the repetitive tasks. The first of GT based parametric program for CAD was PEP (*parametric element processor*) developed by Computervision. Today many software developers provide parametric capability (*i.e GRIP by United Computing Corp, PRO ENGINNEER, Autocad,* etc.). Harrison *et al [1986]* believes that parametric programs can be grouped into several categories each suitable for a particular function. However the type which is most suitable for the workshop oriented turning system is called parametrised components *[Harrison 86] [Wilkes 91]*. This method is commonly used to generate drawing or manufacturing instructions (*i.e process planning, NC code*) for a specific component *[Allen 89] [Black 91]*. The use of a part family database as an extension of the workshop oriented turning system, coupled with the parametric representation of a component, provides a powerful tool which can significantly enhance code generation.

13.5 - Part Family & Parametric Design

The key to the development of part families is to organize and retrieve similar components by classification and coding *[Gallagher 86]*. In broader terms, classification is used to arrange objects, ideas and information into groups. The members of each group have one or more characteristics in common and may have the same size, shape or process *[Allen 89]*. The aim is to make things easy to locate and help in the study of concepts, ideas, or processes. For the workshop oriented turning system a part family database is essential and should embody those parts which are similar in shape and are produced frequently in the plant. As shown in figure 13.1, a user can generate part programs through a normal path. This path as depicted provides the appropriate user interface to perform setup planing and geometrical description by using the technological user support system and then performing operation planing and finally generating the manufacturing code (*these steps are covered extensively in chapters 8,9,10,11 and 12*). The shaded area highlighted in the picture represents the part family database which allows the user to design a component for the relevant family and parametrise it. The component can then be produced in different sizes using the same program from the part family database. The problem was how to establish the means by which part families for the workshop oriented NC planning were represented. Since the main objective of this part of the research has been the generation of code for parametrised components, less emphasis is given by the author to the concept of the part family per say. The primary reason for having a part family is that a basic framework should be provided to embody components which are similar in basic shapes but vary in attributes. It is not the intention of this research to establish a broad basis for part family classification as it relates to group technology, but merely to provide a limited and controlled environment so that those components which are identical in shape, and are continuously programmed and frequently produced in different sizes, can be parametrised and hence, reduce or eliminate the repetitive task of programming a part from scratch every time. The cost savings and other numerous advantages which emanate from this

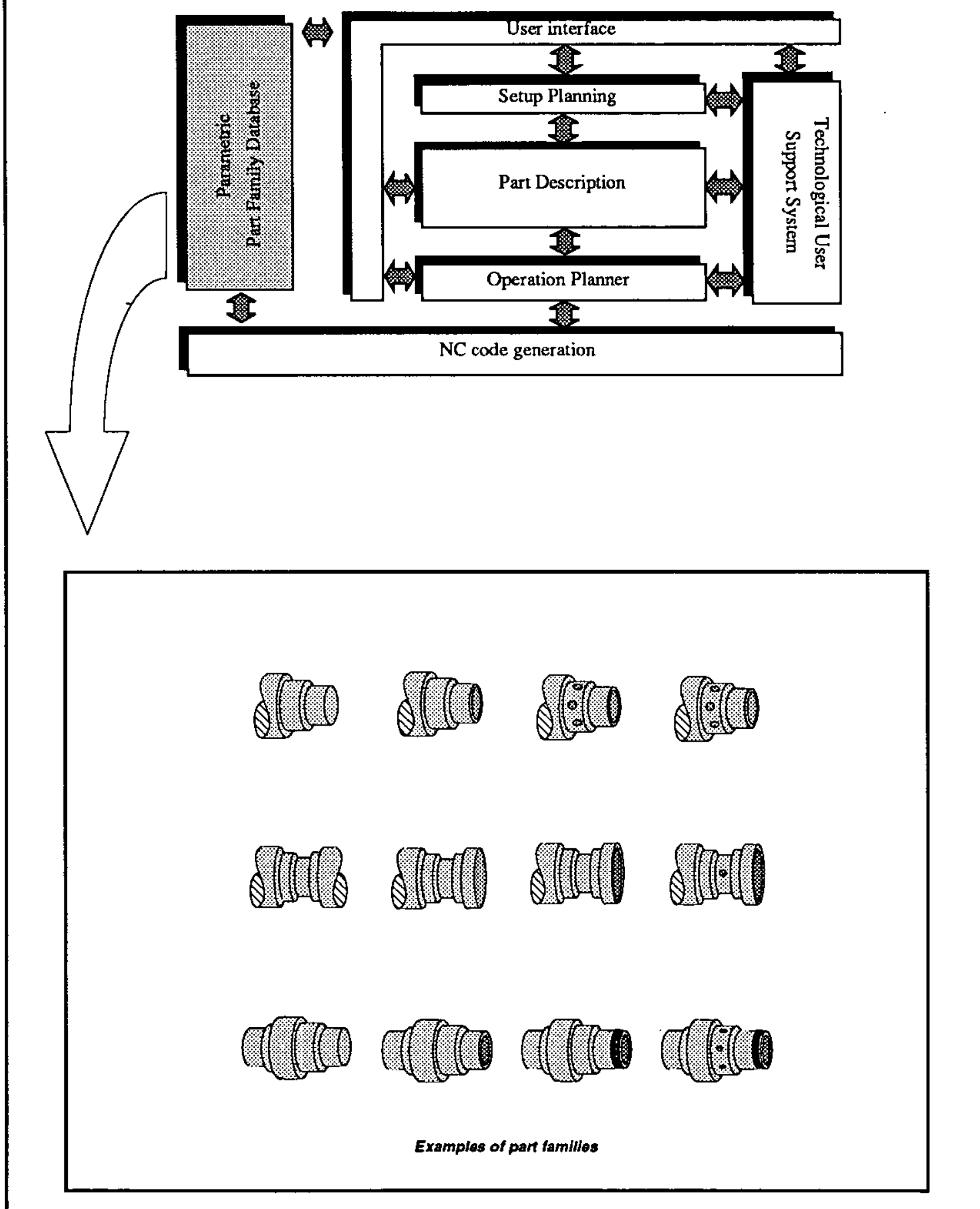
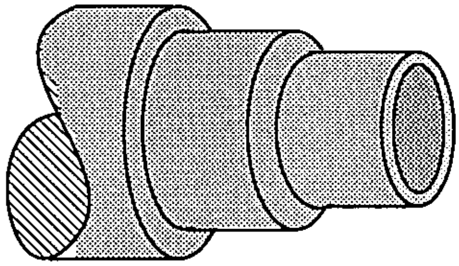


Figure 13.1	Parametric part family database	L.U.T CAD/ CAM

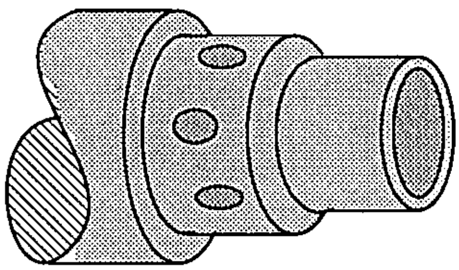
method are reported to be significant *[Allen 89]*. The method used by Xerox forms the basis for this work. This method as described by Allen *[1989]* is the first icon based classification system of its kind and was devised in 1985 by Karla Kusawinski of Xerox corporation thus opening up a whole new opportunity for computerized classification and design. Kusawinski developed his system to generate process plans. A similar approach is used by the author, however, since this approach is modified for the workshop oriented NC planning, it introduces a novel and powerful tool for defining a parametrised component from a family of parts which can then be programmed and machined in different sizes. This approach uses an icon based part family database as the basis for it's expansion and it may be also used as a powerful classification system. Nonetheless this exceeds the scope of this research and therefore is not pursued further. This method is used to develop part programs at the machine rapidly and mainly represent workpieces with predetermined shape. As shown in figure 13.2 four primary families are designed. The first family represent those components which require turning, grooving and threading. The second family is concerned with workpieces which require live tooling operations (*i.e. turning, grooving, threading, drilling, milling, mill-grooving and milling*) and are machined in single setting. The third and forth families are similar to the first and second but they need to be machined either by double setting or using a multiplex turning centre using a single setting.

13.6 - Method for Representing Parametrised Components

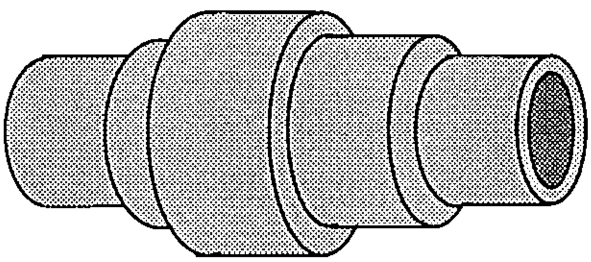
The purpose of designing the parametric system is to rationalize the task of part programming by using a GT based approach. In many manufacturing plants identical components are produced in different sizes. Traditionally the CAM systems available have programmed the component from the beginning by going through a lengthy process to describe the geometry for every workpiece. However what is proposed and designed for the workshop oriented turning system alleviates this problem by providing a family of predetermined shapes. As is depicted in figure 13.3 the design of icons



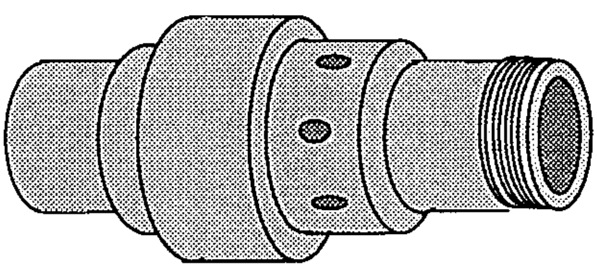
Family type: # 1
Component shape: Single sided
Operation: Turning, Grooving, threading
Machine tool req.: 2 axes CNC lathe
Setup: 1



Family type: # 2
Component shape: Single sided
Operation: Turning, Grooving, milling, drilling
Machine tool req.: 3 axes CNC turning centre
Setup: 1



Family type: # 3
Component shape: Double sided
Operation: Turning, Grooving, threading
Machine tool req.: 7 axes CNC turning centre
Setup: 1 or more



Family type: # 4
Component shape: Double sided
Operation: Turning, Grooving, milling, drilling
Machine tool req.: 7 axes CNC turning centre
Setup: 1 or more

Figure 13.2	Component classification for part programming	L.U.T CAD/CAM

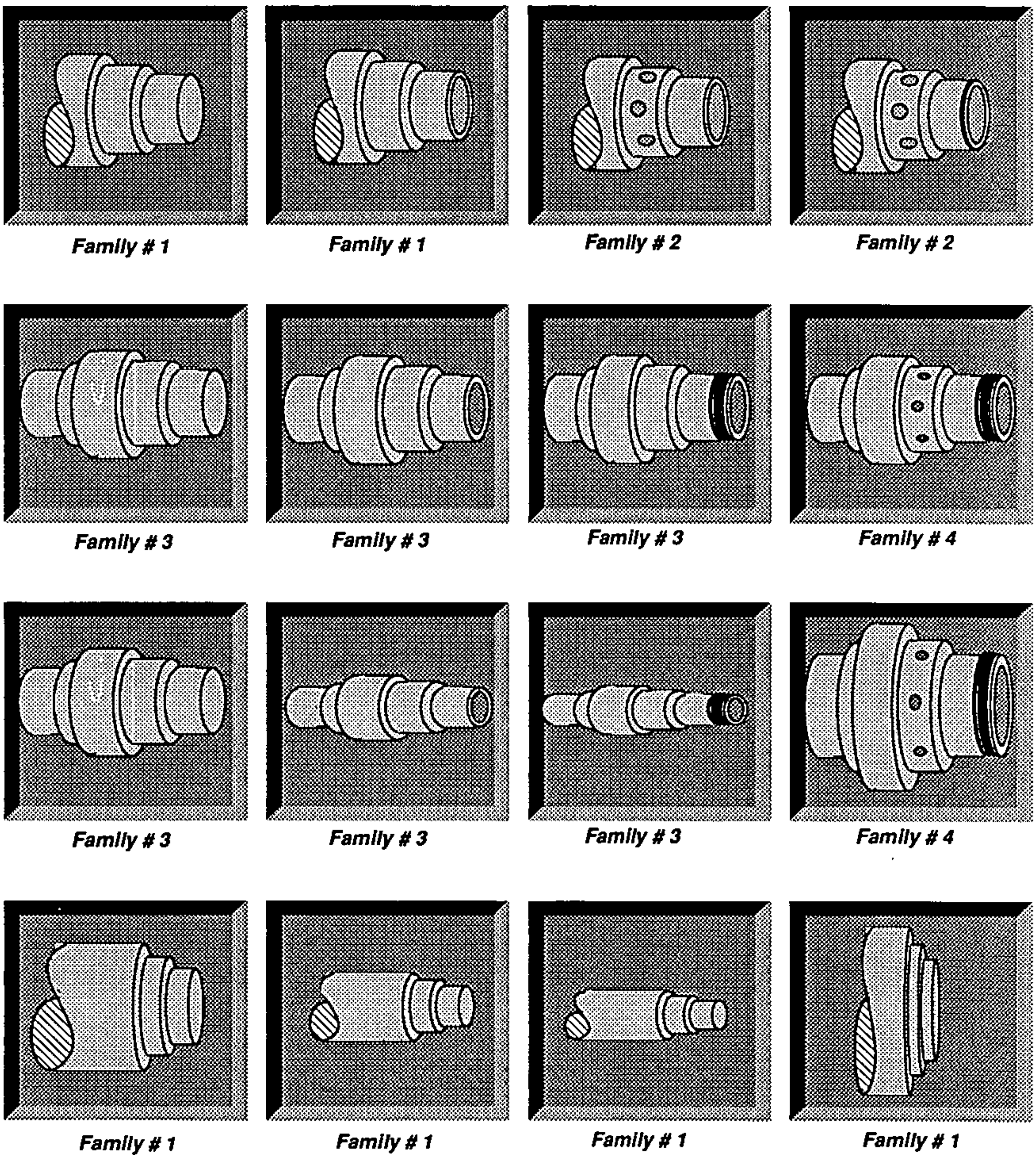


Figure 13.3	Icon based family representation for part programming	L.U.T CAD/CAM

representing a component provides a powerful and easy way to access facilities which offers a unique opportunity to the user to define a parametrised component and generate programs for different size components. This method requires a minimum of input of geometry and technological attributes in order to generate a new program for each predetermined workpiece.

13.7 - Description of Parametrised Component

As is depicted in figure 13.4 the part family database is principally described and defined by two basic and essential parameters, namely the shape (*icon*) and the attributes. These parameters are provided to identify the type of components that need to be produced by the user. The experimental system accommodates a sample part family which illustrates and proves the concept. A parametrised component is defined by several geometric and technological variables. The basic geometric features for each component are fixed. The user is provided with a pull down menu to select the appropriate family. The next activity is concerned with selecting the appropriate component. By activating the icon representing the specified workpiece the input table which represents the geometric and technological values appears. As shown in figure 13.4 four parameters are displayed. The first parameter represents the shape of the component. Several features which form the shape are specified. It is important to note that these features cannot be altered by the user. The second parameter is the dimension which represents the geometrical value of each feature. This is a variable value. The next parameter is concerned with the geometrical attributes represented by chamfer and corner, the appropriate value for each attribute can be assigned by the user. The last parameter is concerned with the technological data associated with each feature such as the surface finish value. Other technological attributes are specific to the component (*Material, stock Dia., rough feedrate rough speed, depth of cut, finish margin, roughing and finishing tool as well as tool path*). The example illustrated in 13.5 demonstrates explicitly the type of information involved in programming a parametrised component.

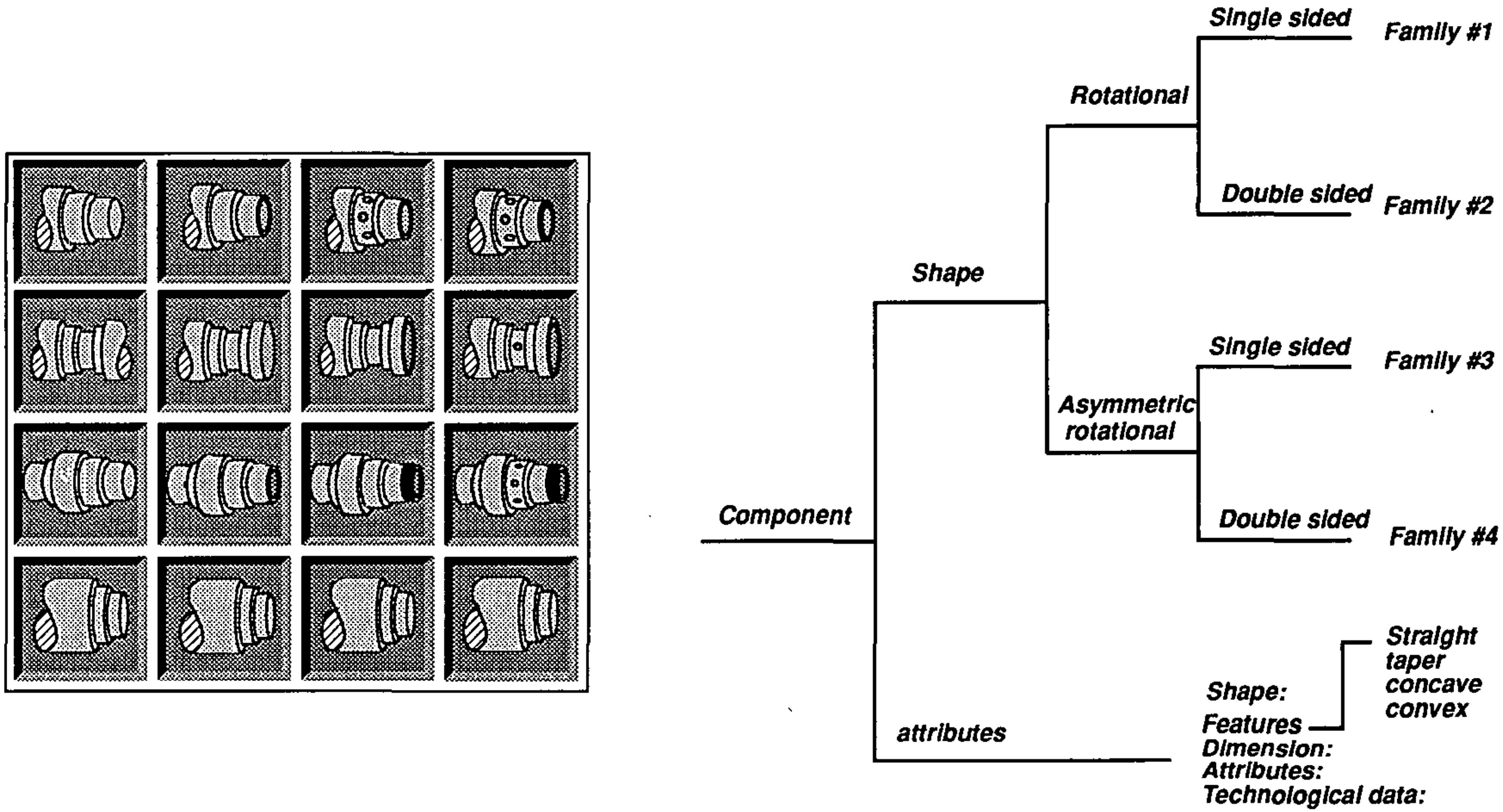


Figure 13.4	Decision tree for icon based parametric part family programming	L.U.T - CAD/CAM

13.8 - The Participation of Functions

Several functions or disciplines participate in the decision making process. It is extremely important that management understands, supports and monitors the parametric part family programming, just as one would for a large capital investment. The disciplines involved in the decision making process are: *[Nichols 80]*

i- Management

ii- Design

iii- Manufacturing engineering

iv- NC part programming

iiv- Shop floor (*operator*)

The design engineer working with the manufacturing engineer develops the standard geometric shape and size of each family of components. Subsequently the appropriate macros to generate the component are designed by the NC programmer. The close interaction between design and manufacture has further importance, because of possible engineering changes. The manufacture engineer participates and assists in the design of operation sequences and the selection of tooling. The NC part programmer also applies his knowledge of computer programming to design the relevant macros for each component. The final stage is the participation of the operator and the shop floor which allows the operator to provide assistance and guidance when designing the part program.

13.9 - Benefits

The cost advantages and savings directly derived from parametrised part family programming can justify the use of this concept. The savings and the benefits as seen from the management view are:

i- It increases the control over costs, methods, tooling, manufacturing and capi-

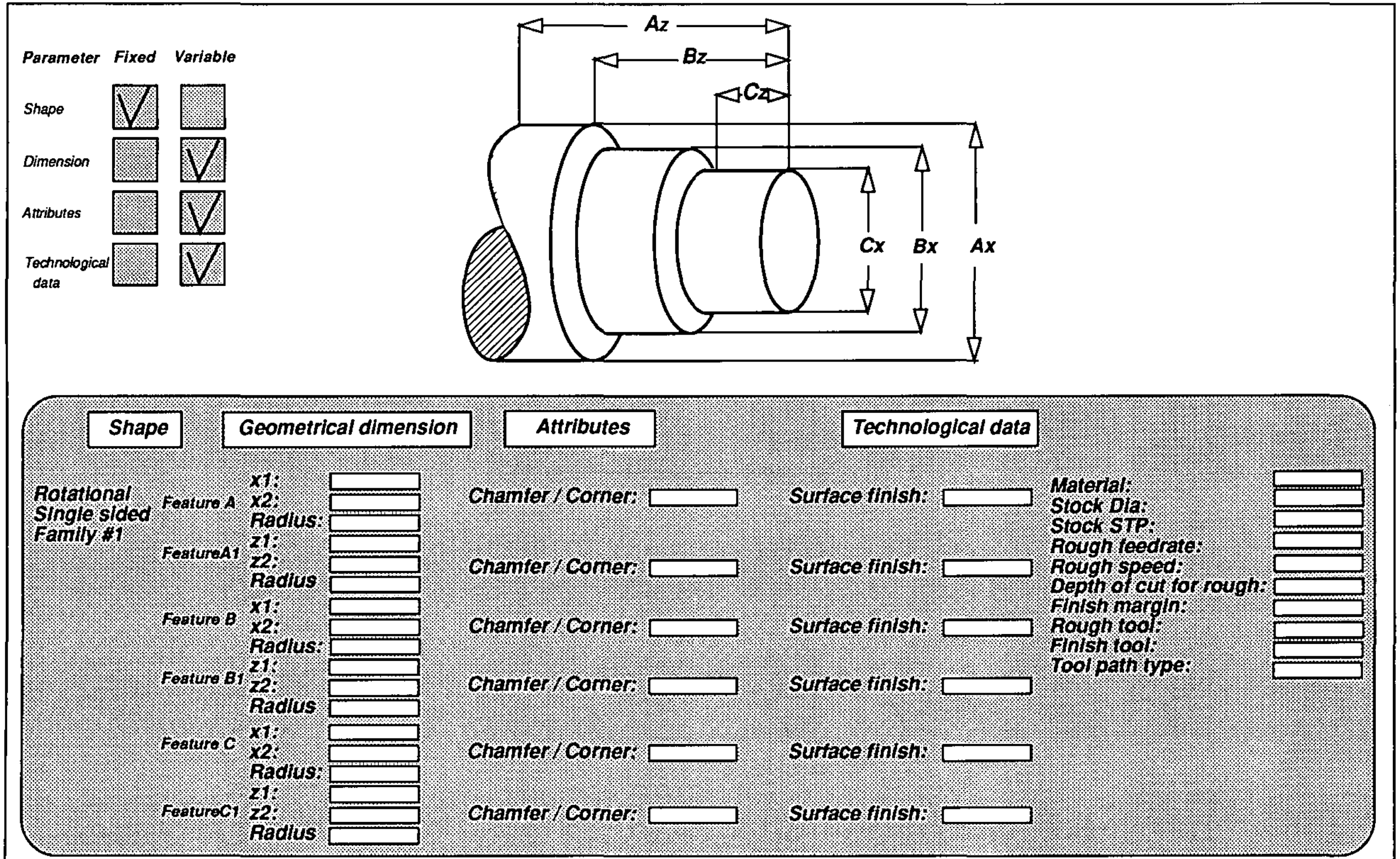


Figure 13.5	Geometrical & technological input for parametrised component	L.U.T - CAD/CAM

tal

equipment purchases.

ii- Standardise product design

iii- Reduces scrap rate

iv- Increase the resources productivity

iiv- Reduces lead time and eliminates errors and mistakes.

From the manufacturing engineering point of view the use of this method standardizes the manufacturing methods, equipment types, fixtures and cutting tools and reduces documentation and storage hence resulting in the production of accurate machining times. In addition it eliminates time used for program proofing and allows the rapid loading of part programs onto NC machines consequently reducing any machine collision damage due to programming error.

From the NC programming point of view it reduces the complexity of inputting information and thus simplifies part programming. It also eliminates the documentation made by the programmer for pre-set, setup and operator instruction and provides the opportunity to rapidly generate the part program for various size components by inputting the basic geometrical and technological data. It reduces the cost of part programming and standardizes feed, speed and depth of cut for each material and machine. The introduction of this method to the shop floor will also reduce the programming man power.

13.10 - Implementation & Procedure

As is depicted in figure 13.6, after the participation of various functions involving the designer, manufacturing engineer and NC programmer, the variables which can effectively represent a component are designed by the NC programmer and the relevant logic which can generate the NC output is listed. This would be the basis for producing

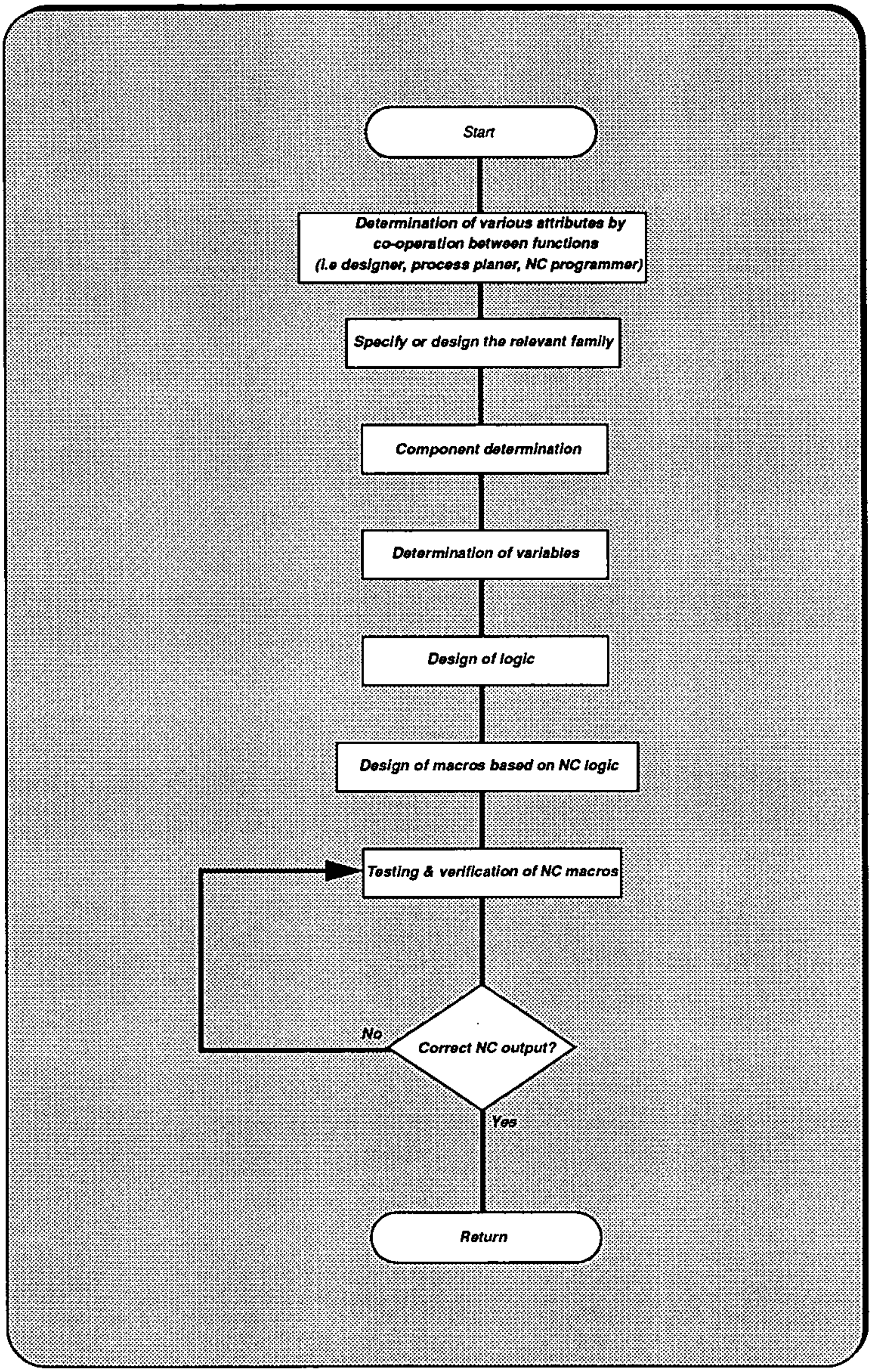


Figure 13.6	Principle activities for designing parametric part program	L.U. T - CAD/ CAM

the NC macros. The final activity would be to test each program and verify the output.

13.11 - Parametric Program Modules

The parametric program consist of a series of modules which assist in generating the NC output. These modules are:

i- Start-up block consisting of the main heading as well as part number and post processor.

ii- The geometric variable input

iii-The technological variable input

iv- Features representing the basic shape

iiv-The macros generating NC code

Chapter 14

NC Code Generation

14.1 - Introduction

The purpose of this chapter is to discuss the output which is generated by the workshop oriented NC turning system. The importance of code generation stems from the fact that all the ideas and concepts which are extensively explained in the previous chapters are in essence concentrated and demonstrated in the final NC output. In order to gain a perspective on NC code generation as well as various elements which participate in it's formation, the subsequent sections are presented.

14.2 - Scope of Code Generation

The purpose of NC code generation in the NC planning is to produce the desired shape by using the description scheme developed and presented in this thesis. The final objective of this research has been to enhance the code generation activity by providing a frame of reference (*i.e. region, feature scheme*) which can be used for efficiently generating NC data. The ability to transform a neutral format (*CLDATA*) to a dependant format (*machine tool format*) is embedded in the system. The code generation activity is constrained by the available resources (*machine tool type*). The NC format accommodated by the workshop oriented NC planning system is designed so as to function on a MAZAK T32-2 controller.

14.3 - IDEF0 Representation

IDEF0 effectively models the code generation activity by displaying the necessary steps required to generate the NC output (*See appendix III-node A1.4*). The first activity demonstrates the generation of an NC macro for each region. The prerequisite for generating the NC macros (*i.e the input*) is the provision of machine independent data (*CLDATA*). The prerequisite for this data is the description of the relevant region and feature. Consequently the output generated is used for operation sequencing. The format which represents the cutter location data is compatible with the Mazak/Fanuc format. Two methods for generating cutter location data are available: The first approach uses an *EIA/ISO* command to produce the geometric offset and generate the NC program. The second approach calculates the necessary steps for generating cutter offset (*i.e the template for generating the cutter offset is devised but not utilised, the former approach is used for generating the NC code*)

The workshop oriented NC planning system is based on a modular design. The final NC output is generated by several independent NC macros. These macros are each associated with the relevant regions. The type of region or feature influences the way each macro functions. An interactive support tool is designed for each region so as to generate the NC code and enhance the flexibility of this system by providing a MDI facility by which the user can manually alter the NC program. The NC program for the workpiece can be fed into the simulator for final verification. Subsequently the output is checked and the necessary steps are taken so as to modify the NC program.

14.4 - NC Code Generation

The NC program which is generated must concisely reflect the dimensional and surface finish requirements specified during the geometrical and technological description. Since the majority of CNC controllers have limited memory capacity, it is therefore, essential that programs are produced as compact as possible. This task has been carried out by selecting a clear coordinate system and effectively using sub-program and macros to omit the unnecessary and redundant coding. Therefore, the introduction of sub-programs & NC macros have significantly reduced the size of a NC program. An appropriate structure is designed which can readily transform the program to *EIA/ISO* format. The objective is to accomplish the part programming tasks efficiently by establishing a novel discipline for code generation using the framework provided in the earlier chapters (*see chapters 7 to 12*). This system is basically designed to perform several functions based on the principles cited below:

i. Description of part (*i.e. regions & features which are used to specify a cutter toolpath*).

ii. Description and setup specification.

iii. Perform operation planning

iv. Determination of cutting tool path.

*iiv.*Generation of NC tool path in a machine understandable language (*EIA/ISO*)

As depicted in figure 14.1 and described above, the last activity in the work shop oriented NC planning system is the generation of manufacturing code.

14.5 - The NC Code Generation Steps

As stated in the section 14.4, prior to generating any manufacturing code the selected operations have to be sequenced such that the precedence relationships are ensured *[Eversheim 82]*. See section 12.10 for further detail. The provision of tools and methods (*see chapter 11*) that can be used for operation sequencing ensures that this task is performed efficiently. As depicted in figure 14.2, the NC code icon can be activated in order to generate the final NC program for the workpiece. The major steps in the generation of NC code involves the recognition of operations (*these operations are associated with each region, see chapter 12*) and subsequently the generation of NC macros. Three methods are generally used for toolpath verification:

i. Graphic (*Dynamic & static simulation*)

ii. Syntax (*Interactive*)

iii. Displaying messages (*interactive*)

The information which is generated is tested to check the inconsistencies in NC output formats. The syntax is checked at two nodes: the input node and output node. The pro-

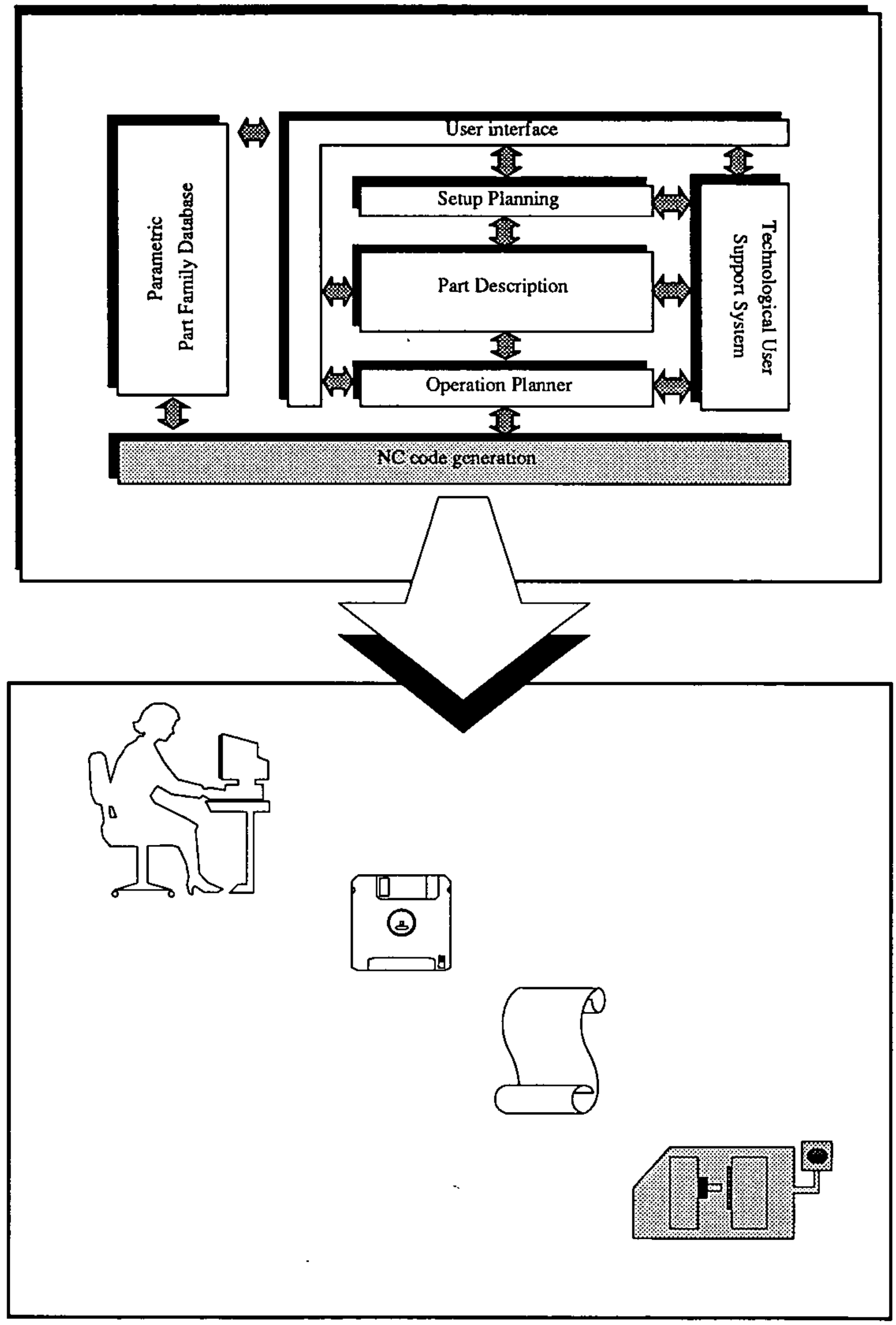


Figure 14.1	Manufacturing code generation	L.U.T - CAD/ CAM

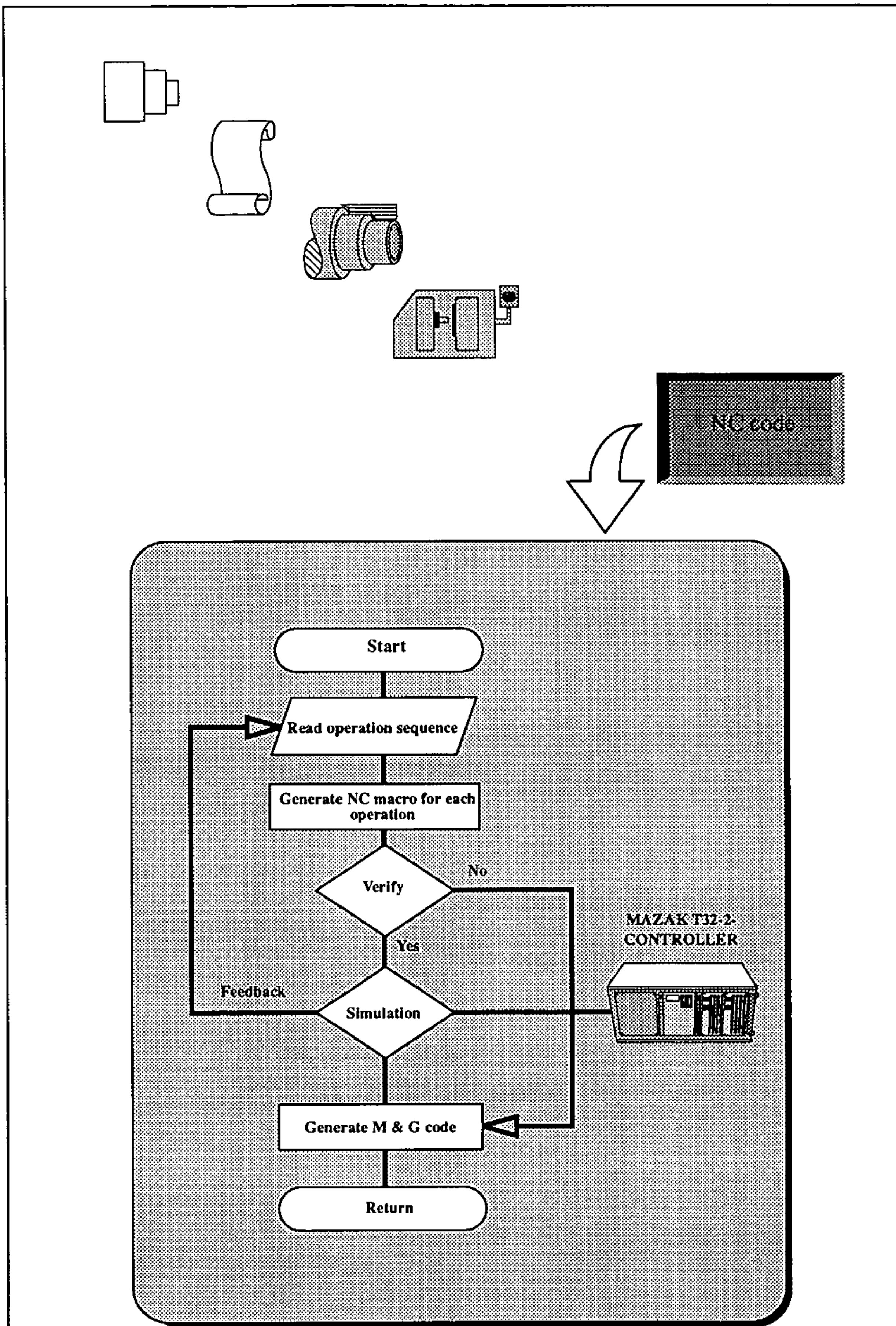


Figure 14.2	The code generation steps	L.U.T - CAD/ CAM

vision of displayed messages enables the user to respond to any mistakes and make the necessary correction. Despite the careful input of part programs and internal safety filters, programming errors cannot be avoided, therefore the provision of simulation can significantly enhance the verification process *[Spur 82]*.

Traditionally the NC programs have been tested by plotting the output. This method has been useful for detecting any possible tool path errors, however, it is inefficient when dealing with tests that have to be performed in a shop-floor environment. The advent of dynamic simulation systems has allowed the machining sequence to be displayed on the graphic screen, consequently reflecting conditions of the machine and the workpiece more accurately (*see figure 14.3*). The dynamic simulation system performs two principal functions *[Spur 82]*:

i- Depiction of complex function on the graphic screen in real time operation.
ii- Monitoring of technological limit values.

The experimental software has been designed so as to allow the output for each region to be tested and verified by using the MAZAK T32-2 controller using *EIA/ISO* format. After verification the NC code for a given component can then be generated.

14.6 - The Design of NC Macros

The NC planning system is based on a modularised NC structure which is devised in order to efficiently generate the correct NC code (*i.e. EIA/ISO*). Different macros are designed for each operation. The macros are designed to emulate the MAZAK/FANUC format. In some instances, customized macros are introduced for generating the tool path. The purpose of using macros and sub-programs is to generate a more compact code and therefore reduce the size of NC data. NC macros are assigned to each region so as to produce the correct NC output for the selected operations.

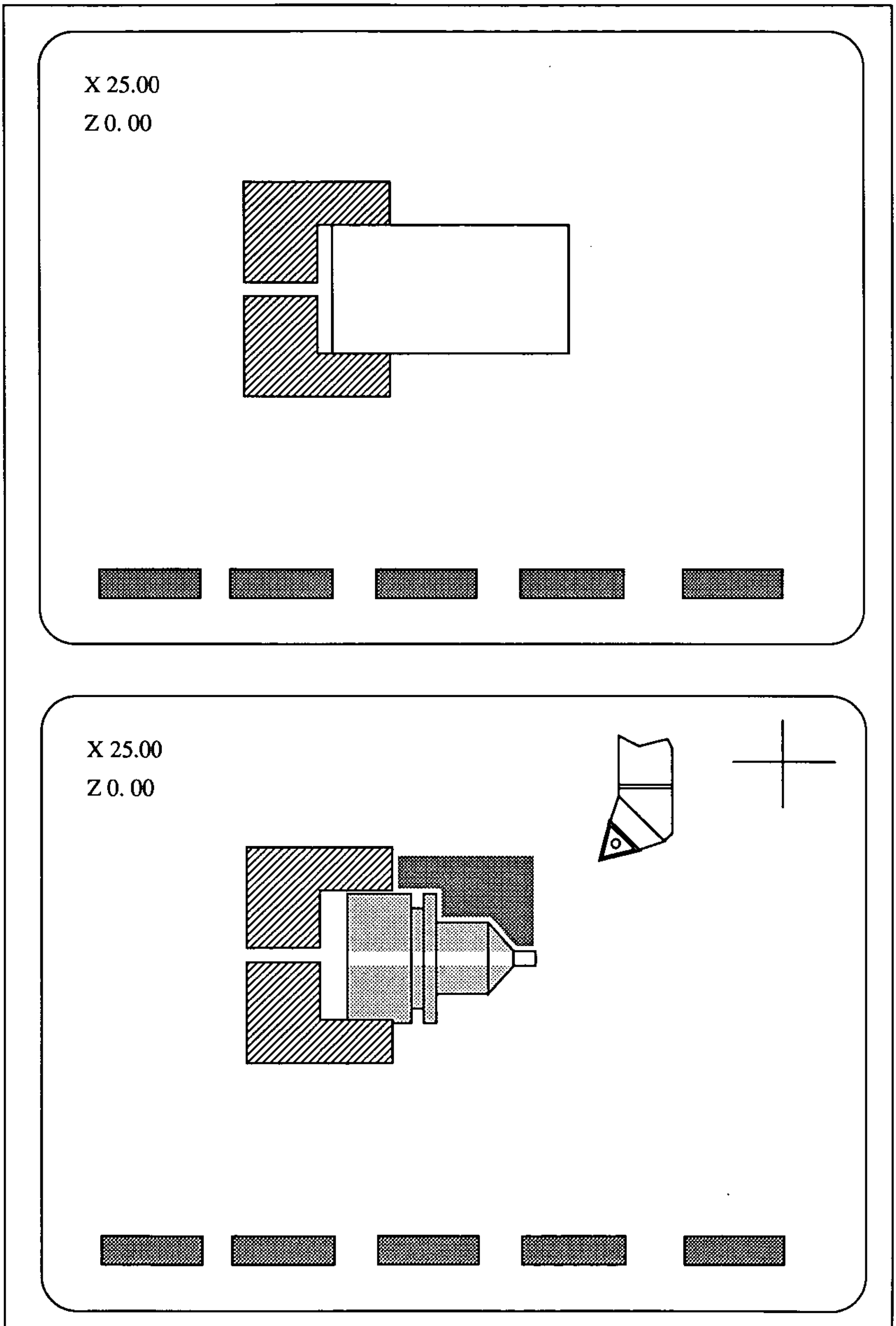
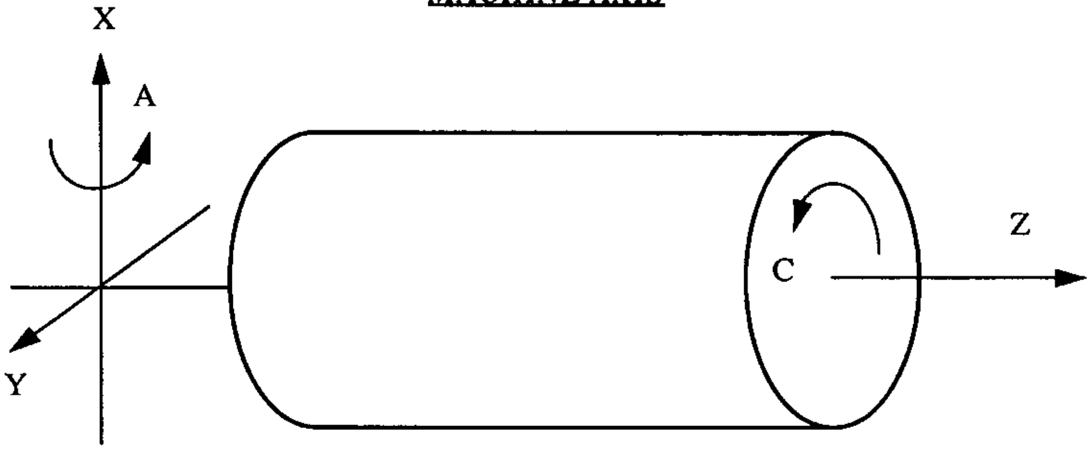


Figure 14.3 | Dynamic simulation | L.U.T - CAD/ CAM

MACHINE AXIS



X & Z axis are used for conventional two axes CNC lathe
Y, & C & A are used for turning centre
A axis is used for Y axis tool
C axis is embodied in the rotational movement of chuck

figure 14.4a

MACHINE PROGRAM FORMAT

% EOB
: 1369 EOB
N10...........................EOB
N20...........................EOB

(T01 TURN & FACE) EOB

N30...........................EOB
.
.
.
.N580 M30 EOB
EOB
:26 EOB
N10..........................EOB
.
.
.
.
.
N220 M99 EOB
%

Program N Address	: (or O)
End of record	%
End of block	LF (& CR)
Control out	(
Control in	)

Figure 14.4b	Machine Axis & format	L.U.T - CAD/ CAM

14.6.1 - The NC Template

14.6.1.1 - The Machine Tool Configuration

As depicted in figure 14.4a several axes are used in order to program the machine tool and produce the NC codes for asymmetric rotational components. Traditionally the *Z* and the *X* axis have been used for turning, grooving and threading operations. However, with the ever increasing complexity of components, and the advent of turning centres, new axes have been introduced which are devised to produce the asymmetric features. The primary axes used for live tool operations (*i.e. drilling, millgrooving and milling*) are performed by the *C* axis. In addition complex features can be produced using the *Y* axis.

14.6.1.2 - The Machine Program Format (Output)

An example of parameters used to generate the output are depicted in figure 14.4b. The parameter's format is designed for a MAZAK T32-2 which is represented in terms of *EIA/ISO* format. These parameters are used and embedded in the final NC output. As shown in figure 14.5 three distinct geometric planes are used for generating the NC data. The conventional plane which has been commonly used by all the CNC lathes is highlighted by the *X-Z* cylindrical planes. However, the introduction of the *X-Y* planes and the *Y-Z* planes are the two important geometric planes which are essential for drilling, milling and millgrooving operations on the side and face of the asymmetric rotational workpiece. These planes are employed in the NC code generation module.

14.6.1.3 - The Structure of NC Data for Macro

The program designed embodies three distinct sections. The first section is designed to accommodate the starting *M & G* code parameters representing the technological setting. The middle section embodies the appropriate sub-programs to produce the features. The ending section cancels the sub-programs (*i.e. the middle section)* and

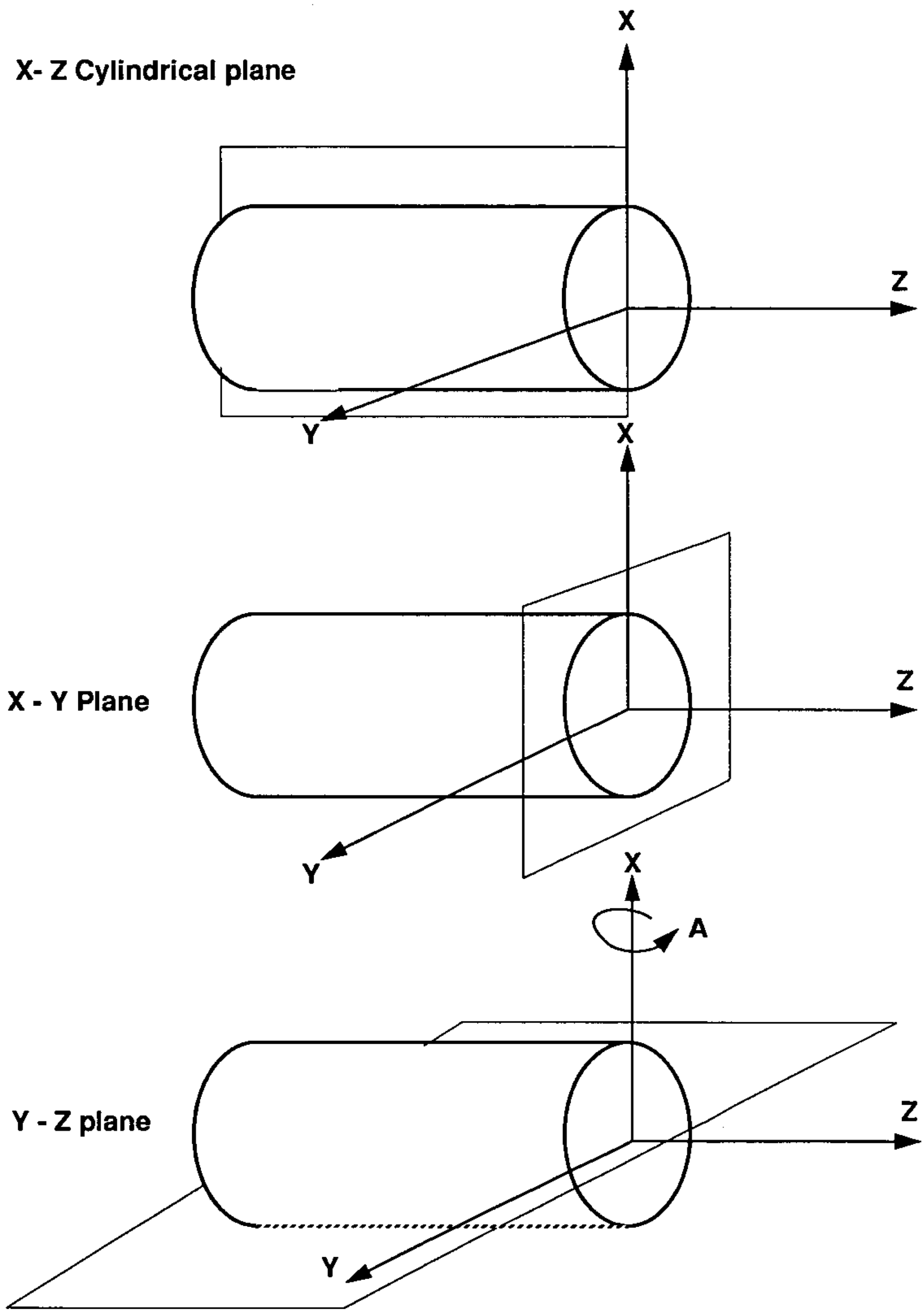


Figure 14.5	Geometric plane for turning	L. U. T CAD/CAM

terminates the NC program. Each NC macro within the program is further divided into three distinct sections:

i- Start-up block

ii-Middle block

iii-End block

As is depicted in figure 14.6, the start up block embodies the actual macro *ID* and the technological setting required to activate the macro. The middle block, or program block, contains the geometrical tool path which generates the features or region. The end block is designed to terminate the *M* and *G* functions such as coolant and the optional stop. More descriptive information about the different elements which are embedded in the NC output is depicted in figure 14.7.

14.6.1.4 - The EIA/ISO Code Format

The coding format used is depicted in table *1&2* which contains the necessary *M & G* codes to produce the tool path for an asymmetric rotational workpiece. The *EIA/ISO format* used is based on the Mazak format which is used by the Mazak T32 controller.

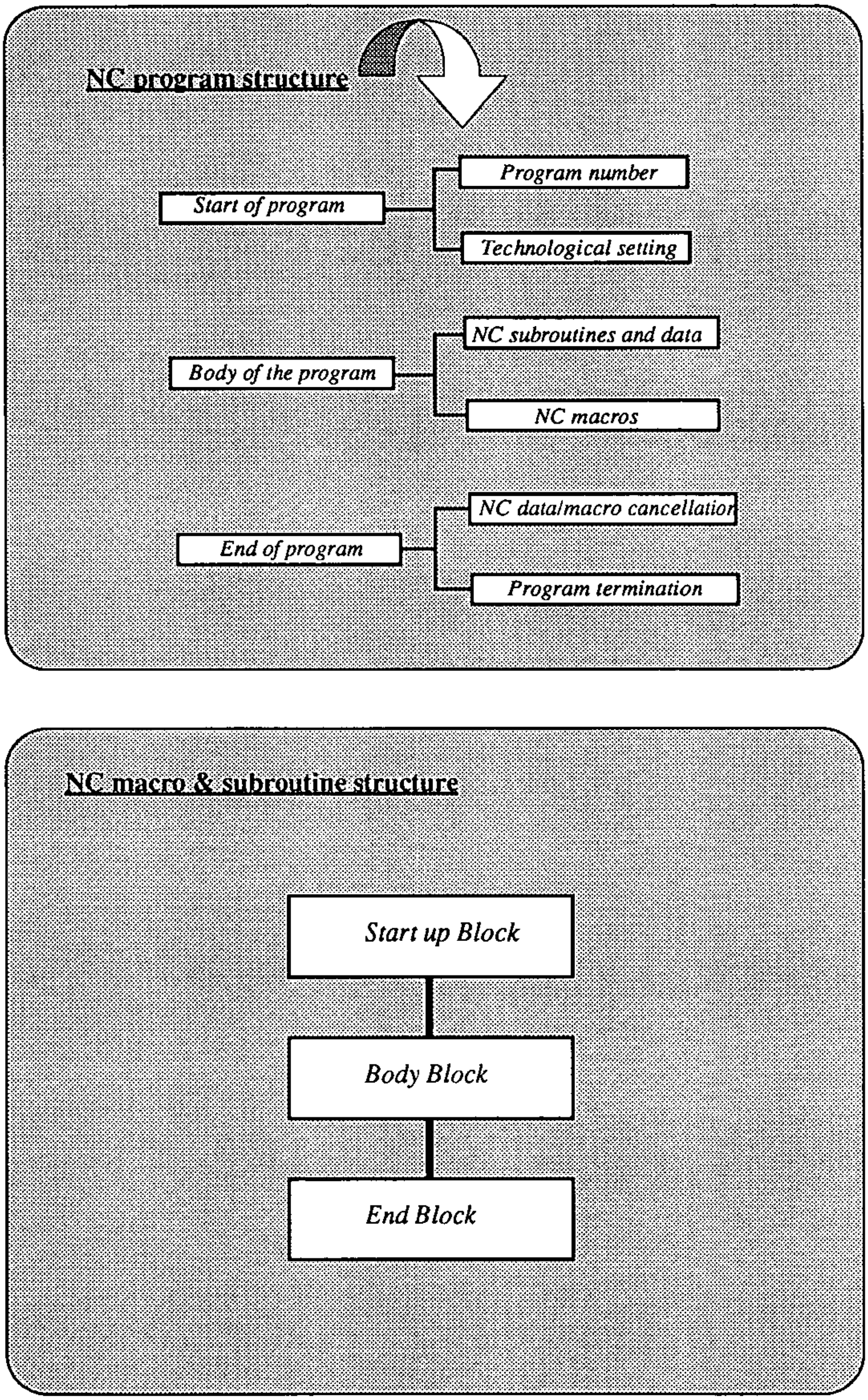


Figure 14.6	NC program internal structure	L.U.T - CAD/ CAM

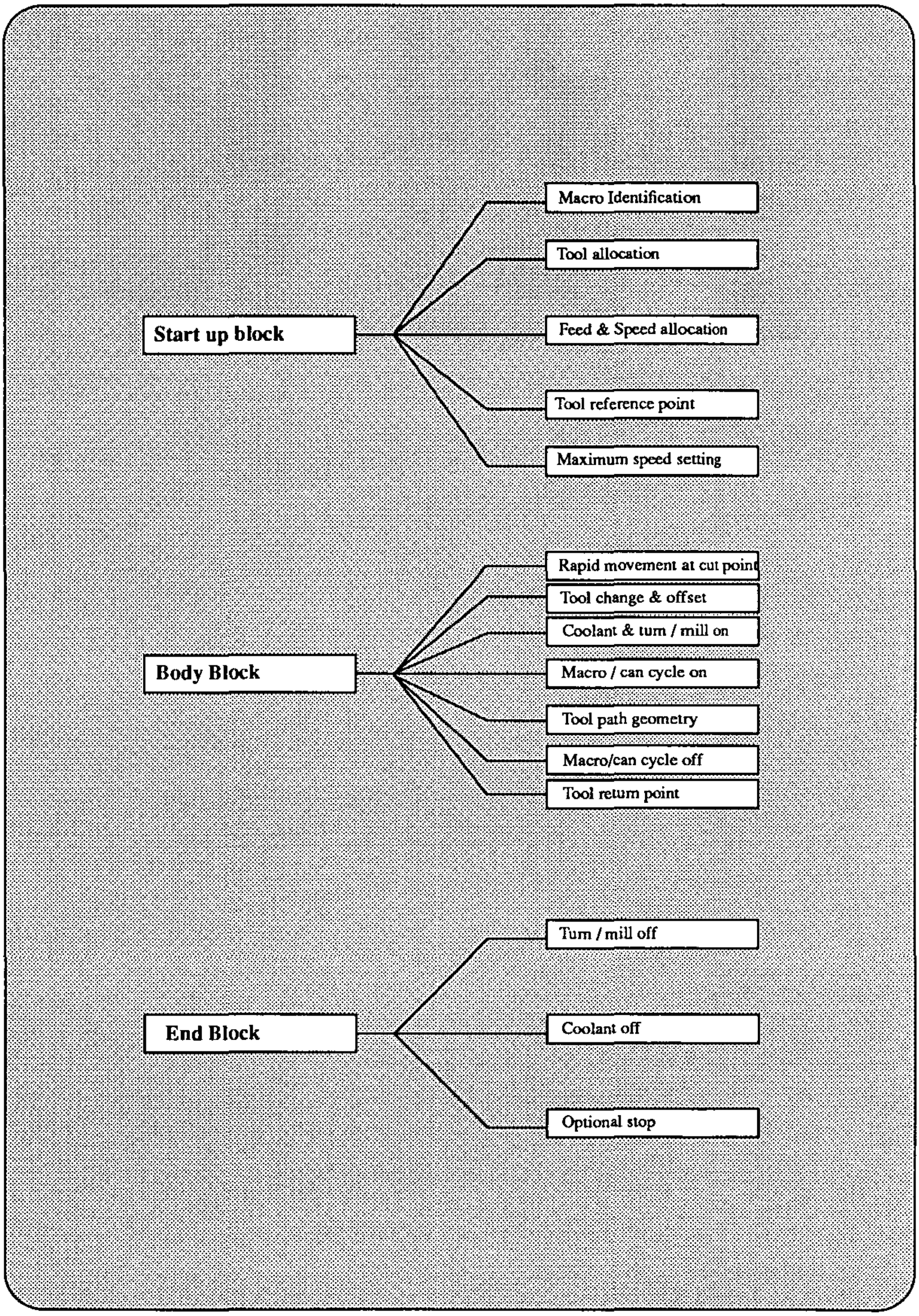


Figure 14.7	Body/middle of program block	L.U.T - CAD/ CAM

Table 1: G codes for MAZAK & FANUC controller

Number	Description	MAZAK	FUNUC
1	Positioning	G00	G00
2	linear interpolation	G01	G01
3	Circular interpolation (C)	G02	G02
4	Circular interpolation (CC)	G03	G03
5	Dwell	G04	G04
6	Exact stop	G09	G09
7	Data Setting	G10	G10
8	Milling Mode	G12.1	G12.1
9	Milling mode cancel	G13.1	G13.1
10	YZ cylinder plane	G16	G16
11	Plane selection Xp-Yp	G17	G17
13	Plane selection Yp-Zp	G19	G19
14	Inch command	G20	G20
15	Metric command	G21	G21
16	Reference pt. return check	G27	G27
16	Reference point return	G28	G28
18	Return from reference pt.	G29	G29
19	2ed reference point return	G30	G30
20	Facing tool, rest mirror on	G68	G68
21	Skip function	G31	G31
22	Thread cutting	G32	G33
23	Measurement preparation	G36	G36
24	Measurement calculation	G37	G37
25	Too R compensation cancel	G40	G40
26	Tool compensation left	G41	G41
27	Tool Compensation right	G42	G42
28	Compensation Auto.	G46	G46
29	Coordinate /clamp speed	G50	G92
30	Mazatrol coordinate cancel	G52	G52

Table 1: G codes for MAZAK & FANUC controller

29	Coordinate /clamp speed	G50	G92
30	Mazatrol coordinate cancel	G52	G52
31	Mazatrol coordinate select	G53	G53
32	Face drill cycle (Z-axis)	G83	G83
33	Face tap cycle (Z axis)	G84	G84
34	Face boring cycle (Z-axis)	G85	G85
35	Drilling cycle (X axis)	G87	G87
37	Facing tool rest image off	G69	G69
38	Finishing cycle	G70	G70
40	Face rough machining	G72	G72
41	Stock removal rough	G73	G73
42	Face cut off cycle	G74	G74
43	Longitudinal cut-off cycle	G75	G75
44	Multiple repetitive thread	G76	G76
45	Hole machining	G80	G80
46	Boring cycle (X axis)	G89	G89
47	O.D turning canned cycle	G90	G77
48	Thread cutting canned cyc.	G92	G78
49	Face turning canned cycle	G94	G79
50	Constant speed control	G96	G96
51	Constant speed cancel	G97	G97
52	Asynchronous feed	G98	G94
53	Synchronous	G99	G95
54	Absolute value	-	G90
55	Incremental value	-	G91
56	Hole machining return	-	G98
57	Hole machining ref., pt. ret.	-	G99

Table 1: G codes for MAZAK & FANUC controller

29	Coordinate /clamp speed	G50	G92
30	Mazatrol coordinate cancel	G52	G52
31	Mazatrol coordinate select	G53	G53
32	Face drill cycle (Z-axis)	G83	G83
35	Drilling cycle (X axis)	G87	G87
36	Tapping cycle	G88	G88
37	Facing tool rest image off	G69	G69
38	Finishing cycle	G70	G70
39	Long. rough machining	G71	G71
40	Face rough machining	G72	G72
41	Stock removal rough	G73	G73
42	Face cut off cycle	G74	G74
43	Longitudinal cut-off cycle	G75	G75
44	Multiple repetitive thread	G76	G76
45	Hole machining	G80	G80
46	Boring cycle (X axis)	G89	G89
47	O.D turning canned cycle	G90	G77
48	Thread cutting canned cyc.	G92	G78
49	Face turning canned cycle	G94	G79
50	Constant speed control	G96	G96
51	Constant speed cancel	G97	G97
52	Asynchronous feed	G98	G94
53	Synchronous	G99	G95
54	Absolute value	-	G90
55	Incremental value	-	G91
56	Hole machining return	-	G98
57	Hole machining ref., pt. ret.	-	G99

Table 1: G codes for MAZAK & FANUC controller

58	Dual process program ctr.	G109	G109
59	Cross maching command	G110	G110
60	Cross maching cancel	G111	G111
61	M,S,T,B output for connected system	G112	G112

Table 2: M codes

M code	Description
M00	Program stop
M01	Optional stop
M02	End of program
M03	Spindle forward revolution
M04	Spindle reverse revolution
M05	Spindle stop
M06	Chuck open
M07	Chuck closed
M08	Coolant on
M09	Coolant off
M48	Part catcher extended
M49	Part catcher retracted
M53	Chamfer off
M54	Chamfer on
M98	EIA subprogram call
M99	EIA return from subprogram
M200	Milling mode point machining
M201	Milling mode line machining
M202	milling mode off
M203	Milling tool forward revolution
M204	Milling tool reverse revolution
M205	Milling tool revolution stopped

Chapter 15

The Experimental Application Software

15.1 - Introduction

This chapter describes the modules which form the experimental system. These modules act as a tool with which the proposed ideas are developed and implemented.The experimental software is developed to the extent in which the ideas and argument that have been addressed throughout the thesis could be modelled, developed and tested. An integrated workshop oriented CNC experimental system was designed which has enabled the author to successfully demonstrates the ideas that are put forward in this thesis.

15.2 - The Application Software & Interface

With in a highly interactive system, communicating information between the user and the computer constitutes the bulk of elapsed time in accomplishing a part programming task. The majority of software that is developed for CAD/CAM systems is designed in a way that usually requires an average user to spend a great deal of time attempting to tell the computer what to do, as opposed to the computer actually doing it. Monkiewicz *[1992]* states that the culprit is the user interface, the system which dictates the way in which we describe our intention to the application software. David Kieras at University of Michigan *[USA]* believes that the majority of CAD/CAM systems are far more complex than necessary, and that the obvious functions that can enhance them are left out. This is especially true with some of the workshop oriented systems that are commercially available in the market. It is further suggested that an interface which can seriously enhance the system's function could increase the user productivity by a factor of two *[Monkiewicz 92]*. Therefore, great care has been taken in the design of the application software and in particular the graphic user interface in order to enhance the programming process and make life easier for the user. The screen interfaces that represent the application software are depicted at the end of this chapter.

15.3 - The Software Elements

There are many elements which have participated in the design of the workshop oriented software. The aim has been to design software which can effectively emulate the work shop oriented environment for part programming. Several high level languages and software environments were used to build the system:

i- Window environment

ii- Graphic user interface (*GUI*)

iii-Excel macro & database

iv-C language(*UNIX*)

v- Visual basic

vi-Microsoft write

vii-Suntool graphic interface (*UNIX*)

Both the parametric and the workshop oriented approach function through a user interface. The parametric feature based programming (*See appendix IV*) has been designed using the Sun Windows environment, C language and suntool graphic interface (*see figure 15.8*). However the workshop oriented turning system described (*see chapters 7,8,9,10,11,12,13*) runs on a PC using a Microsoft Windows environment. The machining databases embedded in the workshop oriented system utilize the microsoft Excel database functions. The layouts for the system are designed with the Microsoft graphic user interface (GUI). The DDE (*dynamic data exchange*) is used to communicate between different application modules (*see figure 15.3 to 15.8*).

15.4 - The Application Software Layout

As depicted in figure 15.1, in order to demonstrate the functional activities which have been addressed in the core of this thesis, a tree diagram is provided with which the user

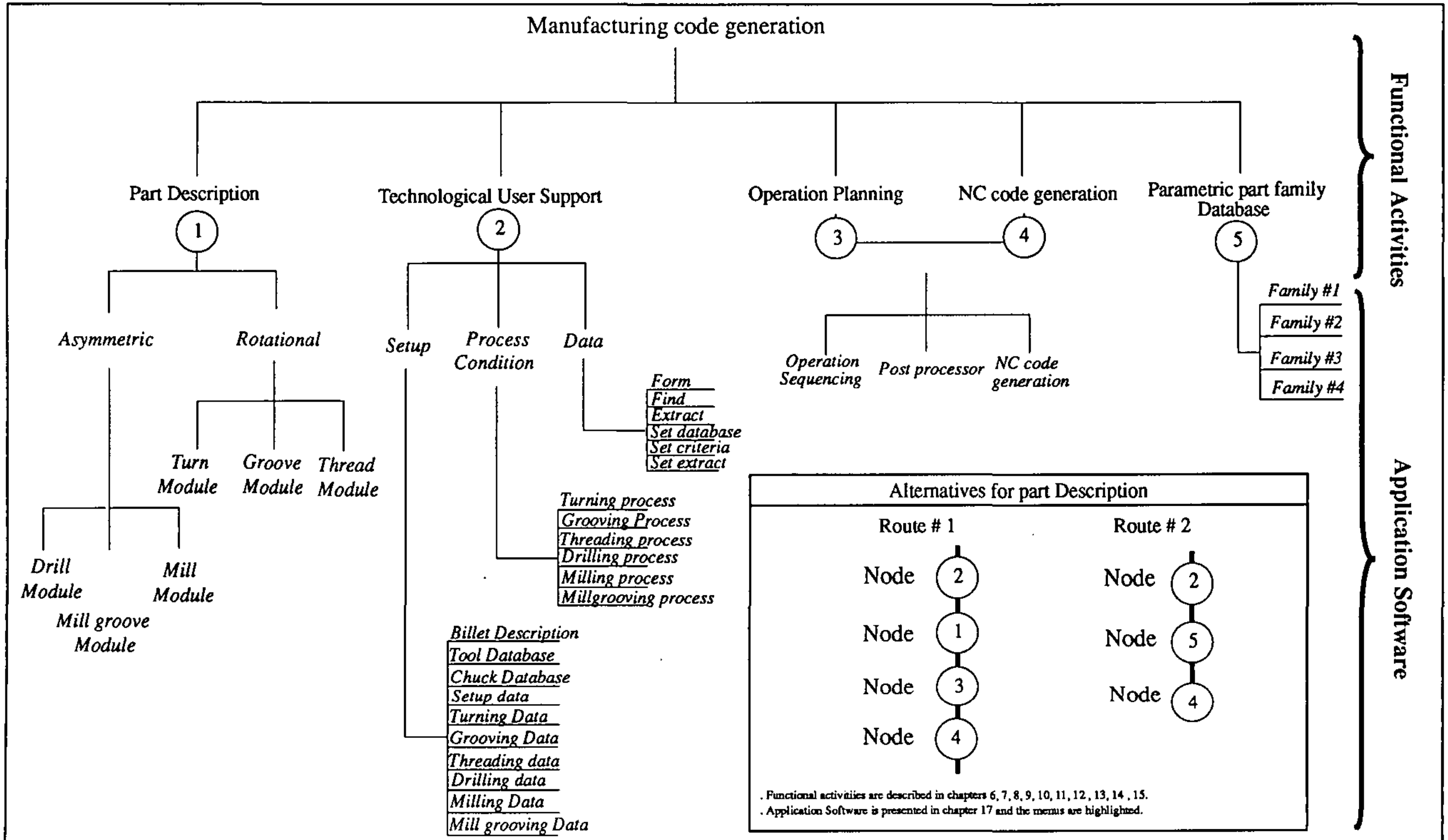


Figure 15.1	The Application Software Layout	LUT - CAD/CAM

can systematically use the application software by using the menus to generate manufacturing code. The five nodes which have been highlighted in figure *1* are each discussed in this thesis. Two distinct methods are presented for generating manufacturing code. The fist route or method requires the user to select node 2, 1, 3 and 4 respectively. For using the alternative method *(i.e part family database)* the route *#2* can be used which requires the user to select nodes 2, 5 and 4 respectively.

15.5 -The Software Interface & Menus

15.5.1 - The Workshop Oriented Interface

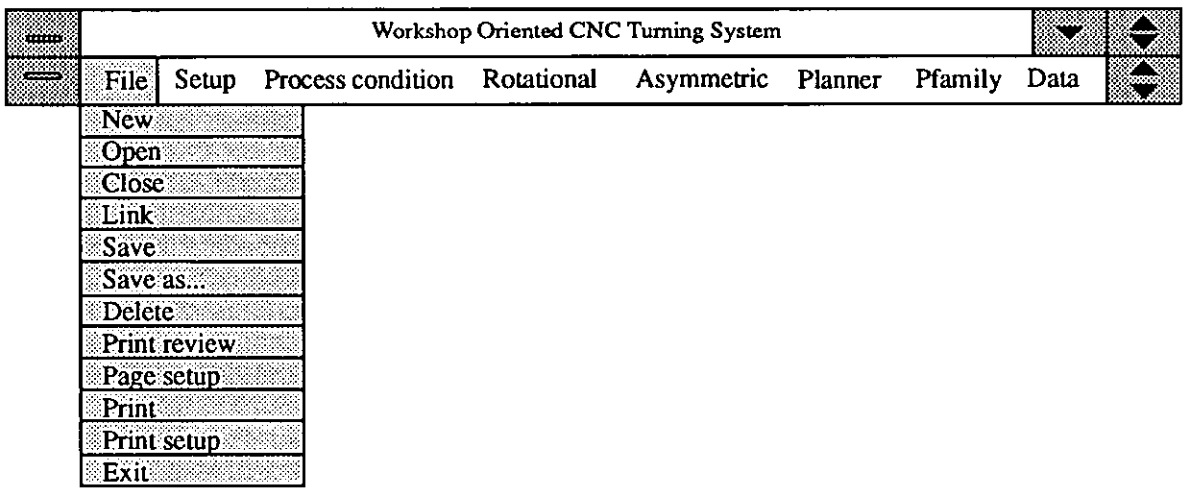
The menu system represents and embodies the different functions which are designed to interrelate together and consequently generate manufacturing code. These functions are:

i- The filing module
ii-The setup module
iii-Process condition module
iv- Rotational module
v- Asymmetric module
vi- Planner module
vii-Part family module
viii-Database module

The programming modules listed above form the structure of the experimental system in which the theory and application of concepts proposed in the core of this thesis are implemented. The subsequent sections describe each module. The interfaces for some of the modules are depicted in figures 15.9 to 15.28.

15.5.2 - The File Management Module

The file management module contains several commands which can create new files, save those files, open and close existing files, and exit from the program. As depicted below these sub-functions are contained in the pull down menu.



File - New: Create new data file on the system

File - Open: Open an existing file.

File - Close: Close an existing file.

File - Link: Enables two files to be linked (*used for the data base files*).

File - Save/Save as: Save the file which is created by the system

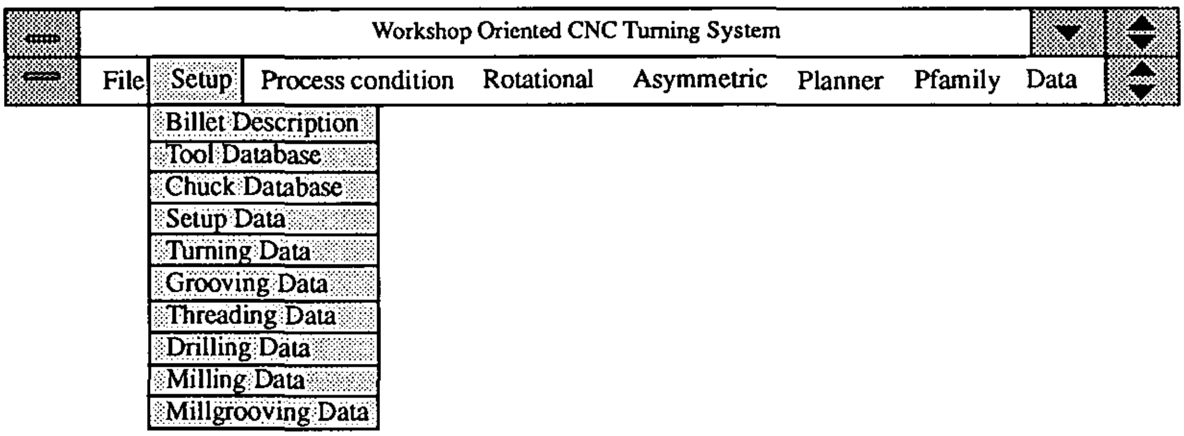
File - Delete: Delete an existing file.

File - Print review / Page setup/ Print: Print file.

File - Exit: Exit from the software into Windows.

15.5.3 - The Setup Module

The setup module consist of several files which preform the setup functions. This module consist of tooling data file, chuck data file, setup data file, machining data for turning, grooving, threading, drilling, milling and the billet description file. The pull down menu depicted below embodies the files.



Setup-Billet description: Describe the billet.

Setup-Tool database: Access cutting tool database.

Setup-Chuck database: Access cutting chuck database.

Setup-Setup data: Input the set up data for the machine & part.

Setup-Turning data: Access the machining data for the turning.

Setup-Grooving data: Access the machining data for the grooving

Setup-Threading data: Access the machining data for the threading.

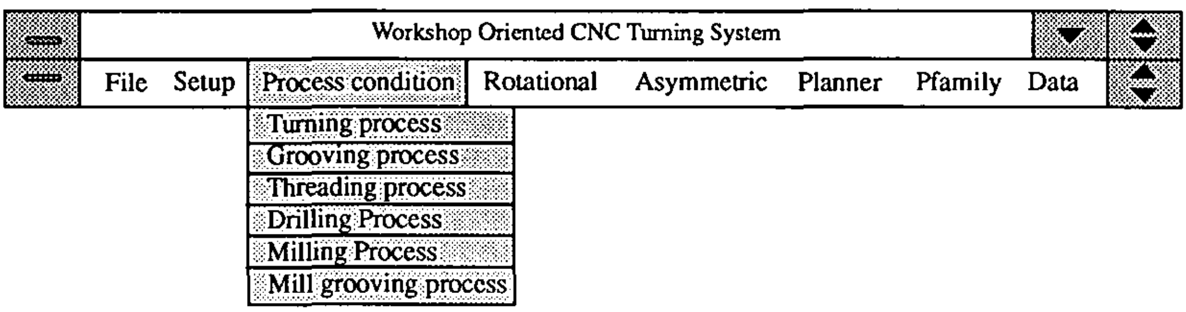
Setup-Drilling data: Access the machining data for the drilling.

Setup-Milling data: Access the machining data for the milling.

Setup-Mill grooving data: Access the machining data for the mill grooving.

15.5.4 - The Process Conditions Module

The process conditional module uses six distinctive files each for a particular process. These files provide useful information about each process and are designed to guide and assist the system user. The pull down menu depicted below can be activated for further selection.



Process condition-Turning: Information database for turning process.

Process condition-Grooving: Information database for grooving process.

Process condition-Threading: Information database for threading process.

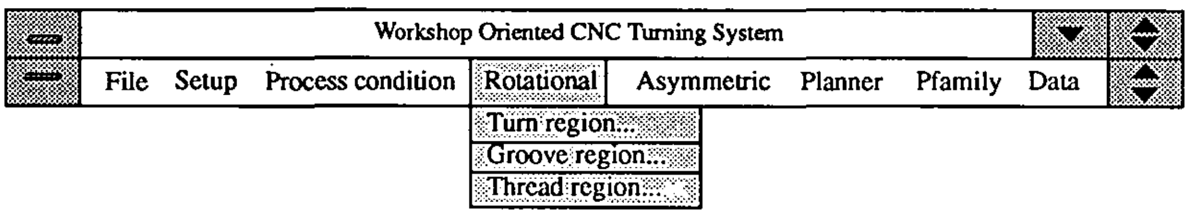
Process condition-Drilling: Information database for drilling process.

Process condition-Milling: Information database for milling process.

Process condition-Mill: Information database for millgrooving process.

15.5.5 - The Geometric (*rotational*) Module

The rotational module contains three basic files: Turn file, groove file and thread file. The turn file embodies several more files, the groove and thread files also embody five associated files. Each file is designed to support the activates which are described in chapters 7,8,9. The pull down menu is depicted below.



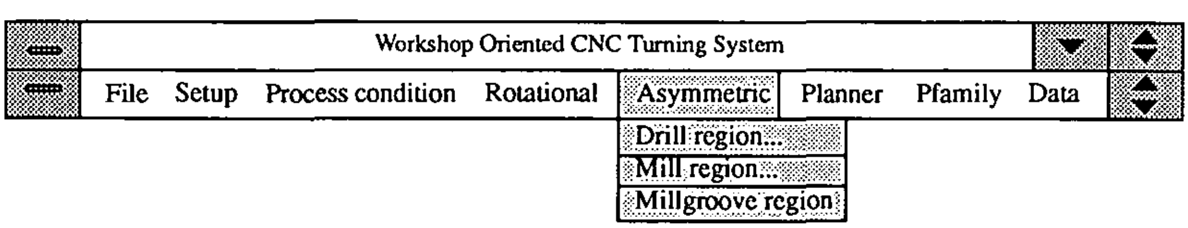
Rotational-Turn region: Representing turn module

Rotational-Groove region: Representing Groove module

Rotational-Thread region: representing thread module

15.5.6 - The Geometrical (*asymmetric*) Module

The asymmetric module embodies three basic functions: Drill, mill and mill groove. These files are used to describe the geometry of those regions which are principally asymmetric. Each file contains several more files which function as templates for input & output of geometry as well as technological information. The menu depicted below represents the asymmetric regions.



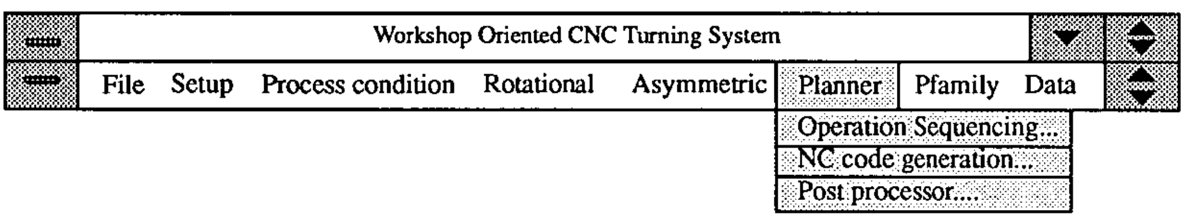
Asymmetrical-Drill region: representing the drill module

Asymmetrical-Mill region: representing mill module

Asymmetrical-Millgroove region: representing mill groove module

15.5.7 - The Planner Module

The planning module consist of three files: operation sequencing file, NC code file and post processor file. These files are designed to implement the issues that are addressed in the thesis (*chapter 11,12 and 14*). The pull down menu shown below contains these files.



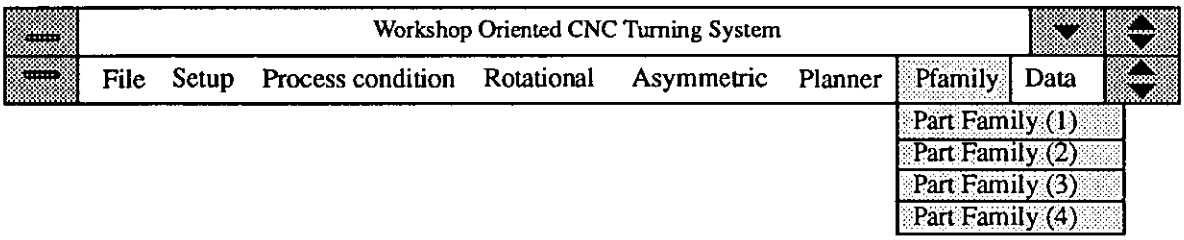
Planner-Operation sequencing: Represents the operation planner.

Planner-NC code generation: Represents the Code generator.

Planner-postprocessor: Represents the postprocessor.

15.5.8 - Part Family Module

The Part family module was designed to support the GT based parametric part family data base. This menu provides four distinct part families. The description, as well as function, of this module is listed in chapter 13. The pull down menu depicted below consist of the following modules.



Pfamily-part family (1): The part family database module #1.

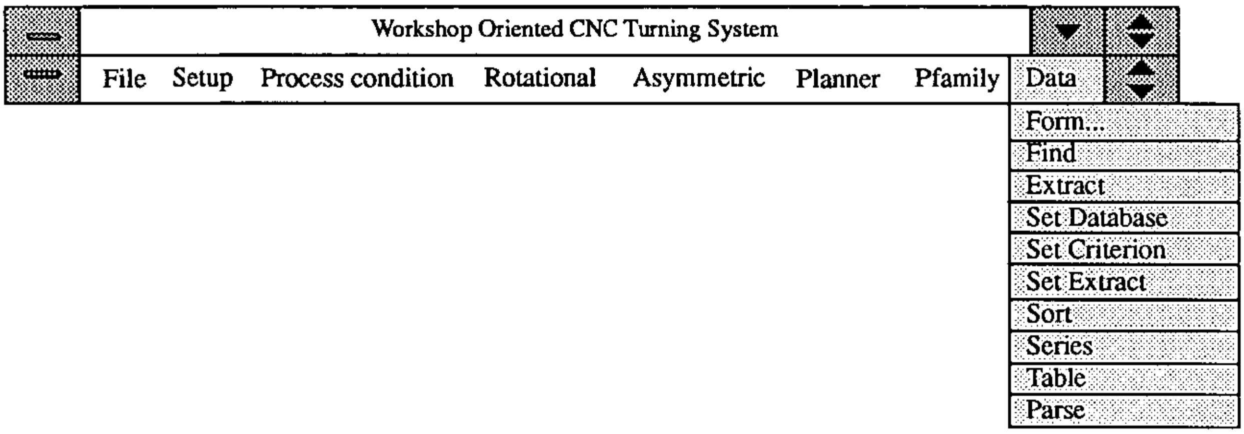
Pfamily-part family (2): The part family database module #2.

Pfamily-part family (3): The part family database module #3.

Pfamily-part family (4): The part family database module #4.

15.5.9 - The Database Module

The database module is designed to support the information embedded in several program files. The functions contained in this module are designed to perform certain functions.The commands as well as the corresponding function are explained below and are depicted in the pull down menu.



Data Set Database	SET.DATABASE()
Data Set Database	SET.CRITERIA()
Data Form	DATA.FORM()
Data Find	DATA.FIND (*log-exp*) *log-exp* = TRUE for data find, FALSE for data EXIT FIND DATA.FIND.NEXT() Select the next matching record of the database if none, function value is false. DATA.FIND.PREV() Select the previous matching record of the database if none, function value is false.
Data Extract	EXTRACT(*log-exp*) *log-exp*=TRUE (turnon unique checkk box), FALSE (turn off unique check box).
Data Delete	DATA.DELETE()

15.6 - The User Interface

The graphical representation of each file is designed to support the activities listed throughout this thesis. Great care is taken to design the interface so as to provide a clear guidance to the user and rationalise shop-floor programming. The design of each interface has been based on investigating the needs of a user as well the internal data requirement by the system. The user interface developed for each menu uses the following facilities to communicate with the user.:

i- Dialogue box for prompt
ii-Dialogue box for displaying messages
iii-Dialogue box for interaction input
iv-Graphic icons for selection purposes
iiv-Graphic icons for help and file management
v- Graphic icons for data transfer

15.7 - The User System Interface

A brief explanation is given of the way in which the user can approach the experimental system to obtain output via one of the two routes depicted in figure 15.2. It should be noted that this explanation is kept brief as it will be repeated in particular case study examples in a number of occasions in the latter chapter. Two basic information flows are described for the experimental system. The information flow is performed by two mechanisms, namely the input templates and query templates. For each activity described in the core of this thesis, the corresponding route is depicted and the relevant module is numbered. The user can retrieve or input information for each task and sub task. The two basic routes for code generation are depicted.

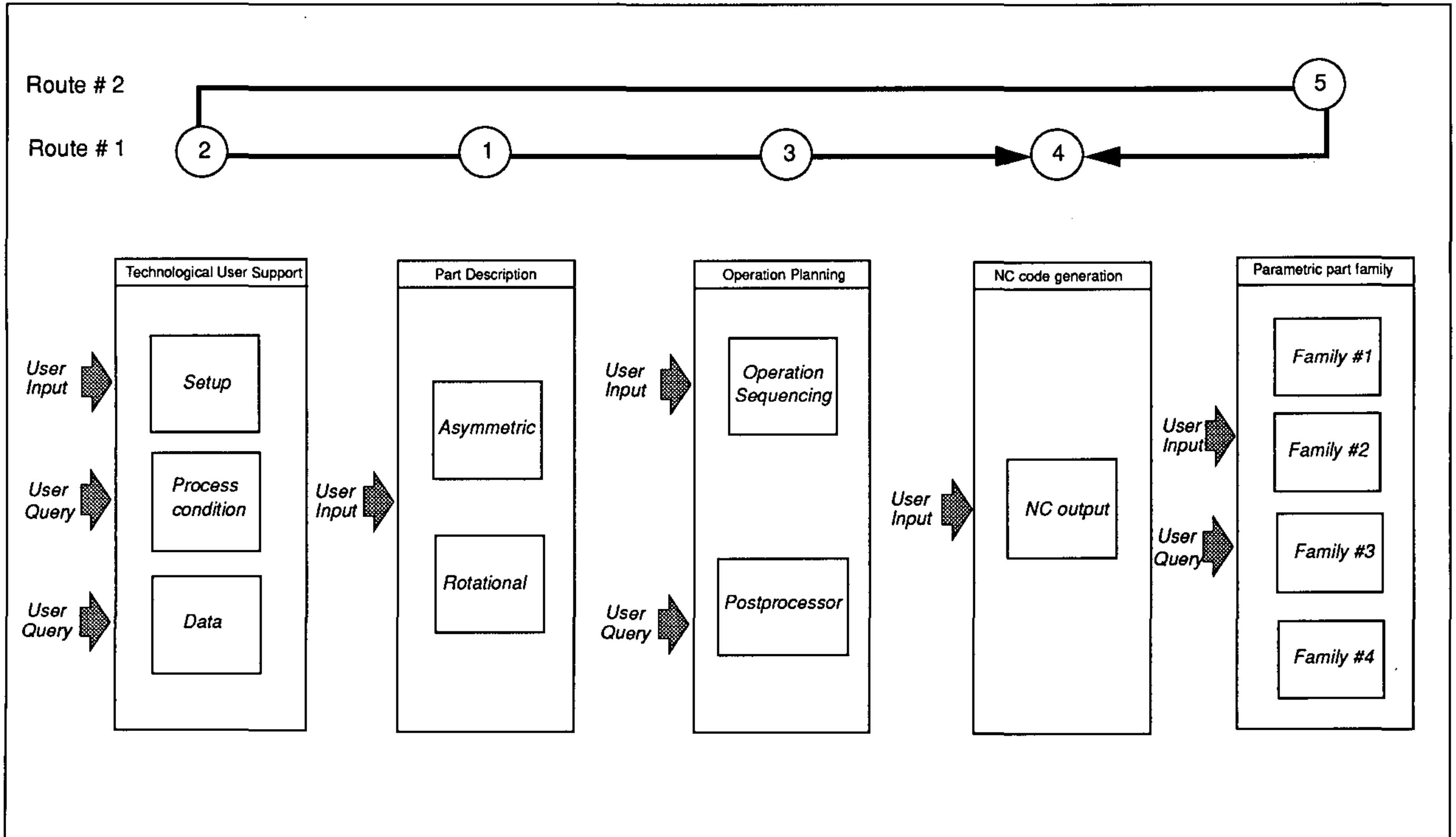


Figure 15.2	Workshop Oriented NC planning System	LUT - CAD/CAM

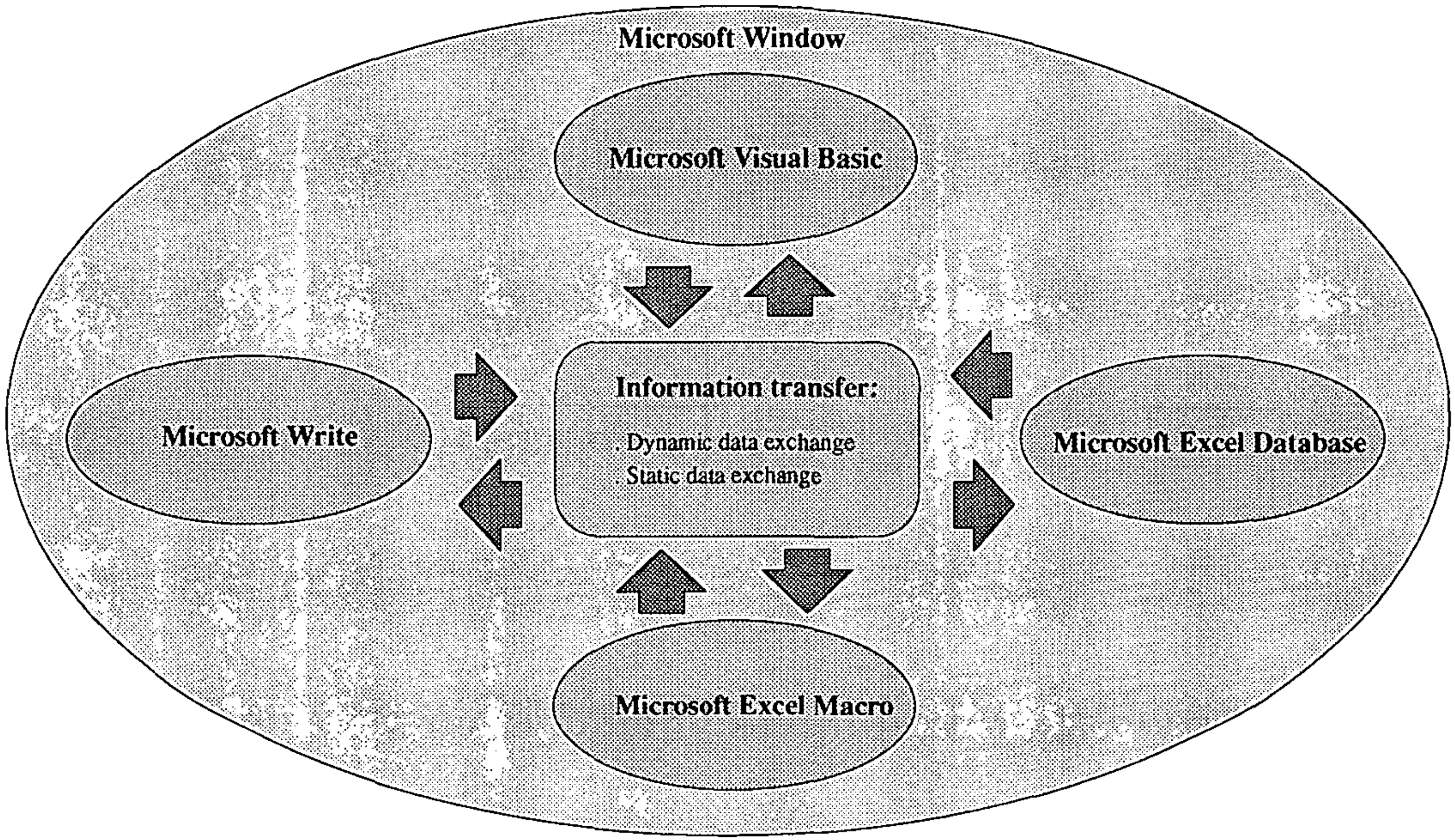
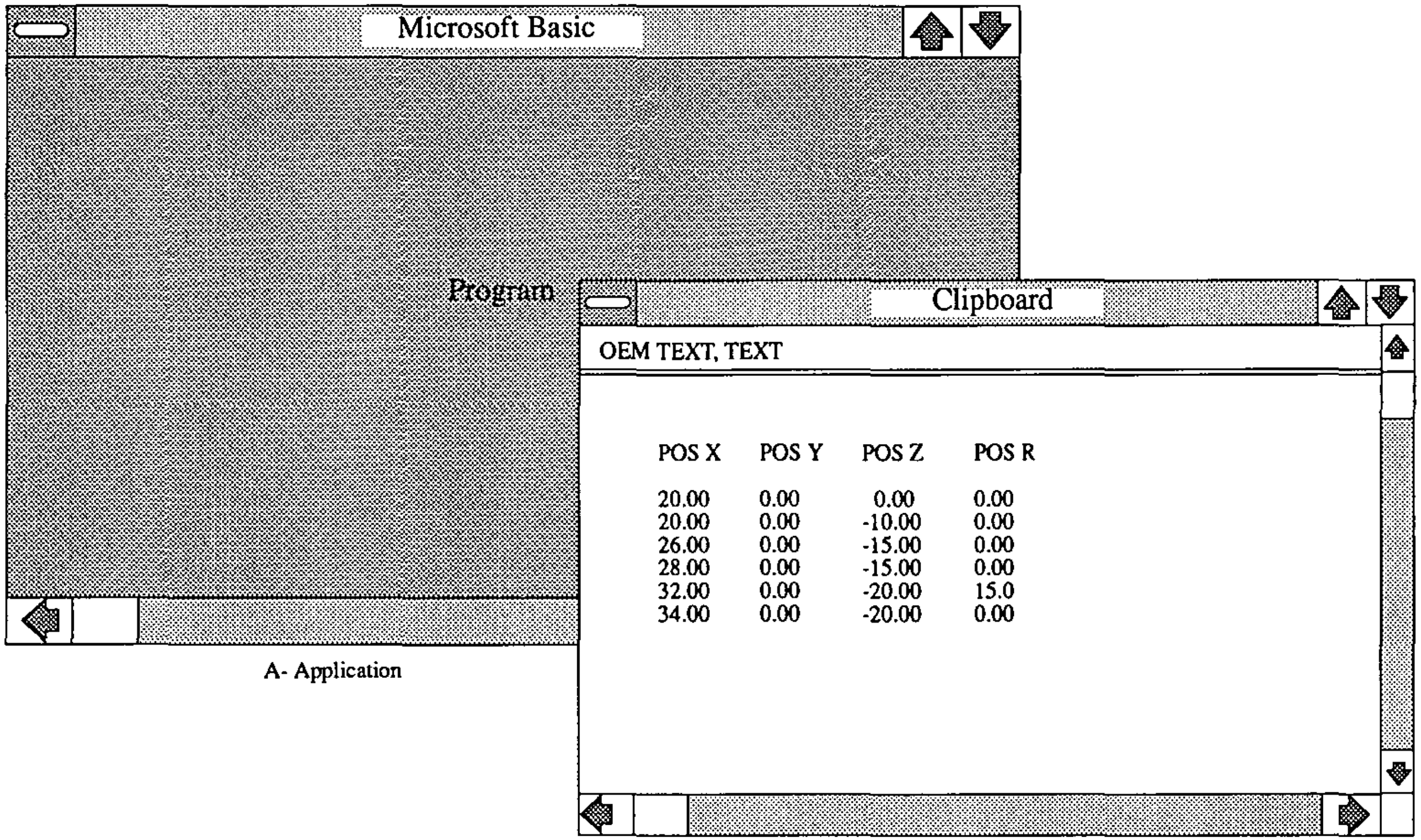


Figure 15.3	The Application Software Layout	LUT - CAD/CAM



A- Application

B - Output

Figure 15.4	An Application Designed to Run Under Windows and it's Output Copied into Clipboard	LUT - CAD/CAM

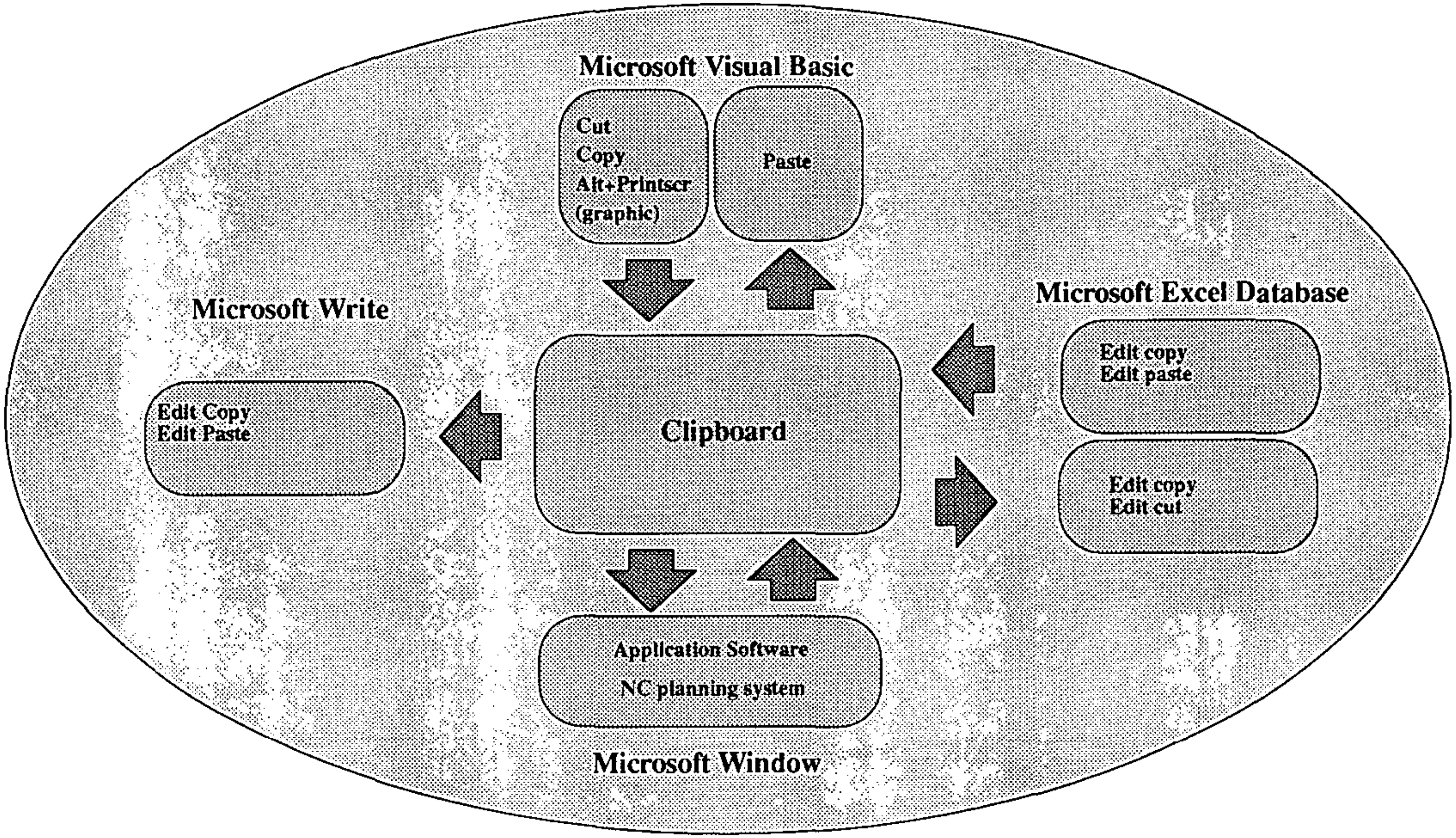


Figure 15.5	Information Transfer- Static Data Exchange	LUT - CAD/CAM

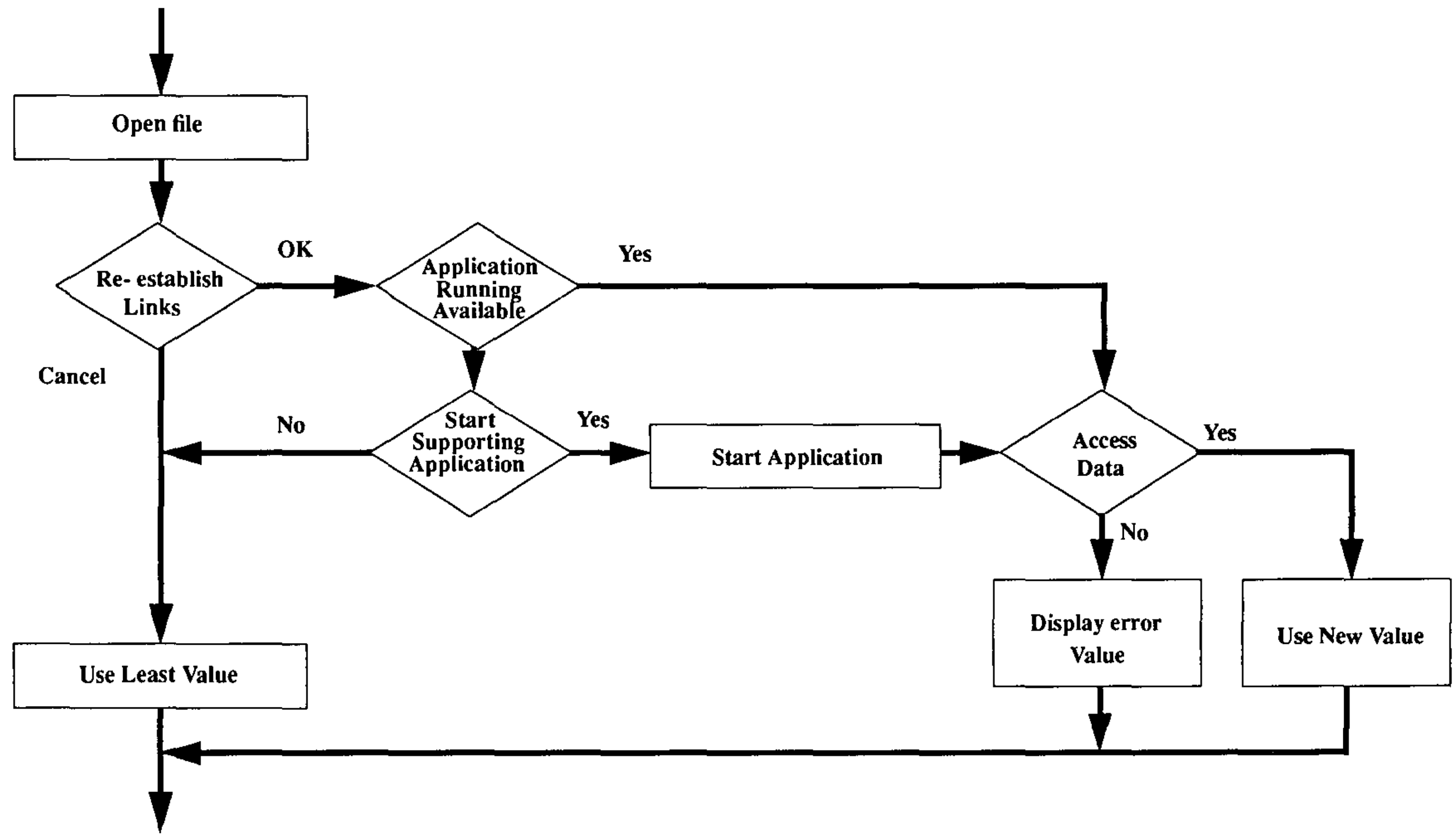


Figure 15.6	Information Transfer (Dynamic) DDE Updating value for Open Linked Document	LUT - CAD/CAM

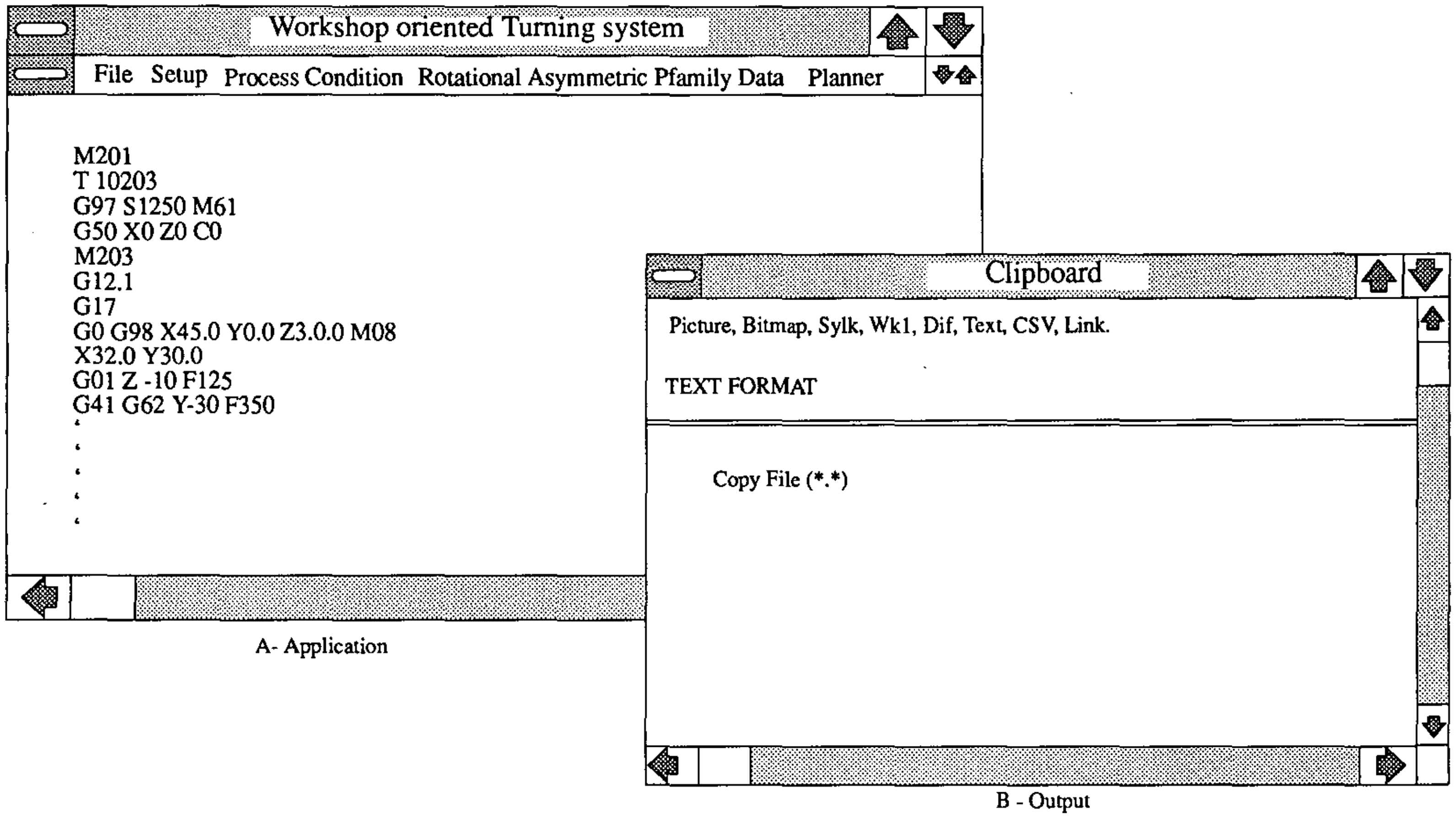


Figure 15.7	Out put Transfer From Application To Microsoft Write	LUT - CAD/CAM

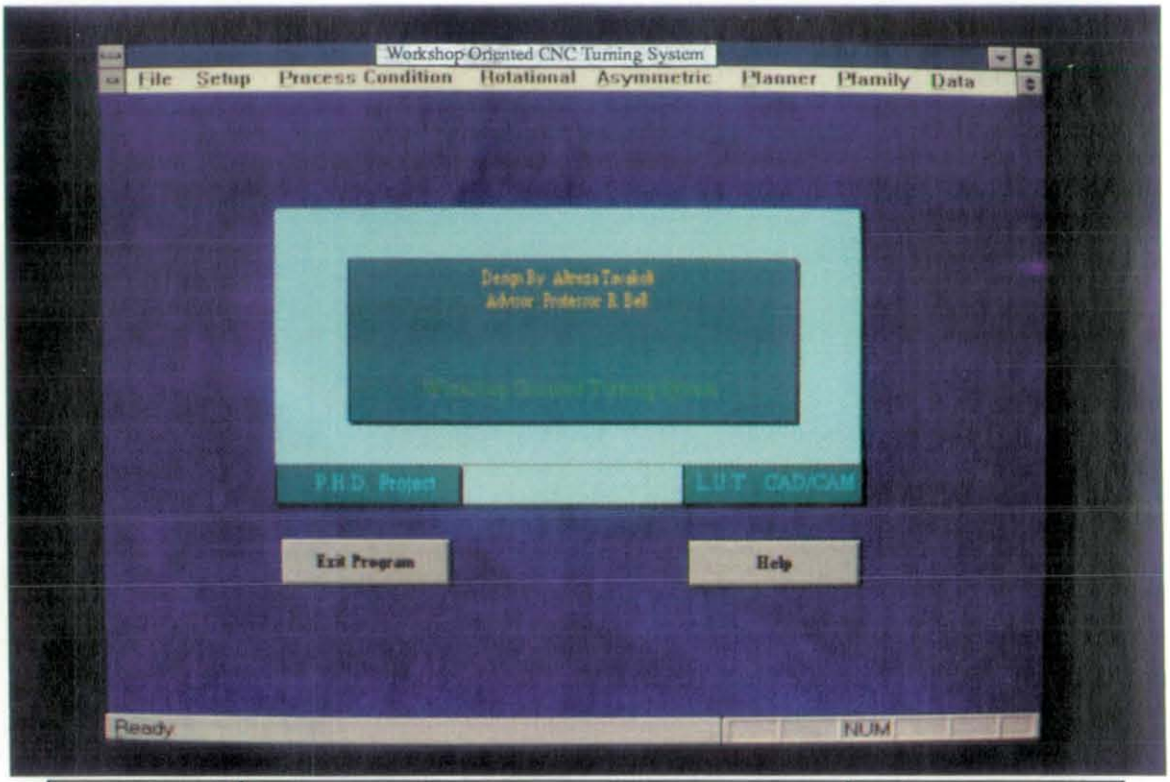


Figure 15.9	Workshop oriented NC planning	LUT- CAD/CAM

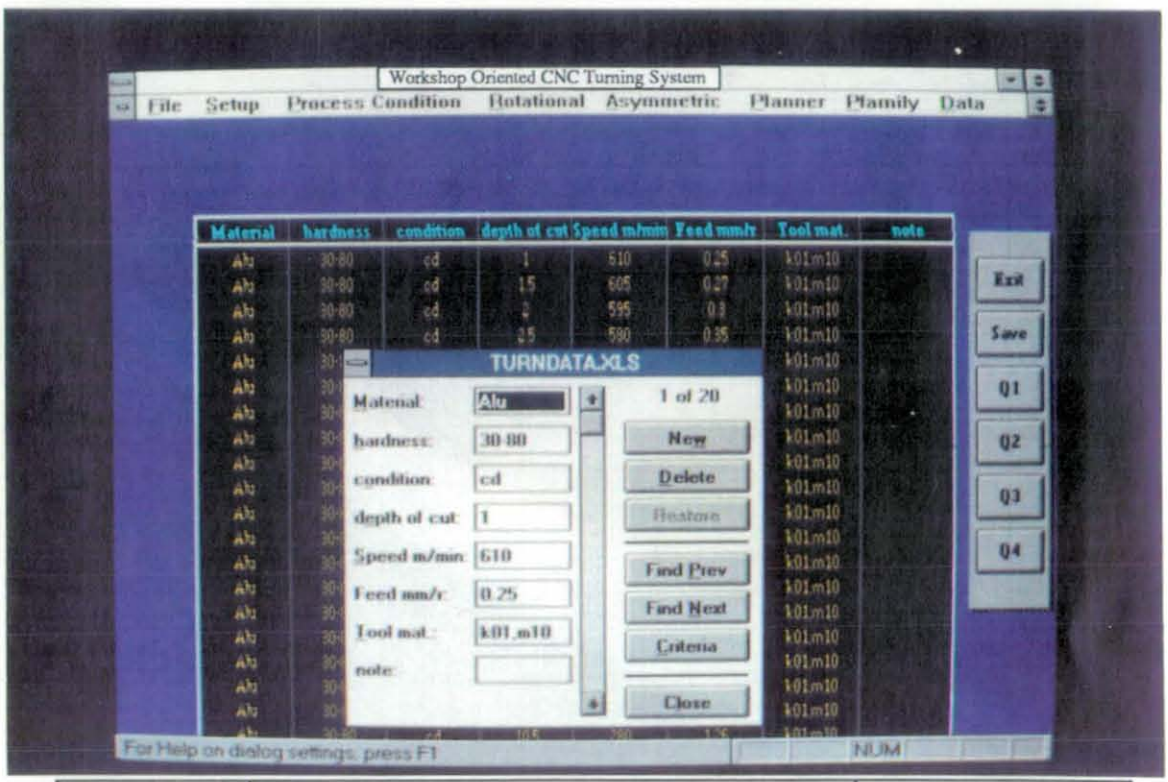


Figure 15.10	The Machining database for turning	LUT- CAD/CAM

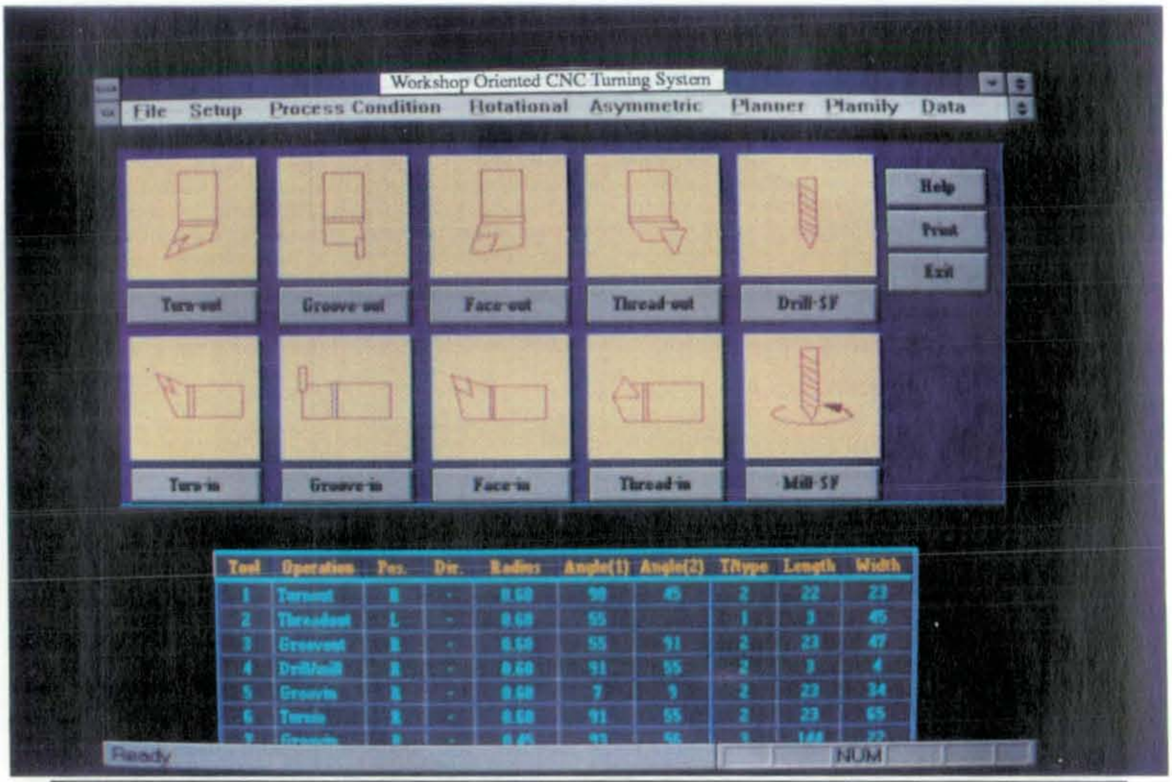


Figure 15.11	The cutting tool database	LUT- CAD/CAM

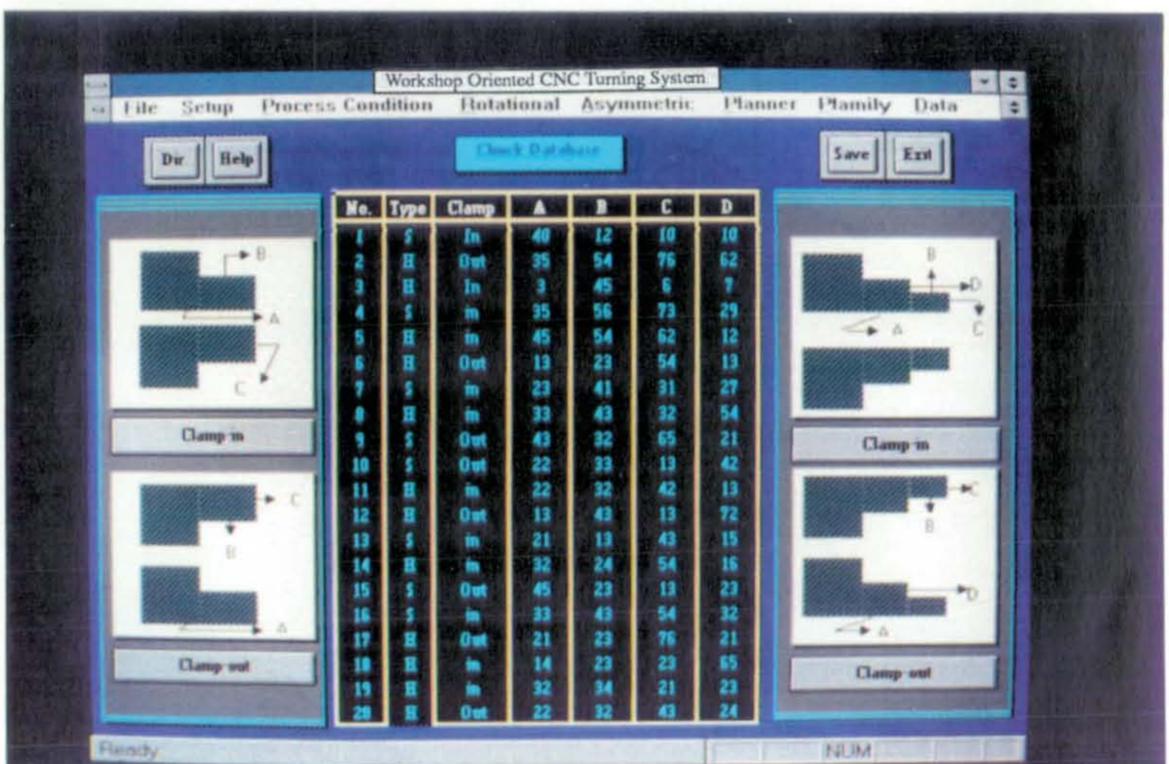


Figure 15.12	The Workholding Database	LUT- CAD/CAM

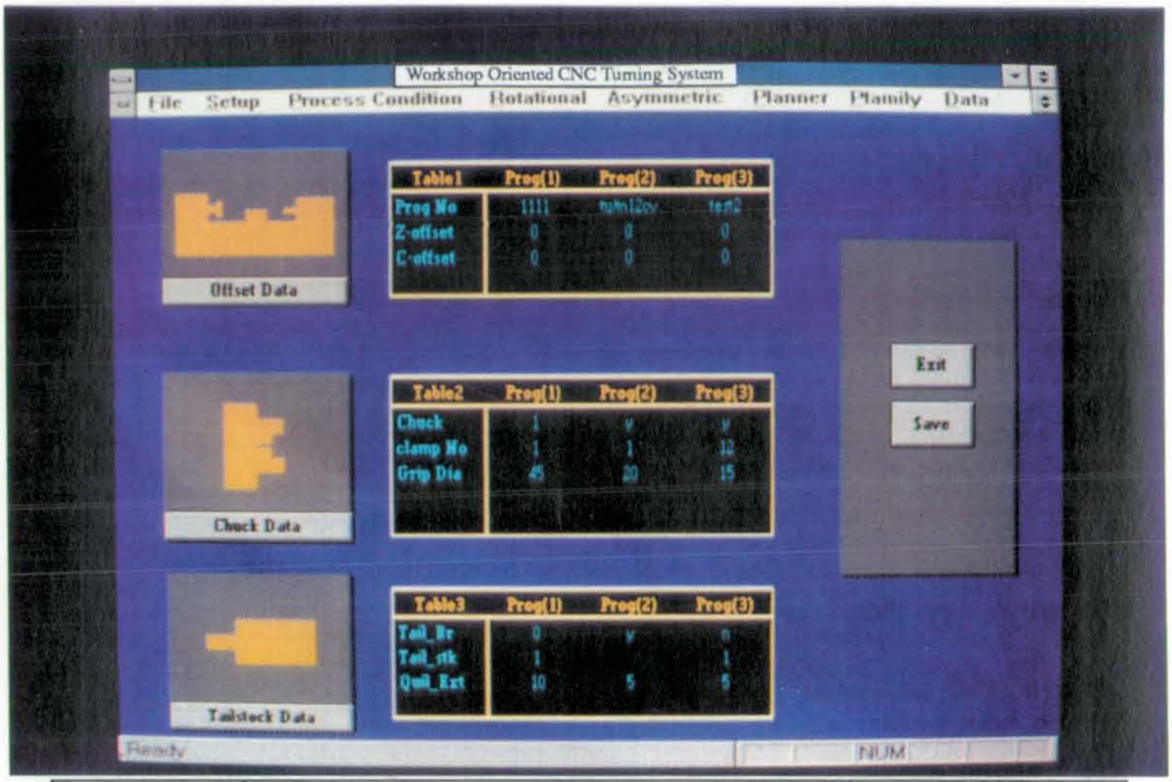


Figure 15.13	Setup	LUT- CAD/CAM

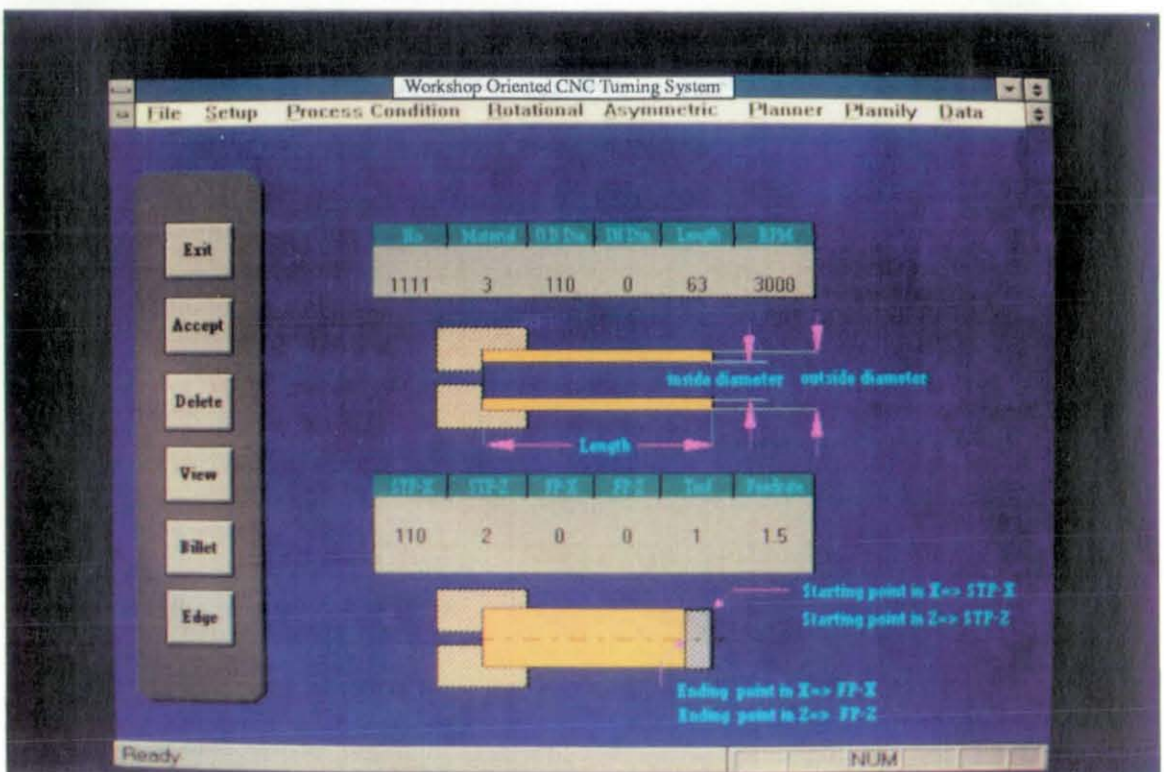


Figure 15.14	Billet Description & Setting	LUT- CAD/CAM

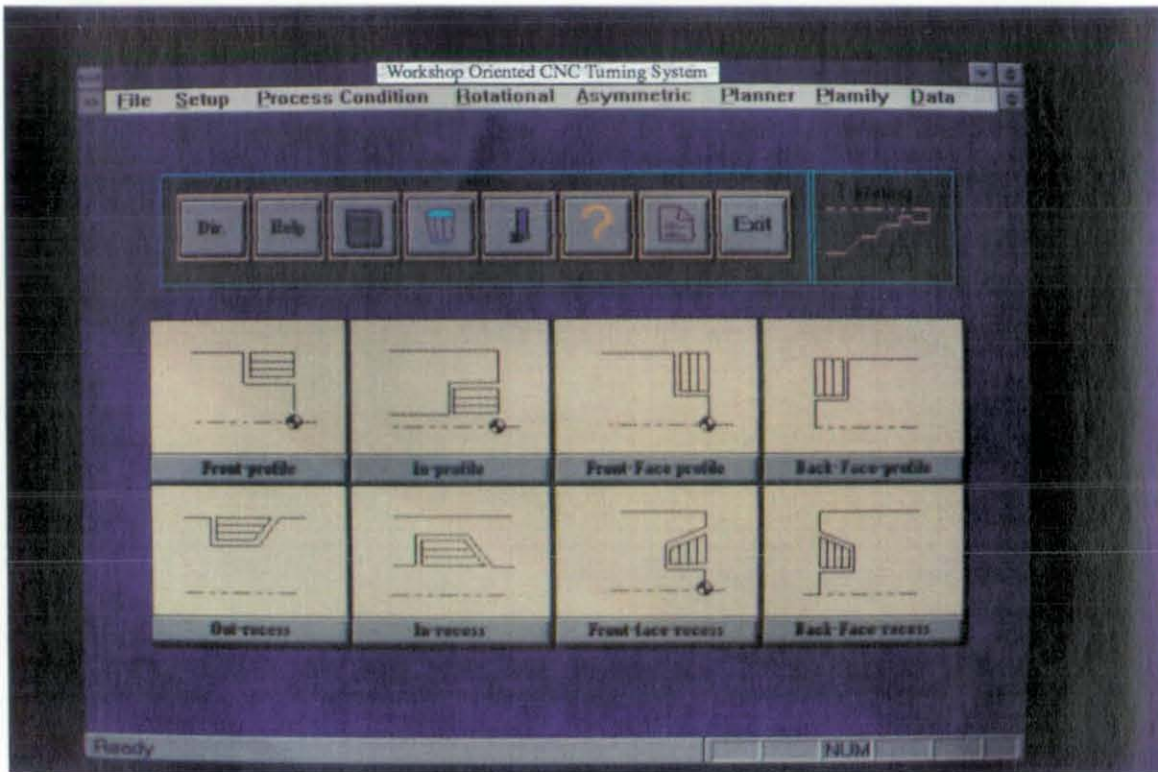


Figure 15.15	The Turn Region	LUT- CAD/CAM

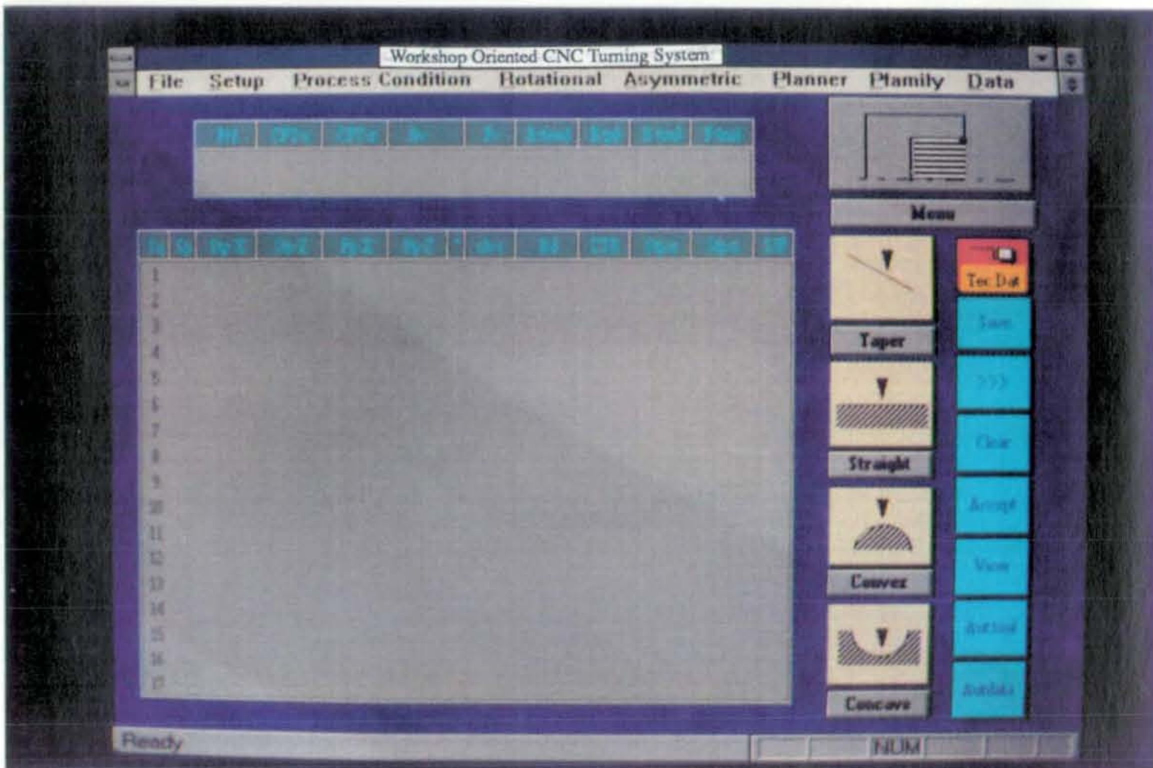


Figure 15.16	The Template for Turn Region	LUT- CAD/CAM

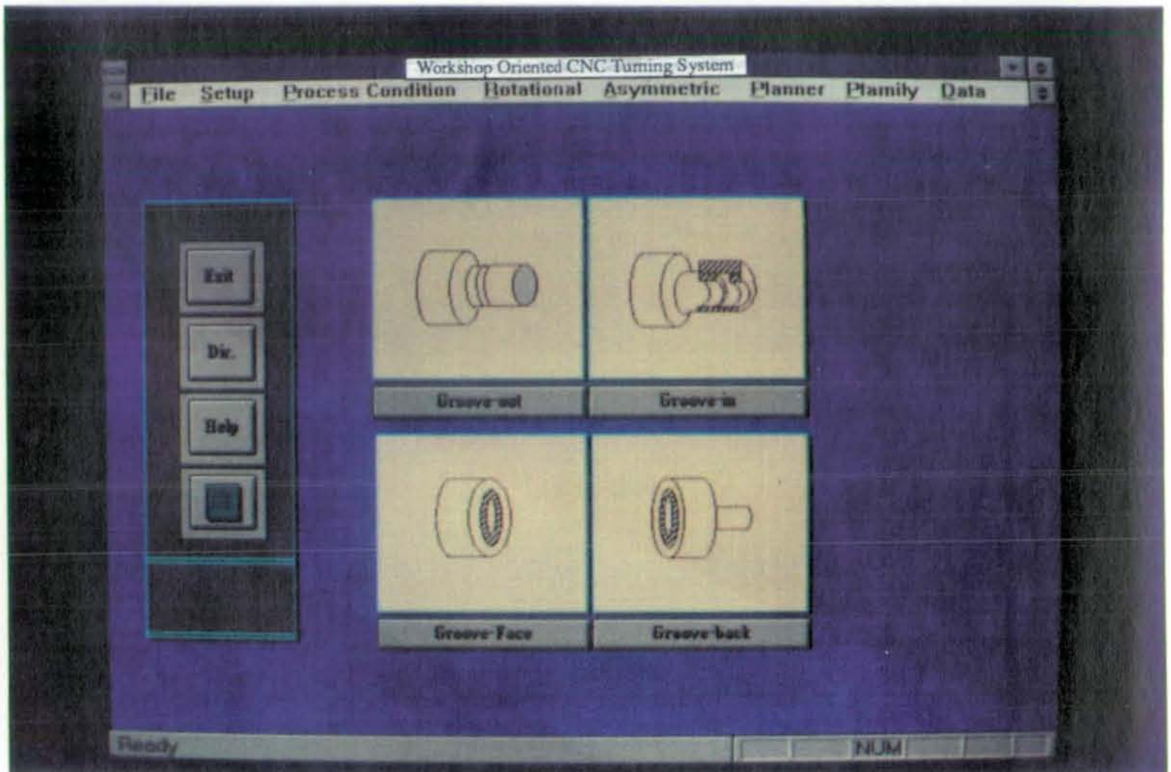


Figure 15.17	The Groove Region	LUT- CAD/CAM

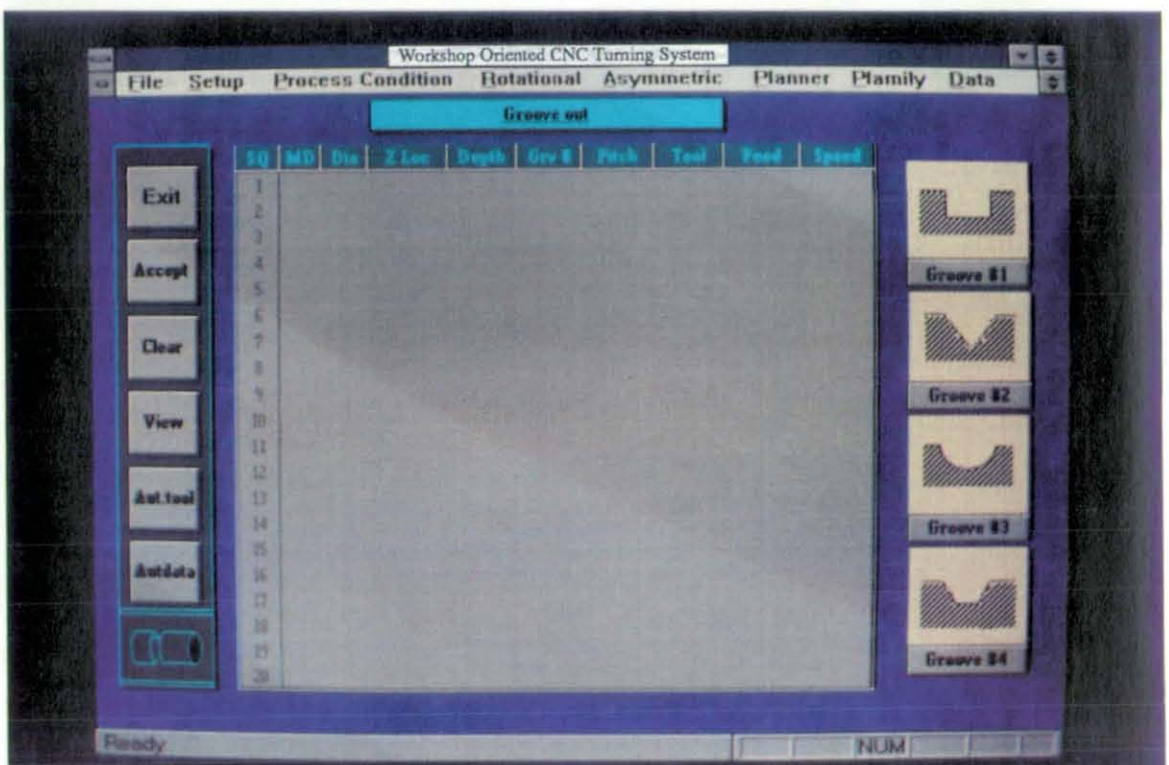


Figure 15.18	The Template for Groove Features	LUT- CAD/CAM

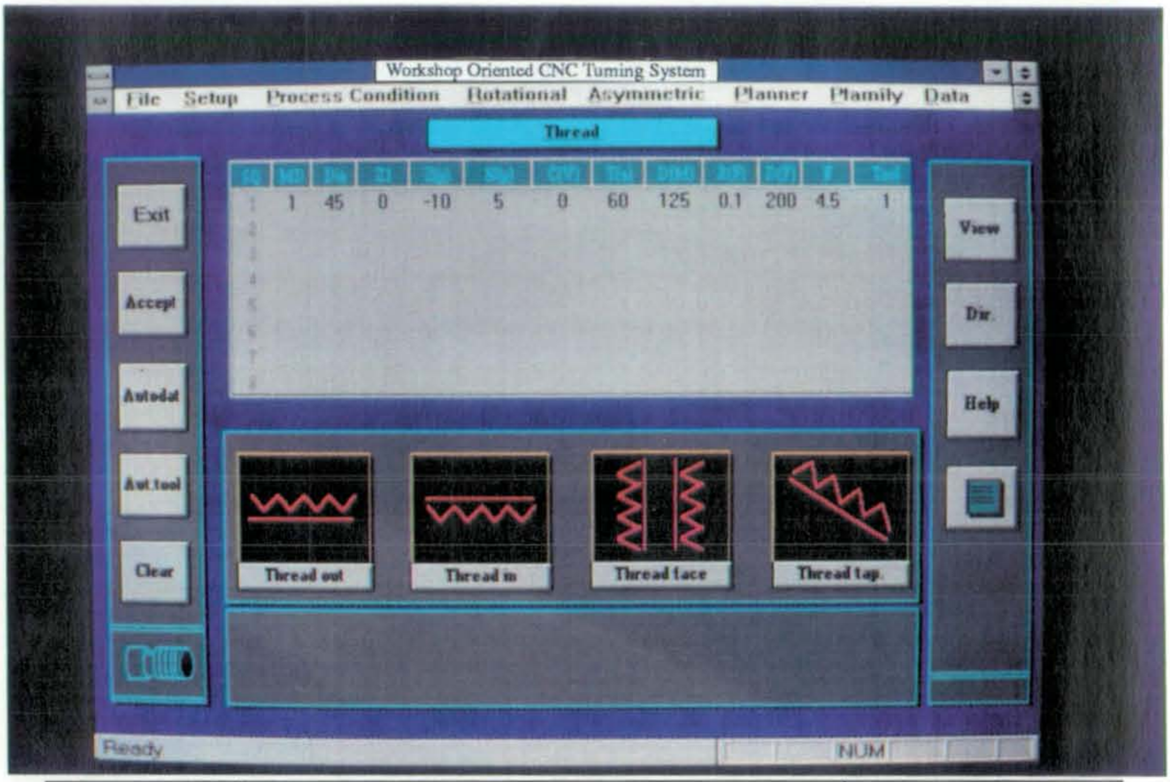


Figure 15.19	The Thread Region	LUT- CAD/CAM

Figure 15.20	The Mill, Drill and Mill-Groove Region	LUT- CAD/CAM

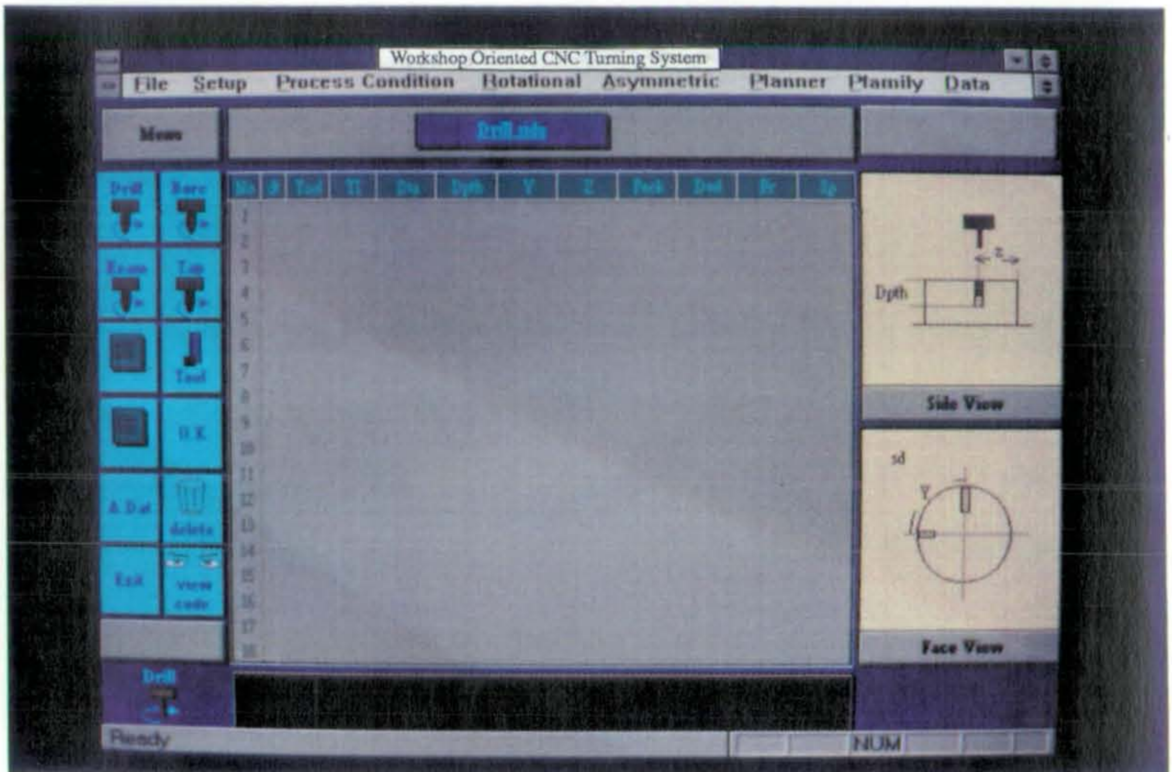


Figure 15.21	The Template For Drill-Side Region	LUT- CAD/CAM

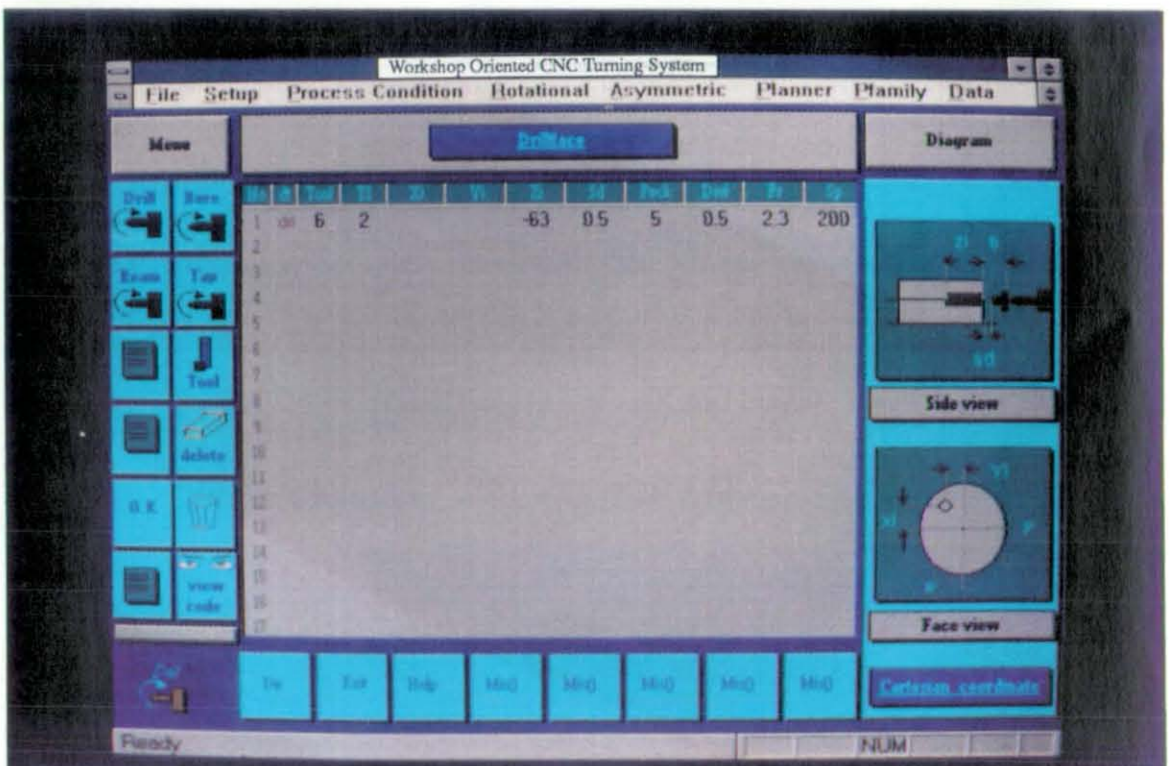


Figure 15.22	The Template For Drill Face	LUT- CAD/CAM

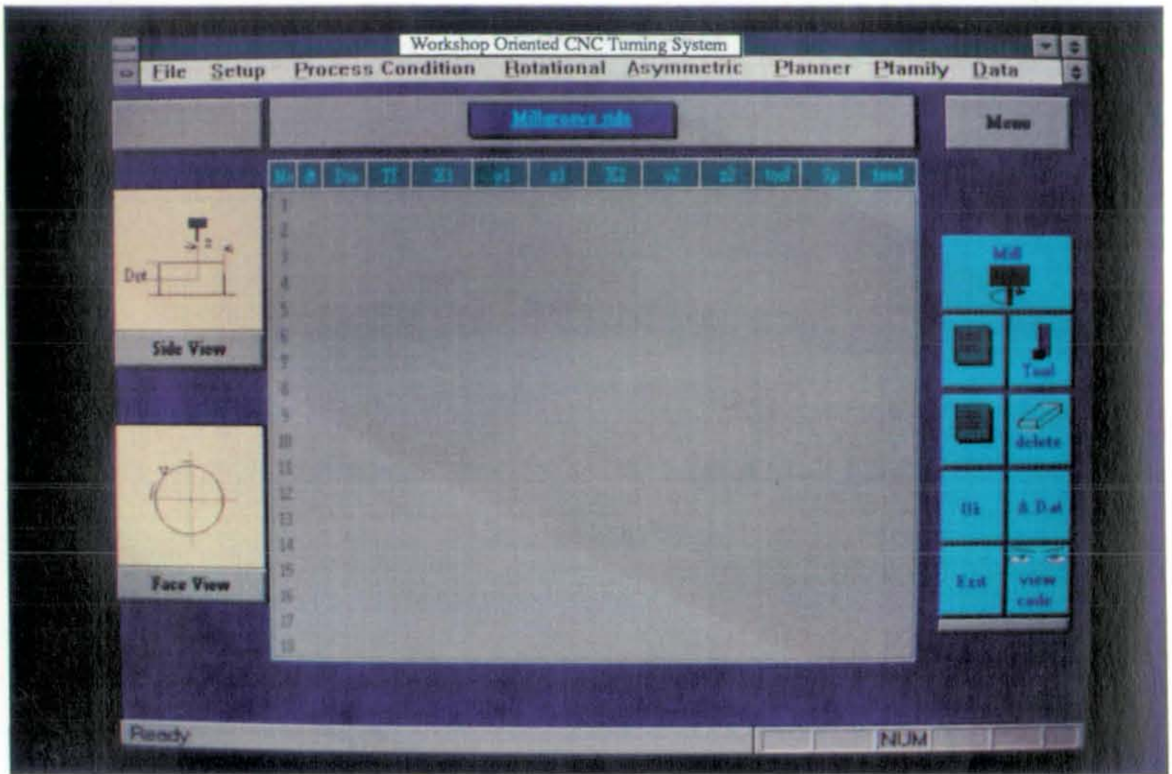


Figure 15.23	The Template for Mill-Groove -Side	LUT- CAD/CAM

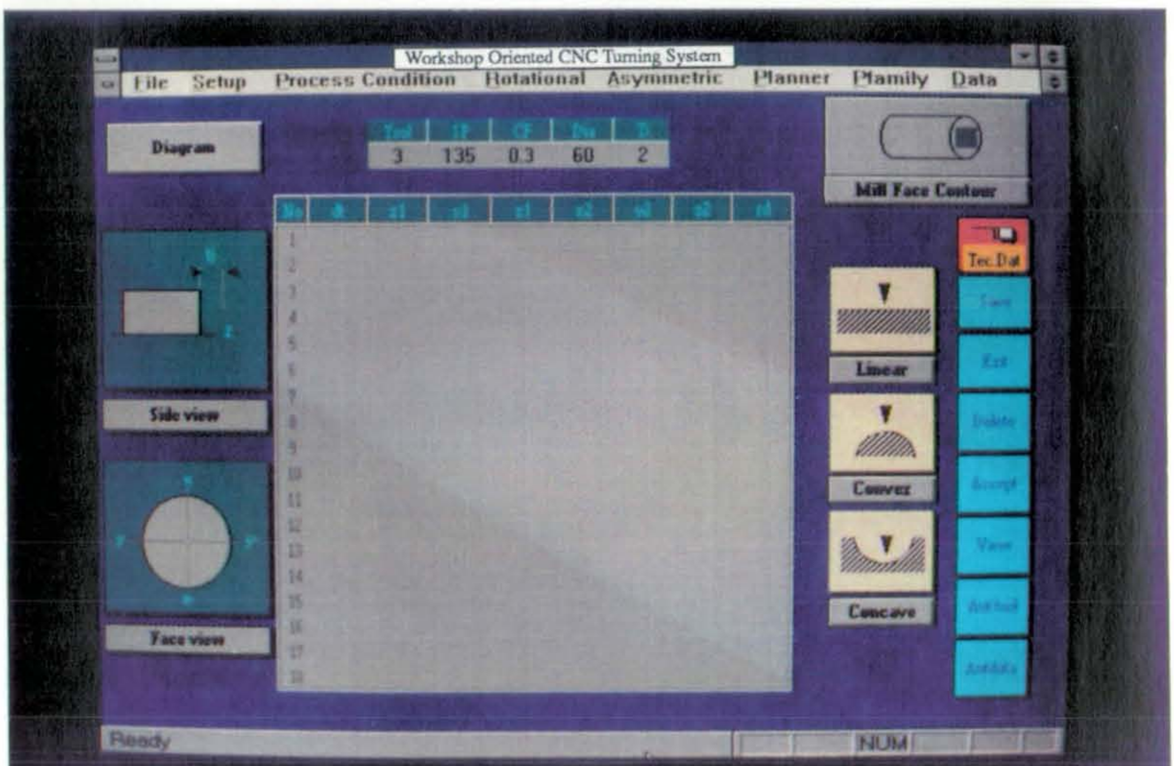


Figure 15.24	The Template For Mill-Face- Region	LUT- CAD/CAM

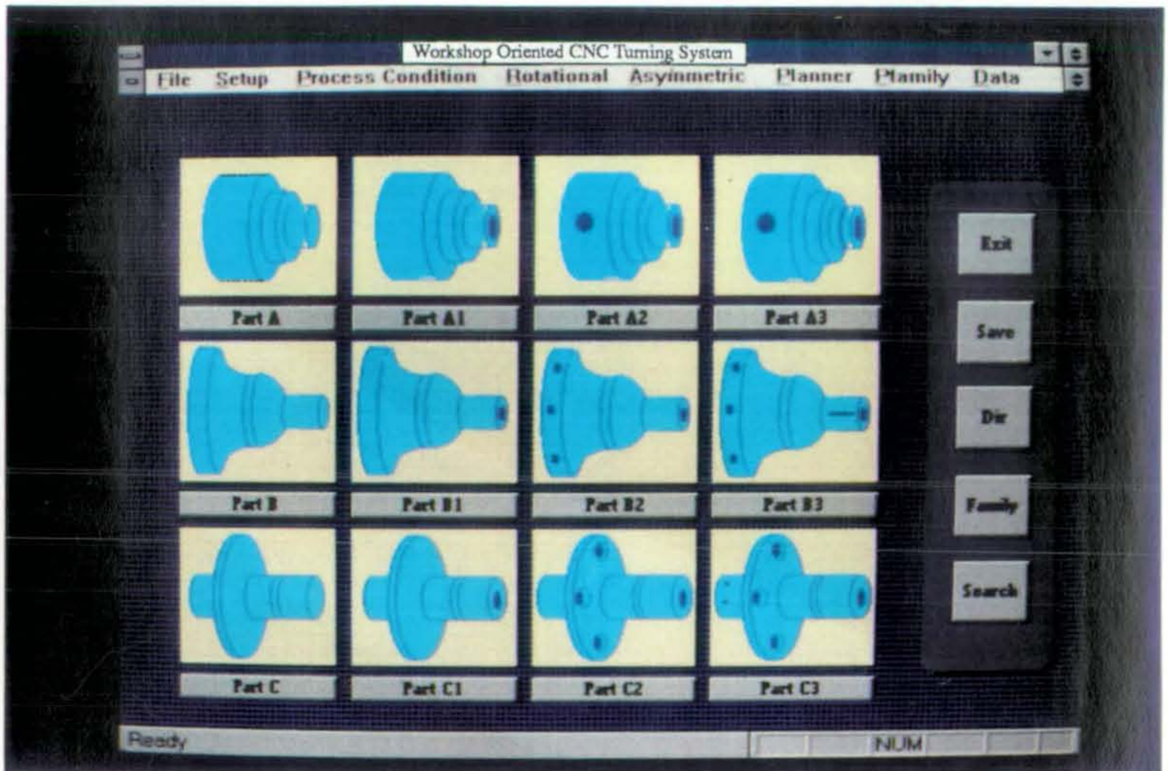


Figure 15.25	Parametric Part Family Database	LUT- CAD/CAM

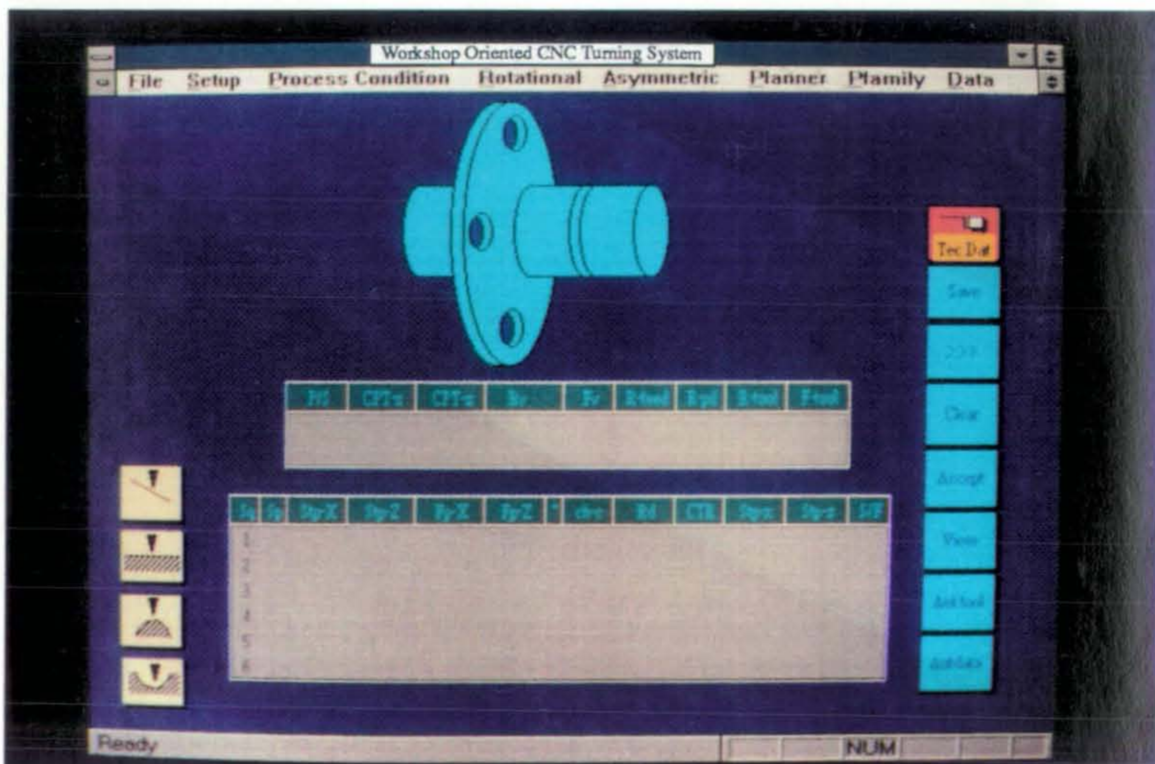


Figure 15.26	The Template for Parametric Part Description	LUT- CAD/CAM

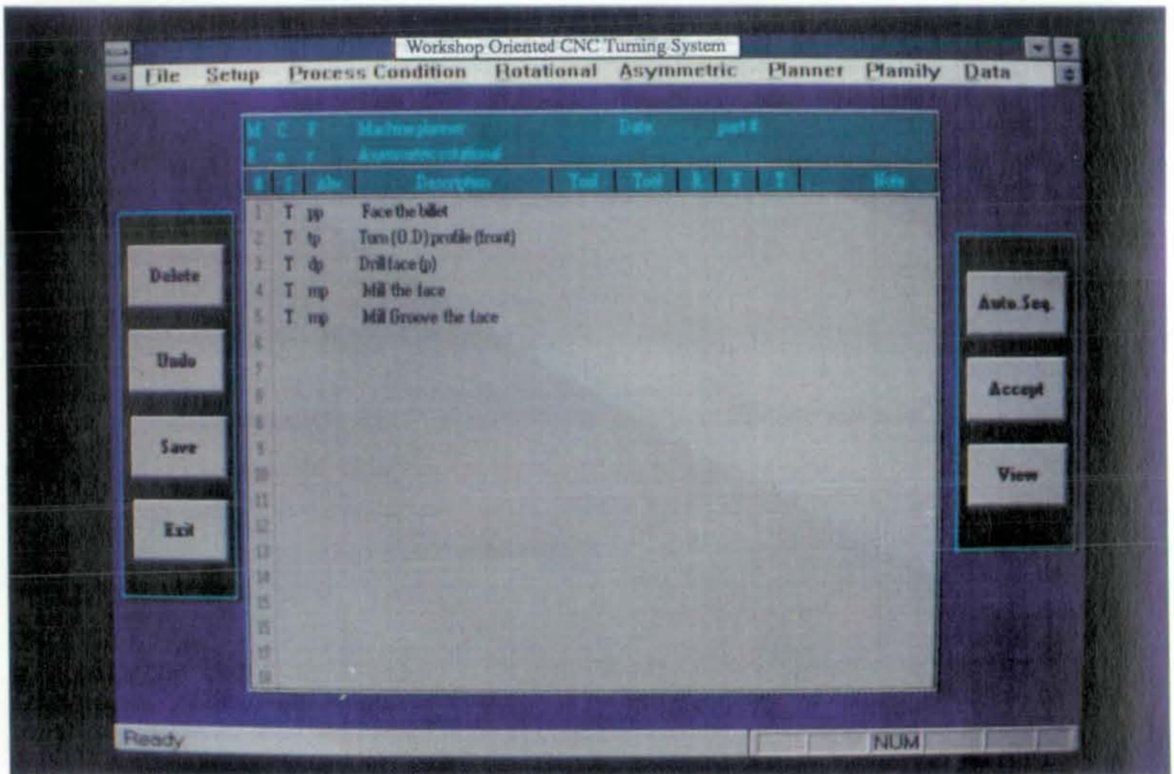


Figure 15.27	Operation Planner	LUT- CAD/CAM

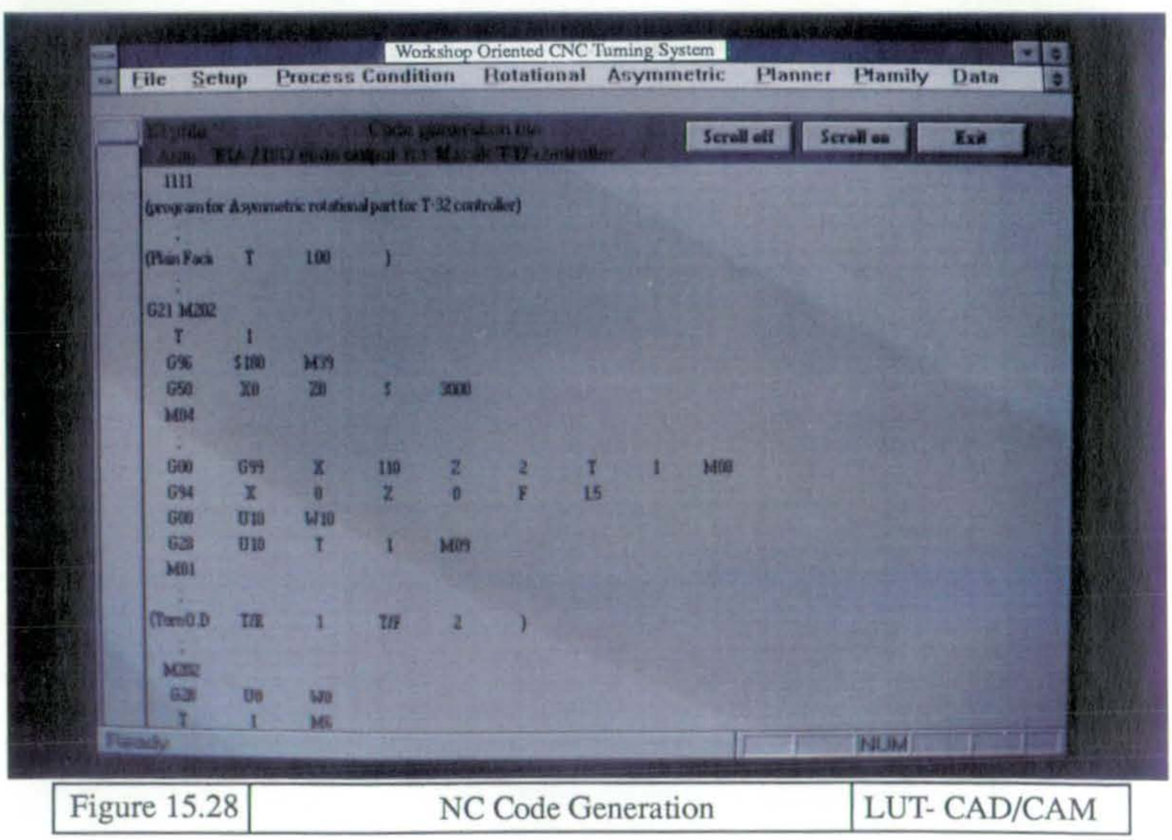


Figure 15.28	NC Code Generation	LUT- CAD/CAM

Chapter 16

Case Study

16.1 - Introduction

This chapter describes the experiments which were carried out at MAZAK to demonstrate the steps required to plan NC data for both rotational and asymmetric rotational components. This experiment has allowed the application software to model, define and subsequently generate NC toolpaths for the selected components.

A CNC turning centre has been used to simulate the NC programs so as to implement and evaluate the decisions taken during the preparation of NC data by the experimental system.

This chapter includes a description and illustration of each component and the related NC data. The Appendix V contains illustrations of the actual tool path and the NC programs. The scope of the case study, as well as the purpose of the experiment, is described. In addition, the associated data for each component and the representation of their regions and features are listed and defined. The necessary setup data and operation planning steps, and in particular the operation sequences for each component, are described. Finally, the NC data for each component is produced and the related problems faced during the testing are analysed. Finally, the conclusions drawn from the experiment are stated.

16.2 - Scope of the Tests

Due to unexpected circumstances the range of components which were initially planned to be tested had to be limited to two components. The tests were performed using a MAZATROL T32-2 to simulate the NC tool path.

16.3 - Facility & Environment

The tests were performed at MAZAK (U.K) who provided the author with the necessary simulation facilities to carry out the tests. The MAZATROL T32 -2 was used for simulation and was setup to emulate the *Super Quick Turn 15* turning centre. This machine tool was equipped with live tools. The tests are listed in the subsequent sections of this thesis.

16.4 - The Purpose and Criteria for Component Selection

As stated in section 16.2, two components have been selected to demonstrate the novel concepts that were put forward in the core of this thesis. The first component has been selected to represent only rotational components. As stated in chapter 5, from the 47% of products which are principally rotational only 25% are completely rotational. The remaining 75% contains a mixture of rotational and asymmetric features. Component *A* was selected to represent rotational features. Component B however represents both rotational features and asymmetric features. These two components will further demonstrate the concept of regions and features (*see figure 1*).

16.5 - The Component Representation (*regions & features*)

The components which are selected demonstrate the different regions that can be machined. As stated in section 16.4, some of these regions are rotational and therefore can be machined by turning, grooving and or threading operations. However some regions are asymmetric and therefore require milling, drilling and or mill grooving operations. It must be noted that all the components used for test are principally rotational. The regions and features that are represented by the components reflect the structure that help us navigate (*i.e. through region scheme*) and select the appropriate regions & features (*see the taxonomy in chapter 8 for regions and features*).

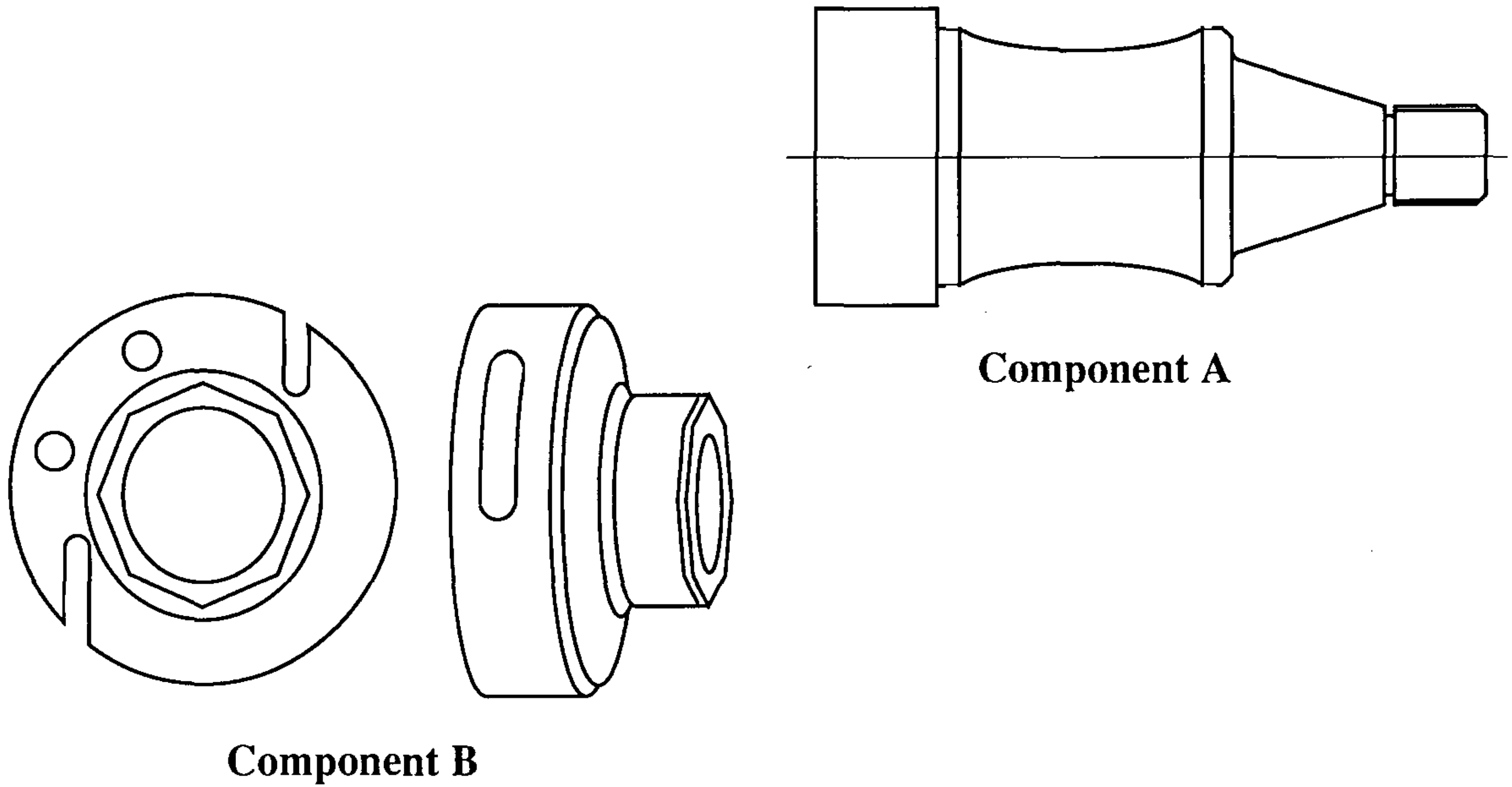


Figure 1	The workpieces for experiment	LUT - CAD/CAM

16.6 - The Description of Regions & Features

For each component the regions and features that are represented are described using the scheme that has been put forward in chapter 9. The geometry and technological data is embodied and depicted in the relevant geometrical and technological templates. The type of information embedded in those templates is depicted in the subsequent sections.

16.7 - Setup Data & the Use of Technological Support System

Each component requires accurate setup data so as to reflect the conditions of the tooling and the turning centre. The provision of a technological user support system which embodies several databases enables the determination of setup data for each component. The components that have been selected for testing are designed for a turning centre, therefore, a single setting is used. All the operations, including both the static and live tool operations, require only one set up, thus increasing the accuracy of features as well as eliminating extra setup time.

16.8 - Operation Planning

The sequence of operations, as well as tool and machining data selection is provided for each component. The operation planning decision module is used to sequence the operations and subsequently plan the steps which are needed to machine the workpieces. In addition the tooling requirement for each component is explicitly defined.

16.9 - The Problems & Feed back

The problems faced at each phase and the possible corrections which alleviate them are described and the necessary steps taken to modify them is presented for each test.

16.10 - The Criteria for Selecting Component (*A*)

As stated briefly in section 16.4, the purpose for selecting component *A* is that it represents certain rotational regions. It is not designed to represent all the regions and features but only to highlight an example from each category. Component *A* illustrates and demonstrates the way the application software is used to model the workpieces. (*see figure 2.0*). A more detailed description of the application software provided in the subsequent sections in order to improve the users understanding of the system.

16.10.1 - Representation of Regions & Features for Component *A*

Table *1* illustrates the regions that are represented in component *A*. According to the scheme or taxonomy depicted in chapter 8, this component consist of three regions. The basic region (*#1*) represents the segment called *turn-front-profile.* The second segment (#2) is a *groove-out* region. The final segment is represented by the *thread-out* region.

Table *2* provides a decomposed view of each region. Region *#1* which is principally concerned with the basic external profile of component *A* consist of eight features and three feature's attributes. The features that shape the profile are represented by the surface features in table *2*. Four straight features as well as one tapered are used to describe the *turn-profile-front*-region. Region #2 is represented by a square groove feature (*this groove is called groove #1 in the application software*). The third region is a thread region which is represented by a metric thread feature.

Table 1: Regions of component (A)

Region No.	Region
Region # 1	Turn-Front-profile
Region # 2	Groove-out

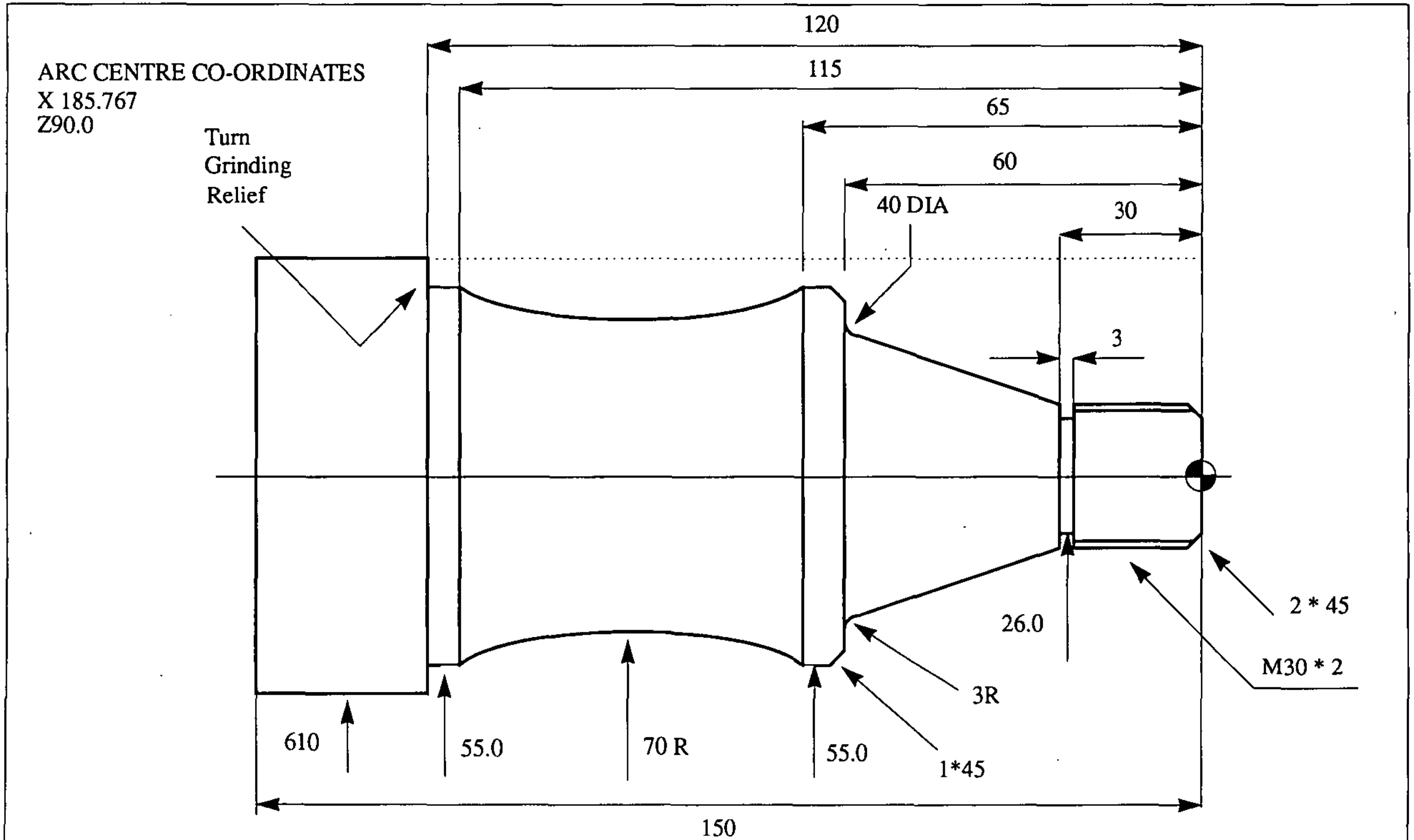


Figure 2 | Component A | LUT - CAD/CAM

Table 1: Regions of component (A)

Region No.	Region
Region #3	Thread-out

Table 2: Features for component (A)

Regions	Associated features	Number of features
Region #1	- Straight/ tapered feature - Concave feature Feature attributes: - Chamfer - Corner	7 1 2 1
Region #2	Square Groove	1
Region #3	Metric Thread	1

16.10.2 - The Setup Data for Component *A*

The set up data for component A is depicted in tables *3* and *4*. The first table includes the program number which is used by the controller to identify the NC output. Any number can be used to represent the program, however a zero value must proceed the number.

The second table (*table 4*) represents the actual edge which has to be faced prior to any operations. At this stage the edge of the billet which needs to be machined is specified by the parameters depicted in table 4. The table includes the associated tool and fee-drate.

Table 3: component setting

Setting parameter	Data
Program No	01111
Material	Aluminium
Max. O.D diameter	75
Max I.D diameter	0

Table 3: component setting

Setting parameter	Data
Max. length	150
Max RPM	300

Table 4: Component setting #2

Billet parameter	Data
STP - X	75
STP - Z	3
FPT - X	0
FPT - Z	0
TOOL	1
FEEDRATE	1.2

16.10.3 - The Technological User Support System

The use of several manufacturing databases is vital for the setup preparation. The provision of a workholding database, as illustrated in table 5, allows the user to interactively select the appropriate clamps that are required for the machining operations. In addition, the database is used to input the relevant tools that are suitable for the rotational component. As depicted in table 6 the parameters within the tool database are devised so as to provide the essential information with regard to the geometrical and technological attributes of the cutting tools. Therefore the user, after selecting the appropriate tool, is interrogated so as to define all the attributes of the cutting tool.

Table 5: Technological User Support system (workholding data)

Workholding parameter	Workholding Data
Number	1
Type	H
Clamp	OUT

Table 5: Technological User Support system (workholding data)

Workholding parameter	Workholding Data
A	55
B	15
C	8
D	10

Table 6: Cutting Tool database

Tool Parameter	Tool data	Tool data	Tool data	Tool data
Tool No.	0100	0200	0300	0400
Operation	Ext. turning	Ext. turning	Ext. groove	Ext. thread
Position	LH	LH	RH	RH
Direction	Forward	Forward	Forward	Forward
Insert radius	0.6 mm	0.6 mm	3 mm	0.6 mm
Cutting angle	91	95	-	55
Included angle	55	35	-	-
Tool shank position	# 2	# 2	# 2	# 2
Shank length	35	35	35	35
Shank width	8	8	8	8

16.10.4 - The Machine Setting for Component *A*

As shown in table *7* three pieces of information are required for machine setting: the output file name, the *Z* offset and the *C* offset. The *Z* offset is used to alter the datum so as to satisfy the geometry of the workpiece. The *C* offset can be used to reflect a different datum value for the *C* axis. The *Z* offset together with the *C* offset are usually set at a default zero and so no value is assigned to them. Table *8* is concerned with specify or selecting the chuck from the workholding database, in other words, referencing the clamp that is most suitable for the workpiece from the workholding database. The gripping diameter of the chuck is also specified. Component A utilizes clamp No *#1* with a gripping diameter of 75 *mm* (*the diameter of the billet*). Table *9* is concerned with tailstock information. The tail stock option is not used for component *A*. However the variables that are listed in table *9* represent whether the tail stock barrier is on or off and it can be further used to specify the tail stock number as well as the effective quil extension.

Table 7: Machining setting

Machining parameter	Data
Filename	Component (A)
Z - Offset	0
C - Offset	0

Table 8: Workholding setting

Clamping parameter	Clamping data
Chuck	1
Clamp No	1
Grip Dia.	75.00

Table 9: Tail stock setting

Taistock parameter	Data
Tail on/off	0
Tailstock	-
Quil-Extension	-

16.10.5 - The Description of Regions & Features for Component *A*

Tables *1* & *2* have specified the regions that are embodied by component *A*. The purpose of this section is to clearly show the geometric and technological templates that are associated with each region. The first region's templates are demonstrated in tables *10* and *11*. Table *10* represents the geometrical and technological template for the *turn-profile front* region. The template's parameters are concerned with the following information:

1- Machine cycle

2- X coordinate of region at cut point

3- Z coordinate of region at cut point

4- Cutting speed for rough machining

5- Feedrate for rough machining

6- Depth of cut for roughing

7- Roughing tool

8- Finishing tool

All the items that are described above are inputted by the user. However, the *auto data icon* (*see chapter 11*) can be used so as to automatically select the appropriate machining data (*i.e. items 4 and 5 & 6*).
The items 7 & 8 can be manually input. Alternatively the *autool icon* (*see chapter 11*) can be activated in order to automatically select the appropriate cutting tool for the *turn-profile-front* region. Cutting tools #1 & #2 were selected for this region.

Table 10: Front profile region (Geometrical & Technological template for component A)

Region parameter	Data
PS	2
CPT - X	75
CPT - Z	0
RV	160 - 180
FV	0.65 - 0.6
Depth of cut for rough	2.4
Tool for rough	0100
Tool for finish	0200

16.10.6 - Description of Features for Profile-Front Region

The purpose of the geometrical & technological template for each features is to interrogate and subsequently extract the appropriate information for each surface element or feature. Table *11* reflects the parameters which best convey the geometrical and technological information. The first *2* parameters represent the feature number and type. The remaining parameters are designed to describe the geometry of each feature. The region *profile-front* represents eight surface features. These features are augmented by feature attributes which consist of chamfer or corner (*i.e. as listed only some of the features have feature attribute*). In addition each feature is described technologically (*i.e. with the appropriate surface finish roughness code*). These codes closely reflect the design and functional specification of *profile-front* region.

Table 11: Surface features for region front-profile (Geometrical & Technological template)

Feature parameter	Data	Data	Data	Data	Data	Data	Data	Data
Feature No.	1	2	3	4	5	6	7	8
Feature type	straight	straight	taper	straight	straight	concav e	straight	straight
X-STP	0.0	30.0	30.0	40.0	55	55	55	55
Z-STP	0.0	0.0	-30.0	-60.0	- 60.0	- 65.0	- 115.0	-120.0
X-FPT	30.0	30.0	40.0	55.0	55.0	55.0	55.0	61.0
Z-FPT	0.0	-30.0	-60.0	-60.0	-65.0	-115.0	-120.0	-120.0
Chamfer	2	-	-	1	-	-	-	-
Corner	-	-	3	-	-	-	-	-
Radius	-	-	-	-	-	70.0	-	-
Centre	-	-	-	-	-	-	-	-
STP-X	-	-	-	-	-	185.76	-	-
STP-Z	-	-	-	-	-	90	-	-
Surface finish	3	3	5	4	4	7	6	2

16.10.7 - The Description of Groove-Out Region

As described in section 16.10.1 the region *groove-out* forms and represents a specific area of component A. Table 12 contains the information that can best describe the *groove-out* region.The region diameter and initial location as well as the appropriate cutting tool are listed.

Table 12: Groove region (geometrical & technological template for component A)

Region parameter	Data
Sequence No.	1
Region Dia.	30.0
Region Z-STP	-27.0
Tool	0300

16.10.8 - The Description of Groove Feature for Groove-Out Region

The groove feature is associated with the region *groove-out.* Table 13 represents the feature template which is designed to acquire the appropriate information concerning the groove. The parameters embedded in the template consist of the groove type (*groove #1 which is a square groove is chosen to represent the component A*), The groove depth as well as the number of grooves on the region (*only one groove for component A is needed*). The pitch / width, feed and speed values which are listed in table 13.

Table 13: Groove feature (geometrical & technological template for component A)

Feature data	Data
Groove type	square groove (#1)
Groove depth	4.0 mm
No. of groove	1
Groove pitch	3mm
Feed	1.5 m/min
Speed	180 RPM

16.10.9 - The Description of the Thread-Out Region

The *thread-out* region for component *A* is defined in table *1*. The aim of this section is to describe the parameters that define the thread region. Table 14 shows the values that are assigned to describe the thread region (*component A*). The parameters that are embedded in the region template embody sufficient data so as to generate the correct information for NC code generation.

Table 14: Groove Thread (geometrical & technological template for component A)

Region parameter	Data
Sequence No.	1
Region Dia.	30.0
Region Z-STP	0.0
Tool	0400

16.10.10 - The Description of the Thread Feature

The thread feature selected for region *thread-out* reflects the engineering drawing specification. A metric thread is therefore used to represent that region. The parameters that are represented in the feature template fully describe the thread. The thread is described by its type, geometry, technological value and NC parameters. Some of the parameters that are depicted in table 15 are complex and time consuming to find or calculate, therefore the *auto data* option within the thread region can be activated to generate this technological data.

Table 15: Thread feature (geometrical & technological template for component A)

Feature parameter	Data
Sequence No	1
Thread type	Metric thread
Z-STP	0
Z-FTP	-27

Table 15: Thread feature (geometrical & technological template for component A)

Feature parameter	Data
Number of passes	Auto
Chamfer Value	2
Thread angle	55
Min cutting depth	Auto
Finish allowance	Auto
Depth of cut for finish pass	Auto
Thread pitch value	Auto

16.10.11 - Operation Planning for Component *A*

Several operations are associated with each region and feature. Component *A* requires several machining operations. These operations are listed below:

1-External turning operation

2-External thread operation

3-External grooving operation

The sequence with which the regions are selected and described is essential. However if regions are selected based on no predetermined sequence then the resulting operations reflect a similar order. The sequence of operations therefore have to be examined to make sure that they meet the operation planning requirements. Two methods can be used to sequence the operations: manual mode and auto mode. The operation planning function *auto sequence* can be used to automatically sequence the operations. For the selection of cutting tools and the technological data the *auto data* and *auto tool* function can be activated to automatically retrieve the appropriate data. As depicted in figure *1* the appropriate operation sequence for component A is selected by using the *auto sequence icon*. The sequence of machining operations for component *A* is listed below:

Step #1- Face the billet

Step #2- Rough turn the outside profile(*front*)

Step #3- Finish turn the outside profile(*front*)

Step #4- Thread the external diameter

Step #5- Groove the O.D profile

16.10.12 - Tool Path for Component *A*

The sequence of machining operations for component A is depicted in figure *3*. Component A has been tested on a MAZATROL T32-2. It is important to note that this program passed the simulation test.

16.11 - The Criteria for Selecting Component *B*

As stated briefly in section 16.4 the purpose for selecting this component is that it represents both the rotational and asymmetric rotational regions. This component represents about 75% of the rotational components. This workpiece is therefore used to demonstrate the ability of the application software to model the different segments (*regions*). The descriptive steps that explicitly define each element are presented in the subsequent sections of this chapter so as to allow the user to understand the concepts presented in the core of this thesis. This component B is shown in figure *4*

16.11.1 - Representation of Regions & Features for Component *B*

Table *16* illustrates the regions that represent component *B*. According to the scheme/taxonomy presented in chapter *8*, regions are classified to assist the user to navigate through the tree representation and select the region that corresponds to a particular portion of the workpiece. Five regions are represented by component B. The first region is *turn-front profile* which is used to define the external profile of component B. The second region represents the *mill-(contour)-face*. The third region represents the groove face (*two vertical grooves are placed on the face of component B*). The fourth region represents three holes on the face of the component. The fifth and final region

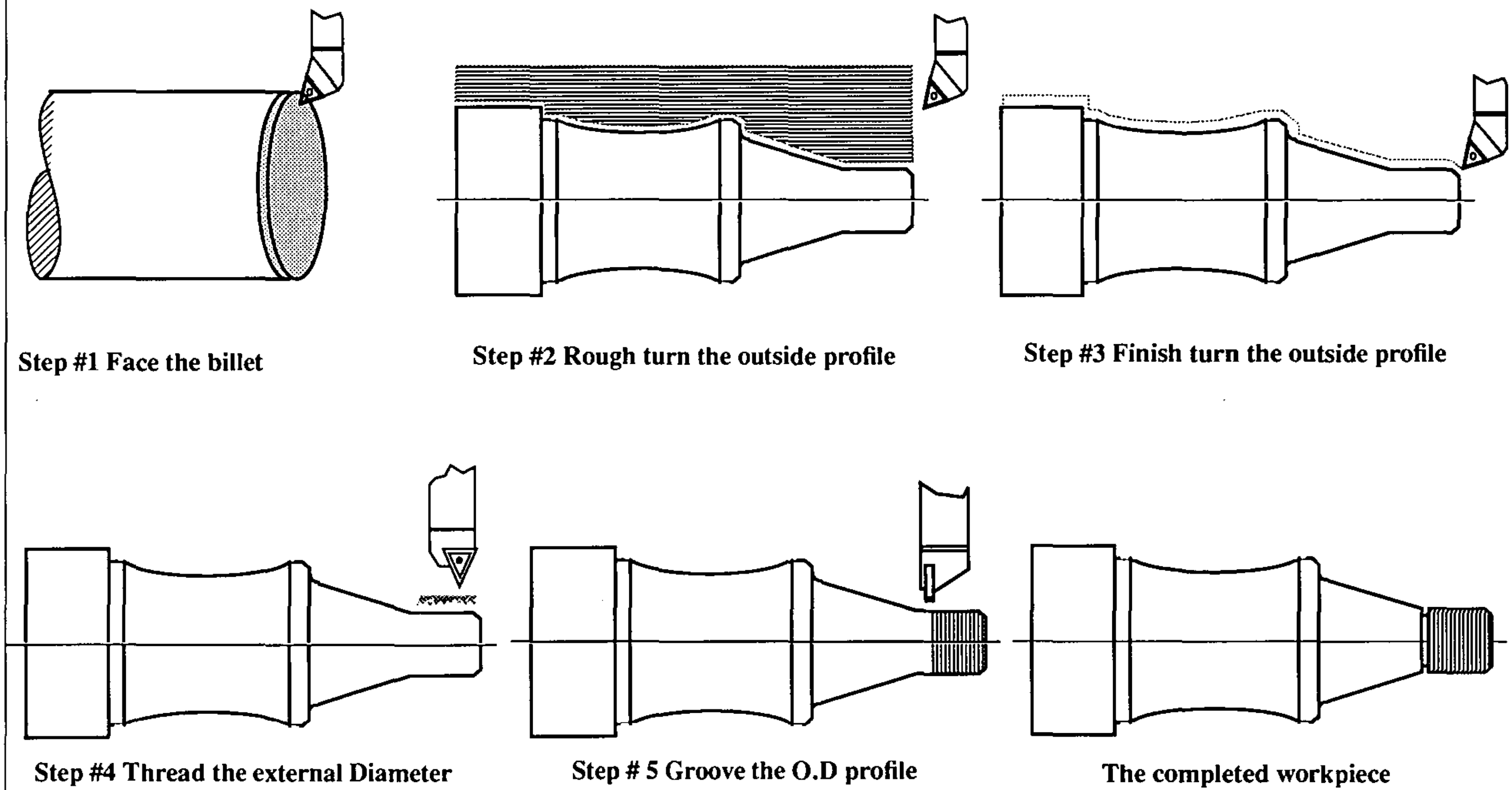


Figure 3	Operation Sequence for Component A	LUT - CAD/CAM

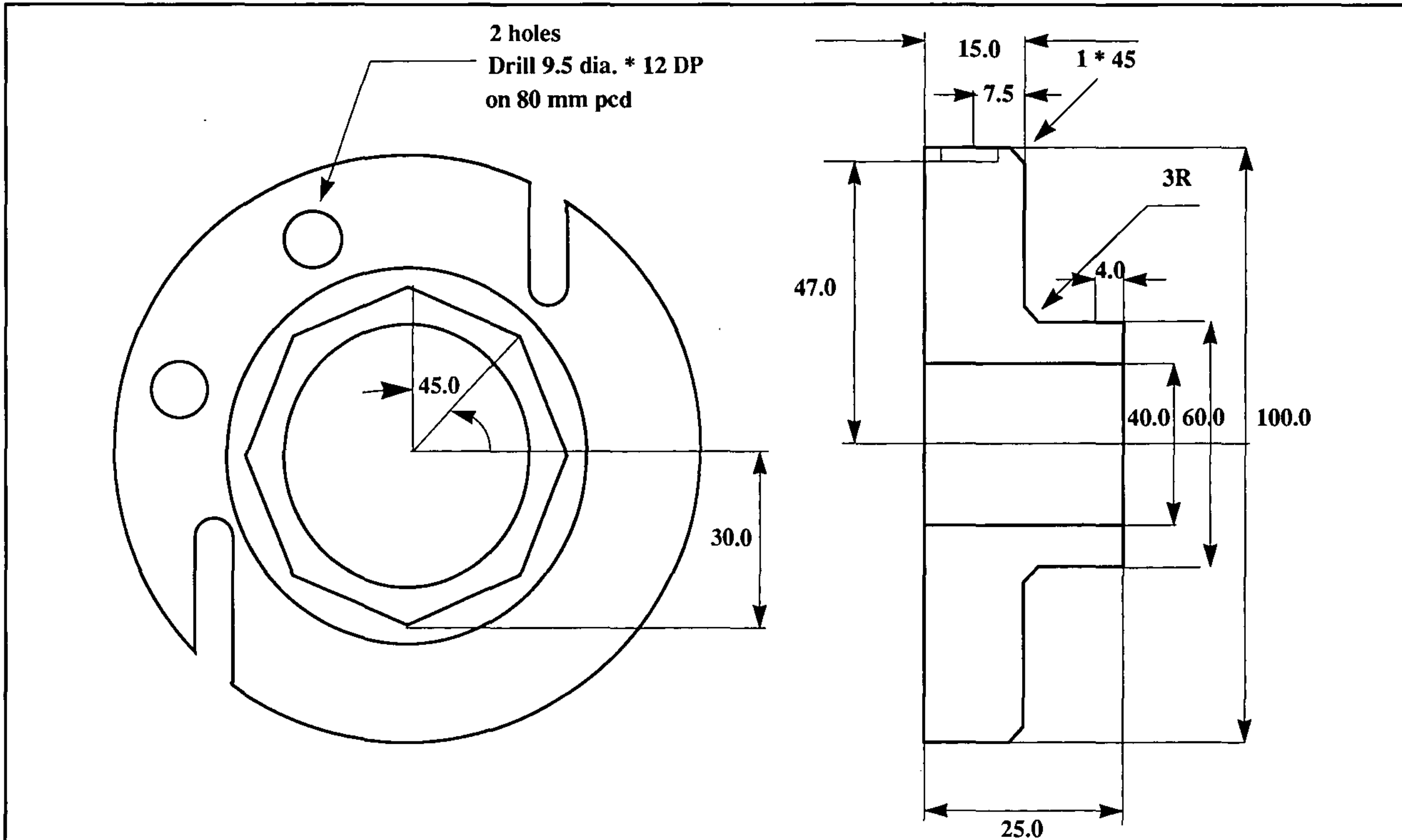


Figure 4	Component B	LUT - CAD/CAM

represents a radial groove on the side of component.The last four regions are asymmetric rotational. Table *16* embodies the features that are associated with each region. Region one consists of four features and two feature attributes (*chamfer &corner*). Region two consists of eight surface features. Region three represents two vertical grooves. Region four represents three holes on the face of the workpiece (*region hole-face*). Table *16* shows the features that form each region.

Table 16: Regions of component (B)

Region No.	Region
Region # 1	Turn-Front-profile
Region # 2	Mill (contour)face
Region #3	Groove-face
Region #4	Hole face
Region #5	Groove-side

Table 17: Features that represent component (B)

Regions	Associated features	Number of features
Region #1	- Straight feature Feature attributes: - Chamfer - Corner	4 1 1
Region #2	Straight(linear)	8
Region #3	Groove feature	2
Region #4	Hole feature	3
Region #5	groove feature	1

16.11.2 - Setup Data for Component *B*

The set up data for component *B* is depicted in table *18* and *19*. The first set up data item is the program number which is used to initialise the NC program. A number starting with zero is required to represent the data for this parameter. However, since a particular machine is used, it is important to specify a similar format to that used by that machine. This table is also used to specify the billet-material, diameter and length. In addition the maximum allowable RPM for the machine is set. Table *19* is chiefly concerned with the geometric parameters of the billet and is subsequently used to define the edge of the billet. This table is also used to include the cutting tool and feedrate for facing the edge.

Table 18: component setting #1

Setting parameter	Data
Program No	0222
Material	Alum/steel
Max. O.D diameter	110
Max I.D diameter	0
Max. length	60
Max RPM	3000

Table 19: Component setting #2

Billet parameter	Data
STP - X	110
STP - Z	3
FPT - X	0
FPT - Z	0
TOOL	1
FEEDRATE	1.2

16.11.3 - The Technological User Support System

The technological user support system consists of several databases that are chiefly used to assist in the preparation of technological data. The provision of a workholding database as illustrated in table *20* is essential. The appropriate clamp for component *B* is interactively input. In addition the cutting tool database is used to input the tools that are appropriate for the operations to machine the asymmetric rotational workpiece (*component B*).

As depicted in table *21* the parameters for the tool database are devised so as to extract the essential information that can best describe the geometrical and technological attributes of the cutting tools. The user is questioned interactively to provide data for each cutting tool.

Table 20: Technological User Support system (workholding data)

Workholding parameter	Workholding Data
Number	1
Type	H
Clamp	OUT
A	55
B	15
C	8
D	10

Table 21: Cutting Tool database

Tool Parameter	Tool data	Tool data	Tool data	Tool data	Tool data	Tool data
Tool No.	0500	0100	0200	0600	1000	0700
Operation	Centre drilling	Ext.turnin g rough-ing	Ext.turnin g finishing	Drilling face	Milling face	mill side
Position	R.H	L.H	L.H	R.H	R.H	R.H

Table 21: Cutting Tool database

Tool Parameter	Tool data	Tool data	Tool data	Tool data	Tool data	Tool data
Direction	Forward	Forward	Forward	Forward	forward	Forward
Insert radius	40 mm dia	0.6 mm	0.6	10 Dia	10 Dia	10 Dia
Cutting angle	-	92	100	-	-	-
Included angle	-	55	35	-	-	-
Tool shank position	# 1	# 2	# 2	# 3	#3	#4
Shank length	35	35	35	35	35	35
Shank width	8	8	8	8	8	8

16.11.4 - The Machine Setting for Component *B*

Table *22* is concerned with the file name for NC output as well the coordinate system. If any offset in *Z* or *C* axis is required, it has to be reflected in this table. For component *B* the default value for coordinate system is used and they are all set at 0 value. Table 23 is used to demons16g device and also reference the clamp number specified in the workholding database and the gripping diameter. Table *24* is chiefly used for the tail stock option, but it must be pointed that no tail stock is required for component *B*.

Table 22: Machining setting

Machining parameter	Data
Filename	Component (*B*)
Z - Offset	0
C - Offset	0

Table 23: Workholding setting

Clamping parameter	Clamping data
Chuck	1
Clamp No	2

Table 23: Workholding setting

Clamping parameter	Clamping data
Grip Dia.	110.00

Table 24: Tail stock setting

Taistock parameter	Data
Tail on/off	0
Tailstock	-
Quil-Extension	-

16.11.5 - Representation of Regions & Features for Component *B*

The regions that represent component *B* are shown in tables *16* and *16*. This section describes each region and feature in detail. The first region as reflected in table *25* describes the external profile of component *B* (*region front profile*). The template parameters that describe the regions are mainly concerned with the following items:

1- Machine cycle
2- X coordinate of region at cut point
3- Z coordinate of region at cut point
4- Cutting speed for rough machining
5- Feedrate for rough machining
6- Depth of cut for roughing
7- Roughing tool
8- Finishing tool

Each parameter is extracted by interactive dialogue. The technological tooling data for the region can however be generated automatically by using the *auto tool*, and or *auto data* icon.

Table 25: Front profile region (Geometrical & Technological template for component B)

Region parameter	Data
PS	2
CPT - X	110
CPT - Z	0
RV	180 - 190
FV	0.35 - 0.6
Depth of cut for rough	2.4/1.7
Tool for rough	0100
Tool for finish	0200

16.11.6 - Description of Surface Features for Region Profile-Front

The purpose of the geometrical & technological template for surface features is to interactively acquire the relevant information for each surface element or feature. Table *26* reflects the parameters which best convey the geometrical and technological information for surface features. The first *2* parameters represent the feature number and type. The remaining parameters are designed to describe the geometry of each feature. The region *profile-front* (*for component B*) is composed of four surface features. The features are also augmented by feature attributes which consist of chamfer and corner for some of the elements or features. In addition the roughness code representing specific surface finish criteria for the *profile-front* region is listed in table 26.

Table 26: Surface features for region front-profile (Geometrical & Technological template)

Feature parameter	Data	Data	Data	Data
Feature No.	1	2	3	4
Feature type	straight	straight	straight	straight
X-STP	0.0	60.0	60.0	100
Z-STP	0.0	0.0	-8.0	-8.0

Table 26: Surface features for region front-profile (Geometrical & Technological template)

Feature parameter	Data	Data	Data	Data
X-FPT	60	60	100	100
Z-FPT	0.0	-8	-8	-25
Chamfer	-	-	1	
Corner	-	3R	-	-
Radius	-	-	-	-
Centre	-	-	-	-
STP-X	-	-	-	-
STP-Z	-	-	-	-
Surface finish	3	4	4	5

16.11.7 - Description of Hole Region (*component B*)

The *face-region* which embodies the feature hole is defined by the parameters listed in table *27*. The regional information is used to guide the tool to the hole position and generate the correct NC toolpath. Table *28* shows the actual parameters that describe the hole feature. The type, the geometric position, and the technological specification are listed and subsequently used to generate the correct tool path. These parameters are described in table *28*.

Table 27: Hole (drill) face region (geometrical & technological template for component B)

Region Parameter	Data
Sequence No	1
Tool Safety Dist.	5
Tool No.	0600
Feedrate	0.4
Speed	110

Table 28: Feature hole for drill face region (geometrical & technological template for component B)

Feature parameter	Data	Data
Feature No.	1	2
Feature Type	Hole-through	Hole through
Operation type	Drilling	Drilling
Hole pattern	Yes	No
Pattern Dia	80.0	-
No. of holes	2	1
Angle of first hole	45	-
Angle between each hole	45	-
Hole depth	-25	-25
Peck value	3	-
Dwell Value	0.5 sec	-

16.11.8 - The Description of Mill (*contour*) Face Region

The contour region parameters, are depicted in table *29*. The data specified for each parameter reflects the geometrical and technological attributes on the engineering drawing. Table *30* contains the surface feature parameters and their corresponding values. These values specify the geometry of each surface feature.

Table 29: Mill region (geometrical & technological template for component B)

Region Parameter	Data
Sequence No	1
Tool Safety Dist.	60.00
Initial tool location	65.0
Tool No.	1000
Feedrate	1600
Speed	75

Table 30: surface Feature For mill (contour) face region (geometrical & technological template for component B)

Feature parameter	Data	Data	Data	Data	Data	Data	Data	Data	Data
Feature No.	1	2	3	4	5	6	7	8	9
Feature Type	linear	linear	linear	linear	linear	linear	linear	linear	linear
Feature STP-X	39	24.04	0	-24.04	-34.0	-24.04	0	24.04	34
Feature STP-Y	0	-24.04	-34	-24.04	0	24.04	34	24.04	0
Feature STP-Z	-4	-4	-4	-4	-4	-4	-4	-4	-4
Feature FTP-X	24.04	0	-24.04	-34.0	-24.04	0	24.04	34	-
Feature FTP-Y	-24.04	-34.0	-24.04	0	24.04	34.0	24.04	0	-
Feature FTP-Z	-4	-4	-4	-4	-4	-4	-4	-4	-4
Radius	-	-	-	-	-	-	-	-	-
Surface Finish	5	5	5	5	5	5	5	5	5

16.11.9 - Description of Groove Face Region

Two grooves are specified in table *32* that form the grooves on the face of component *B*. The geometric description of the groove regions, as well as the groove features, are defined in tables *31* and *32*.

Table 31: Groove face region (geometrical & technological template for component B)

Region Parameter	Data
Sequence No	1
Tool Safety Dist.	60.00
Initial tool location	65.0
Tool No.	1000
Feedrate	1600
Speed	75

Table 32: Groove Feature For Face region (geometrical & technological template for component B)

Feature parameter	Data	Data
Feature No.	1	2
Feature Type	Groove (vertical)	Groove (Vertical)
Feature STP-X	-55.0	55.0
Feature STP-Y	20	-20
Feature STP-Z	-25	-25
Feature FTP-X	-30	30
Feature FTP-Y	20	-20
Feature FTP-Z	-25	-25

16.11.10 - The Description of Groove-Side Region & Feature

Table *33* includes the description of *groove-side* region for component *B*. The groove feature associated with this region is a radial groove which is defined in table *34*. This table describes the feature type and geometry.

Table 33: Groove Side region (geometrical & technological template for component B)

Region Parameter	Data
Sequence No	1
Tool Safety Dist.	100.00
Initial tool location	105.0
Tool No.	0700
Feedrate	1200
Speed	120

Table 34: Groove Feature For Side region (geometrical & technological template for component B)

Feature parameter	Data
Feature No.	1
Feature Type	Groove (radial)
Feature STP-X	47.00
Feature STP-Y	0
Feature STP-Z	-16
Feature FTP-X	47
Feature FTP-Y	45
Feature FTP-Z	-16

16.11.11 - Operation Planning for Component *B*

The operations that are associated with each region are automatically generated when the appropriate regions are selected and defined. The major operations for component *B* are listed below:

-External turning operation

-Milling operation

-Drilling operation

-Mill grooving operation

The regions can be selected in any sequence. The operation planner can automatically sequenced the operations by using decision models. The tool data, as well as technological data, can be automatically generated by using the operation planning facility which has been provided for each region (use *auto sequence*, *auto data*, *auto tool*).
The operation sequence generated for component B is depicted in figure 5 and cited overleaf:

Step #1- face the billet

Step #2- rough turn the outside profile (front)

Step #3- finish turn the outside profile (front)

Step #4- drill face

Step #5- mill the face

Step #6- Mill groove the face

Step #7- mill groove the side

16.11.12 - Tool Path for Component *B*

The component program was tested and simulated on a MAZATROL T32-2 controller. The plot of tool path for the component is provided in the appendix V.

16.12 - Problems During Experiment

The number of case study experiments that were performed had to be limited. The reason was that the author was allowed to visit MAZAK for the simulation of only two workpieces. These two workpieces are named as part *A* and *B* in this chapter. The NC output for component A was basically correct, however, some parameter for threads had to be modified to allow the simulator to recognize the sub-programs. Component B highlighted one error. The cause of the error was based on an assumption made during the cutting tool selection. Because the inside diameter of the workpiece had to be drilled by a U drill (*40mm dia*) it was assumed that the U drill was a live tool. This was incorrect. Even though the simulation of tool path did not detect the error, during the dry run testing of the program on the machine, both the tool and component were not rotating and hence there was no cutting action but collision. The author experienced a lot of incompatibility between the *EIA/ISO* simulation and the actual machining operations. For example, the simulator verified that a hexagonal shape was being milled on the face of the workpiece, but the machine moved in a circular motion instead of point

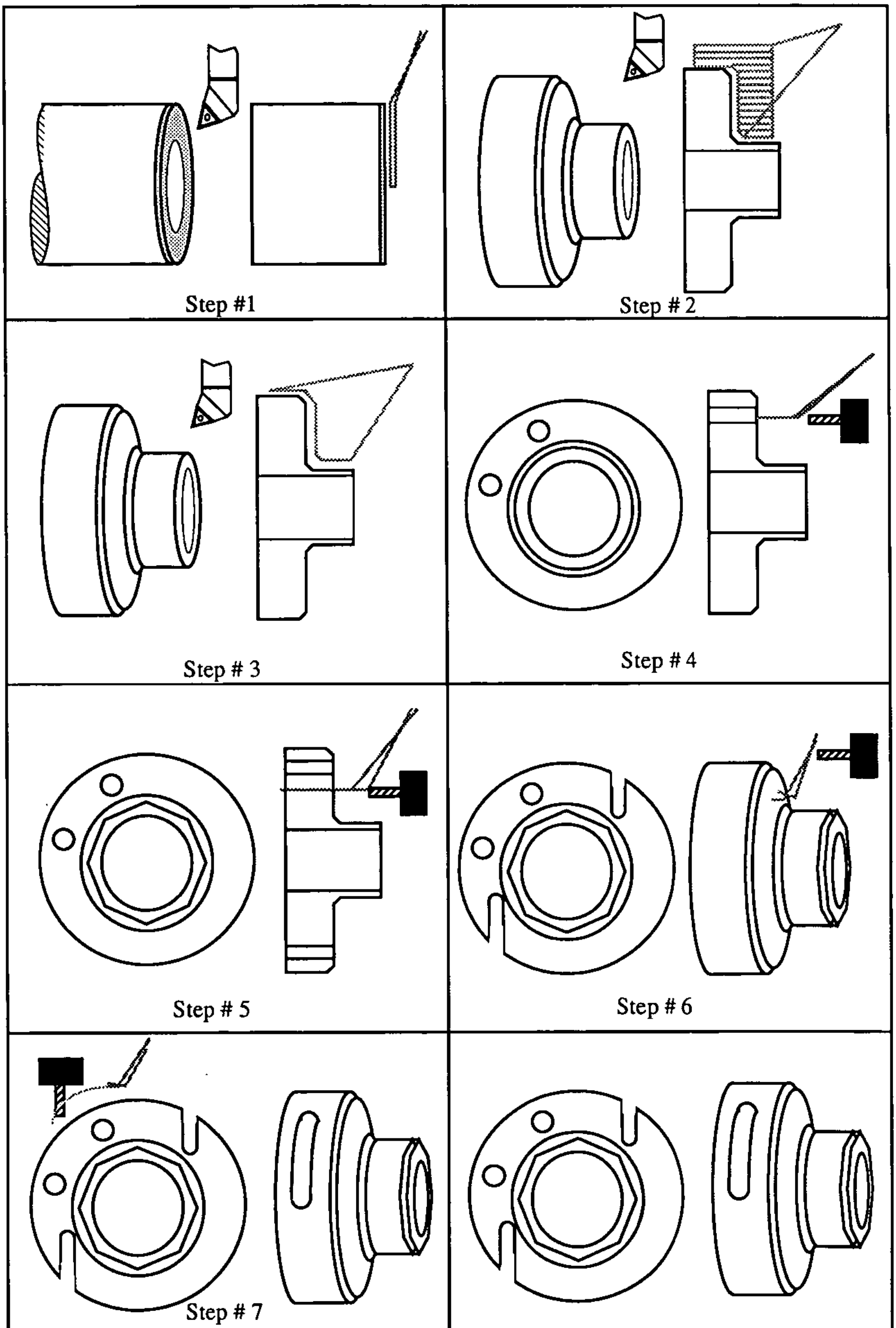


figure 5 | The sequence of operations for component B | LUT CAD/CAM to point movement. As stated in the beginning of this chapter because of special circumstances and constraints that were faced by the author, it was not conceivable to machine the workpieces (*part A & B*) during the limited time available.

16.13 - A Critical Assessment of the Evidence Provided by the Case Studies

The user selects the appropriate regions for component A & B (*see sections 9.15 and 16.11.15*). When describing component A, the surface features for region #1 (*see table #1*) were described from right to left by selecting eight surface features, as listed in table 2. The part description approach which is used is most suitable for shop-floor part programming. It is necessary to minimise the amount of interaction with the user for feature description. However, other form features on component A such as groove and thread require less input. Similarly for component B, as stated in table 16 and 17, the number of interactions with the user must be limited. The length of the description process poses more of a problem for regions 1 & 2 (*see table 16*). However, regions 3, 4 and 5 are far less time consuming to define than turn and mill regions (*i.e. region 1 & 2*).

The effectiveness of the feature and region scheme for the description of workpieces may require further investigation. For instance, for component A, as stated in table 1. The name *turn front profile* is concerned with a surface feature (*see table 2 region #1, concave feature*) which can also be defined as a recess. The question as when a recess is considered a recess, and when can it be as part of *turn front profile* is raised. The current approach is sufficient for the description of the turn regions. For the final refinement, there needs to be more options provided so as to distinguish between the regions which include recess and those that do not.

As stated in sections 16.10.1 to 16.10.6 and 16.11.5 to 16.11.10 the use of predefined regions coupled with the use of form and surface features, can efficiently describe the test piece components. The objective of designing regions and features has been to capture the parameters which best describe each region. This is illustrated in regions 1,2 and 3 of component A (*see 16.10.1*). For component B, as stated in section 16.11.1, the five regions each are associated with the necessary parameters to fully describe workpiece B. However, the number of parameters can be extended (*e.g tolerances, etc.*) so as to shed further light on the shape and the behaviour of each region and feature for process planning purposes.

Part planning within the MDI environment has enhanced shop-floor part programming significantly. The operation planning decisions for each component are cited (*see 16.10.11 for component A and sections16.11.11 for component B*). The type of decisions made are based on the decision model devised to sequence the operations. The manual alteration of operation sequences can also be accommodated in this system. The frame of reference devised can be used to accommodate different decision making techniques for sequencing the operations (*e.g. decision tree, decision table*). However, the decision model used may require further testing so as to ensure the validity of all the logic for operation sequencing.

Operations are defined for component A and B which may be described differently. For instance, the qualifying operation (*i.e facing the billet*) can be replaced by an extra surface feature defining the face of the billet (*see step #1 at 16.10.11 & step #1 section 16.11.11*). The criteria would be the region of cut which has to be faced. For deciding the best option, the cycle time measured at the machine tool for both options have to be compared and obviously the option with less cycle time is more desirable. Whilst the MDI systems are effective and can be used for making these decisions; it must be noted that these type of decisions are better captured within a process planning system than a part programming system. The depth of cut for both components A & B (*see table 10 & table 25*) is decided by the user. Several facilities are provided which can acts as models in order to assist the decision making process. The multipass sequences for the roughing and finishing of both components were shown on the simulator to be effective. However, for roughing component A, the number of roughing cuts could have been reduced. That would require a better understanding of the tool inserts which were used at Mazak and of the machine horse power (*i.e this information was not provided*). The forming operations (*i.e. grooving, threading*) were effective and posed no problems. For component B, the face grooves require a better understanding of depth of cut, and number of cuts, based on the capability of the driven tool. The driven tool might not be capable of performing the face grooving operation in one pass and therefore the limited power of the driven tool may act as constraint.

The technological user support system has been invaluable in assisting the decisions made related to tooling and machining data selection. However, there may be a further need for more explicit information on machine tools. The multipass issues are effectively dealt with for component A & B. The test evidence as supported in sections 16.10.11 and 16.11.11 is encouraging. For component A the MDI planner was used and the decision model was applied to sequence the operations. The qualifying operation which is described in section 16.10.2, is the first operation prior to any major machining operations on the workpiece. The workpiece is then roughed with a multipass cut and a finish margin is left for the finishing operation (*see steps 2&3 16.10.11*). The two final operations (*i.e threading & grooving*) can be sequenced in two ways. The first approach is to thread the outside diameter of the workpiece prior to grooving. The second method is to groove the outside diameter prior to threading. Each approach has an advantage and a disadvantage. If the former approach is used, the advantage would be that the workpiece may be protected from damage (*i.e. bending. etc.*) due to the extra pressure exerted by the threading tool on the workpiece. The disadvantage is that by grooving later a deburring operation may be required as a final operation. If the latter approach is used then the advantage is that the threads at the edge of the groove do not require a deburring operation. However, the potential for damaging the workpiece exists. It must be noted that the disadvantage in using method one is only valid when dealing with exceptionally small diameter workpieces which have relatively long length. As it is stated in 16.10.11 the first approach is used by the decision model i.e. the workpiece is threaded before the grooving operation is performed. For component

B the first operation is a qualifying operation (*i.e. facing the billet*). The workpiece is then machined with multiple passes (*i.e rough turning operation*) and a finishing (*i.e finish turning operation*) operation. The next operation is to drill the second face of the workpiece (*see figure 4*). This is followed by an operation that is concerned with milling the hexagonal. Step 6 (*see 16.11.11*) involves machining the two grooves on the second face of the workpiece. The last operation would be to mill a vertical key-way on the outside diameter of the workpiece. The sequence of operations for component B is according to the logical steps used for generating the shape. The first step is to set the datum by facing the billet, then the second step is to machine the actual rotational profile of the workpiece. The second face is then drilled and the two grooves on that faced are machined before mill grooving the keyway on the side of the workpiece. Many possible and viable sequences of operations may exist for machining the workpiece. For instance, in some cases it would be more appropriate to perform the drilling operation after milling the asymmetric rotational workpiece in order to minimise the material removed by the drilling process. For automatic sequencing of the operations a sequencing model is devised which is based on common and accepted strategies for machining asymmetric rotational workpieces. Because different alternatives for sequencing the operations (*i.e differing from the decision model*) may be plausible, manual sequencing of operations by MDI is provided so as to assist the user in generating the sequence of operations most suitable for their need.

Chapter 17

Conclusions & Recommendations for Future Work

17.1 - Introduction

The research presented in this thesis is intended to explore and design a feature based work shop oriented NC planning system. Experimental application software has been designed to test and implement the ideas and concepts that have been put forward in this thesis. The design of the experimental system, coupled with the experiments which are performed, have enabled the author to present the conclusions that were reached in this work. In addition further recommendations and scope for further work are made available in this chapter.

17.2 - Conclusions

It has been shown that the importance of the techniques and conventions which are addressed in this thesis stems from the recognition that an effective way to improve and enhance part description is to capture the intent of the engineering drawing by devising a medium in which the recurring patterns of an asymmetric rotational component can be modelled for machining.

It has been demonstrated that the use of predefined regions and features can significantly enhance the task of part description and planning, and provide a systematic way to navigate the user and consequently assist in the generation of part programs on the shop-floor.

The use of a highly structured description scheme for predefined regions, coupled with the associated features, significantly improves part programming procedures and consequently captures the intent of the programmer. The descriptive tools are used in order to capture the information related to the engineering drawing specification.

The novel methodology which is devised for part description and planning has provided the opportunity to demonstrate the role of operation sequencing in the MDI systems. The provision of automatic operation sequencing significantly enhances the capabilities of the MDI system which therefore results in efficiently generated manufacturing code.

It has been shown how a feature based workshop oriented approach method for part description can be used as a cohesive and consistent frame of reference (*i.e region/feature scheme*) by which the multi-pass machining task can be addressed. The multipass method for operation planning has been fully implemented but more test is required for the final endorsement.

The provision of a parametrised part family database demonstrates that this approach, coupled with the workshop approach for shop-floor part programming, can significantly enhance the NC planning task and subsequently increases the productivity of manufacturing functions and significantly reduces the programming man power.

It has been demonstrated that the technological user support system for shop-floor programming can function as a manufacturing model which provides information on NC turning process conditions and therefore is an integrated support environment with which the technological information can be stored and retrieved by the system and/or the user so as to assist in the part description and planning activity.

It has been shown clearly that an integrated work shop oriented NC planning system can generate manufacturing code by using the concept of regions. This has been demonstrated in the experimental application software but due to lack of facility only a few components were tested

Experimental application software is realized which demonstrates the design of the work shop oriented turning system for asymmetric rotational components.

17.3 - Recommendations for Further Work

The author has developed a novel and unique frame of reference (*i.e. the classification of regions and features*) for asymmetrical rotational components which has been primarily used for part description and planning so as to generate NC program. It can be also used for process planning, and inspection purposes.

The frame of reference developed and implemented as the core of this thesis can be used for the classification and coding of asymmetrical rotational components. The concept of a parametrised part family which was devised for the NC planning system can therefore be extended by using the frame of reference developed for this work.

The frame of reference (*i.e the classification of features and regions*) provided can be efficiently used for the purpose of designing a process planning system using either a generative or variant approach.

The concept of tool models, within the context of the frame of reference developed, can be extended so as to perform an automatic selection of cutting tools for every region and feature in order to optimise the machining process. The geometrical and technological parameters can function as the basis for optimizing the cutting tool selection.

The concept of features can be greatly enhanced by using a solid modeller. The use of solid modeller to represent regions could simplify the process of description and enable the conveyance of accurate information for each feature. The application of the solid model on the shop-floor is contingent upon it's simplification.

For the NC planning system to have the necessary impact more test are required so as to asses the system's output.

Appendix I

Regions & Features Data Dictionary

The data listed is indispensable for geometric and operation planning description and decision support. The information regarding each region is specified. Each region represents the following information:

i- Region ID
ii-Geometric data
iii-Feature data
iv-Technological data
v-Tooling data
vi-NC parameters

Region ID

Regions ID is used for internal identification and manipulation of information.

Geometric data

The geometric data of a region is concerned with the outer boundary of the region and is utilized by the NC module to calculate the rapid and safety distances. In some cases (e.g. turn region) this information is used to remove the excess material from a region.

Feature data

Each region represents a particular feature, therefore this information is used to describe the geometry of feature. Each feature is represented by different data.

Technological information

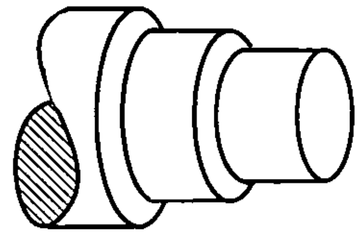
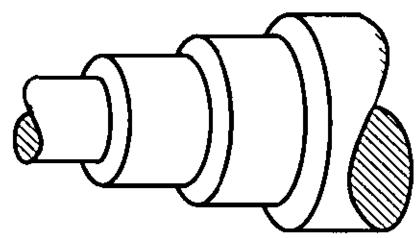
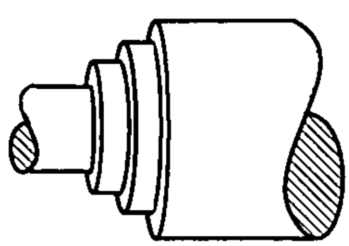
The technological information is concerned with the data that is used by the NC module so as to generate the final NC output.

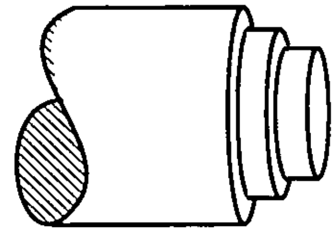
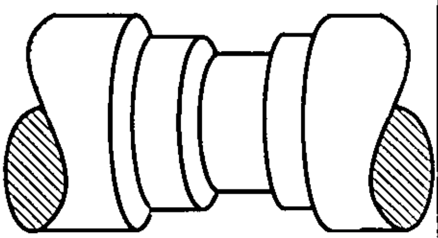
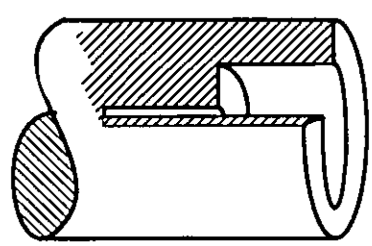
Tooling data

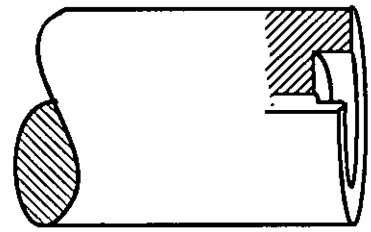
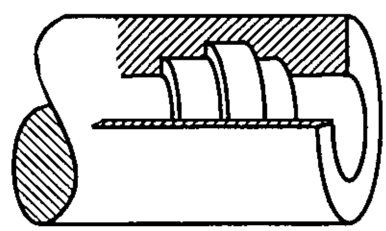
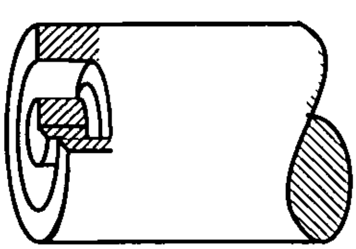
Each region embodies tooling information either directly or indirectly. This information is vital to operation planning and the NC code generation activity.

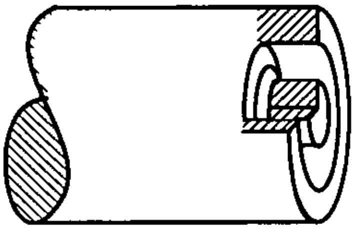
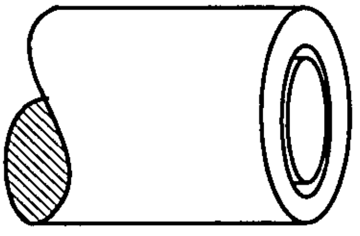
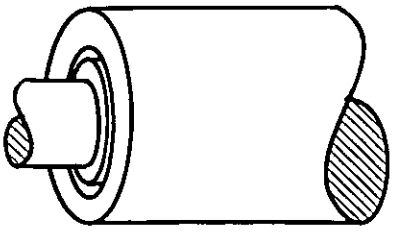
NC parameters

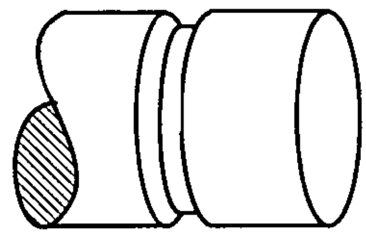
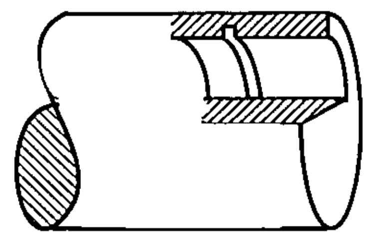
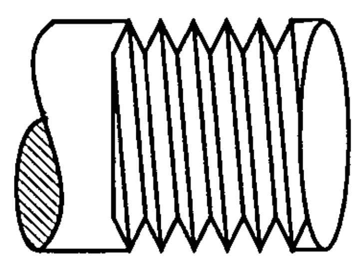
These parameters are instrumental in deciding the NC attributes for each region.

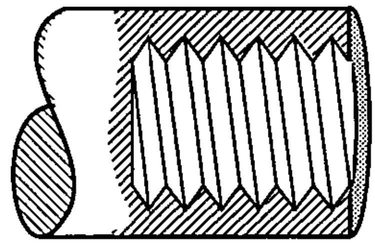
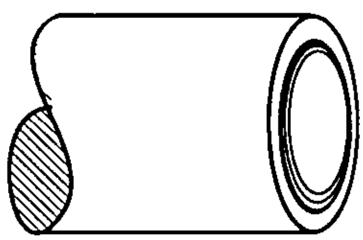
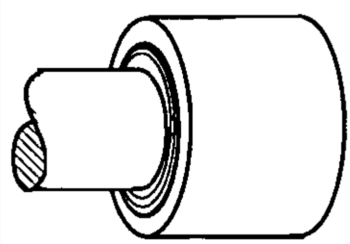
Region	Rules for Identification &Description	Symbolic Representation
Profile-front	***General Description:*** *- This region is defined from 0 datum to the left* *- The length of this region is greater than it's depth (L>D)* ***Description Rules:*** *- The depicted figure is symbolic and represent the region. This region is used to describe shaft & bar.* *- This region is defined by surface features.* *- Surface features include: straight, tapper, concave, convex.* *- The surface features are described from right to left.* *- The surface feature direction must be in negative Z and positive X direction.* *- Up to 25 surface features can be used to describe this region.* *- The tool path which is assigned for this region is parallel with the Z axis.*	
Profile-back	***General Description:*** *- This region is defined from - X datum to the right* *- The length of this region is greater than it's depth (L>D). This region is used mostly for shaft.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by surface features.* *- Surface features include: straight, tapper, concave, convex.* *- The surface features are described from left to right.* *- The surface feature direction must be in positive Z and positive X direction.* *- Up to 25 surface features can be used to describe this region.* *- The tool path which is assigned for this region is parallel with the Z axis.* *- This region is used for double chuck, single setting machining.*	
Face-back	***General Description:*** *- This region is defined from - X datum to the right* *- The length of this region is less than it's depth (L<D). This region is used mostly for shaft.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by surface features.* *- Surface features include: straight, tapper, concave, convex.* *- The surface features are described from left to right.* *- The surface feature direction must be in positive Z and positive X direction.* *- Up to 25 surface features can be used to describe this region.* *- The tool path which is assigned for this region is parallel with the X axis.* *- This region is used for double chuck, single setting machining.*	

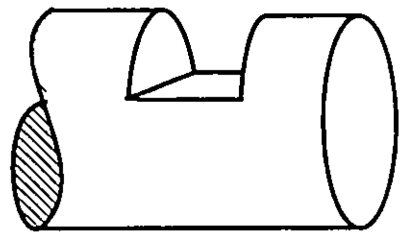
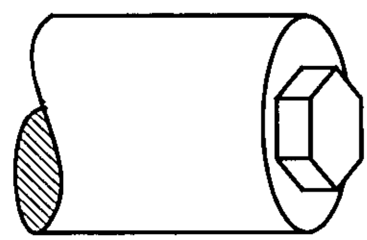
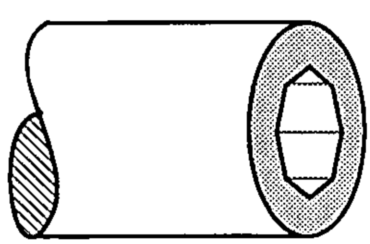
Region	Rules for Identification &Description	Symbolic Representation
Face-front	***General Description:*** *- This region is defined from 0 datum to the left* *- The length of this region is less than it's depth (L<D). This region is used for shaft & Bar.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by surface features.* *- Surface features include: straight, tapper, concave, convex.* *- The surface features are described from right to left.* *- The surface feature direction must be in negative Z and positive X direction.* *- Up to 25 surface features can be used to describe this region.* *- The tool path which is assigned for this region is parallel with the X axis.*	
Recess-out	***General Description:*** *- This region is defined from -X datum to the left* *- The length of this region is greater than it's depth (L>D). This region is either dependent (superimposed on another region) or independent.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by surface features.* *- Surface features include: straight, tapper, concave, convex.* *- The surface features are described from right to left.* *- The surface feature direction must be in negative Z direction.* *- Up to 25 surface features can be used to describe this region.* *- The tool path which is assigned for this region is parallel with the Z axis.*	
Profile-in	***General Description:*** *- This region is defined from 0 datum to the left* *- The length of this region is greater than it's depth (L>D). This region is used for Bar.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by surface features.* *- Surface features include: straight, tapper, concave, convex.* *- The surface features are described from right to left.* *- The surface feature direction must be in negative Z and negative X direction.* *- Up to 25 surface features can be used to describe this region.* *- The tool path which is assigned for this region is parallel with the Z axis.*	

Region	Rules for Identification &Description	Symbolic Representation
Face-in	***General Description:*** *- This region is defined from 0 datum to the left* *- The length of this region is less than it's depth (L<D). This region is used for Bar.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by surface features.* *- Surface features include: straight, tapper, concave, convex.* *- The surface features are described from right to left.* *- The surface feature direction must be in negative Z and negative X direction.* *- Up to 25 surface features can be used to describe this region.* *- The tool path which is assigned for this region is parallel with the X axis.*	
Recess-in	***General Description:*** *- This region is defined from -X datum to the left* *- The length of this region is greater than it's depth (L>D). This region is either dependent (superimposed on another region) or independent.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by surface features.* *- Surface features include: straight, tapper, concave, convex.* *- The surface features are described from right to left.* *- The surface feature direction must be in negative Z direction.* *- Up to 25 surface features can be used to describe this region.* *- The tool path which is assigned for this region is parallel with the Z axis.*	
Recess-face-back	***General Description:*** *- This region is defined from -X datum to the left* *- The length of this region is greater than it's depth (L>D). This region is either dependent (superimposed on another region) or independent.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by surface features.* *- Surface features include: straight, tapper, concave, convex.* *- The surface features are described from right to left.* *- The surface feature direction must be in positive Z and positive X direction.* *- Up to 25 surface features can be used to describe this region.* *- The tool path which is assigned for this region is parallel with the X axis.*	

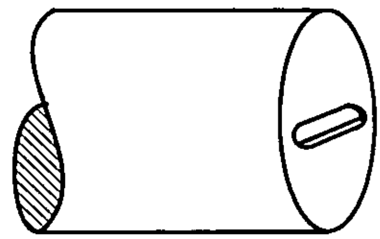
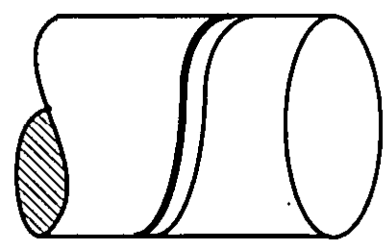
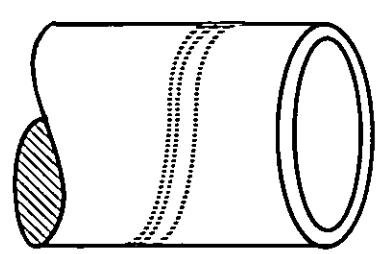
Region	Rules for Identification &Description	Symbolic Representation
Recess-face-front	***General Description:*** *- This region is defined from -Z datum to the left* *- The length of this region is greater than it's depth (L>D). This region is either dependent (superimposed on another region) or independent.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by surface features.* *- Surface features include: straight, tapper, concave, convex.* *- The surface features are described from the lower to upper section.* *- The surface feature direction must be in positive Z and positive X direction.* *- Up to 25 surface features can be used to describe this region.* *- The tool path which is assigned for this region is parallel with the X axis.*	
Groove-face-front	***General Description:*** *- This region is defined from -Z datum to the left* *- This region is located on the face of the workpiece which may be assigned anywhere along the Z axis (the groove may be positioned on multiple faces.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by groove features.* *- Groove features include: Round, square, V, trapezoid, etc.* *- The groove features are described from right to left.* *- The groove feature direction must be in negative Z direction or negative X direction.* *- More than one groove feature can be used to describe this region.* *- The tool path must be parallel with the Z-axis.*	
Groove-face-back	***General Description:*** *- This region is defined from X datum to the right.* *- This region is located on the face of the workpiece which may be assigned anywhere along the Z axis The groove can be used for shaft. For bar a multiplex is required to produce the feature in single setting* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by groove features.* *- Groove features include: Round, square, V, trapezoid, etc.* *- The groove features are described from right to left.* *- The groove feature direction must be in positive X direction and positive Z direction.* *- More than one groove feature General Description can be used to describe this region.*	

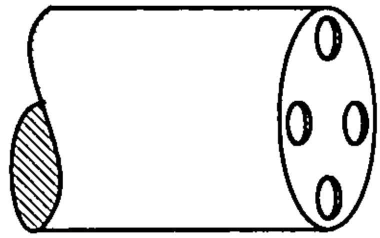
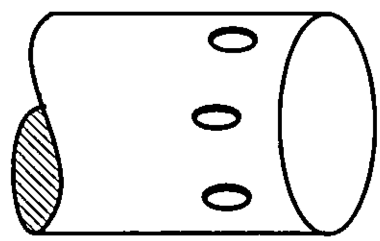
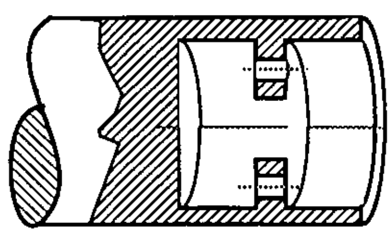
Region	Rules for Identification &Description	Symbolic Representation
Groove-out	***General Description:*** *- This region is defined from Z,X datum to the left.* *- This region is located on the face of the workpiece which may be assigned anywhere along the Z axis The groove can be used for shaft. For bar a multiplex is required to produce the feature in single setting* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by groove features.* *- Groove features include: Round, square, V, trapezoid, etc.* *- The groove features are described from right to left.* *- The groove feature direction must be in negative X and negative Z direction.* *- More than one groove feature General can be used to describe this region.* *- The tool path must be parallel with the X axis.*	
Groove-in	***General Description:*** *- This region is defined from X datum to the right.* *- This region is located on the face of the workpiece which may be assigned anywhere along the Z axis The groove can be used for shaft. For bar a multiplex is required to produce the feature in single setting* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by groove features.* *- Groove features include: Round, square, V, trapezoid, etc.* *- The groove feature is described by it's parameter* *- The groove feature direction must be in positive X direction and positive Z direction.* *- More than one groove feature can be used to describe this region.* *- The tool path must be parallel with the X axis.*	
Thread-out	***General Description:*** *- This region is defined from 0 datum to the left* *- This region is either dependent (superimposed on another region) or independent.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by thread feature.* *- Thread features include: ACME, ISO, UNF, etc.* *- The surface features are described from right to left.* *- The thread feature direction must be in negative Z direction.* *- More than one thread feature can be used to describe this region.* *- The tool path which is assigned for this region is parallel with the Z axis.*	

Region	Rules for Identification & Description	Symbolic Representation
Thread-in	***General Description:*** *- This region is defined from 0 datum to the left* *- This region is either dependent (superimposed on another region) or independent.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by thread feature.* *- Thread features include: ACME, ISO, UNF, etc.* *- The thread feature is described by it's parameters* *- The thread feature direction must be in negative Z direction.* *- More than one thread region can be used to describe the workpiece.* *- The tool path which is assigned for this region is parallel with the Z axis.*	
Thread-face-front	***General Description:*** *- This region is defined from the Z datum.* *- This region is either dependent (superimposed on another region) or independent.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by thread feature.* *- Thread features include: ACME, ISO, UNF, etc.* *- The thread feature is described by it's parameters* *- The thread feature direction must be in negative Z direction.* *- More than one thread region can be used to describe the workpiece.* *- The tool path which is assigned for this region is parallel with the X axis.*	
Thread-face-back	***General Description:*** *- This region is defined from the Z datum.* *- This region is either dependent (superimposed on another region) or independent.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by thread feature.* *- Thread features include: ACME, ISO, UNF, etc.* *- The thread feature is described by it's parameters* *- The thread feature direction must be in negative Z direction.* *- More than one thread region can be used to describe the workpiece.* *- The tool path which is assigned for this region is parallel with the X axis.*	

Region	Rules for Identification & Description	Symbolic Representation
Mill-side	***General Description:*** *- This region is defined from Z datum to the left* *- This region is either dependent (superimposed on another region) or independent.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by surface features.* *- Surface features include: straight, tapper, concave, convex.* *- The surface features are described from right to left.* *- The surface feature direction in a clockwise direction.* *- Up to 25 surface features can be used to describe this region.* *- The tool path which is assigned for this region is parallel with the Z axis.*	
Mill-face	***General Description:*** *- This region is defined from Z datum to the left* *- This region is either dependent (superimposed on another region) or independent.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by surface features.* *- Surface features include: straight, tapper, concave, convex.* *- The surface features are described in a clockwise direction.* *- The surface feature direction must be in positive Z and positive X direction.* *- Up to 25 surface features can be used to describe this region.*	
Mill-face-in	***General Description:*** *- This region is defined from Z datum to the left* *- This region is either dependent (superimposed on another region) or independent.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by surface features.* *- Surface features include: straight, tapper, concave, convex.* *- The surface features are described in a clockwise direction.* *- The surface feature direction must be in negative Z direction.* *- Up to 25 surface features can be used to describe this region.*	

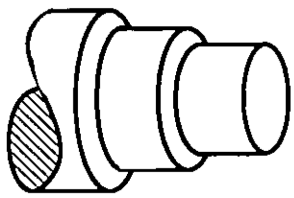
APPENDIX I

Region	Rules for Identification &Description	Symbolic Representation
M-groove-face	***General Description:*** *- This region is defined from Z datum to the left.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by millgroove features.* *- Millgroove features include: Helical, spiral, straight or others.* *- The mill groove feature is described by it's parameters.* *- The groove feature direction is in a clock wise direction.* *- More than one mill groove feature can be used to describe this region.* *- The tool path which is assigned for this region is point to point.*	
M-groove-side	***General Description:*** *- This region is defined from Z datum to the left.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by millgroove features.* *- Millgroove features include: Helical, spiral, straight or others.* *- The mill groove feature is described by it's parameters.* *- The groove feature direction is in a clock wise direction.* *- More than one mill groove feature can be used to describe this region.* *- The tool path which is assigned for this region is point to point.*	
M-groove-in-side	***General Description:*** *- This region is defined from Z datum to the left.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by millgroove features.* *- Millgroove features include: Helical, spiral, straight or others.* *- The mill groove feature is described by it's parameters.* *- The groove feature direction is in a clock wise direction.* *- More than one mill groove feature can be used to describe this region.* *- The tool path which is assigned for this region is point to point.*	

Region	Rules for Identification & Description	Symbolic Representation
Drill-Face	***General Description:*** *- This region is defined from Z datum to the left.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by hole features.* *- Hole features include: single, multiple.* *- The hole features is described in a clock wise direction.* *- More than one hole feature can be used to describe this region.* *- The tool path which is assigned is point to point.*	
Drill-Side	***General Description:*** *- This region is defined from Z datum to the left.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by hole features.* *- Hole features include: single, multiple.* *- The hole features is described in a clock wise direction.* *- More than one hole feature can be used to describe this region.* *- The tool path which is assigned is point to point.*	
Drill-face-in	***General Description:*** *- This region is defined from Z datum to the left.* ***Description Rules:*** *- The depicted figure is symbolic and represent the region.* *- This region is defined by hole features.* *- Hole features include: single, multiple.* *- The hole features are described in a clock wise direction.* *- More than one hole feature can be used to describe this region.* *- The tool path which is assigned is point to point .*	

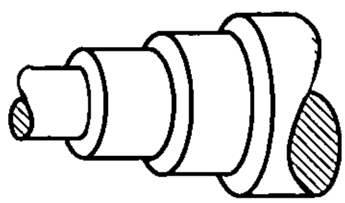
Region

Parameters



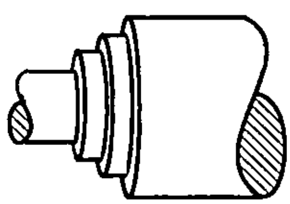
Region: profile-front

ID: T.P.F
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:



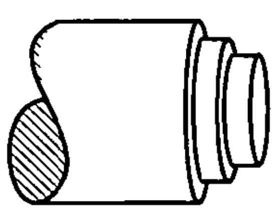
Region: profile-back

ID: T.P.B
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:



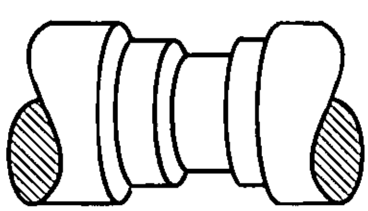
Region: face-back

ID: T.F.B
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:



Region: face-front

ID: T.F.F
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:

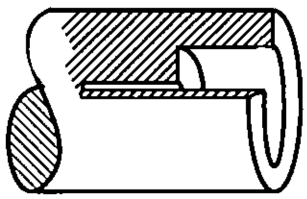


Region:recess-out

ID: T.R.O
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:

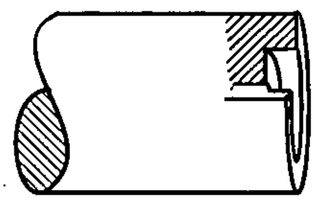
Figure 1	External Turn regions	L.U.T CAD/CAM

Region | **Parameters**



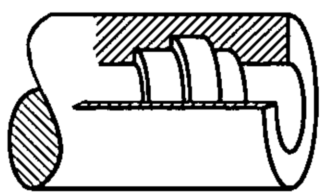
Region: profile-in

ID: T.P.I
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:



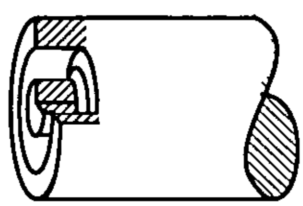
Region: face-in

ID: T.F.I
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:



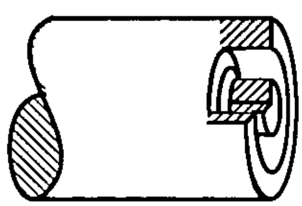
Region: recess-in

ID: T.R.I
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:



Region: recess-face-back

ID: T.R.F.B
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:

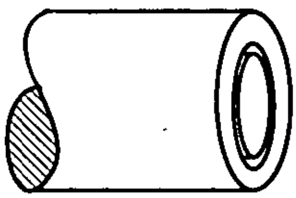


Region:recess-face-front

ID: T.R.F.F
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:

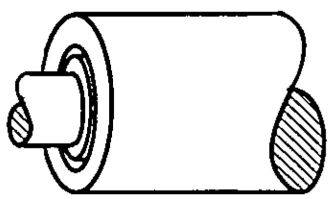
Figure 2	Turn regions	L.U.T CAD/CAM

Region | **Parameters**



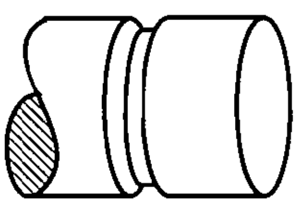
Region:face-front

ID: G.R.F.F
Geometrical data:
STP Lgth (Z)
STP Dia. (X)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:



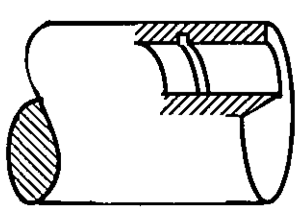
Region:face-back

ID: G.R.F.B
Geometrical data:
STP Lgth (Z)
STP Dia. (X)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:



Region:out

ID: G.R.O
Geometrical data:
STP Lgth (Z)
STP Dia. (X)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:

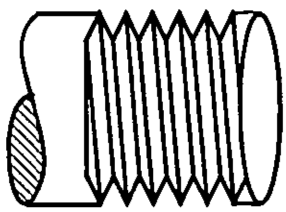


Region:in

ID: G.R.I
Geometrical data:
STP Lgth (Z)
STP Dia. (X)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:

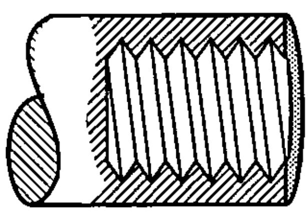
Figure 3	Groove regions	L.U.T. CAD/CAM

Region | **Parameters**



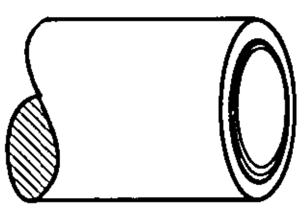
Region:out

ID: T.R.O
Geometrical data:
STP Lgth (Z)
STP Dia. (X)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:



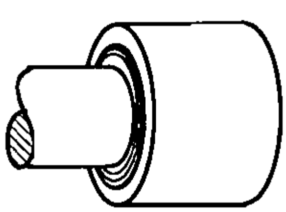
Region:in

ID: T.R.I
Geometrical data:
STP Lgth (Z)
STP Dia. (X)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:



Region:face-front

ID: T.R.F.F
Geometrical data:
STP Lgth (Z)
STP Dia. (X)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:

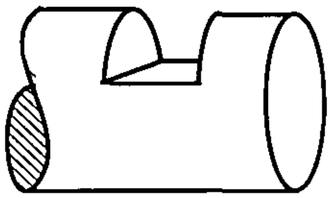


Region:face-back

ID: T.R.F.B
Geometrical data:
STP Lgth (Z)
STP Dia. (X)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:

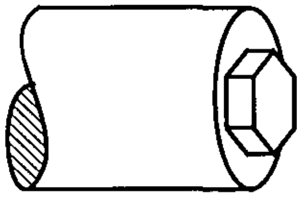
Figure 4	Thread regions	L.U.T. CAD/CAM

Region | **Mill region** | **Parameters**



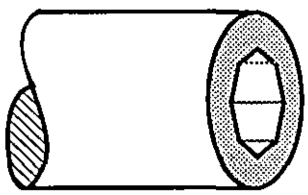
Region: side

ID: M.R.S
Geometrical data:
STP (X)
STP (Y)
STP (Z)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:



Region:face

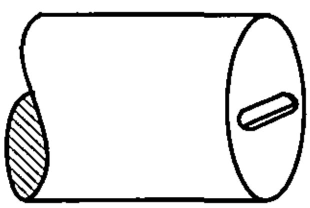
ID: M.F
Geometrical data:
STP (X)
STP (Y)
STP (Z)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:



Region:face-in

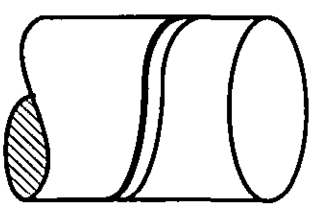
ID: M.F.I
Geometrical data:
STP (X)
STP (Y)
STP (Z)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:

Mill groove region



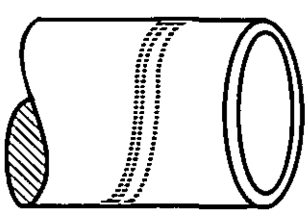
Region:face

ID: M.G.F
Geometrical data:
STP (X)
STP (Y)
STP (Z)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:



Region:side

ID: M.G.S
Geometrical data:
STP (X)
STP (Y)
STP (Z)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:

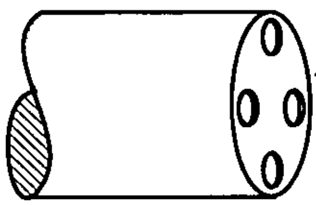


Region: in-side

ID: M.I.S
Geometrical data:
STP (X)
STP (Y)
STP (Z)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:

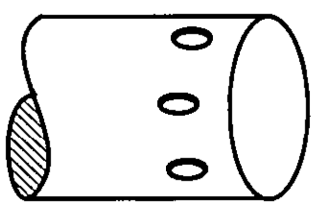
Figure 5	Mill regions	L.U.T. CAD/CAM

Region | **Parameters**



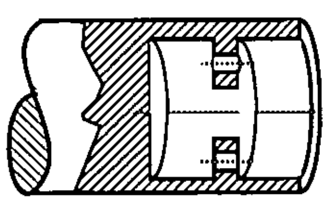
Drill-region-face

ID: M.R.S
Geometrical data:
STP (X) [ ]
STP (Y) [ ]
STP (Z) [ ]
Features: [ ]
Technological data:
Safety dist. [ ]
Entry point [ ]
NC parameters: [ ]



Drill-region-side

ID: M.R.S
Geometrical data:
STP (X) [ ]
STP (Y) [ ]
STP (Z) [ ]
Features: [ ]
Technological data:
Safety dist. [ ]
Entry point [ ]
NC parameters: [ ]



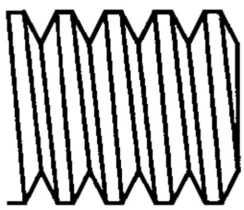
Drill-region-face-in

ID: M.R.S
Geometrical data:
STP (X) [ ]
STP (Y) [ ]
STP (Z) [ ]
Features: [ ]
Technological data:
Safety dist. [ ]
Entry point [ ]
NC parameters: [ ]

Figure 6	Drill regions	L.U.T. CAD/CAM

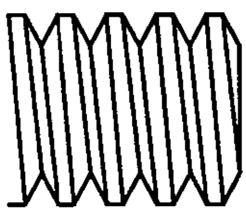
Features

Parameters



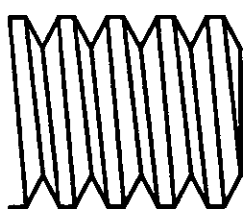
ISO thread

<u>Geometrical data</u>:
Nom. diameter
Length
Major diameter
Minor diameter
Angle
<u>Technological data</u>:
Cutting speed
Pitch
No. passes
Rough pass
Finish pass
<u>Tooling</u>:



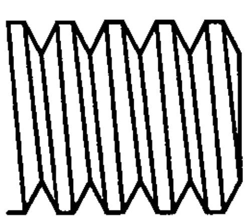
UNF thread

<u>Geometrical data:</u>
Nom. diameter
Length
Major diameter
Minor diameter
Angle
<u>Technological data</u>:
Cutting speed
Pitch
No. passes
Rough pass
Finish pass
<u>Tooling:</u>



ACME thread

<u>Geometrical data:</u>
Nom. diameter
Length
Major diameter
Minor diameter
Angle
<u>Technological data</u>:
Cutting speed
Pitch
No. passes
Rough pass
Finish pass
<u>Tooling</u>:

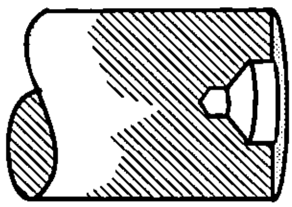


BSF thread

<u>Geometrical data</u>:
Nom. diameter
Length
Major diameter
Minor diameter
Angle
<u>Technological data</u>:
Cutting speed
Pitch
No. passes
Rough pass
Finish pass
<u>Tooling:</u>

Figure 7	Thread form features	L.U.T CAD/CAM

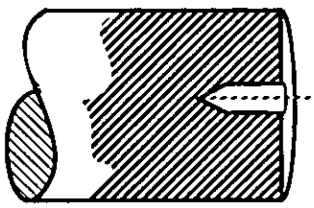
Form features | Parameters



centre bell

Geometrical data:
- Diameter
- Depth

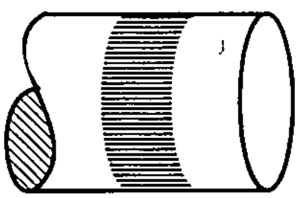
Technological data:
- Cutting speed
- Feed rate
- Tool



straight centre

Geometrical data:
- Diameter
- Depth

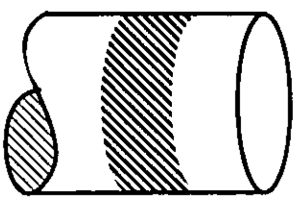
Technological data:
- Cutting speed
- Feed rate
- Tool



Straight knurl

Geometrical data:
- Diameter
- Length

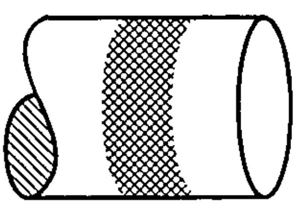
Technological data:
- Cutting speed
- Feed rate
- Tool



Diagonal knurl

Geometrical data:
- Diameter
- Length

Technological data:
- Cutting speed
- Feed rate
- Tool



Diamond knurl

Geometrical data:
- Diameter
- Length

Technological data:
- Cutting speed
- Feed rate
- Tool

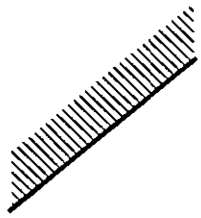
Figure 8	Form features (Knurl and Centre)	L.U.T CAD/CAM

External surfaces

Parameter

Straight

Taper



Geometrical data:
STP X
STP Z
STP Y
EDP X
EDP Y
EDP Z

Technological data:
Surface Finish

Attribute:
Chamfer
Corner

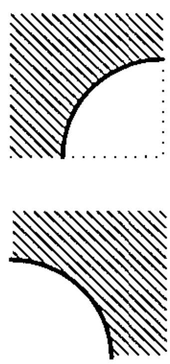
Convex

Geometrical data:
STP X
STP Z
STP Y
EDP X
EDP Y
EDP Z
RAD.

Technological data:
Surface Finish

Attribute:
Chamfer
Corner

Concave



Geometrical data:
STP X
STP Z
STP Y
EDP X
EDP Y
EDP Z
RAD.

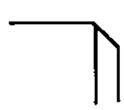
Technological data:
Surface Finish

Attribute:
Chamfer
Corner

Corner

Radius

Chamfer



Angle

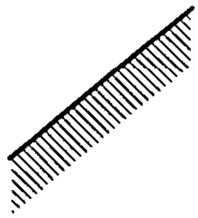
Figure 9	Internal surface features	L.U.T CAD/CAM

Internal elements

Parameter

Straight

Taper

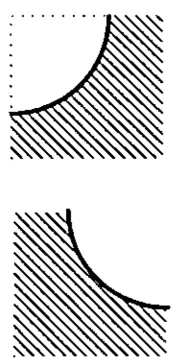


Geometrical data:
STP X
STP Z
STP Y
EDP X
EDP Y
EDP Z
Technological data:
Surface Finish
Attribute:
Chamfer
Corner

Convex

Geometrical data:
STP X
STP Z
STP Y
EDP X
EDP Y
EDP Z
RAD.
Technological data:
Surface Finish
Attribute:
Chamfer
Corner

Concave

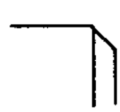


Geometrical data:
STP X
STP Z
STP Y
EDP X
EDP Y
EDP Z
RAD.
Technological data:
Surface Finish
Attribute:
Chamfer
Corner

Corner

Radius

Chamfer

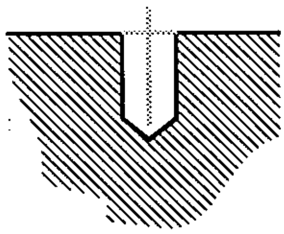


Angle

Figure 10	External surface features	L.U.T CAD/CAM

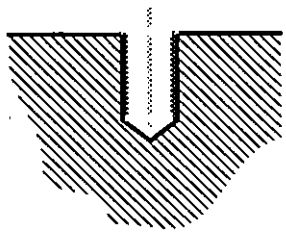
Form features

Parameters



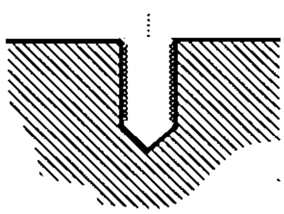
Drill hole

Geometrical data:
Diameter
Depth
Technological data:
Cutting speed
Feed rate:
RV
Tooling



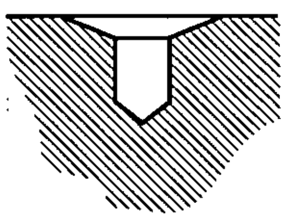
Reamed hole

Geometrical data:
Diameter
Depth
Technological data:
Cutting speed
Feed rate:
RV
Tooling



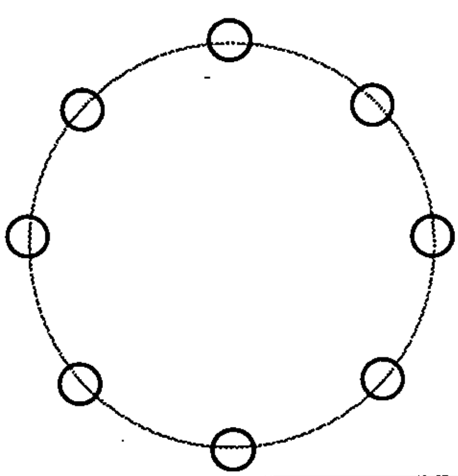
Taped hole

Geometrical data:
Diameter
Depth
Technological data:
Cutting speed
Feed rate:
RV
Tooling



C'sink hole

Geometrical data:
Diameter
Depth
Technological data:
Cutting speed
Feed rate:
RV
Tooling



Geometrical data:
Diameter
Depth
Technological data:
Cutting speed
Feed rate:
RV
Pitch(angle)
Pattern diameter
NO. holes
Start angle
Tooling

Figure 11	Hole Features	L.U.T - CAD/CAM

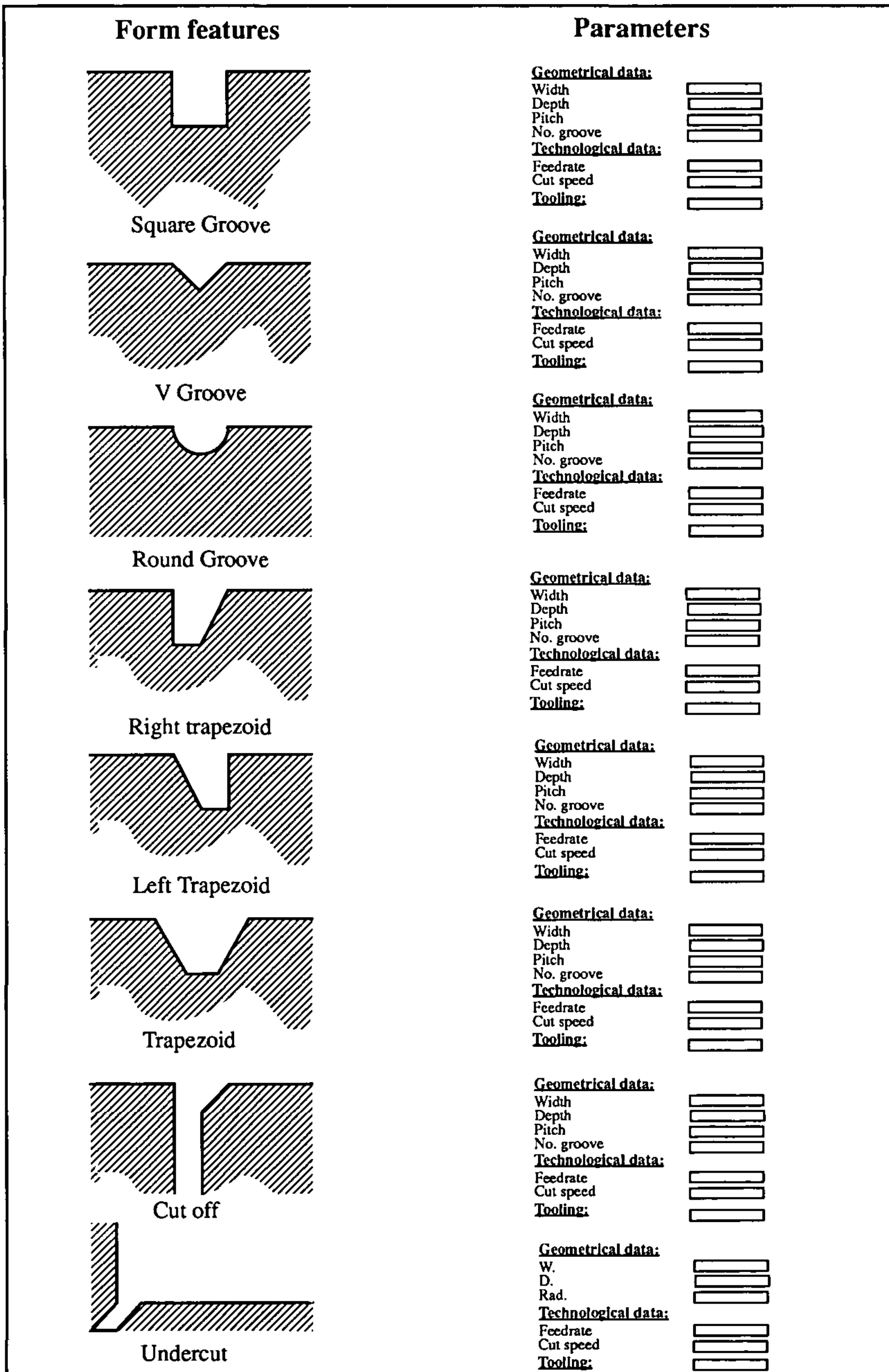


Figure 12	Groove features	L.U.T- CAD/CAM

Appendix II

Selection and Definition Procedure for Features and Regions

The purpose of this information is to capture and subsequently convey the relevant information for each region and feature and to generate the required manufacturing instruction. The features and regions are highlighted with their appropriate taxonomy. Four steps are used to trace the appropriate region and feature and the subsequent definition:

i- The selection of region
ii-The selection of feature
iii-Definition of region
iv-Definition of feature

Selection of Region

The tree representation of taxonomy clearly shows how the relevant region can be readily selected. The road map for selecting each region is depicted.

Selection of Feature

The tree representation illustrates how the appropriate feature for each region can be selected. The appropriate features for each region are clearly depicted.

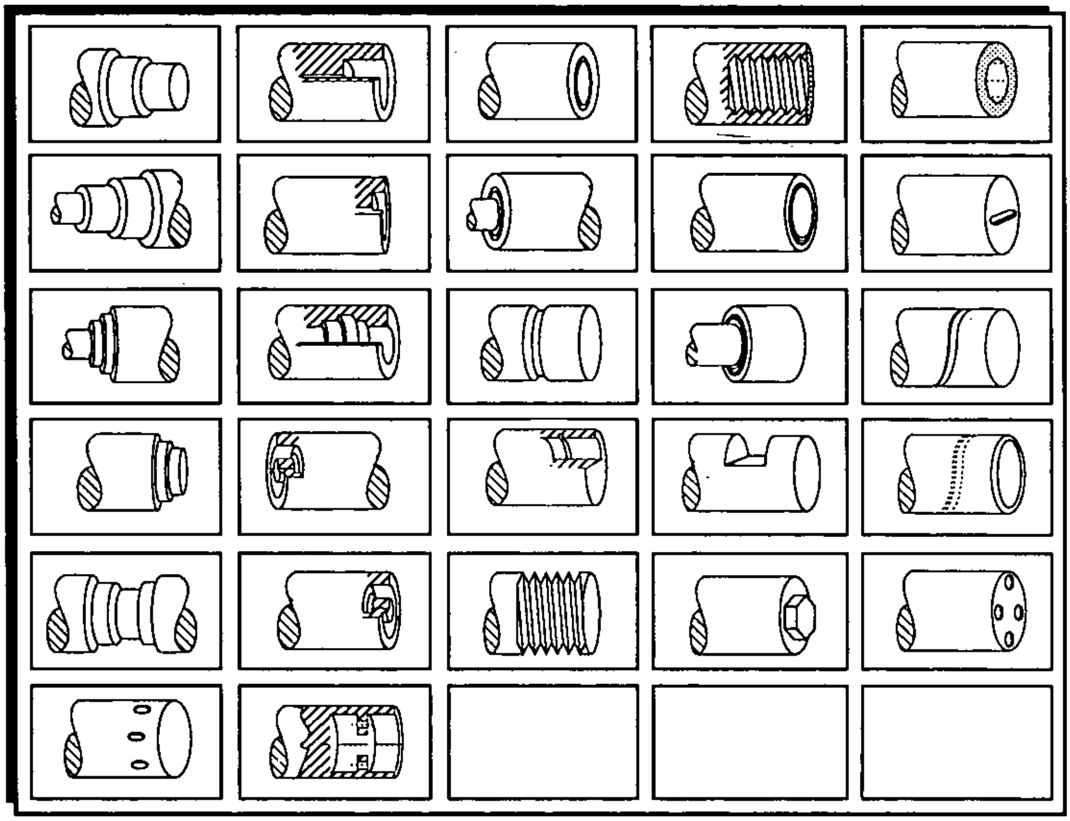
Definition of Region

Each region is defined by several parameters. Each region embodies a set of distinct parameters. These parameters are specified for each region.

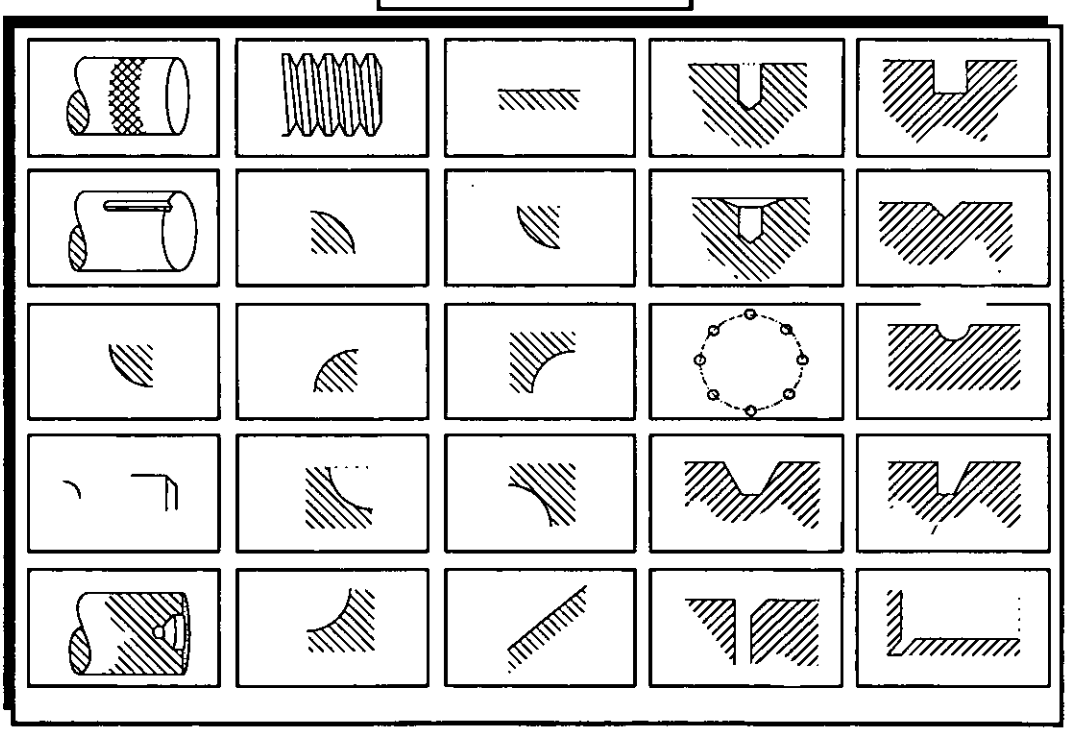
Definition of Feature

Features are defined for each region by specifying the geometric and technological parameters. For each region one feature is depicted and its associated data is specified.

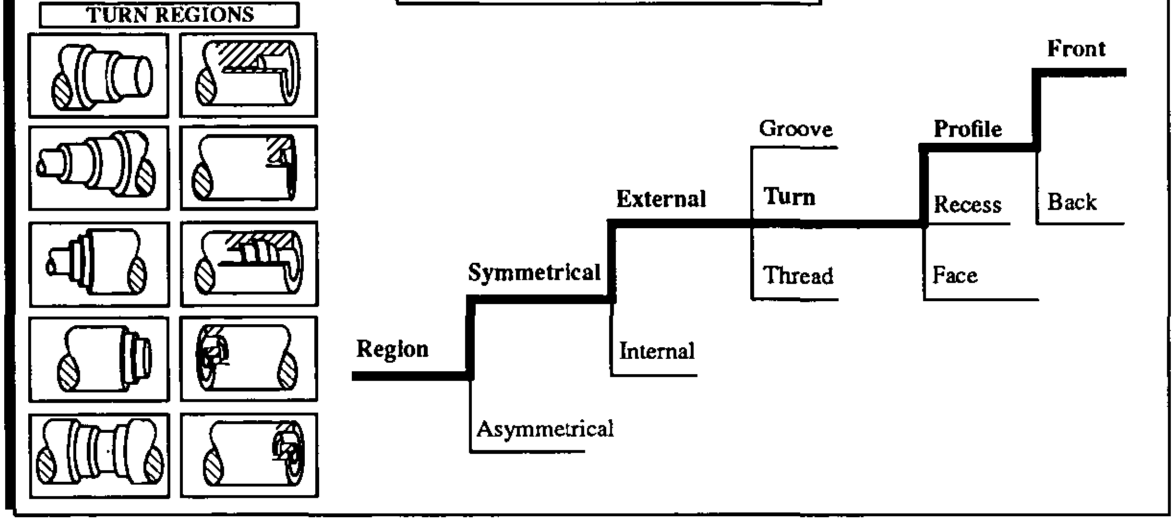
Basic Regions

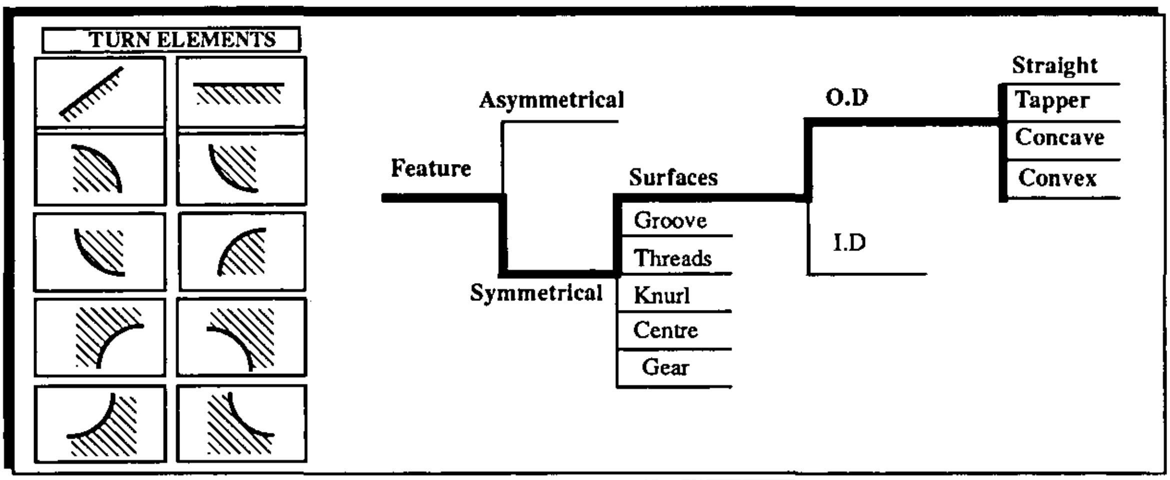


Basic Features

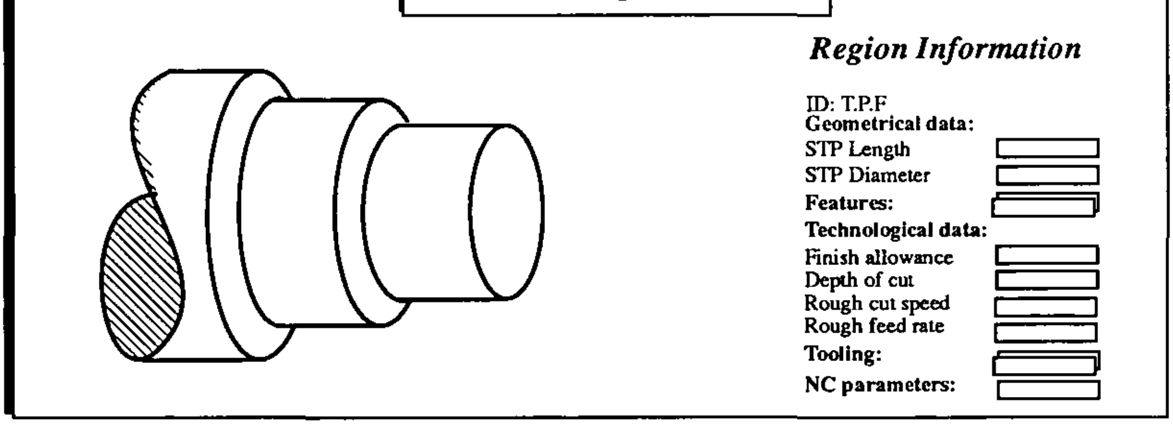


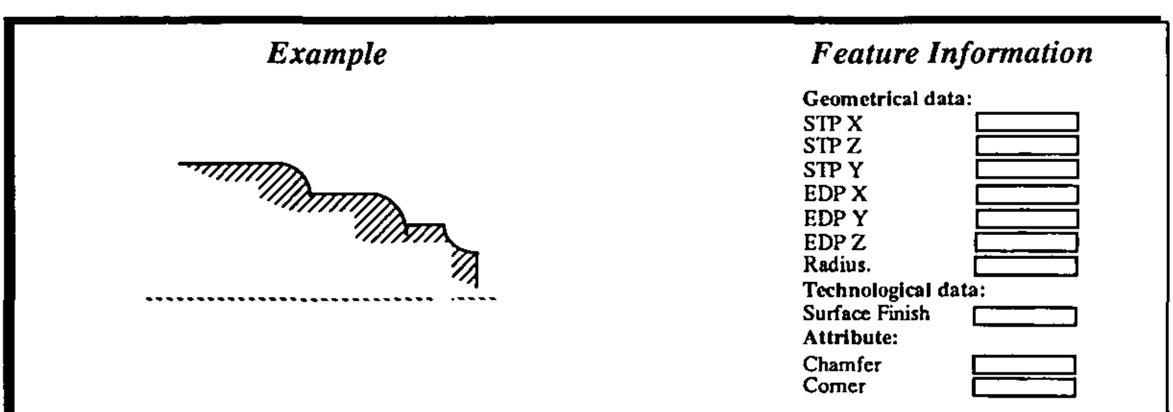
Selection of regions & features

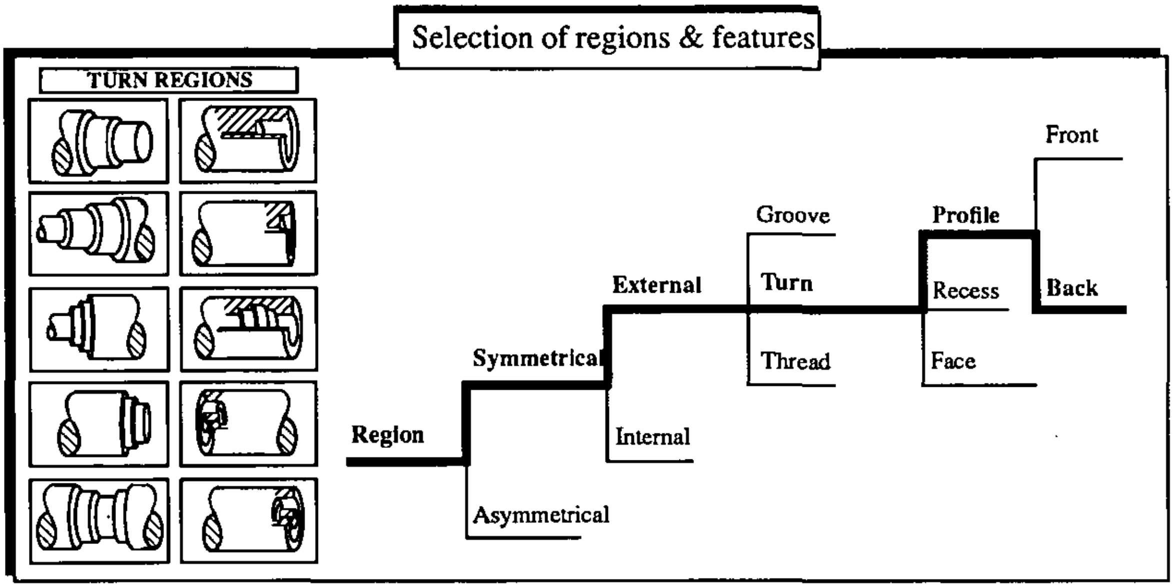


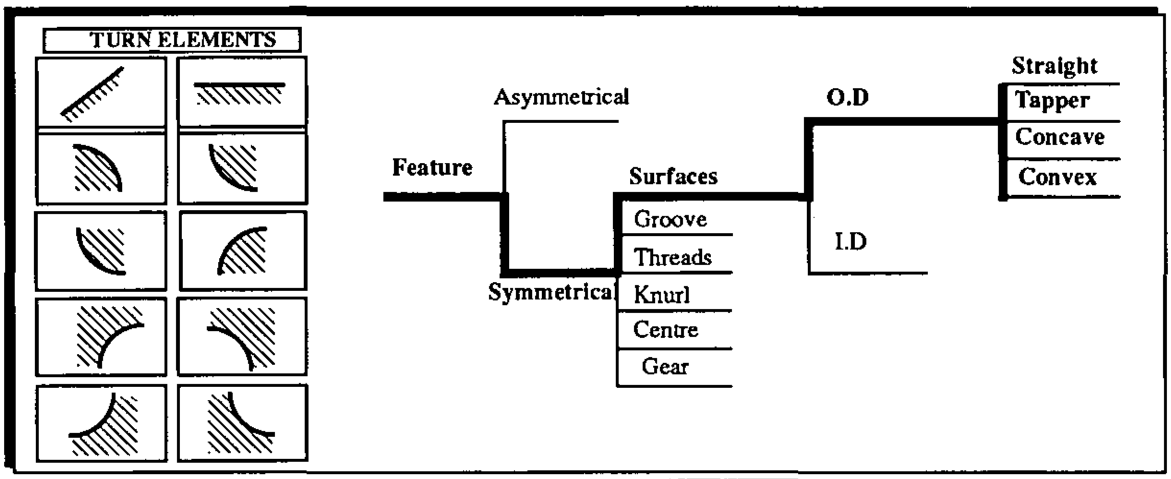


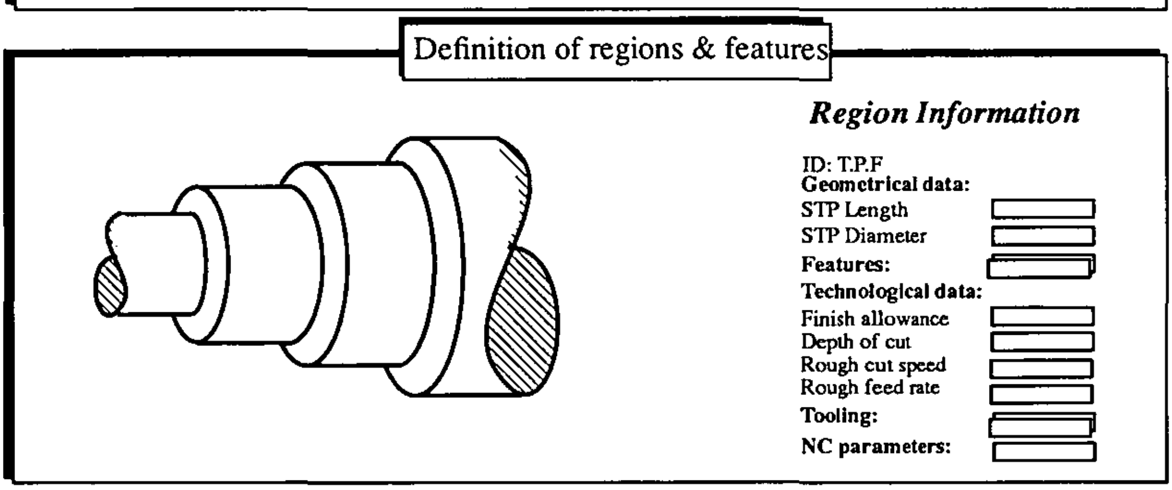
Definition of regions & features

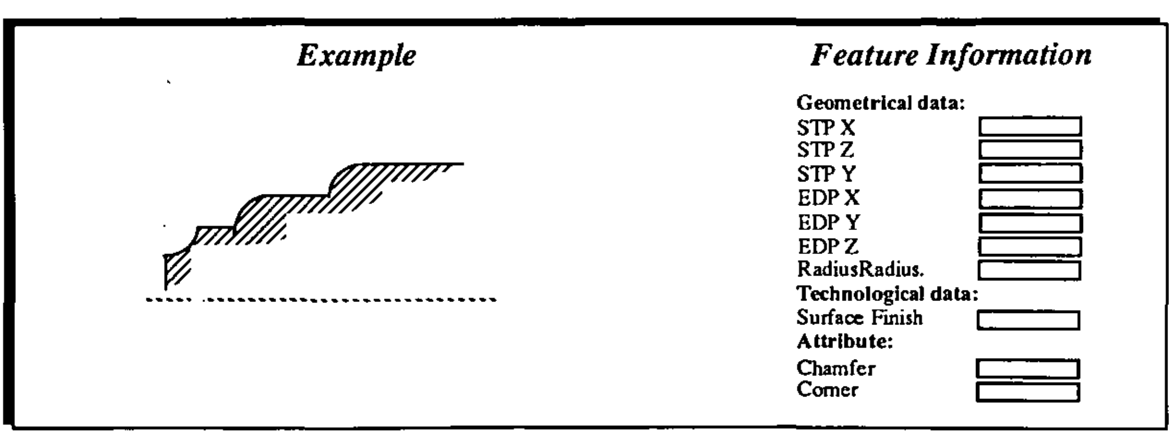


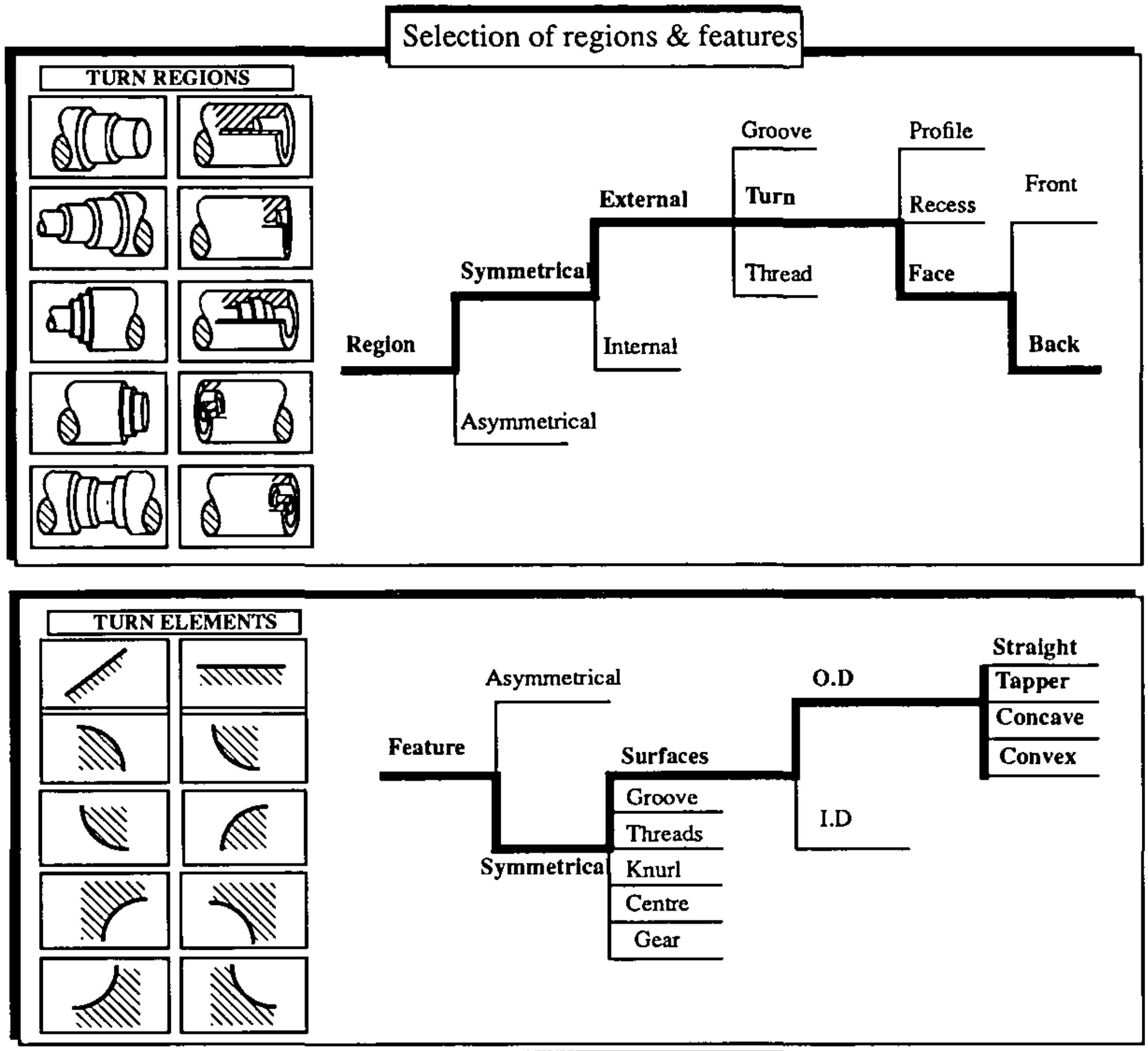


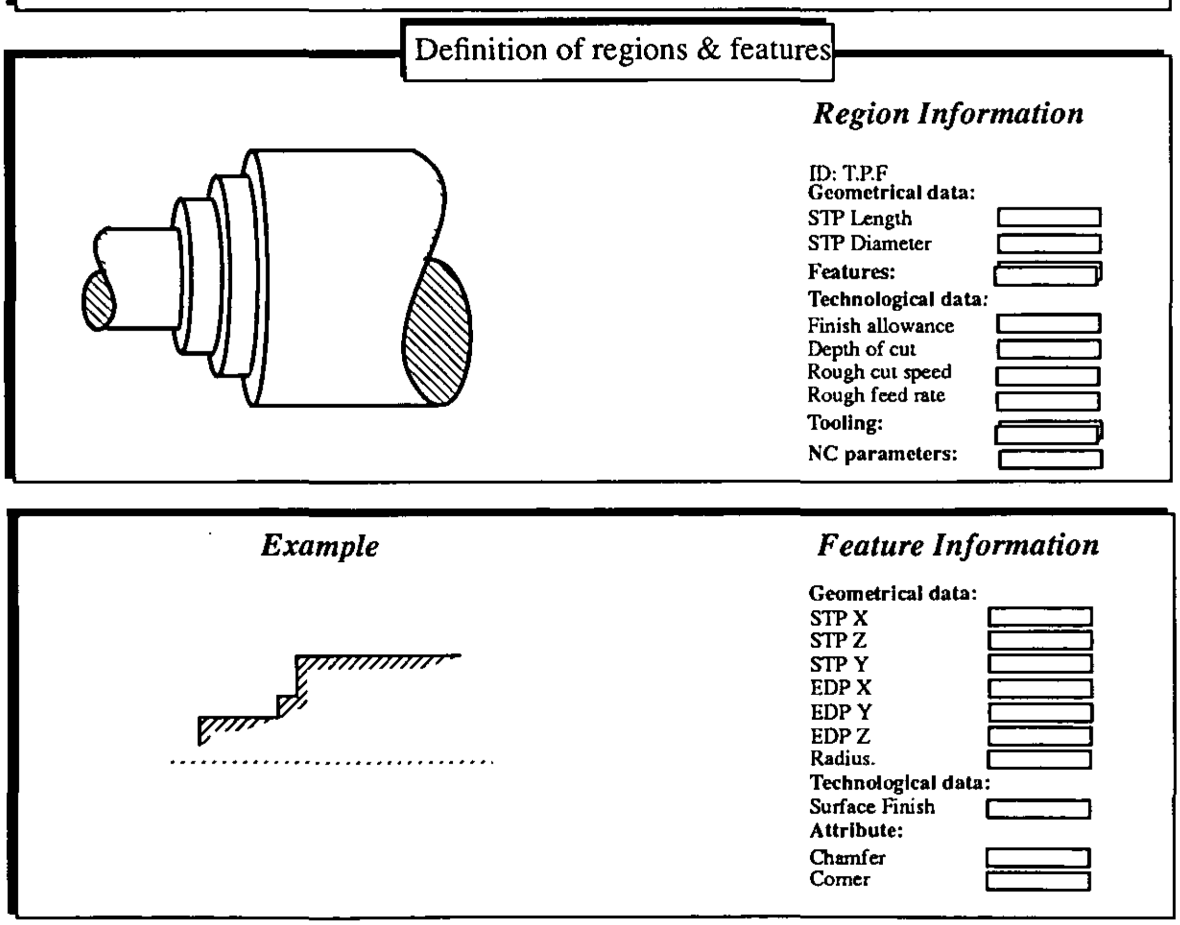

Selection of regions & features
TURN REGIONS
Front
Groove
Profile
External
Turn
Recess
Back
Symmetrical
Thread
Face
Region
Internal
Asymmetrical


TURN ELEMENTS
Straight
Asymmetrical
O.D
Tapper
Concave
Feature
Surfaces
Convex
Groove
I.D
Threads
Symmetrical
Knurl
Centre
Gear

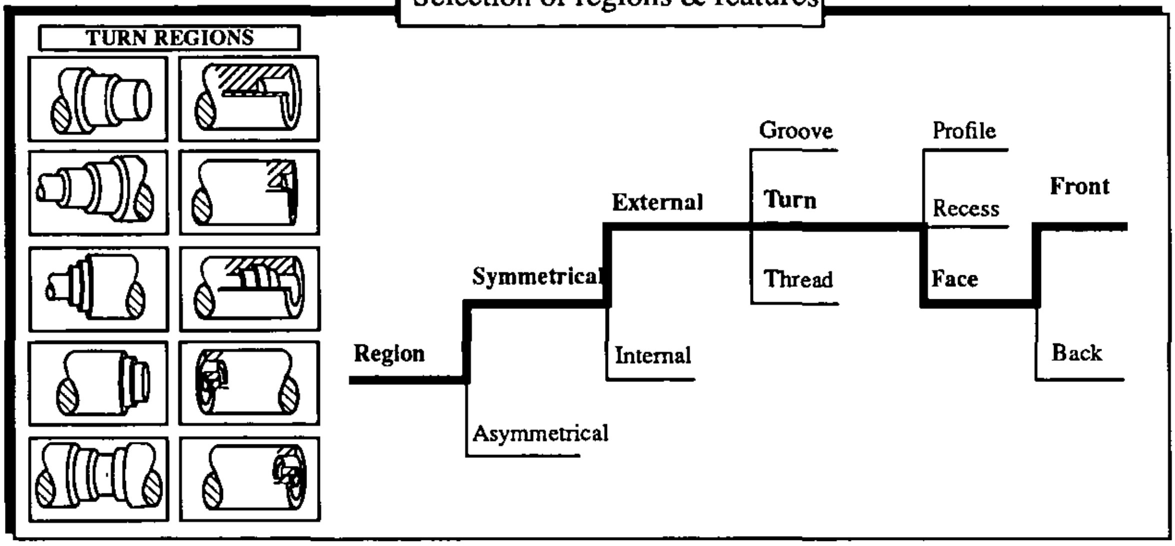

Definition of regions & features
Region Information
ID: T.P.F
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:

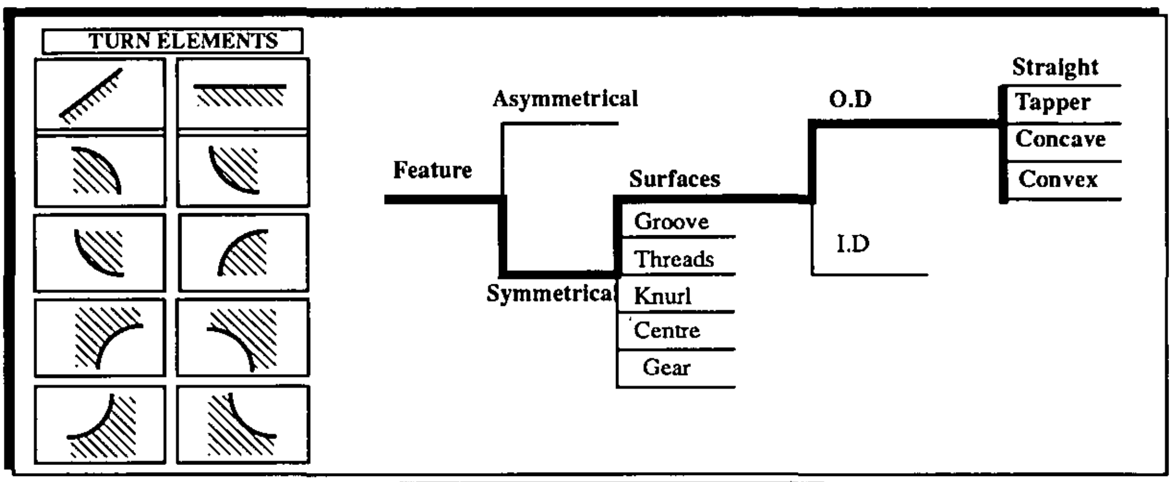

Example
Feature Information
Geometrical data:
STP X
STP Z
STP Y
EDP X
EDP Y
EDP Z
RadiusRadius.
Technological data:
Surface Finish
Attribute:
Chamfer
Corner


Selection of regions & features
TURN REGIONS
Region
Symmetrical
Asymmetrical
External
Internal
Groove
Turn
Thread
Profile
Recess
Face
Front
Back
TURN ELEMENTS
Feature
Asymmetrical
Symmetrical
Surfaces
Groove
Threads
Knurl
Centre
Gear
O.D
I.D
Straight
Tapper
Concave
Convex

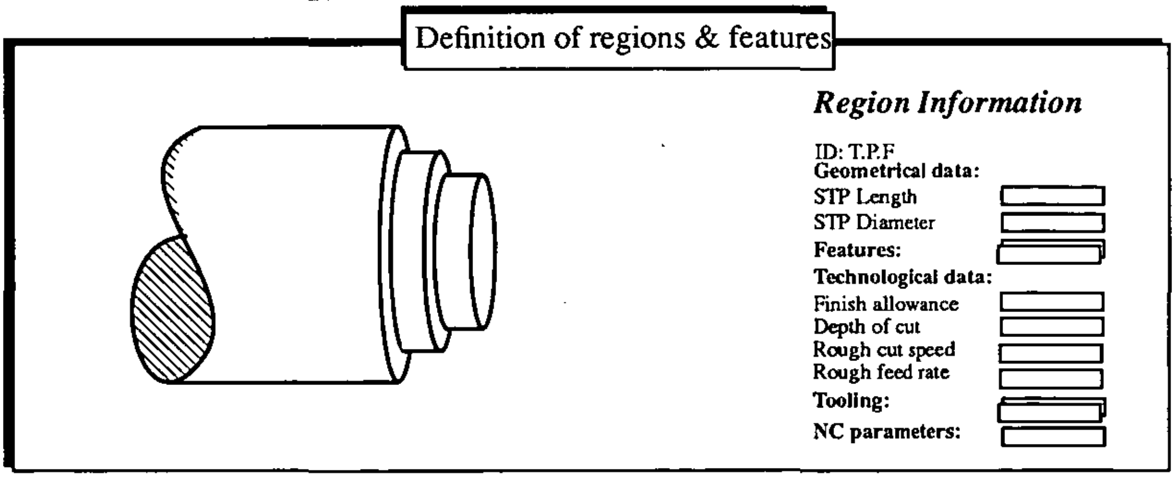

Definition of regions & features
Region Information
ID: T.P.F
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:
Example
Feature Information
Geometrical data:
STP X
STP Z
STP Y
EDP X
EDP Y
EDP Z
Radius.
Technological data:
Surface Finish
Attribute:
Chamfer
Corner

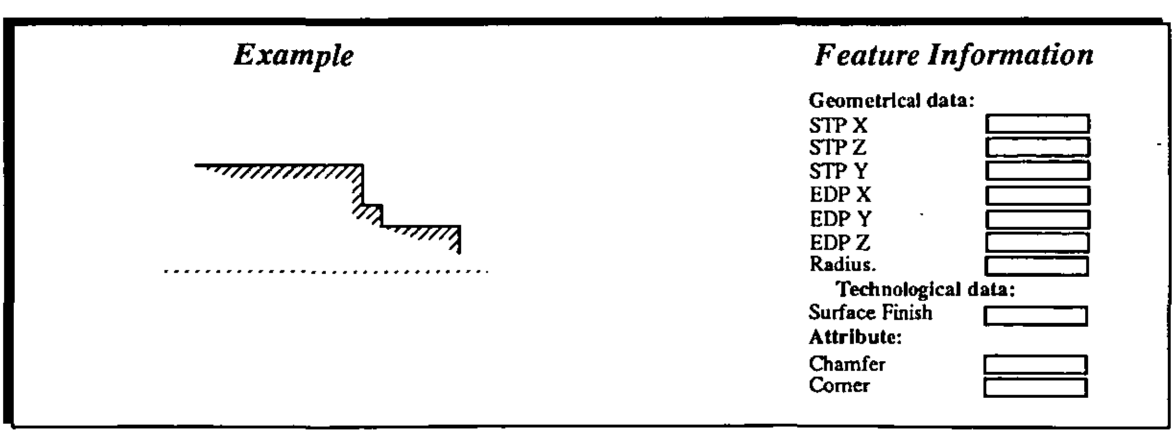
Selection of regions & features



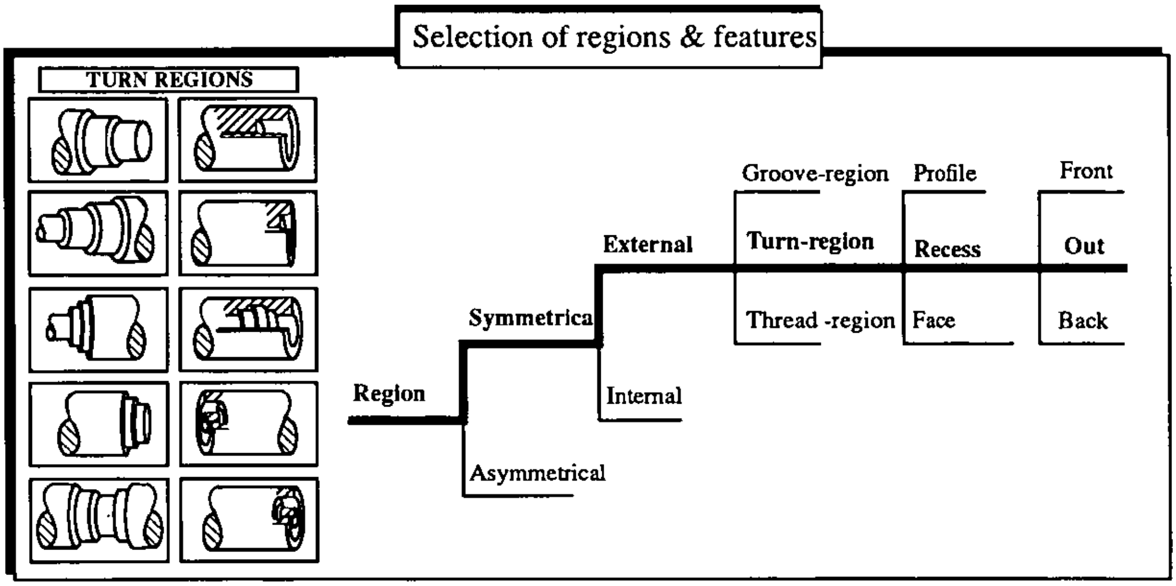


Definition of regions & features

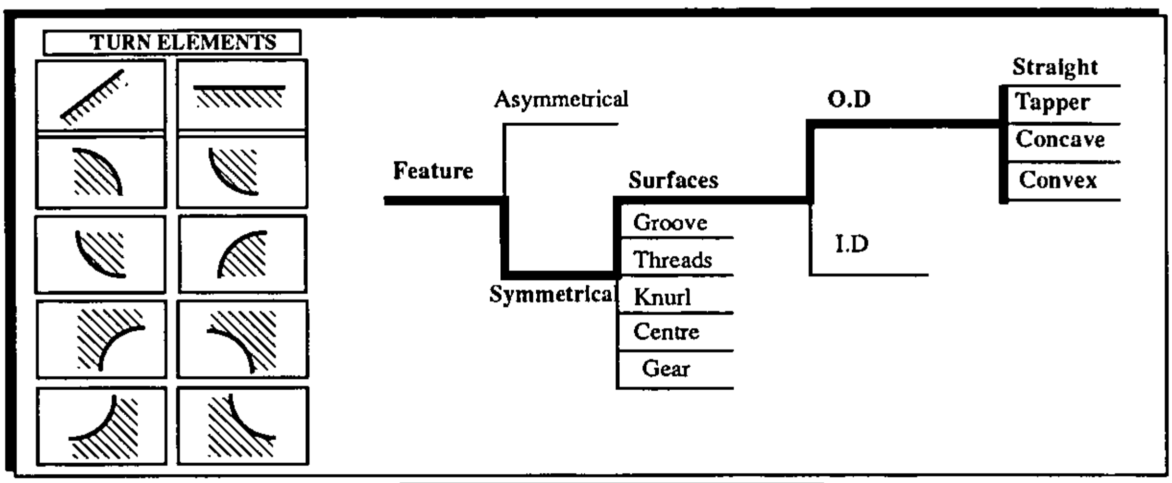




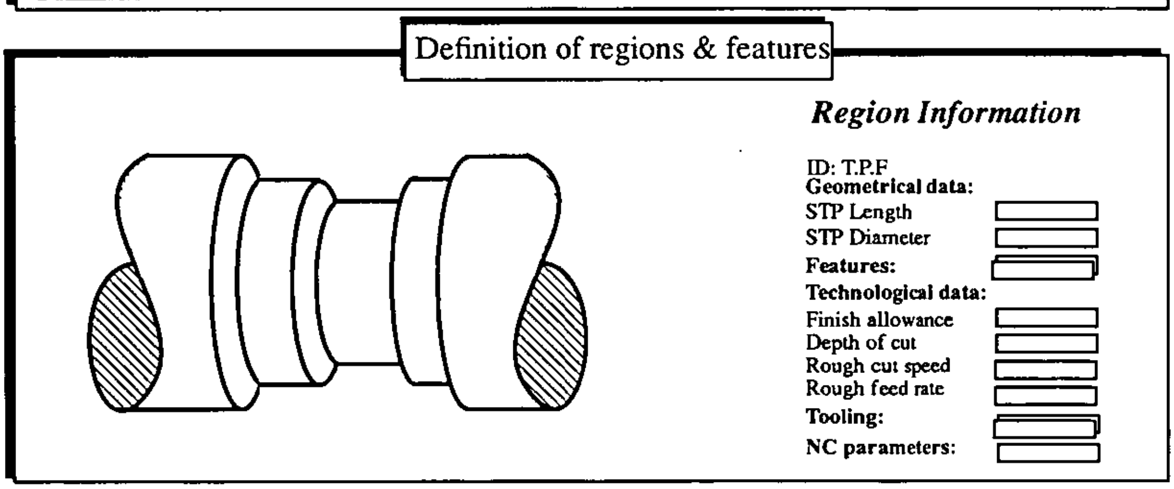
APPENDIX II



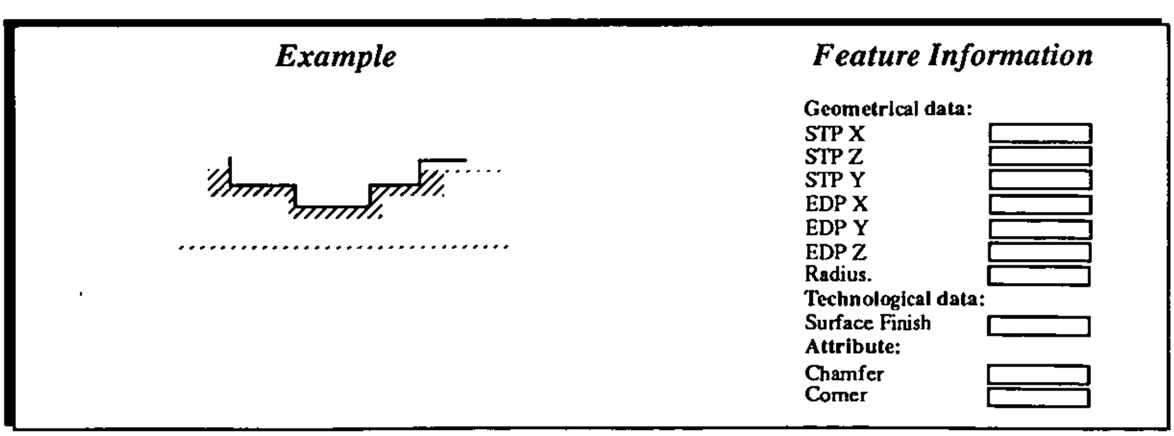
Selection of regions & features
TURN REGIONS
Groove-region
Profile
Front
External
Turn-region
Recess
Out
Symmetrical
Thread -region
Face
Back
Region
Internal
Asymmetrical



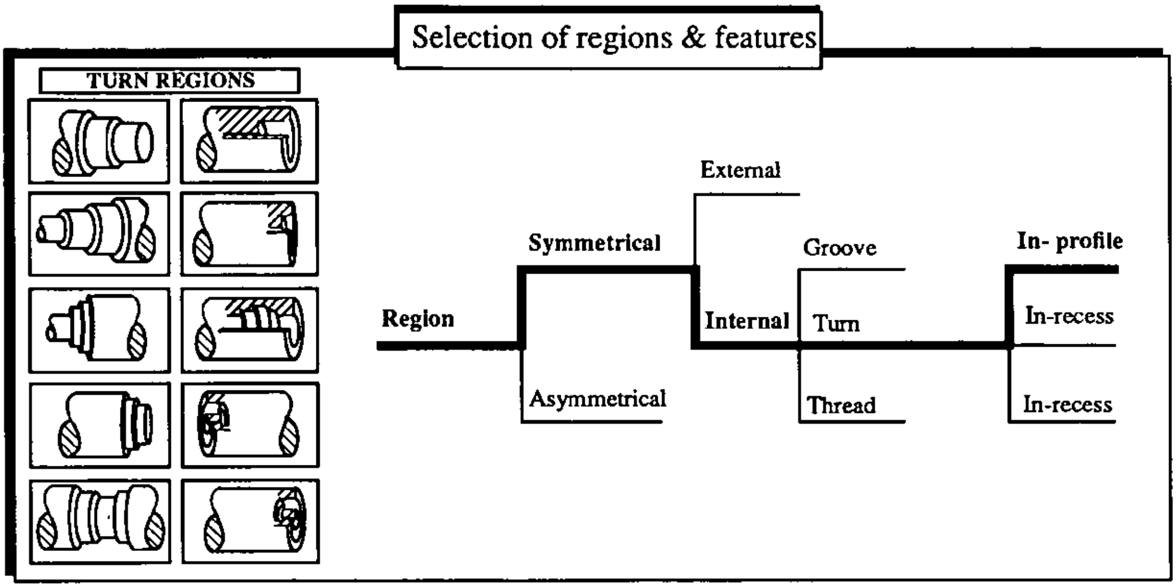
TURN ELEMENTS
Straight
Asymmetrical
O.D
Tapper
Concave
Feature
Surfaces
Convex
Groove
I.D
Threads
Symmetrical
Knurl
Centre
Gear

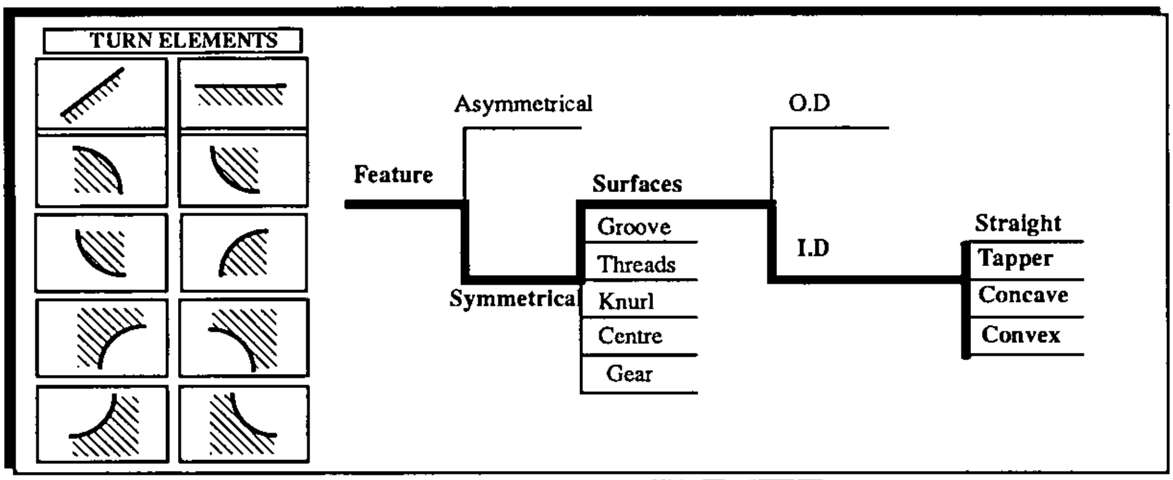


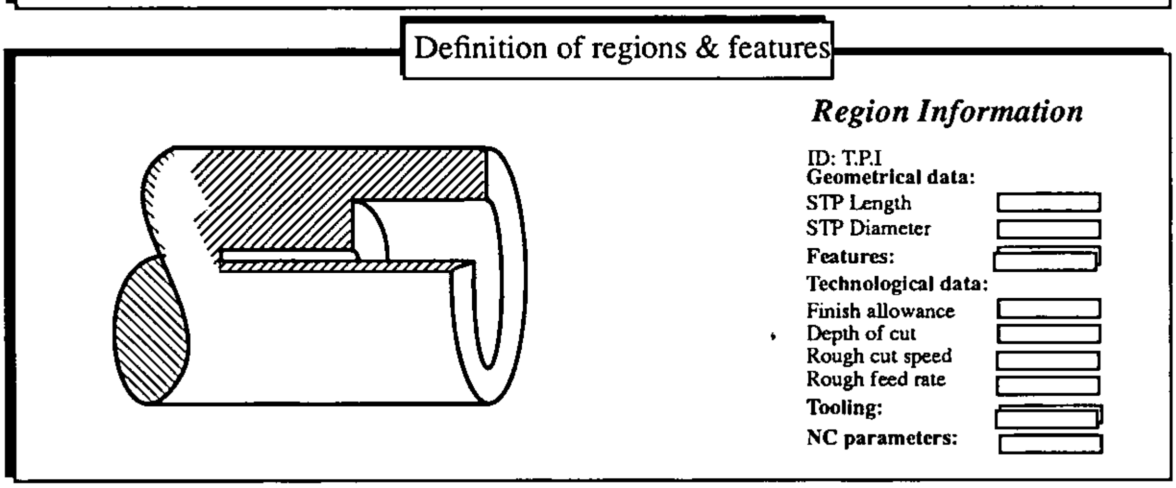
Definition of regions & features
Region Information
ID: T.P.F
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:

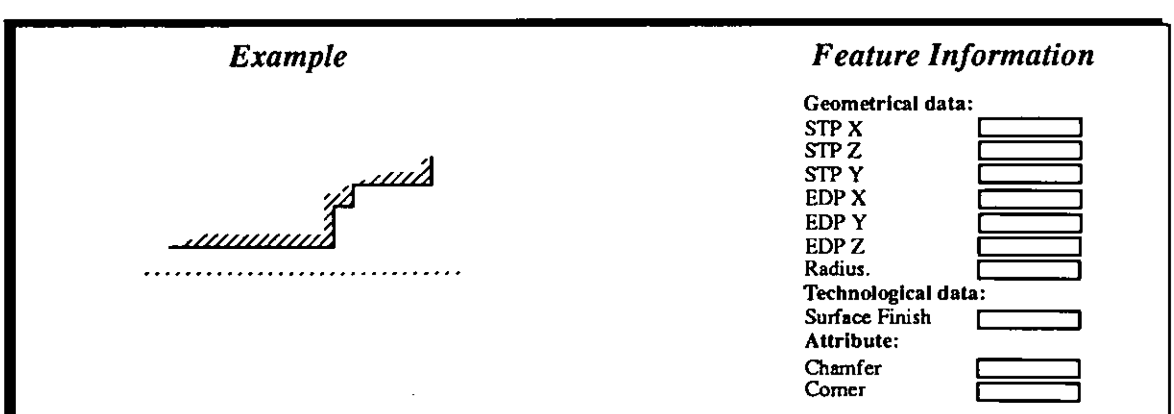


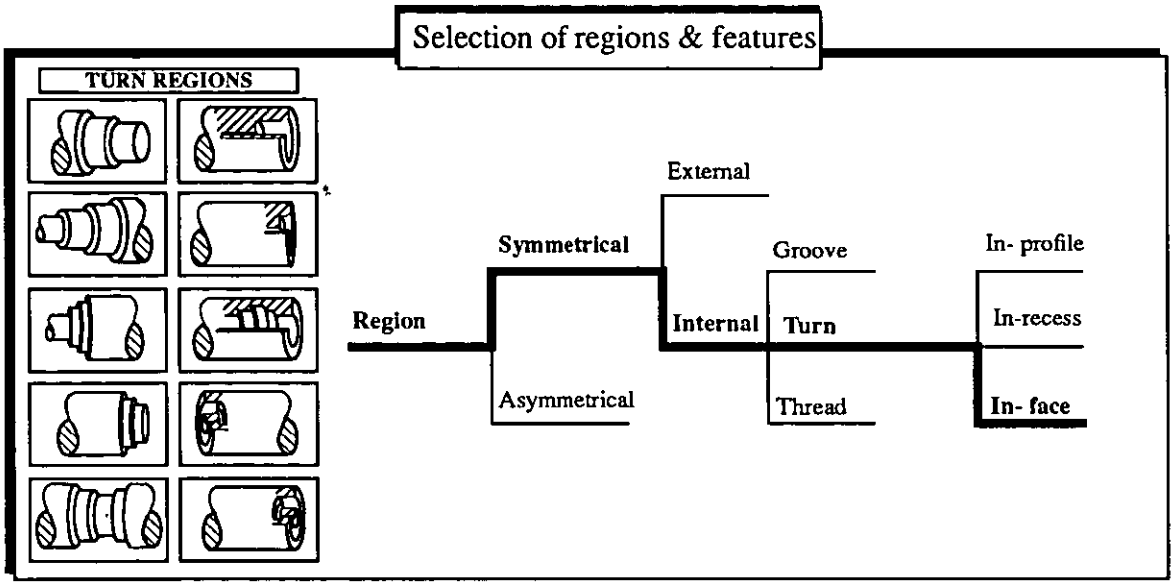
Example
Feature Information
Geometrical data:
STP X
STP Z
STP Y
EDP X
EDP Y
EDP Z
Radius.
Technological data:
Surface Finish
Attribute:
Chamfer
Corner

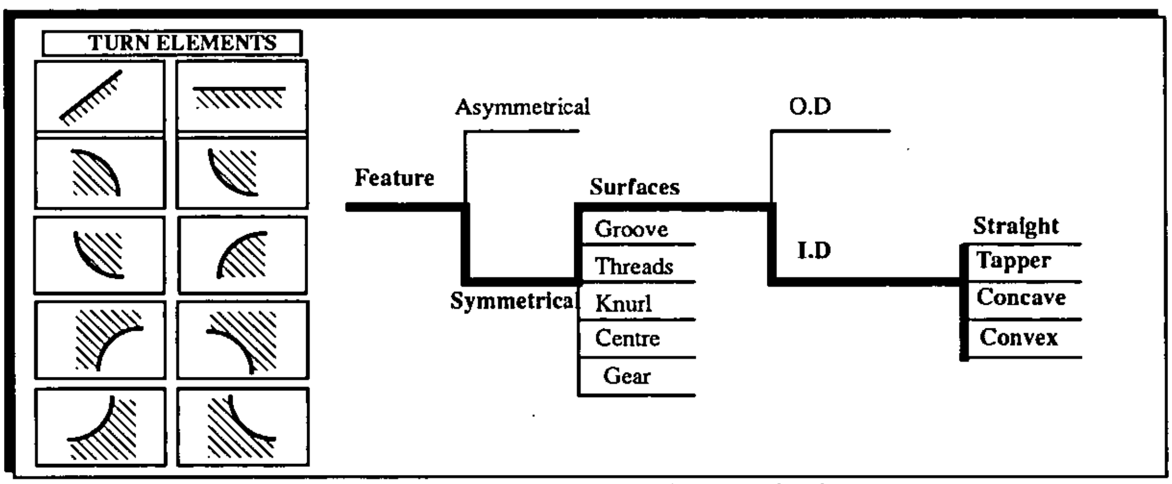

Selection of regions & features
TURN REGIONS
External
Symmetrical
Groove
In- profile
Region
Internal
Turn
In-recess
Asymmetrical
Thread
In-recess

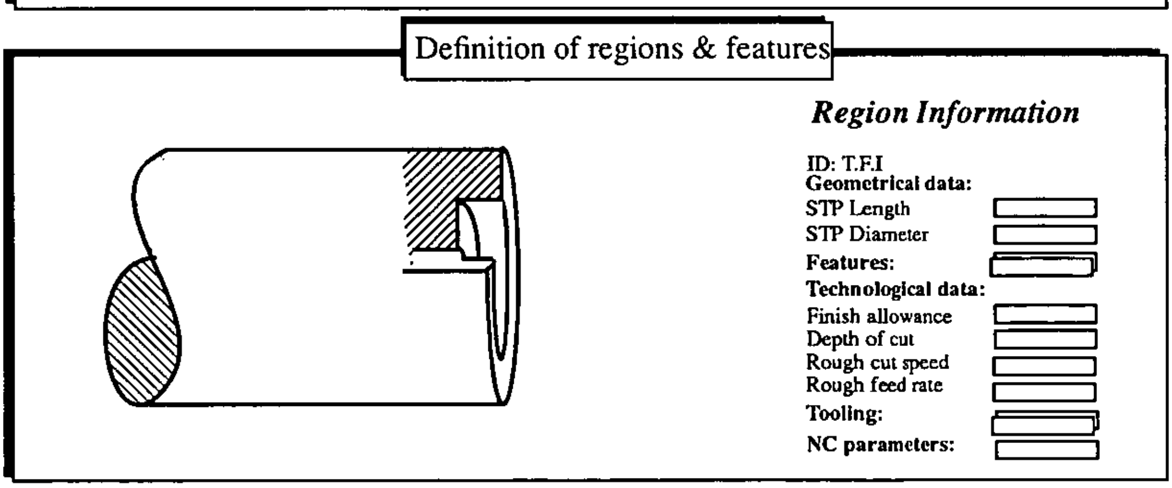

TURN ELEMENTS
Asymmetrical
O.D
Feature
Surfaces
Groove
Threads
I.D
Straight
Tapper
Symmetrical
Knurl
Concave
Centre
Convex
Gear

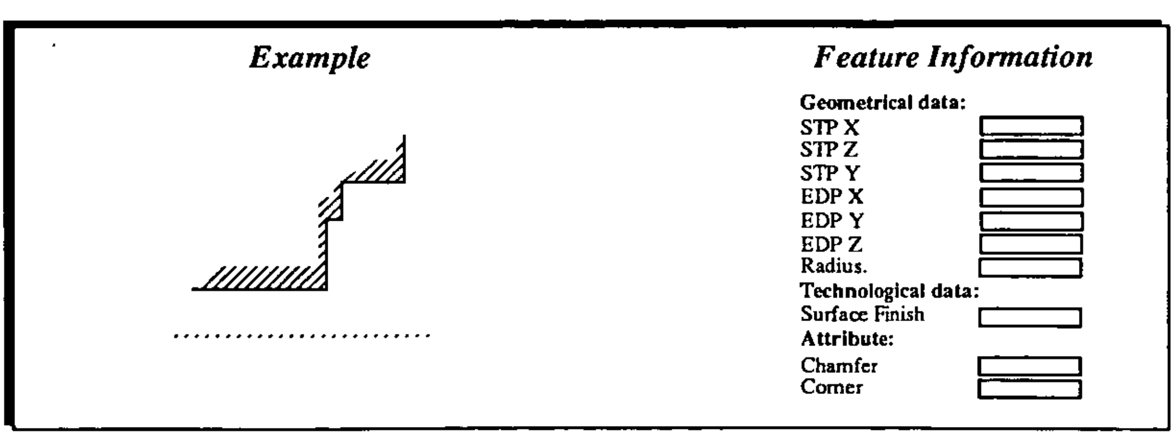

Definition of regions & features
Region Information
ID: T.P.I
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:

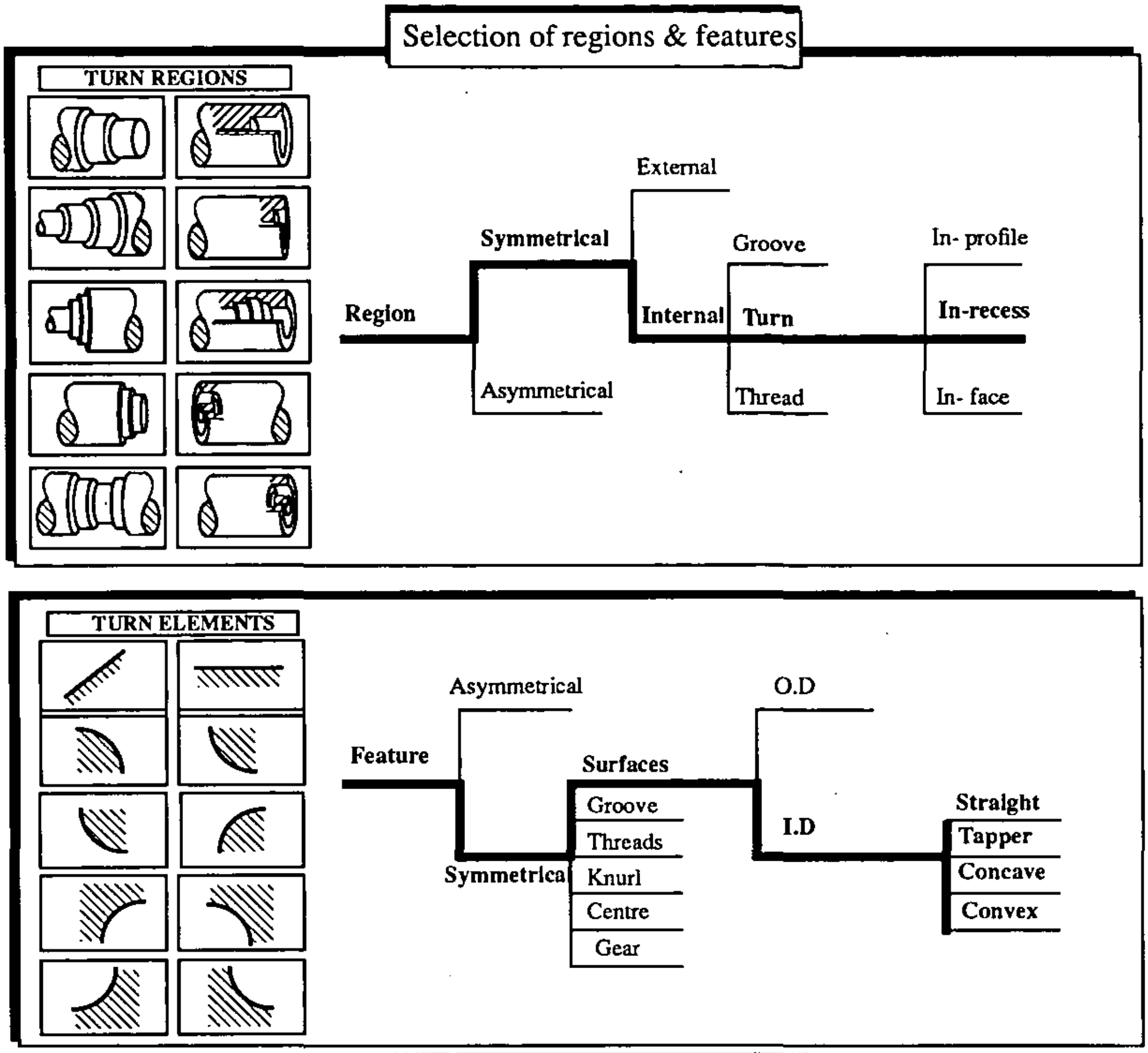

Example
Feature Information
Geometrical data:
STP X
STP Z
STP Y
EDP X
EDP Y
EDP Z
Radius.
Technological data:
Surface Finish
Attribute:
Chamfer
Corner

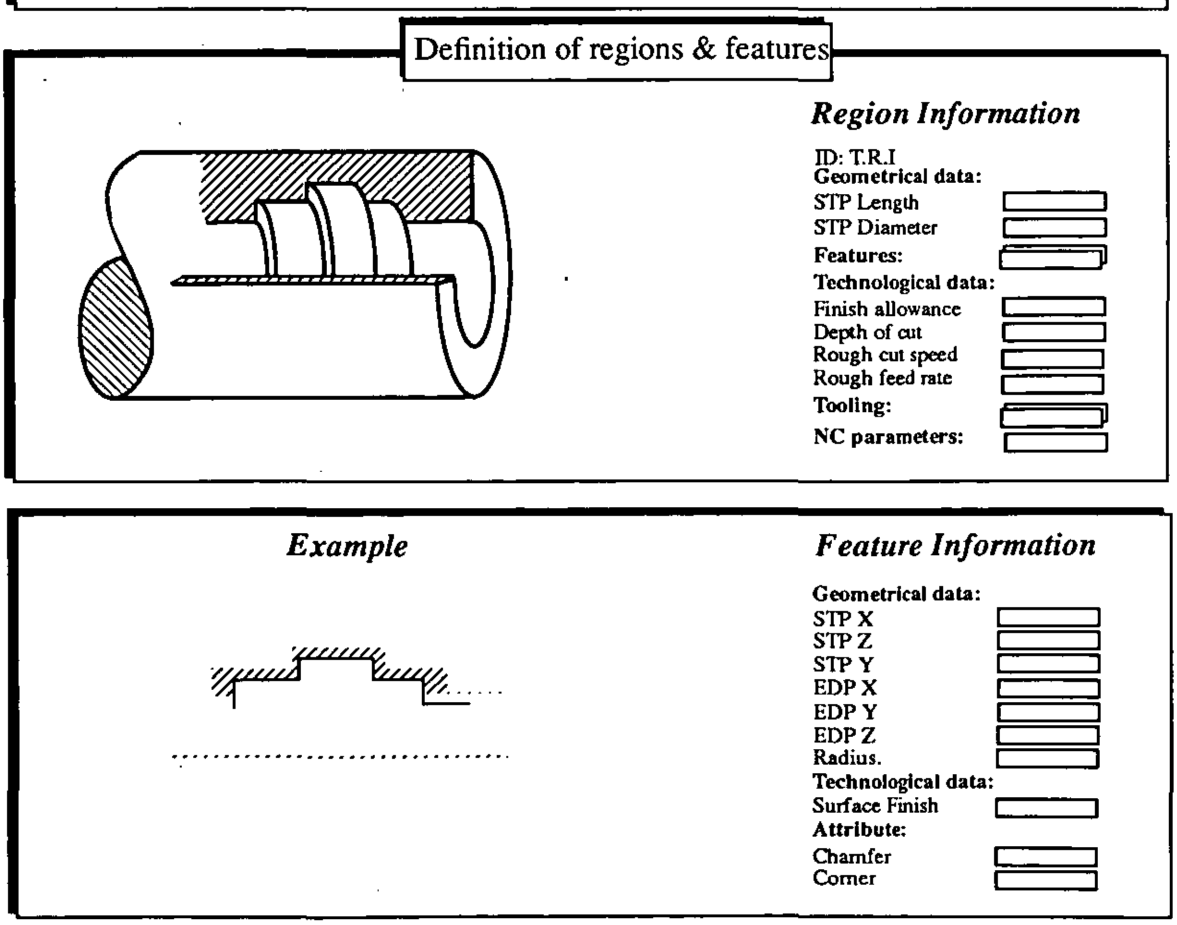

Selection of regions & features
TURN REGIONS
External
Symmetrical
Groove
In- profile
Region
Internal
Turn
In-recess
Asymmetrical
Thread
In- face

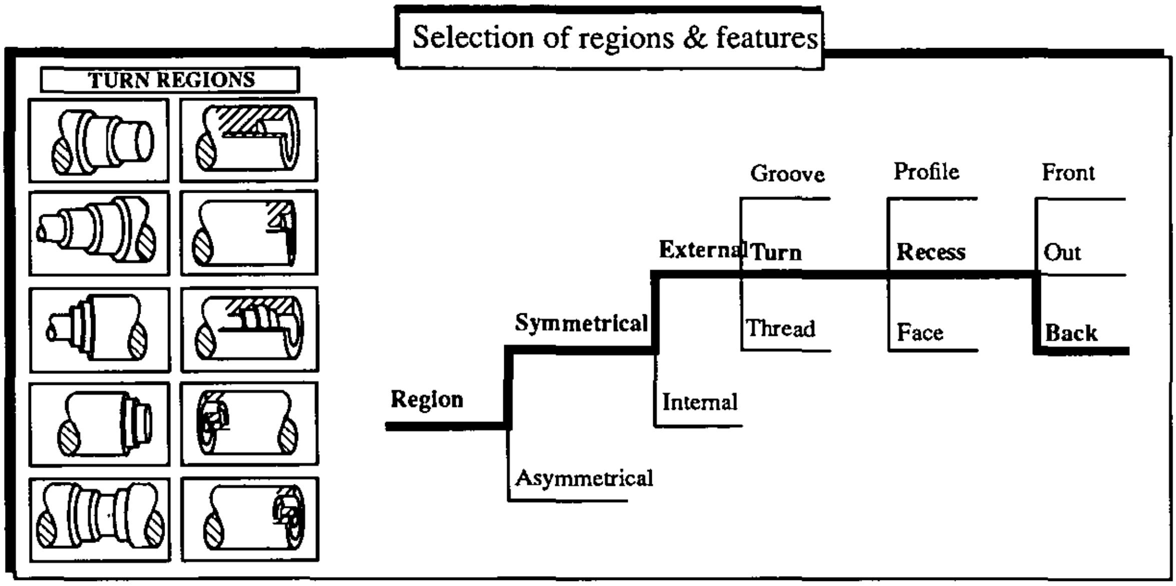

TURN ELEMENTS
Asymmetrical
O.D
Feature
Surfaces
Groove
Threads
Knurl
Centre
Gear
Symmetrical
I.D
Straight
Tapper
Concave
Convex

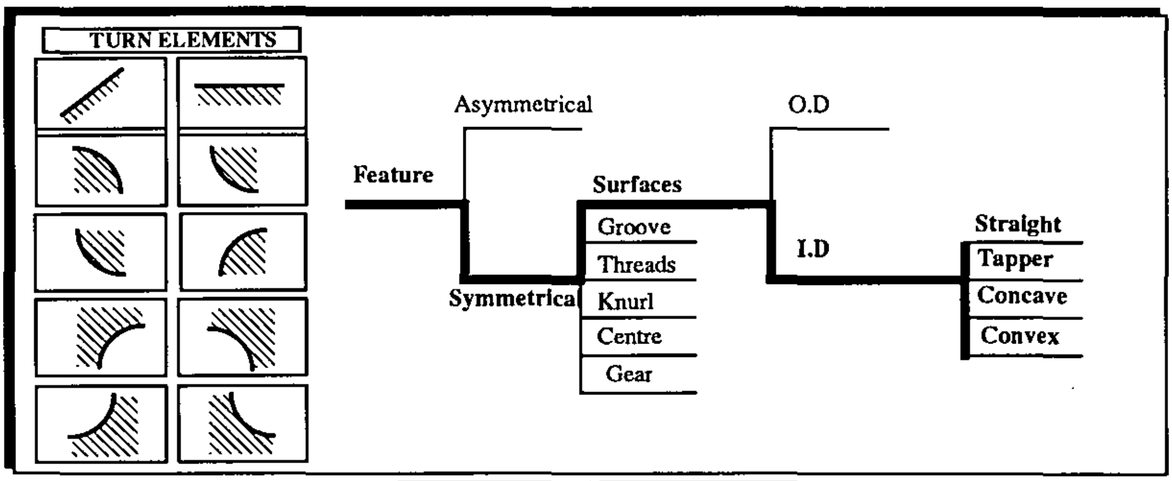

Definition of regions & features
Region Information
ID: T.F.I
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:

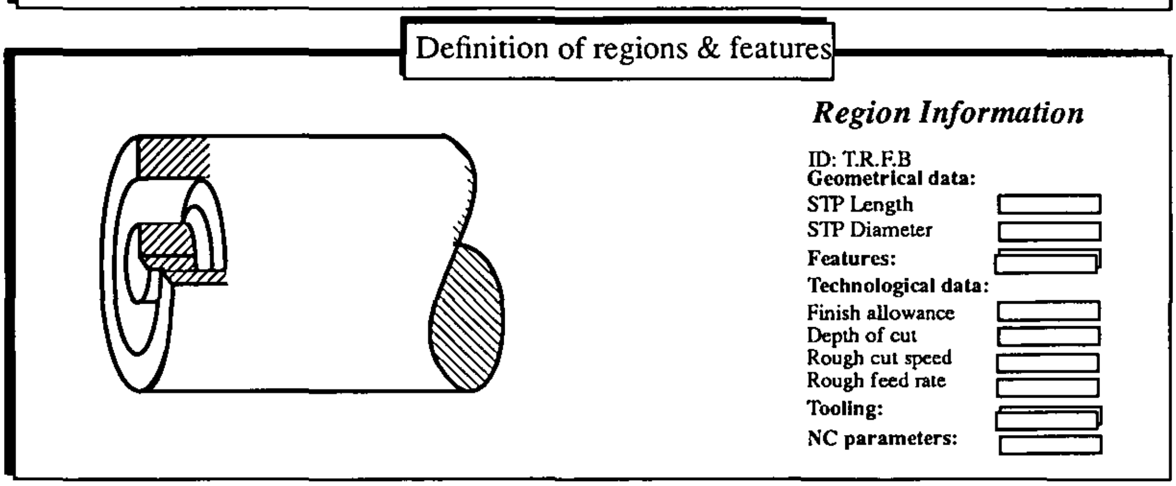

Example
Feature Information
Geometrical data:
STP X
STP Z
STP Y
EDP X
EDP Y
EDP Z
Radius.
Technological data:
Surface Finish
Attribute:
Chamfer
Corner

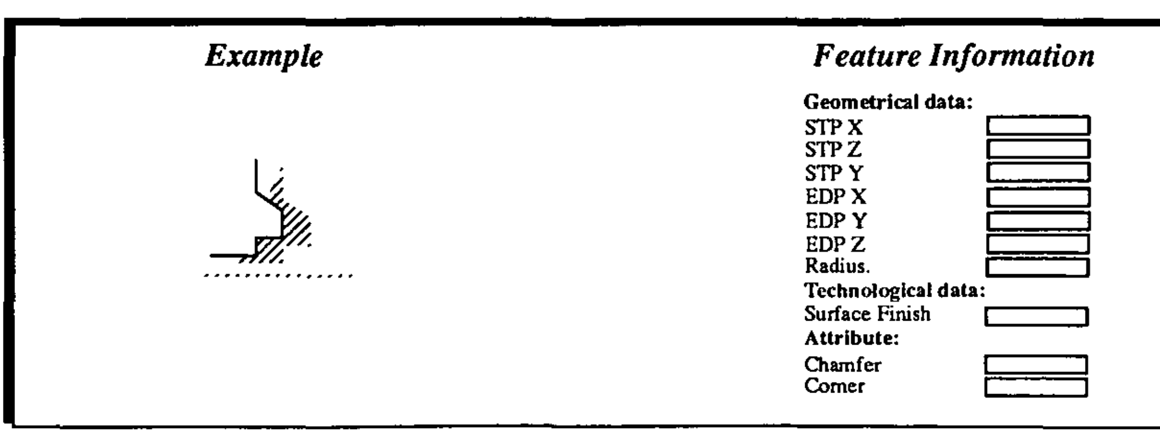

Selection of regions & features
TURN REGIONS
External
Symmetrical
Groove
In- profile
Region
Internal
Turn
In-recess
Asymmetrical
Thread
In- face
TURN ELEMENTS
Asymmetrical
O.D
Feature
Surfaces
Groove
Threads
Symmetrical
Knurl
Centre
Gear
I.D
Straight
Tapper
Concave
Convex

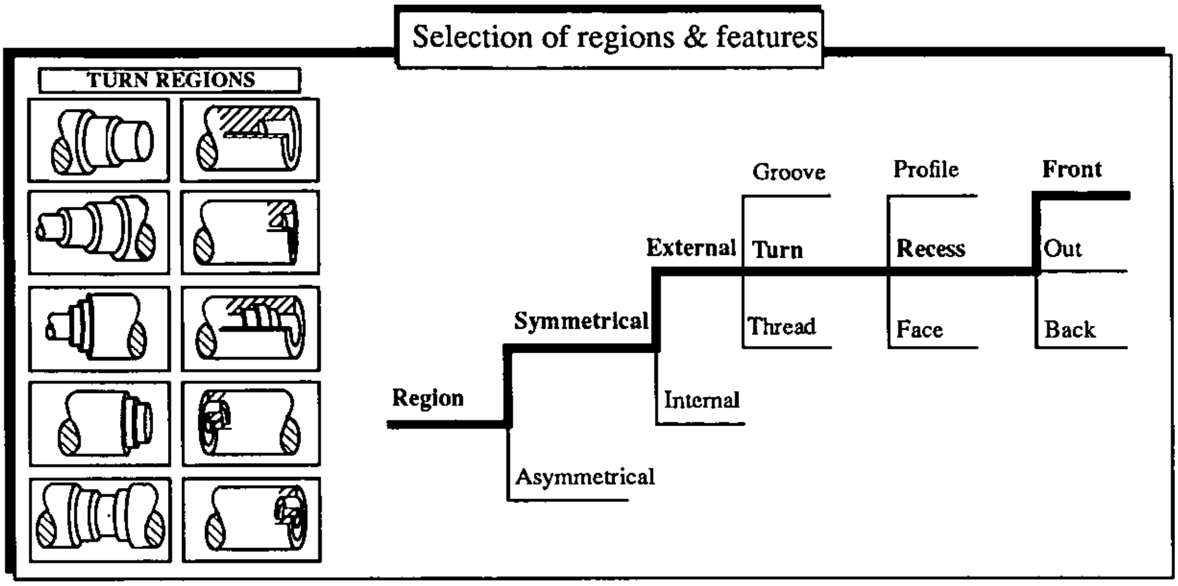

Definition of regions & features
Region Information
ID: T.R.I
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:
Example
Feature Information
Geometrical data:
STP X
STP Z
STP Y
EDP X
EDP Y
EDP Z
Radius.
Technological data:
Surface Finish
Attribute:
Chamfer
Corner

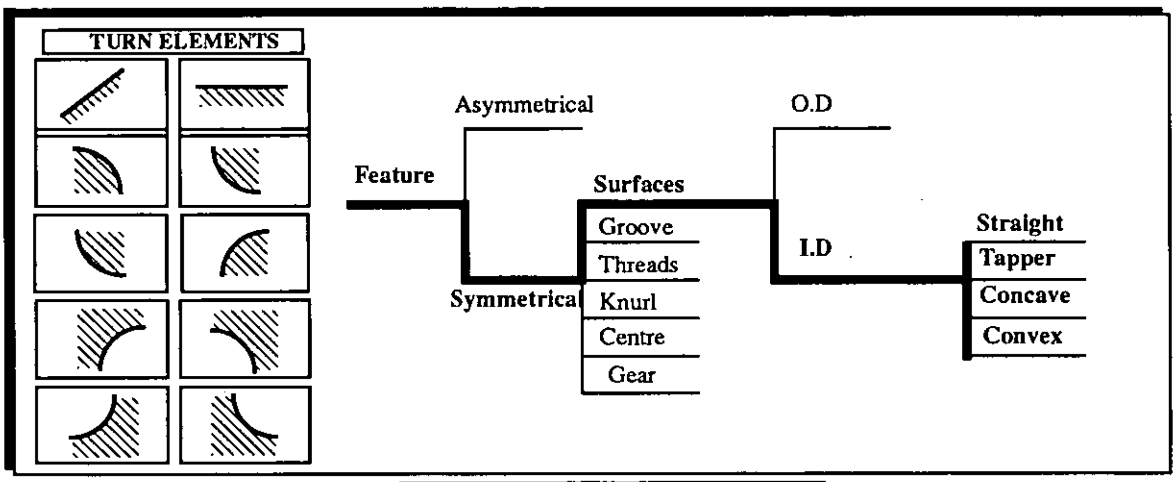

Selection of regions & features
TURN REGIONS
Groove
Profile
Front
External
Turn
Recess
Out
Symmetrical
Thread
Face
Back
Region
Internal
Asymmetrical

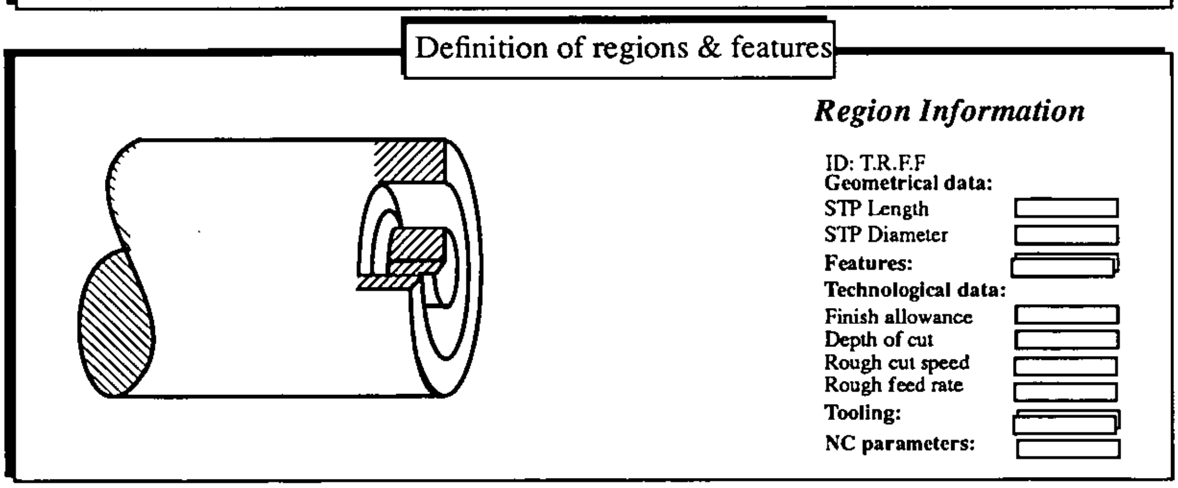

TURN ELEMENTS
Asymmetrical
O.D
Feature
Surfaces
Groove
I.D
Straight
Threads
Tapper
Symmetrical
Knurl
Concave
Centre
Convex
Gear

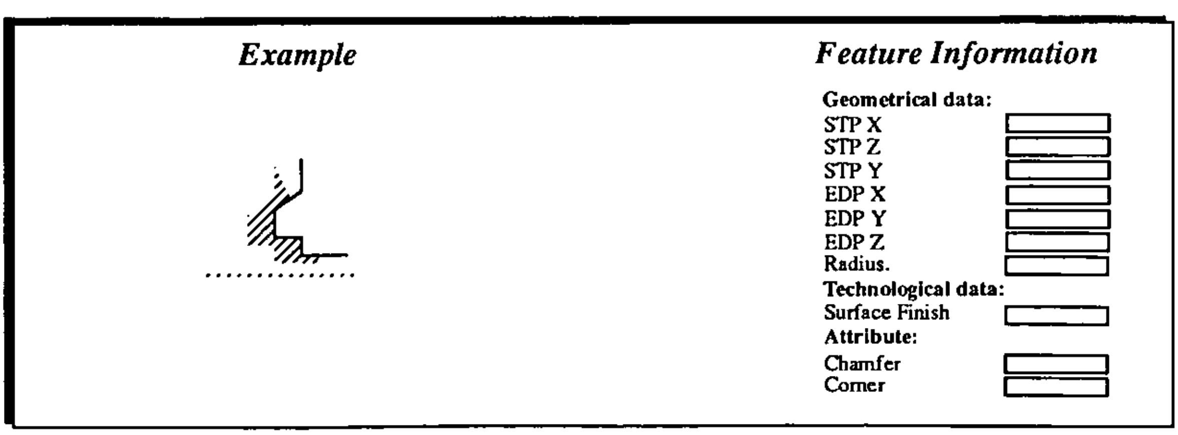

Definition of regions & features
Region Information
ID: T.R.F.B
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:


Example
Feature Information
Geometrical data:
STP X
STP Z
STP Y
EDP X
EDP Y
EDP Z
Radius.
Technological data:
Surface Finish
Attribute:
Chamfer
Corner

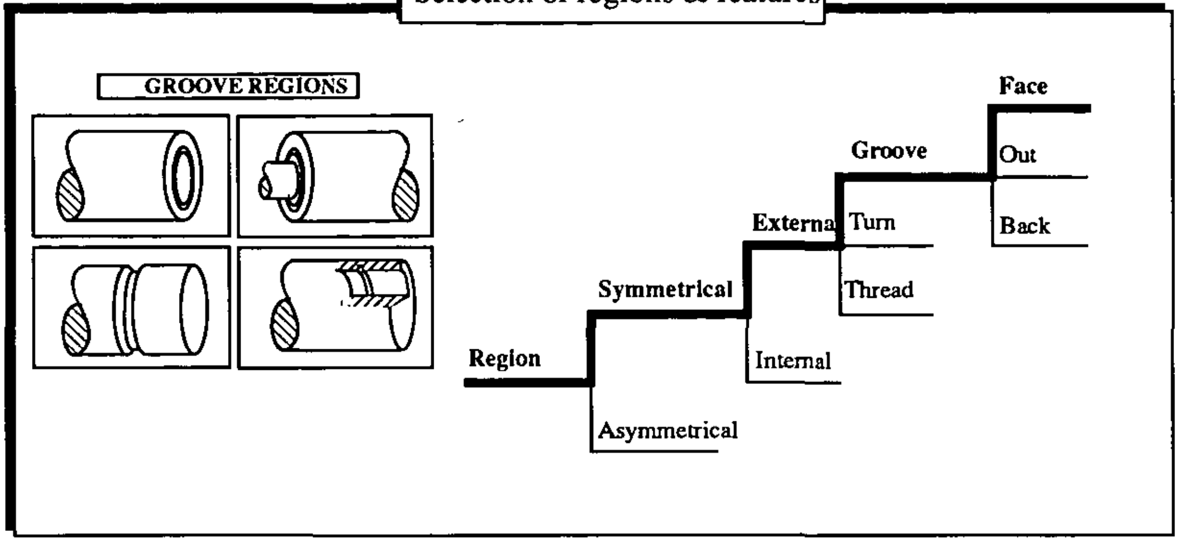

Selection of regions & features
TURN REGIONS
Groove
Profile
Front
External
Turn
Recess
Out
Symmetrical
Thread
Face
Back
Region
Internal
Asymmetrical

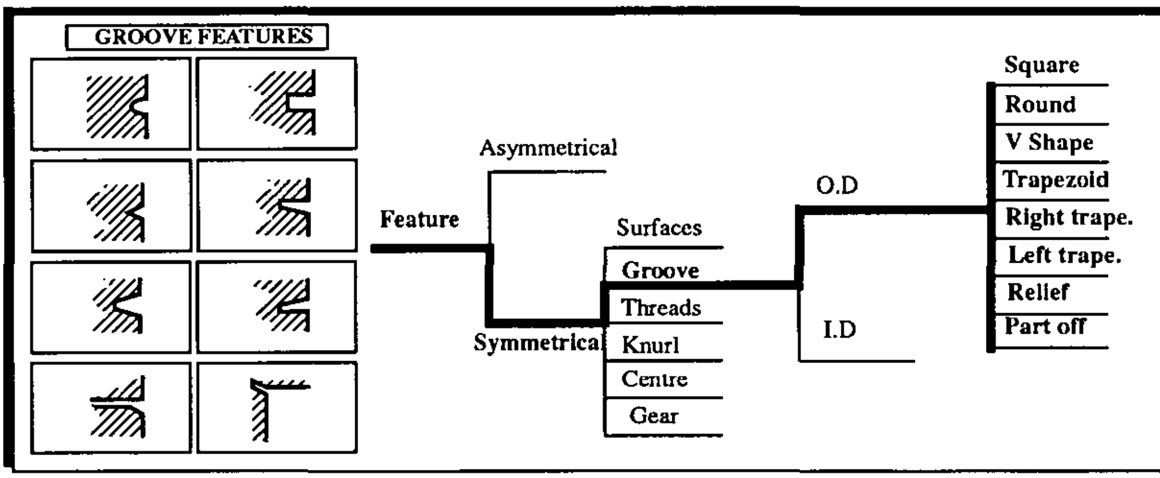

TURN ELEMENTS
Asymmetrical
O.D
Feature
Surfaces
Groove
Threads
Knurl
Centre
Gear
Symmetrical
I.D
Straight
Tapper
Concave
Convex


Definition of regions & features
Region Information
ID: T.R.F.F
Geometrical data:
STP Length
STP Diameter
Features:
Technological data:
Finish allowance
Depth of cut
Rough cut speed
Rough feed rate
Tooling:
NC parameters:

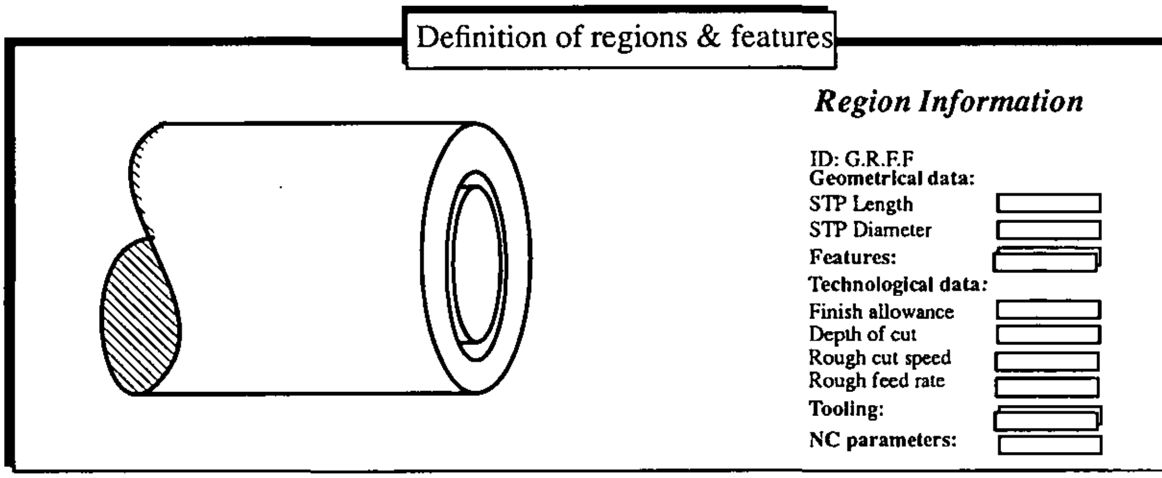

Example
Feature Information
Geometrical data:
STP X
STP Z
STP Y
EDP X
EDP Y
EDP Z
Radius.
Technological data:
Surface Finish
Attribute:
Chamfer
Corner

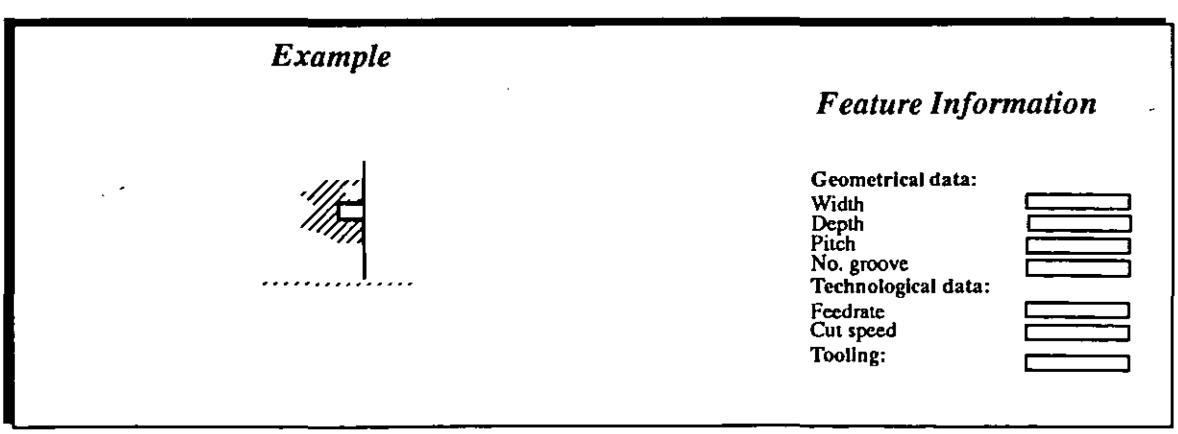
Selection of regions & features

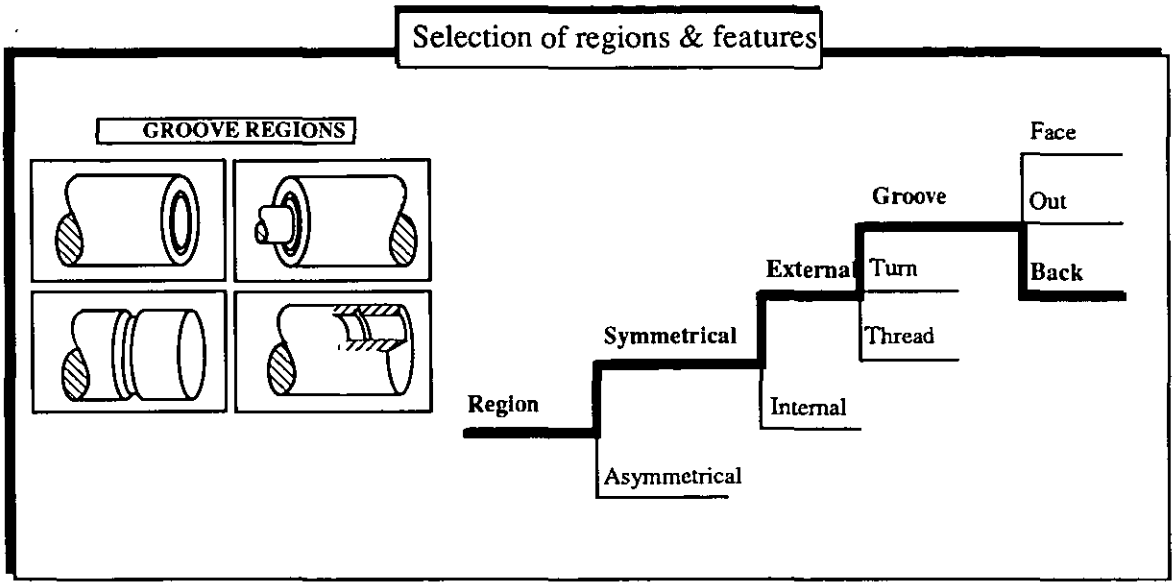


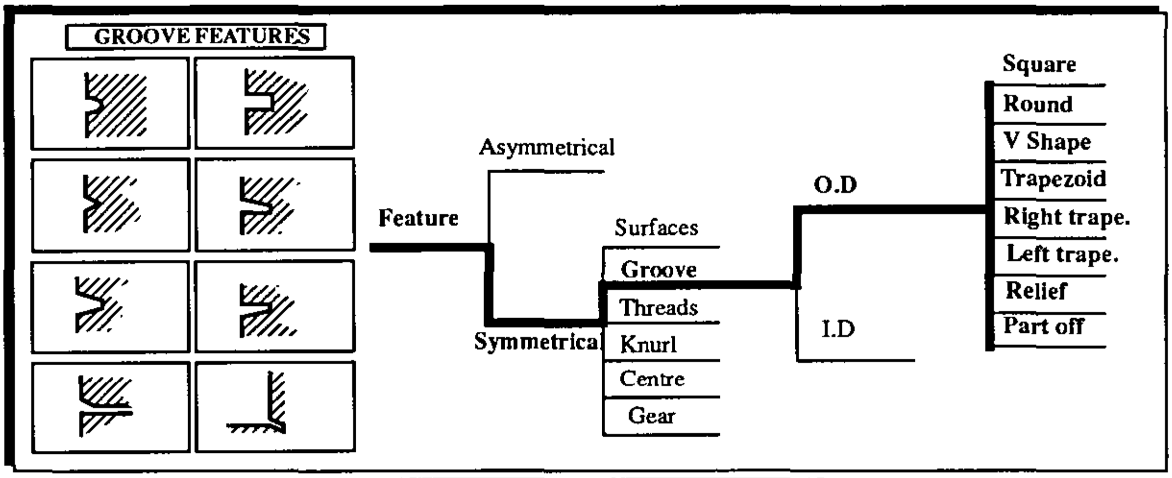


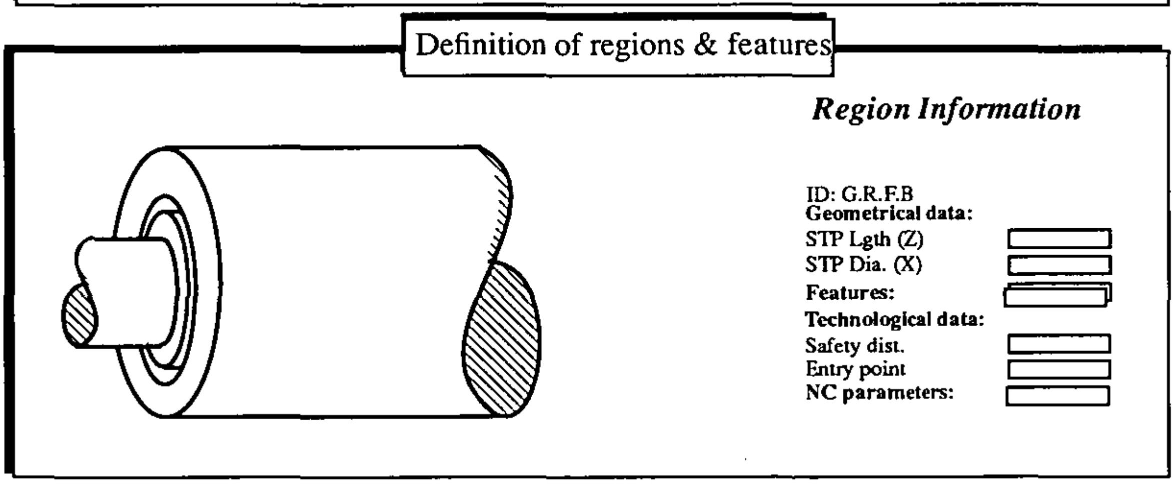
Definition of regions & features

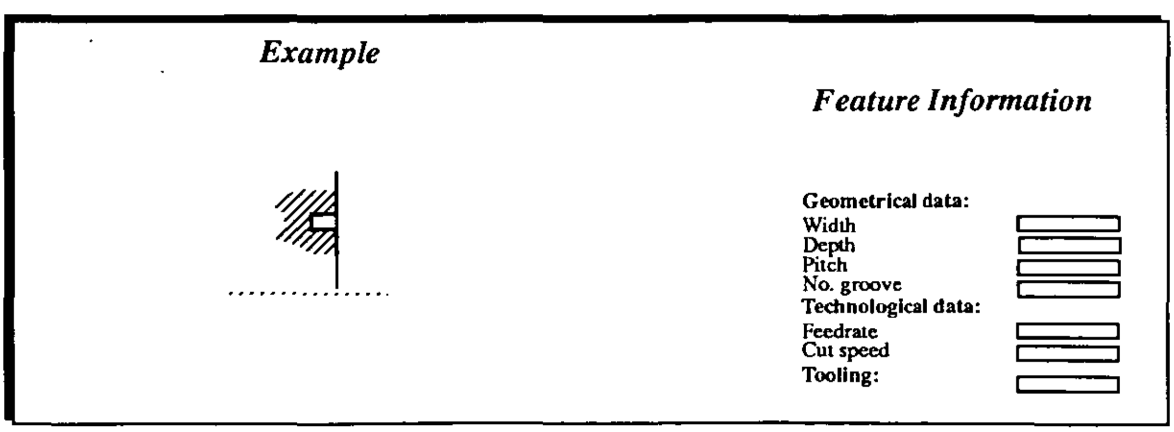




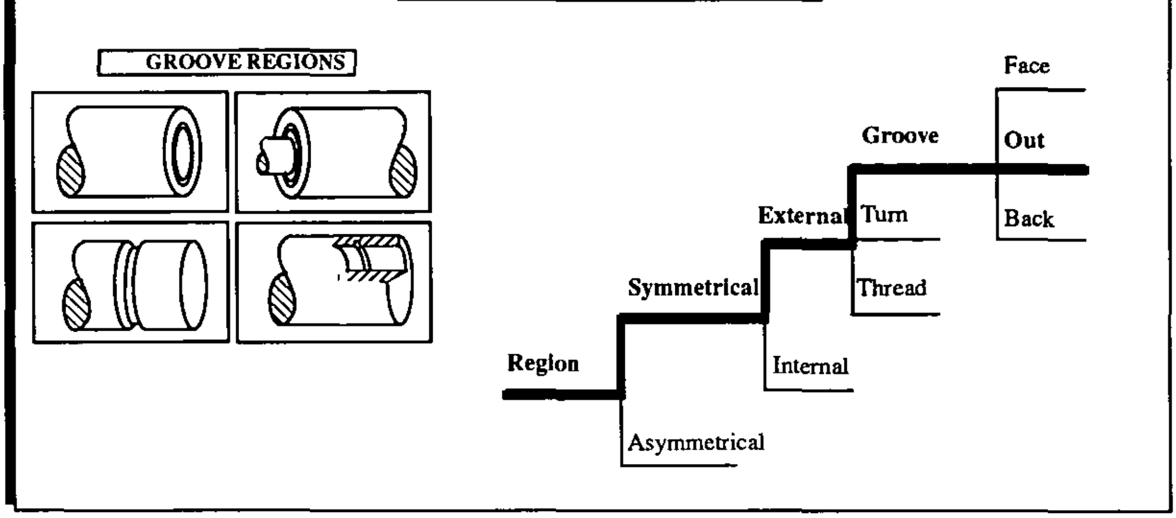

Selection of regions & features
GROOVE REGIONS
Face
Out
Back
Groove
Turn
Thread
External
Internal
Symmetrical
Asymmetrical
Region

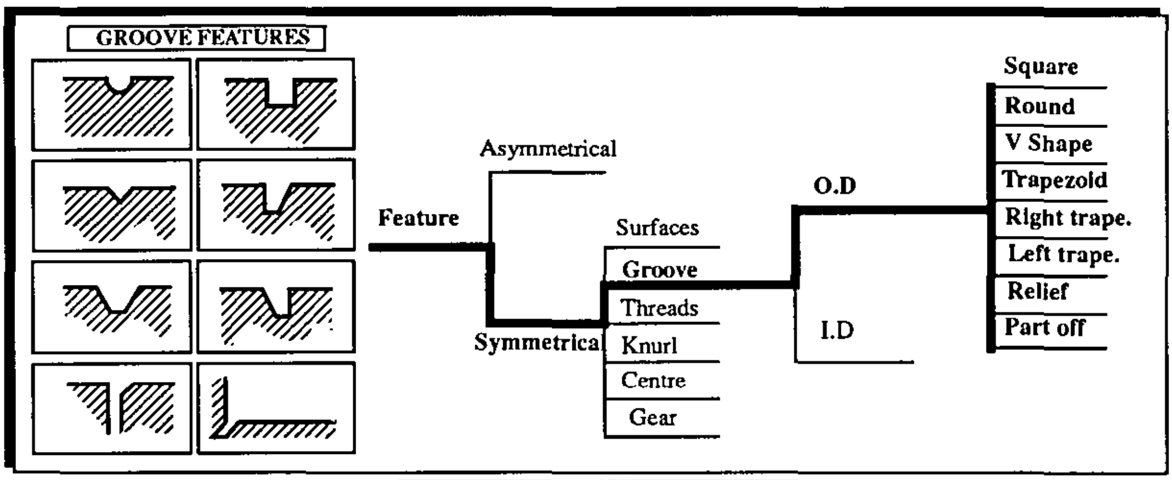

GROOVE FEATURES
Feature
Asymmetrical
Symmetrical
Surfaces
Groove
Threads
Knurl
Centre
Gear
O.D
I.D
Square
Round
V Shape
Trapezoid
Right trape.
Left trape.
Relief
Part off


Definition of regions & features
Region Information
ID: G.R.F.B
Geometrical data:
STP Lgth (Z)
STP Dia. (X)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:

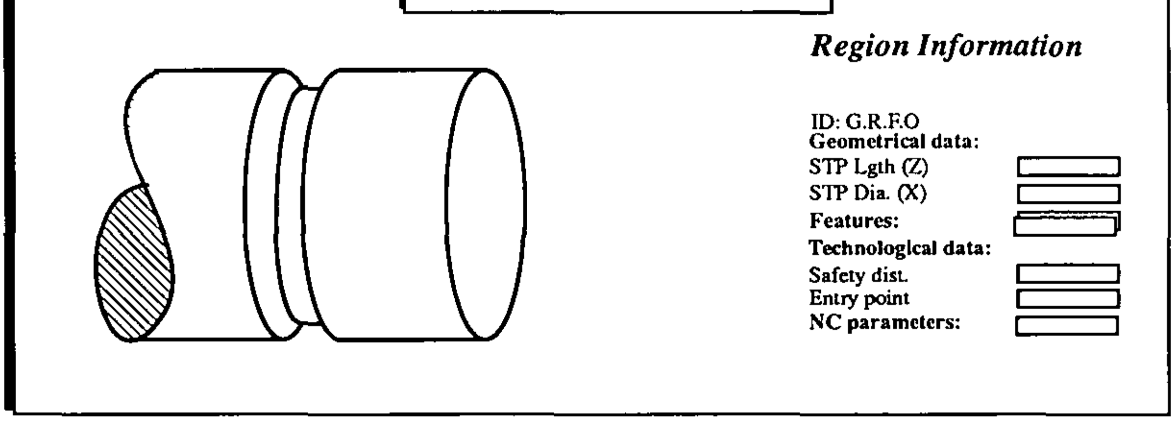

Example
Feature Information
Geometrical data:
Width
Depth
Pitch
No. groove
Technological data:
Feedrate
Cut speed
Tooling:

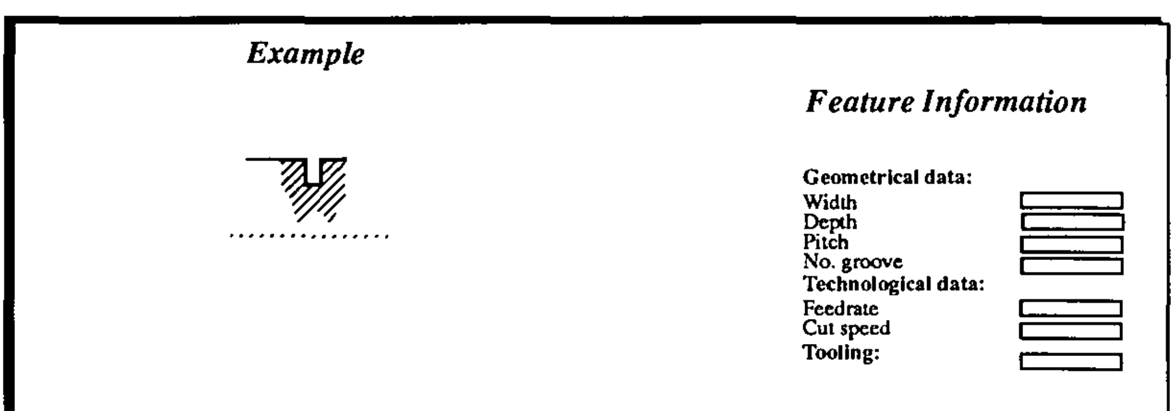
Selection of regions & features



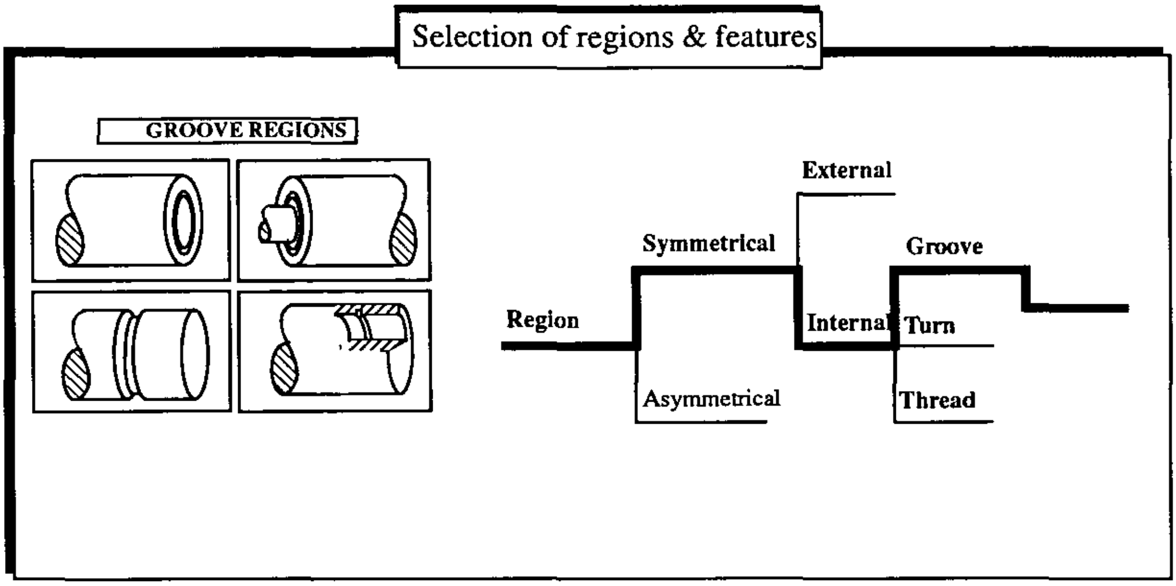


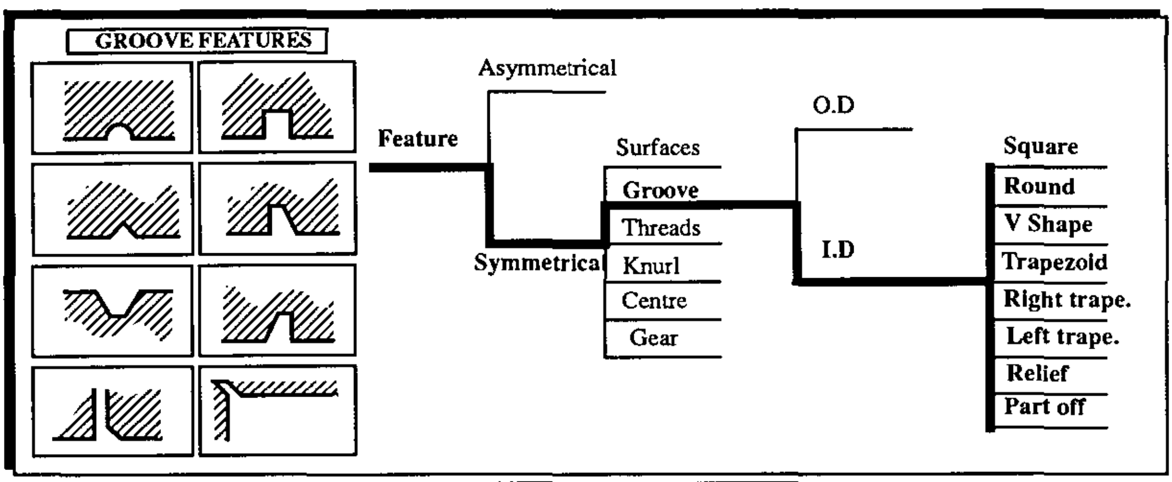
Definition of regions & features

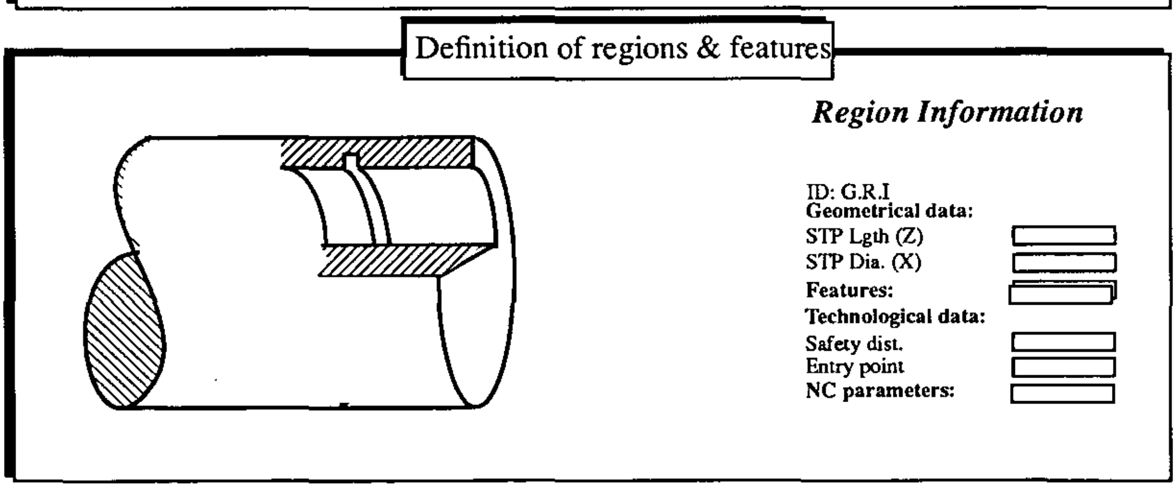


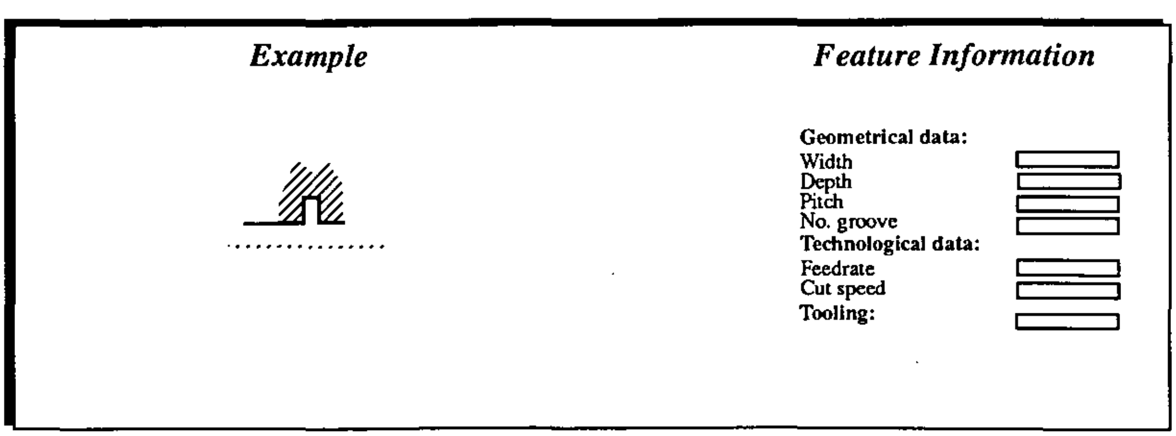


APPENDIX II

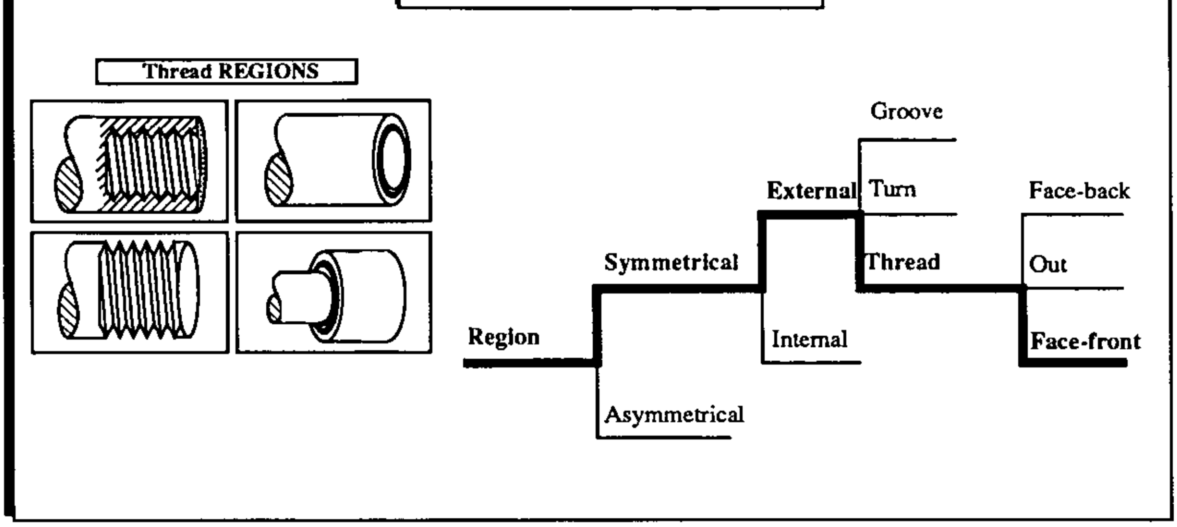

Selection of regions & features
GROOVE REGIONS
External
Symmetrical
Groove
Region
Internal
Turn
Asymmetrical
Thread

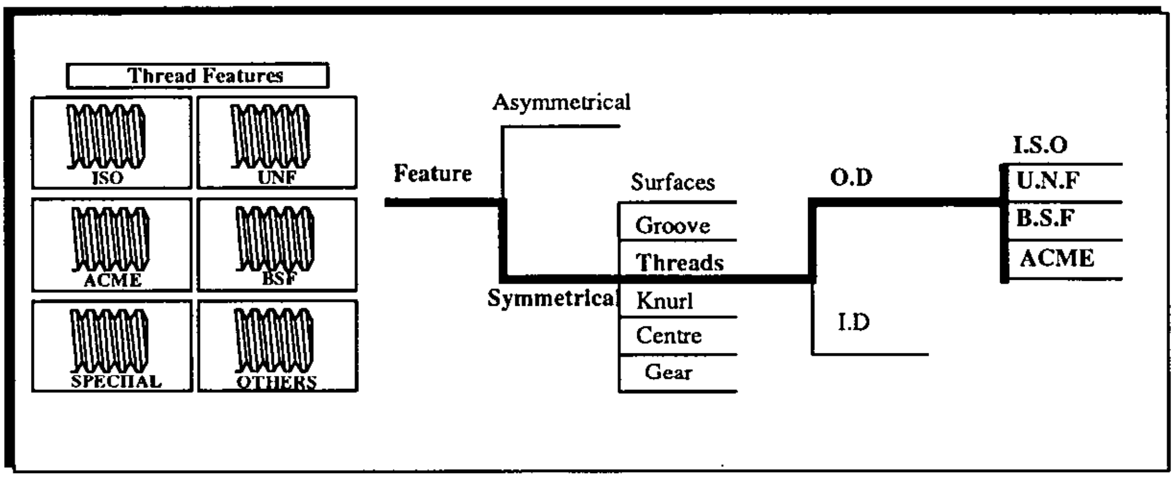

GROOVE FEATURES
Asymmetrical
O.D
Feature
Surfaces
Square
Groove
Round
Threads
V Shape
I.D
Symmetrical
Trapezoid
Knurl
Right trape.
Centre
Left trape.
Gear
Relief
Part off


Definition of regions & features
Region Information
ID: G.R.I
Geometrical data:
STP Lgth (Z)
STP Dia. (X)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:

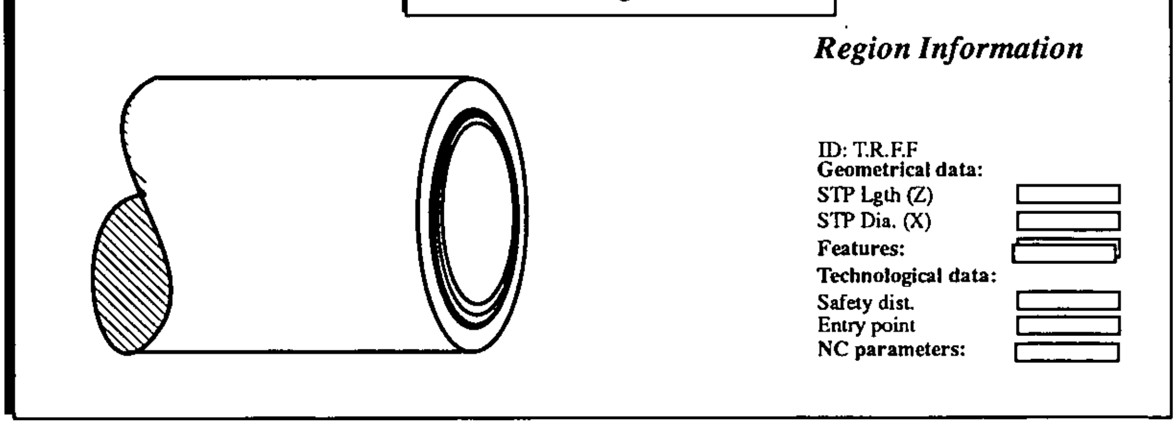

Example
Feature Information
Geometrical data:
Width
Depth
Pitch
No. groove
Technological data:
Feedrate
Cut speed
Tooling:

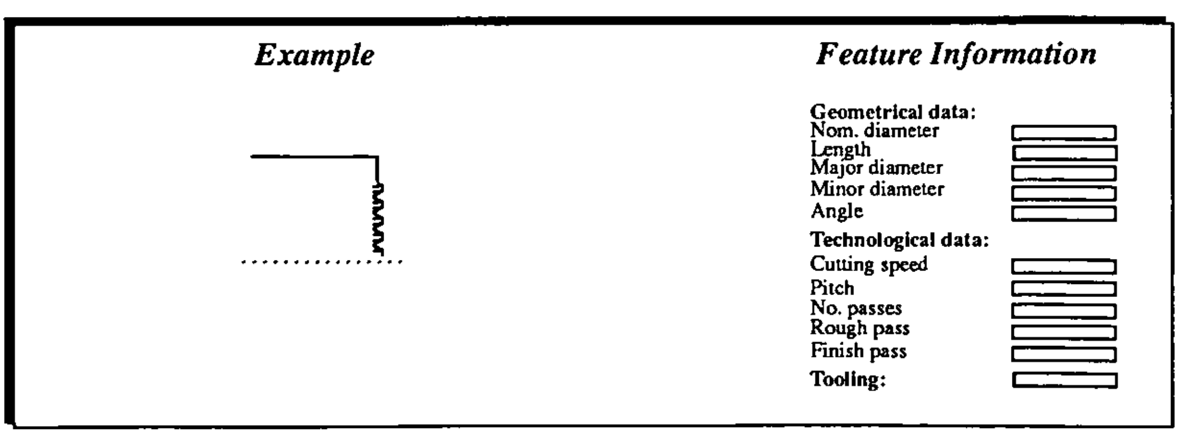
Selection of regions & features

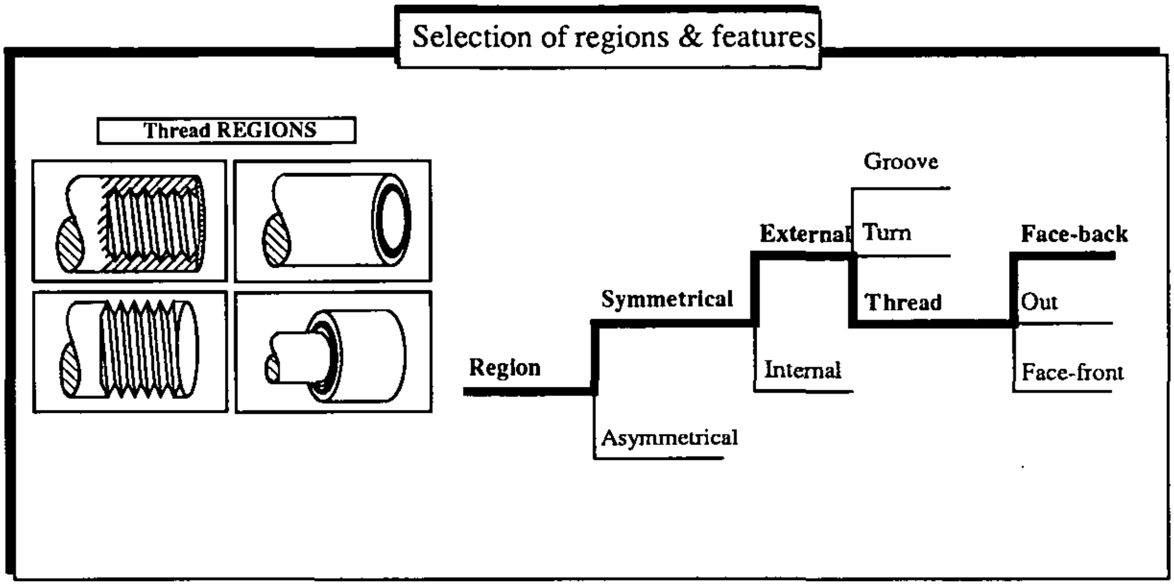


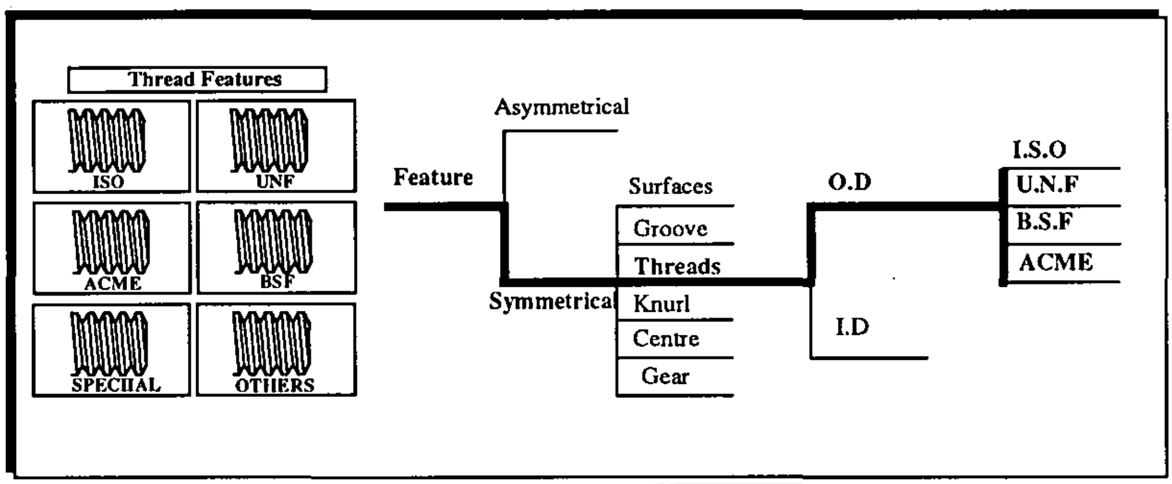


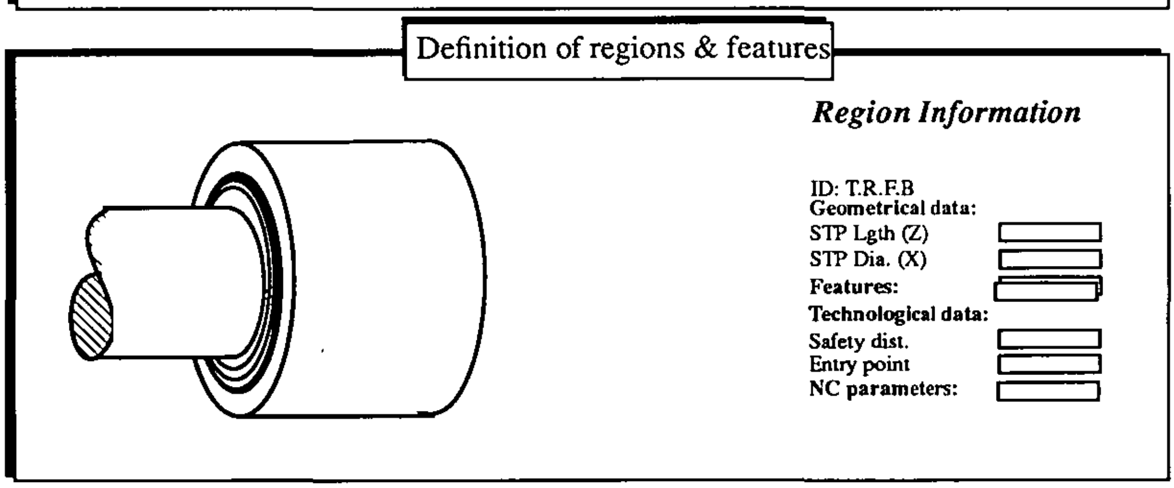
Definition of regions & features

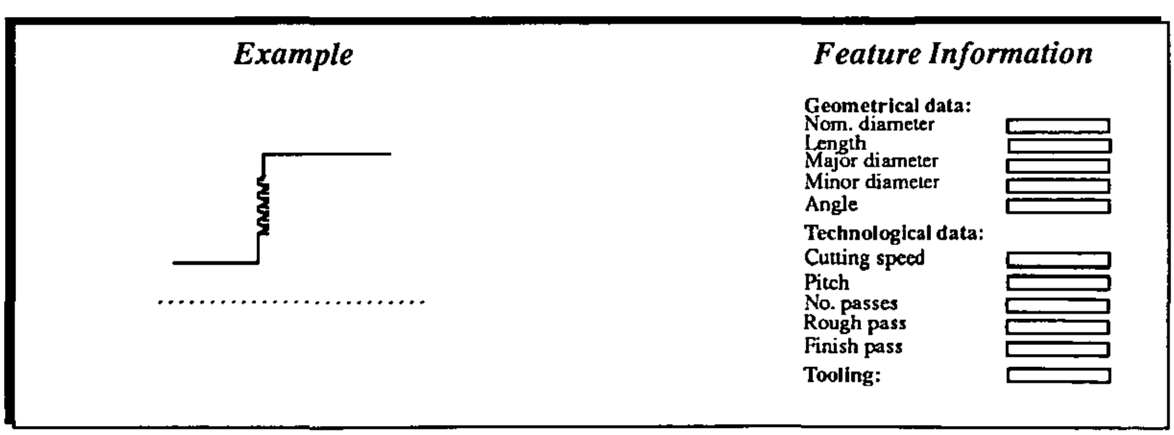


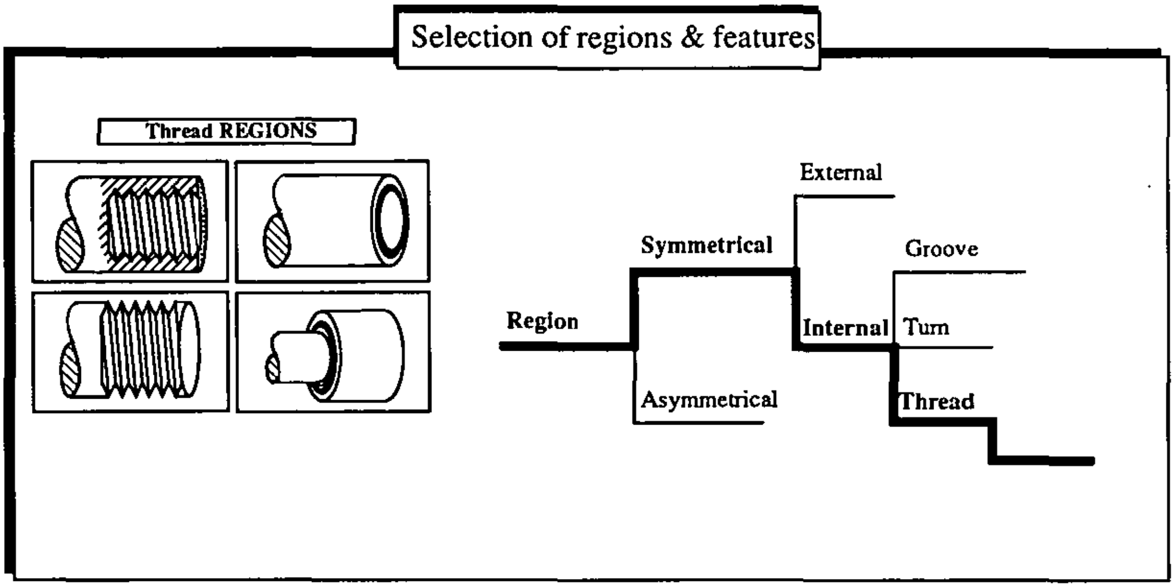


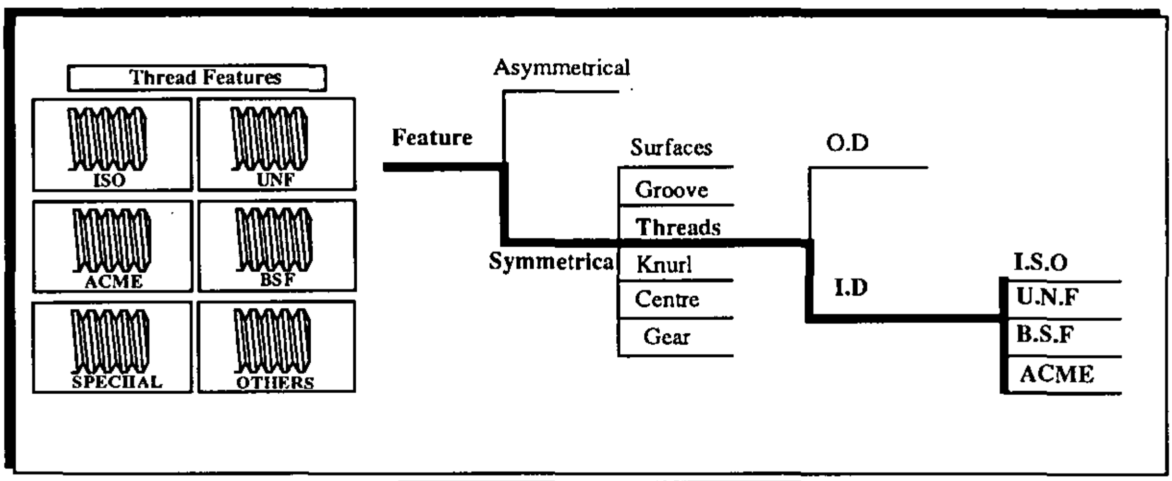

Selection of regions & features
Thread REGIONS
Region
Symmetrical
Asymmetrical
External
Internal
Groove
Turn
Thread
Face-back
Out
Face-front

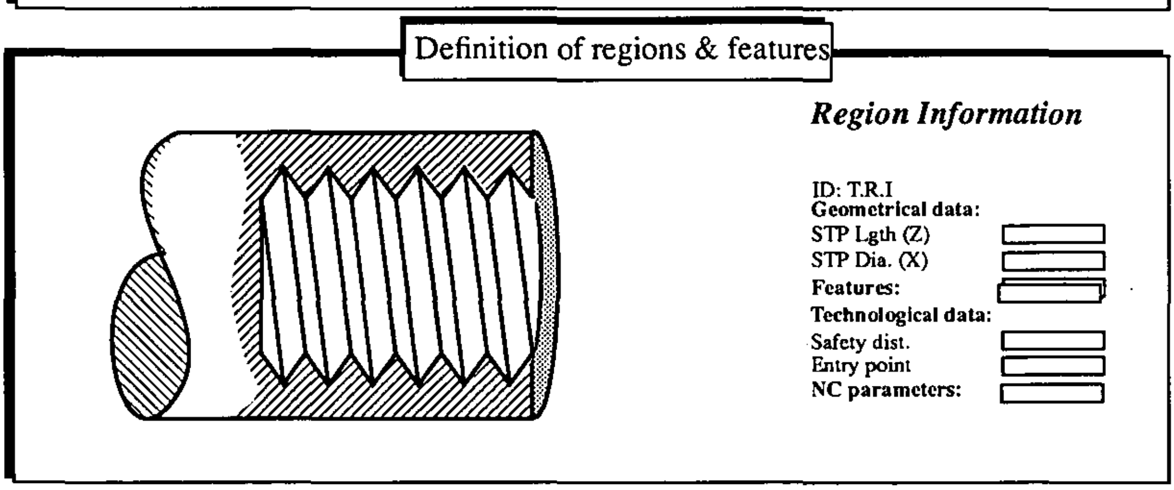

Thread Features
ISO
UNF
ACME
BSF
SPECIAL
OTHERS
Feature
Asymmetrical
Symmetrical
Surfaces
Groove
Threads
Knurl
Centre
Gear
O.D
I.D
I.S.O
U.N.F
B.S.F
ACME

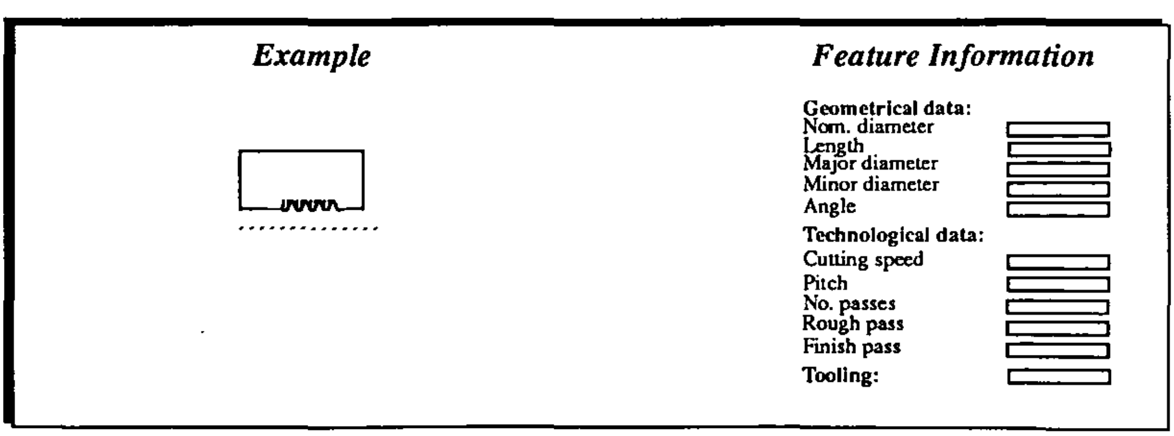

Definition of regions & features
Region Information
ID: T.R.F.B
Geometrical data:
STP Lgth (Z)
STP Dia. (X)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:


Example
Feature Information
Geometrical data:
Nom. diameter
Length
Major diameter
Minor diameter
Angle
Technological data:
Cutting speed
Pitch
No. passes
Rough pass
Finish pass
Tooling:

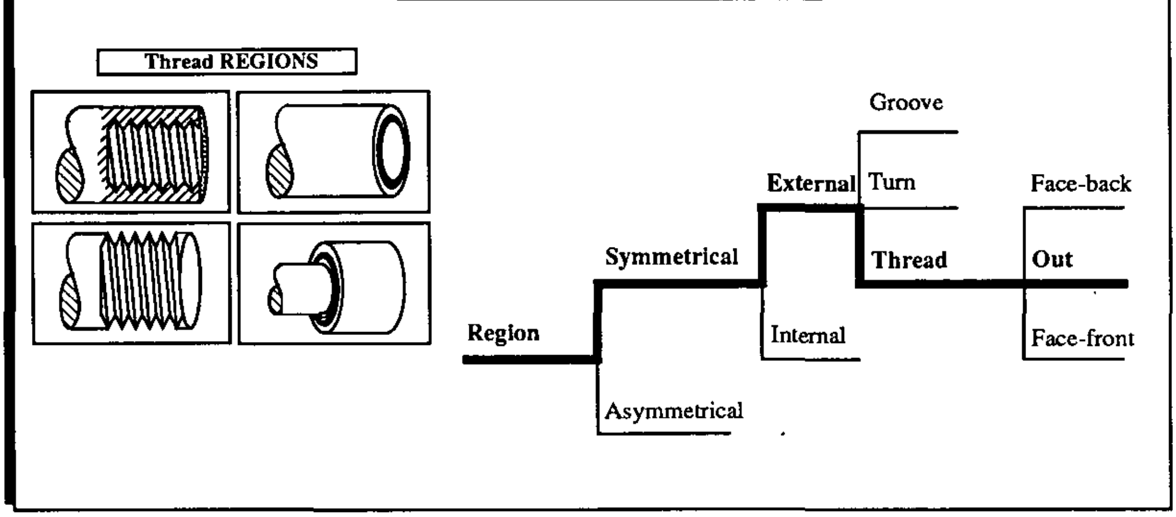

Selection of regions & features
Thread REGIONS
External
Symmetrical
Groove
Region
Internal
Turn
Asymmetrical
Thread

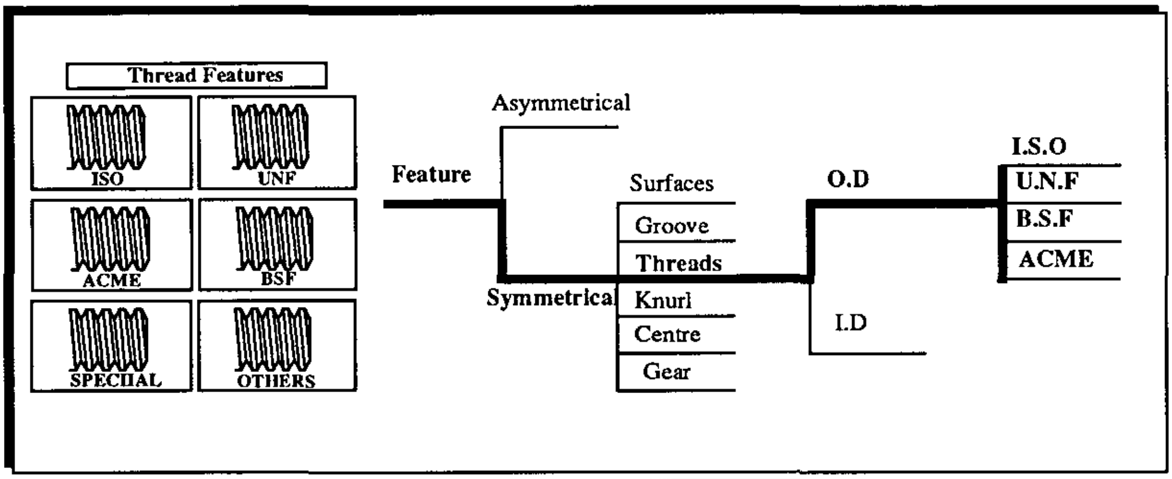

Thread Features
ISO
UNF
ACME
BSF
SPECIAL
OTHERS
Asymmetrical
Feature
Surfaces
O.D
Groove
Threads
Symmetrica
Knurl
Centre
Gear
I.D
I.S.O
U.N.F
B.S.F
ACME


Definition of regions & features
Region Information
ID: T.R.I
Geometrical data:
STP Lgth (Z)
STP Dia. (X)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:

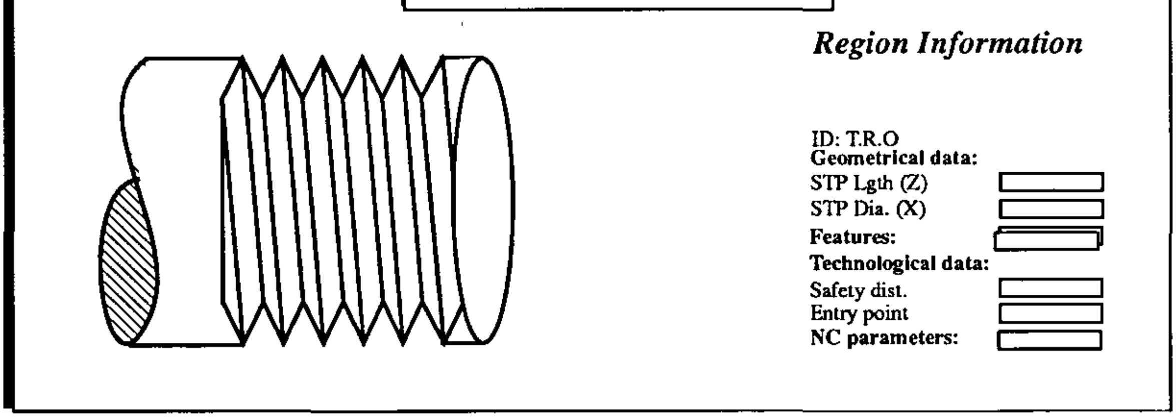

Example
Feature Information
Geometrical data:
Nom. diameter
Length
Major diameter
Minor diameter
Angle
Technological data:
Cutting speed
Pitch
No. passes
Rough pass
Finish pass
Tooling:

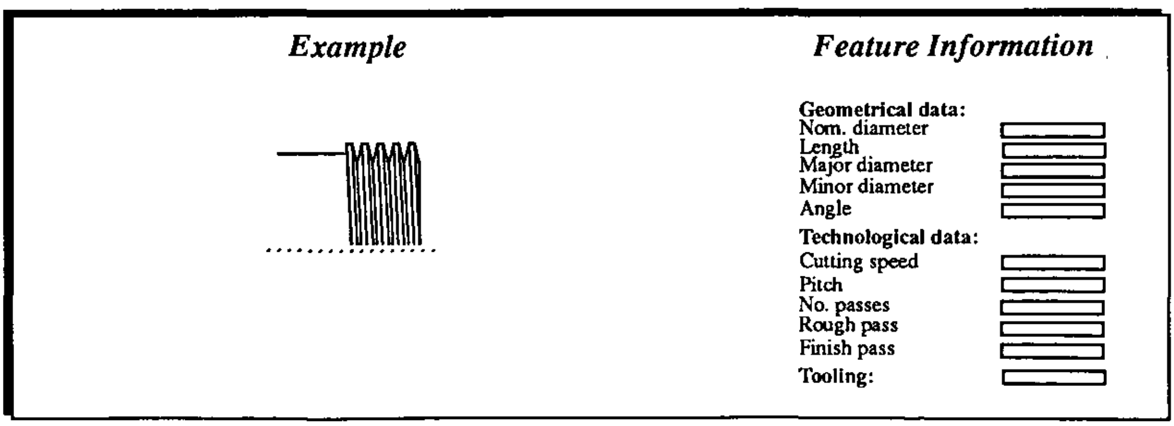
Selection of regions & features





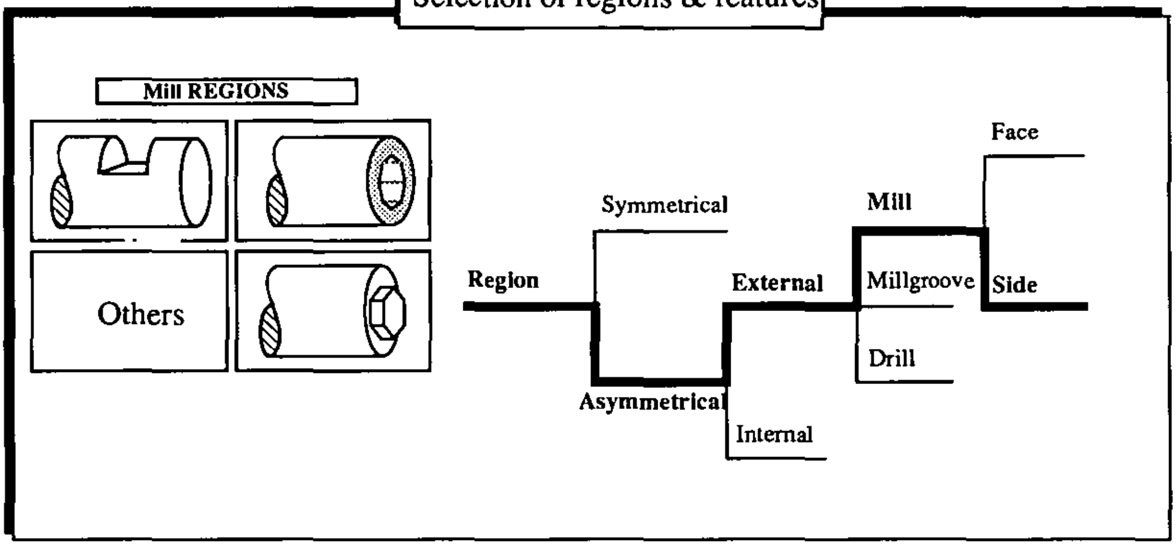
Definition of regions & features

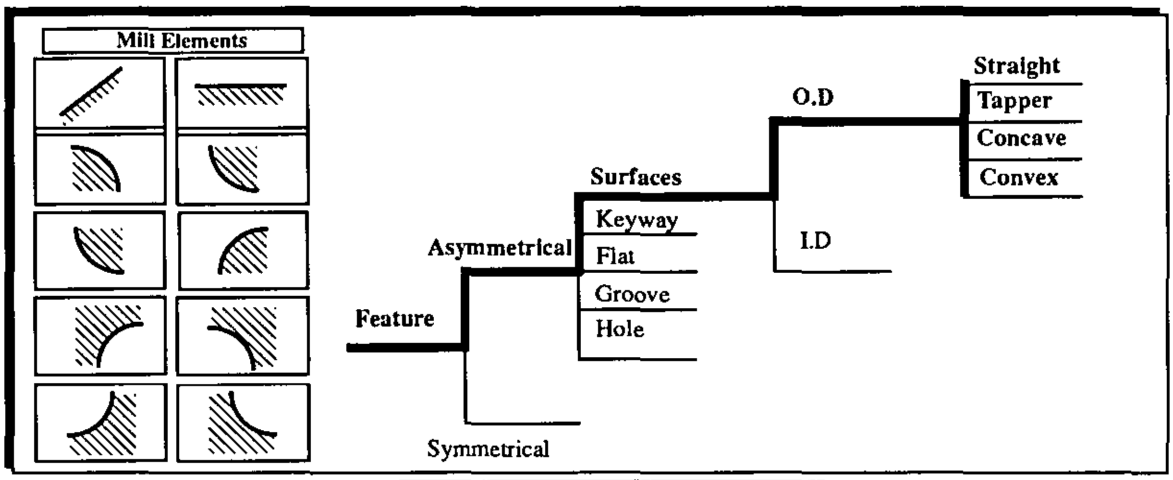




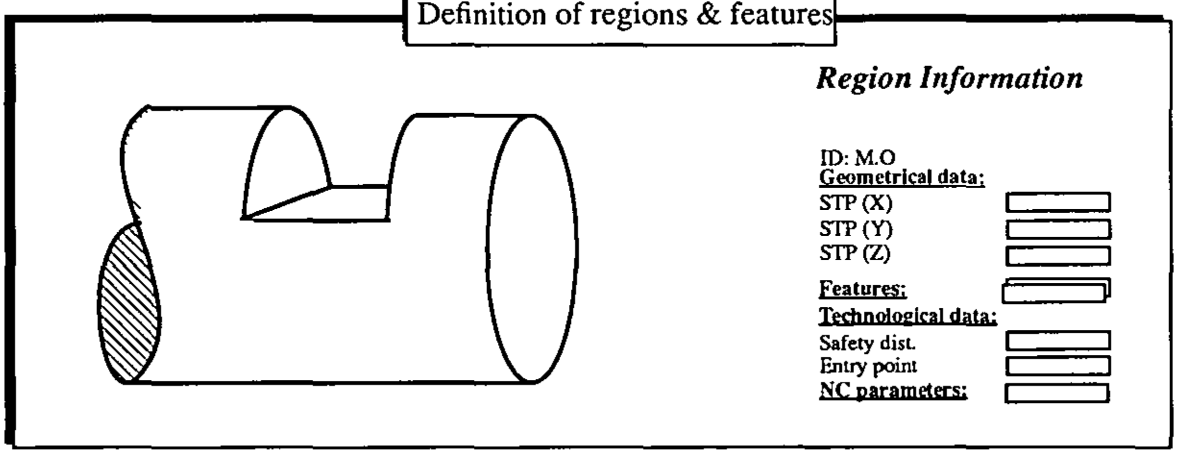
APPENDIX II

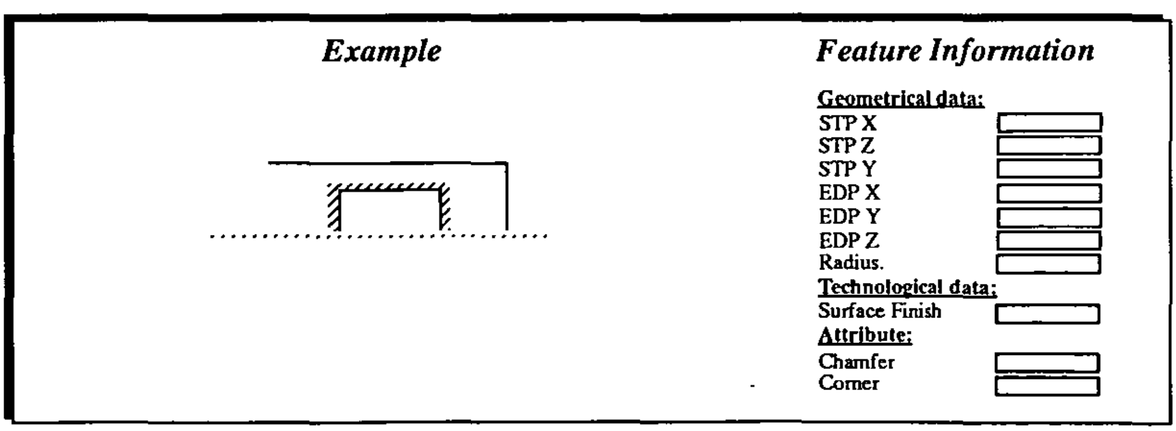
Selection of regions & features



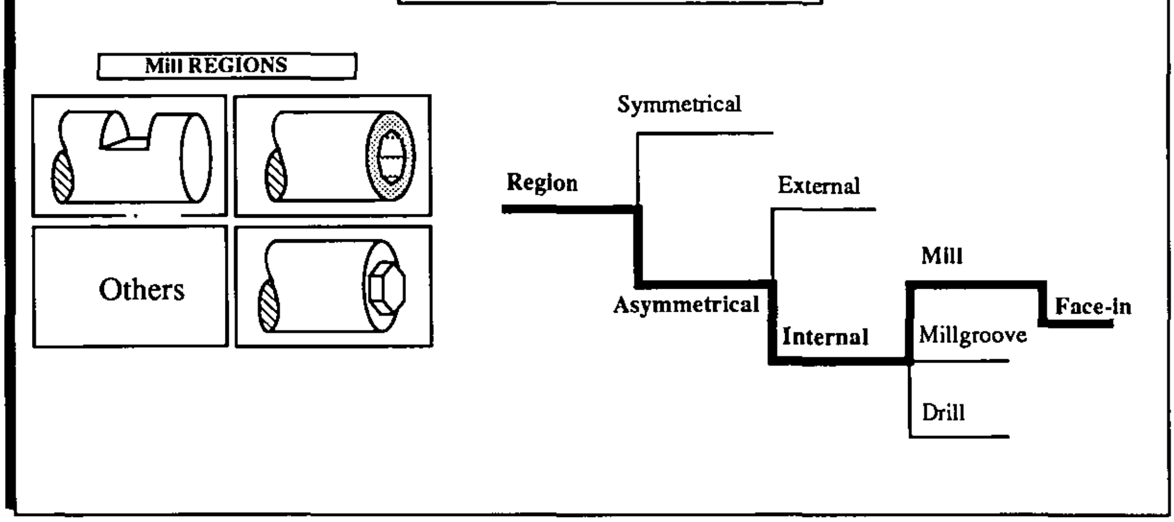


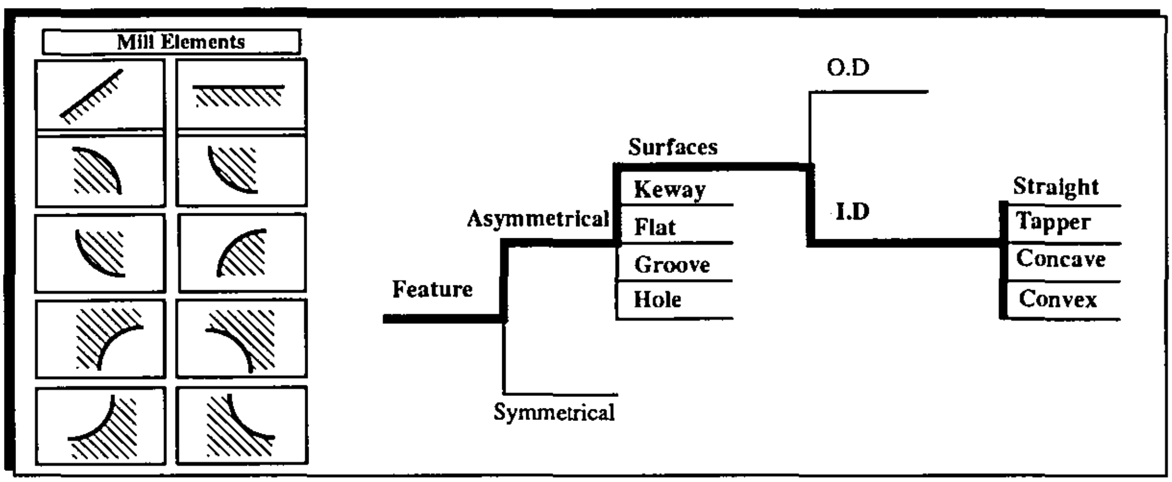
Definition of regions & features



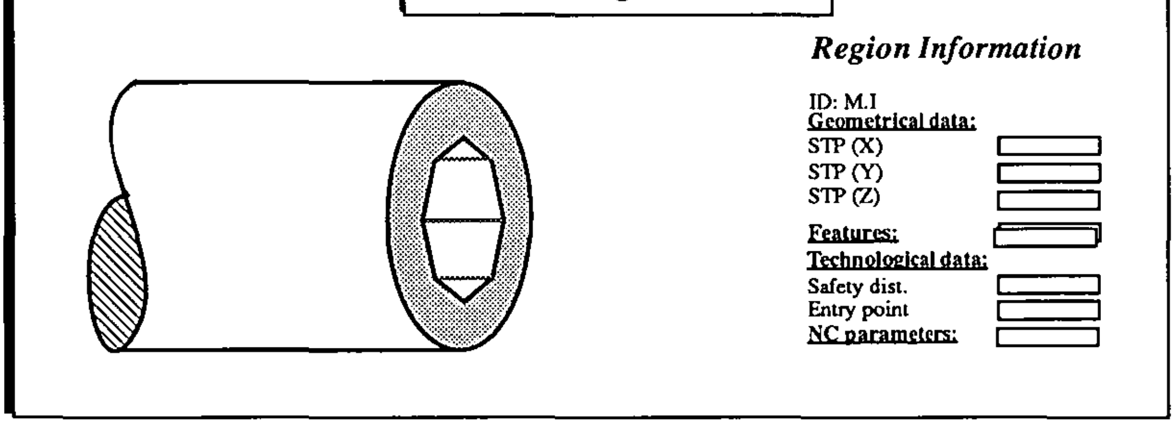


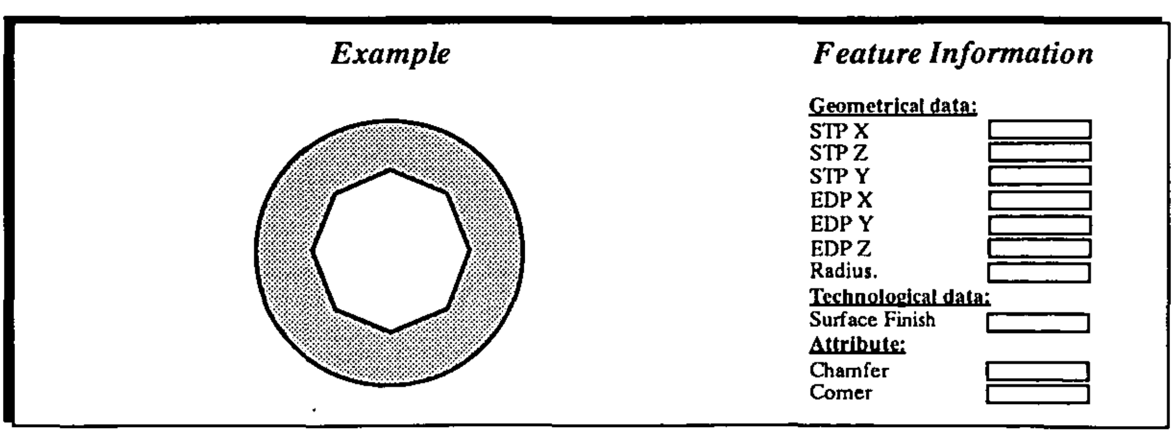
Selection of regions & features



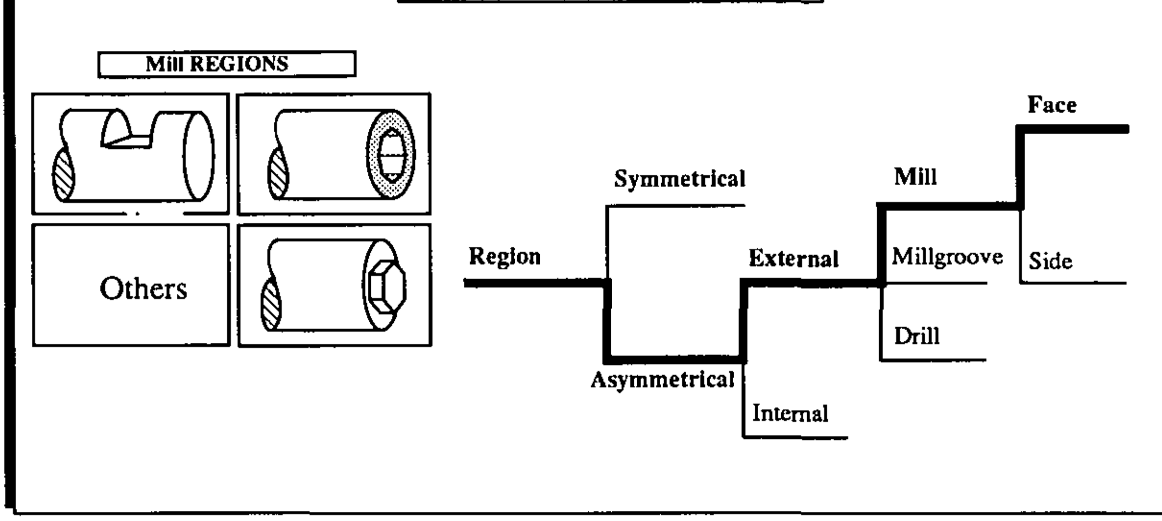


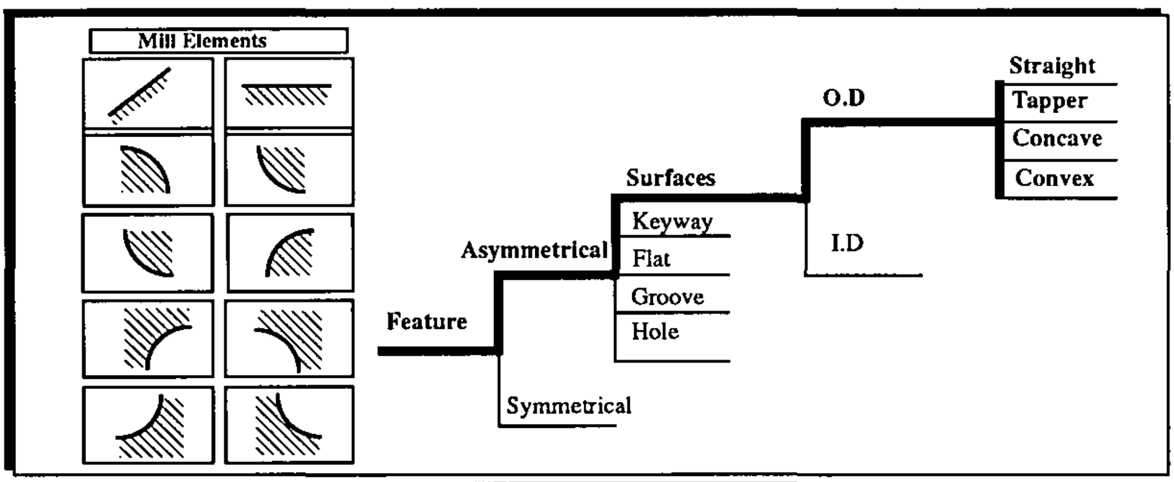
Definition of regions & features



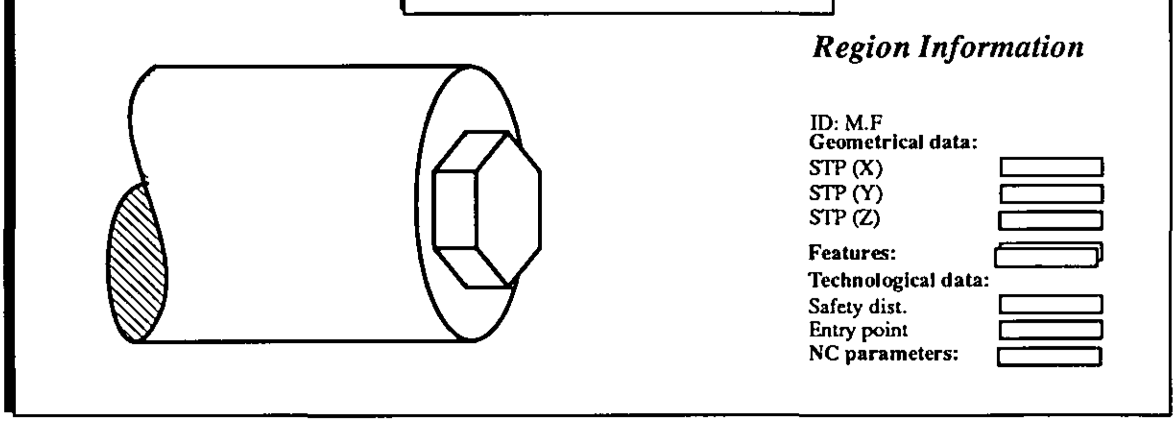


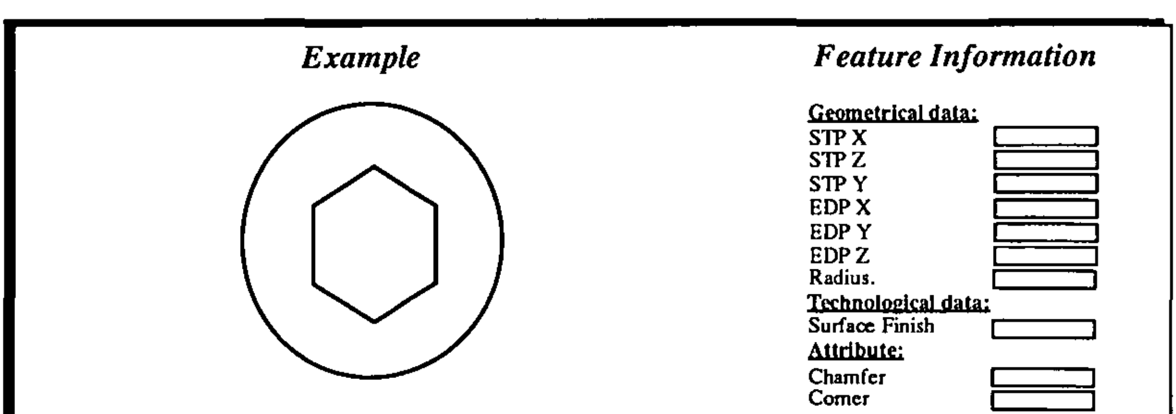
Selection of regions & features

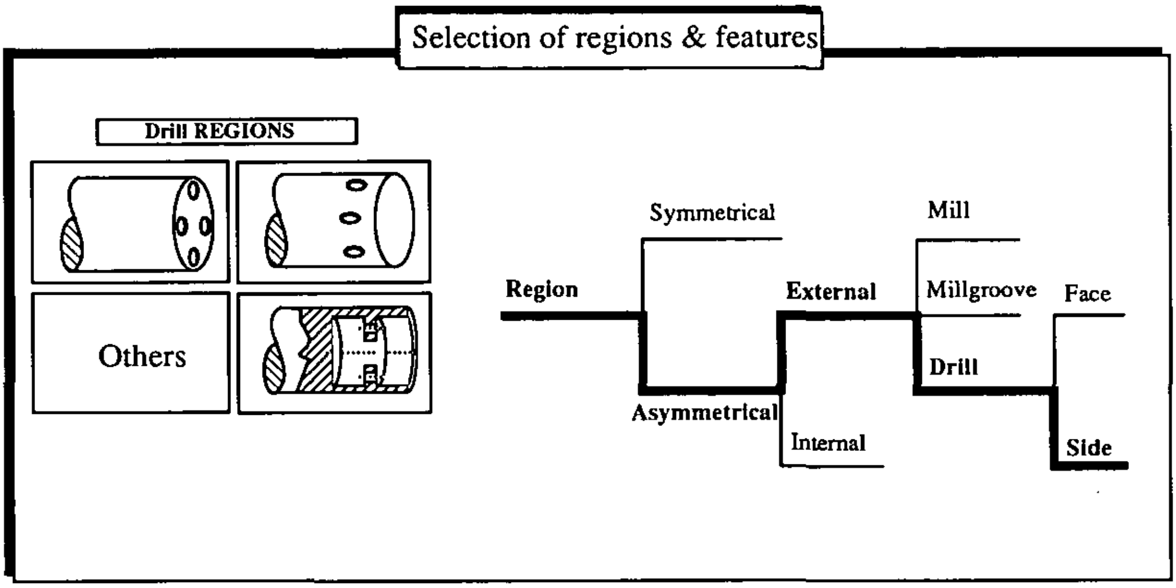


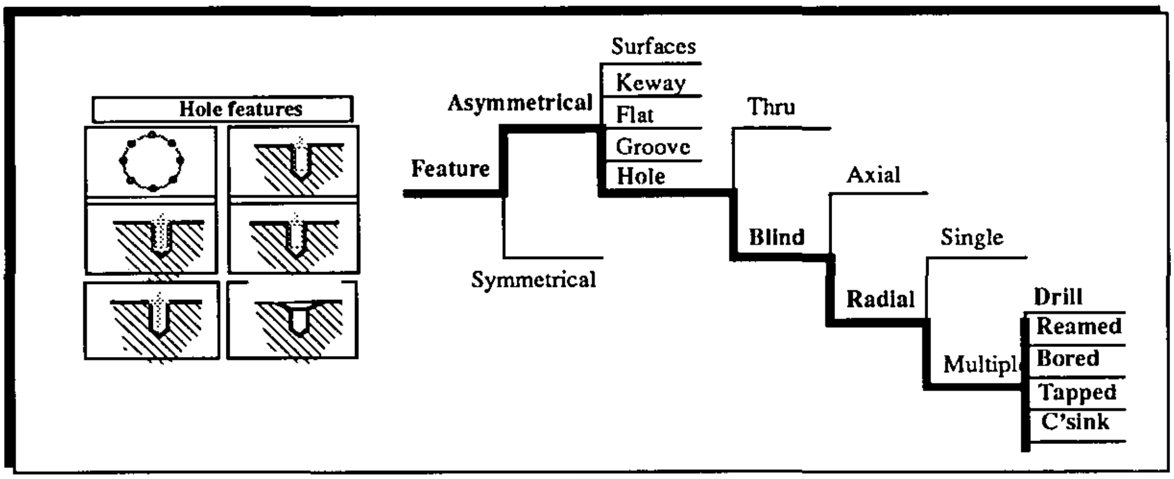


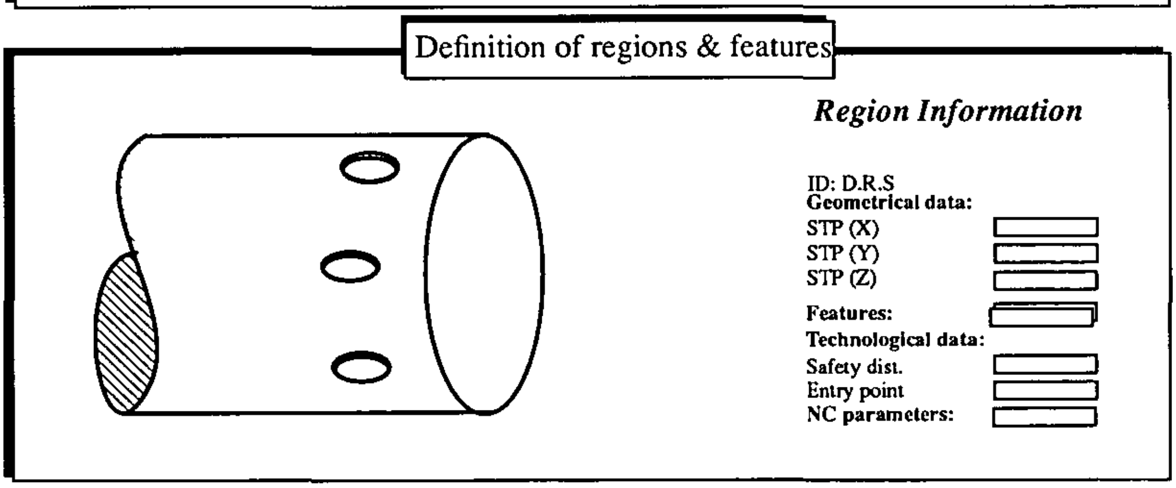
Definition of regions & features

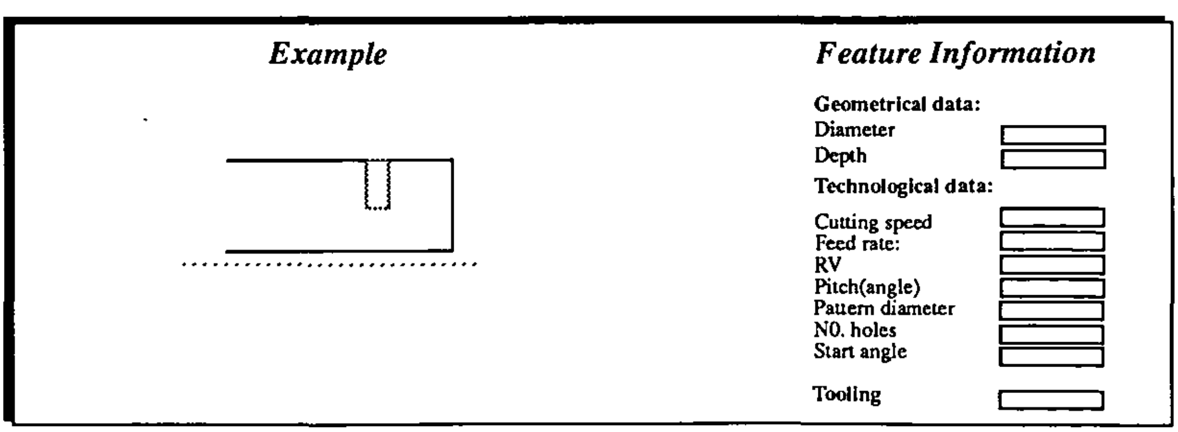


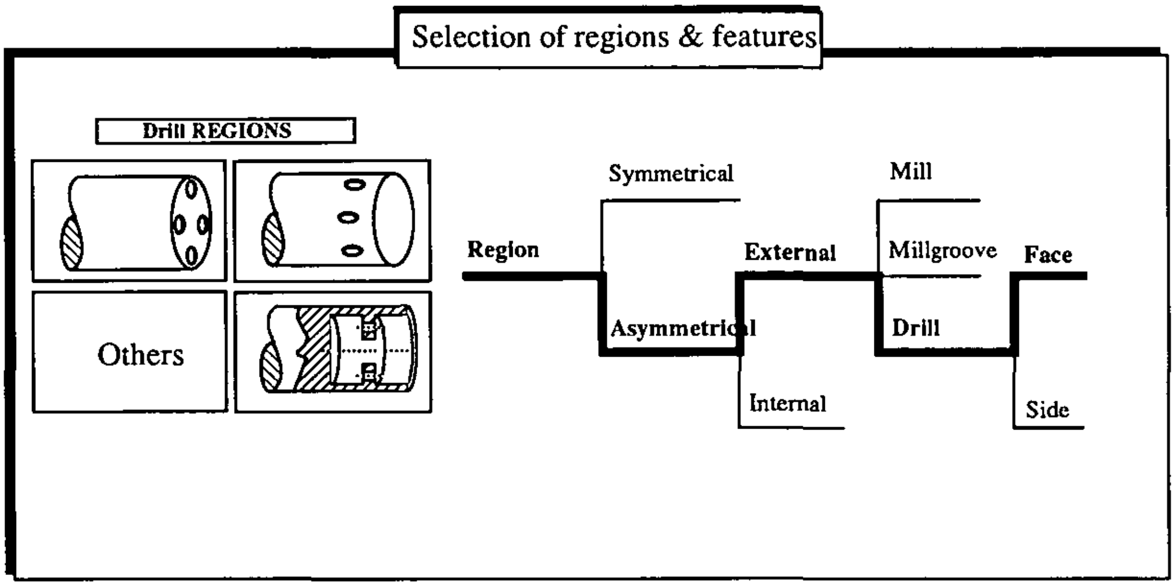


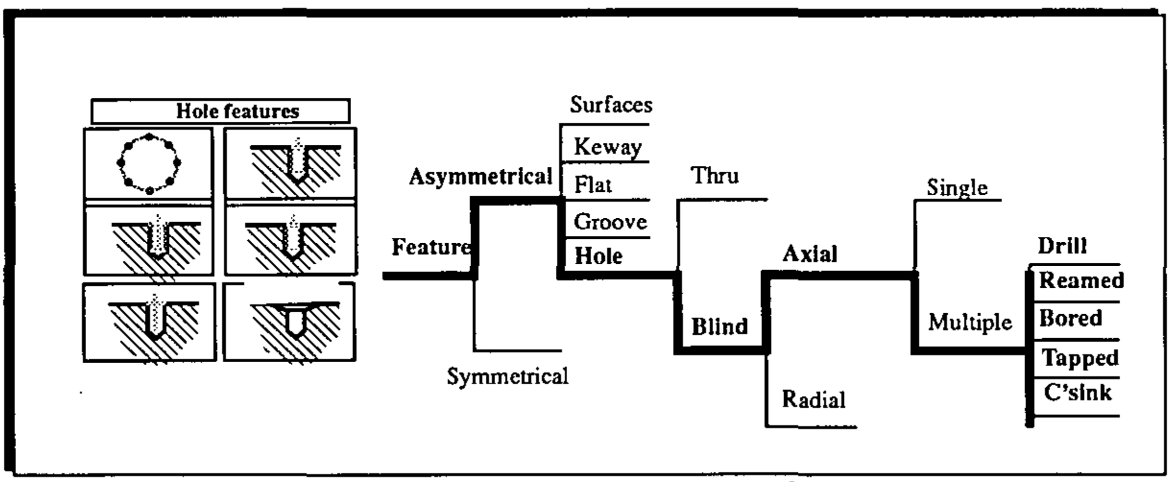

Selection of regions & features
Drill REGIONS
Others
Region
Symmetrical
Asymmetrical
External
Internal
Mill
Millgroove
Drill
Face
Side

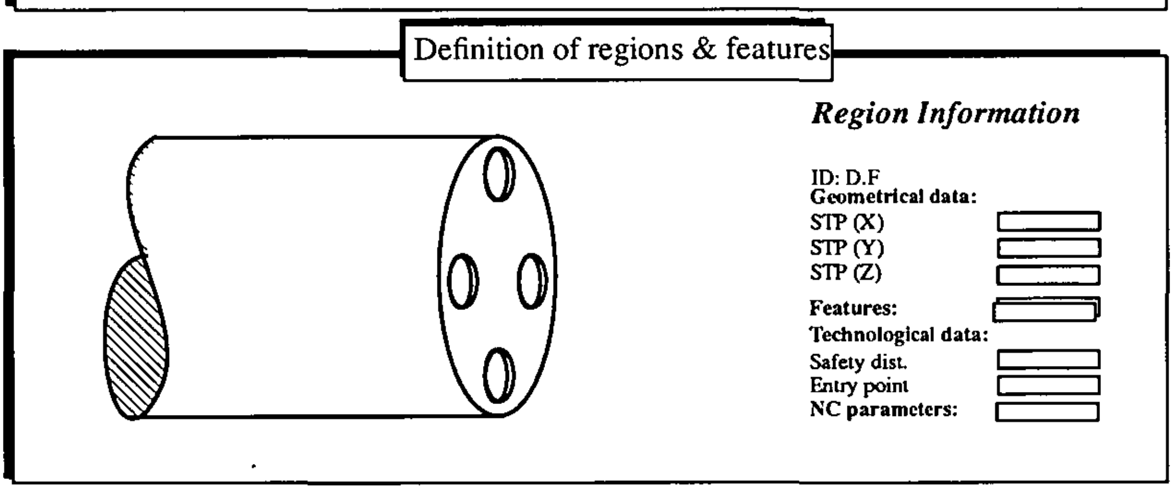

Hole features
Feature
Asymmetrical
Symmetrical
Surfaces
Keway
Flat
Groove
Hole
Thru
Blind
Axial
Radial
Single
Multipl
Drill
Reamed
Bored
Tapped
C'sink

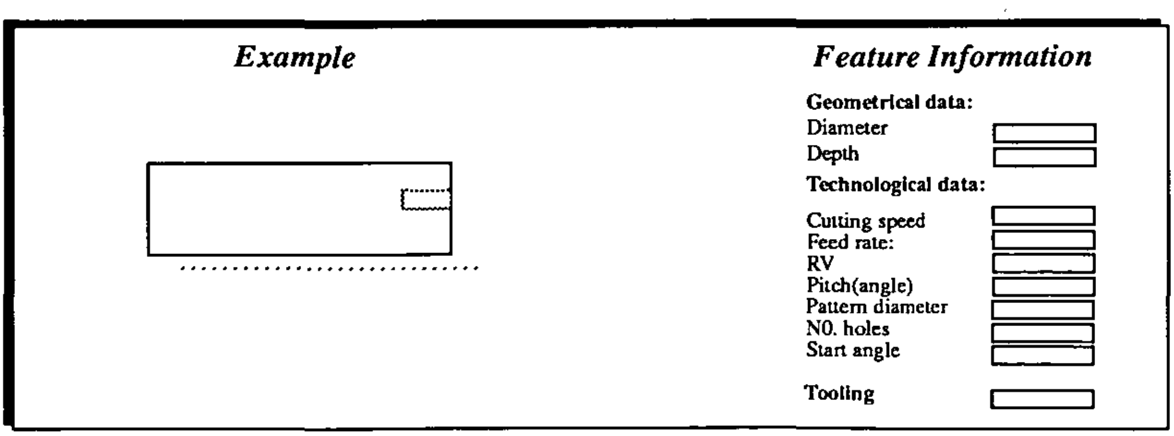

Definition of regions & features
Region Information
ID: D.R.S
Geometrical data:
STP (X)
STP (Y)
STP (Z)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:

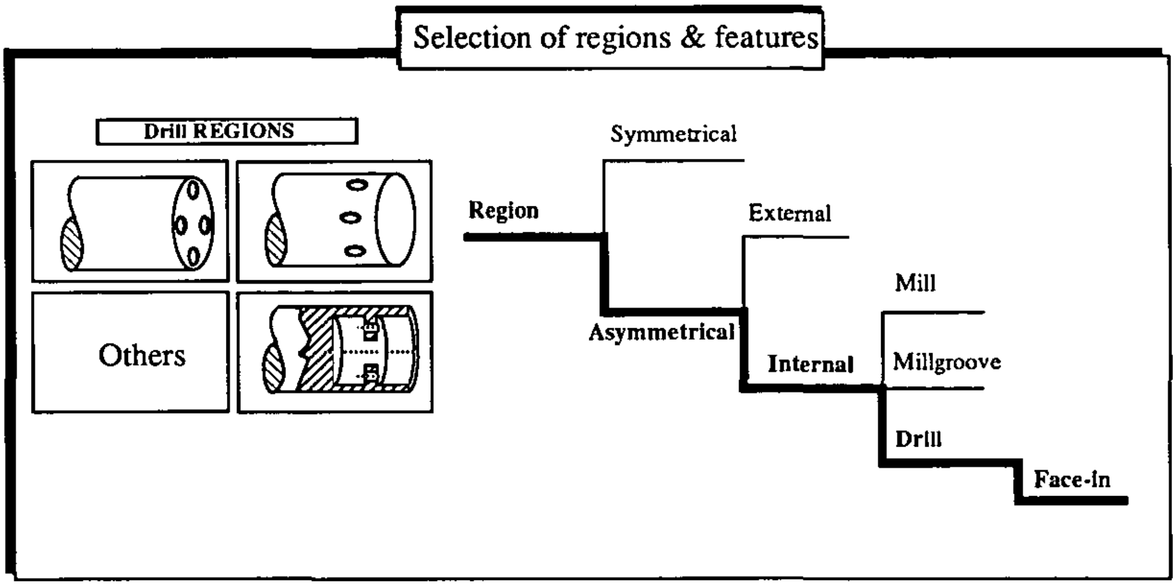

Example
Feature Information
Geometrical data:
Diameter
Depth
Technological data:
Cutting speed
Feed rate:
RV
Pitch(angle)
Pattern diameter
NO. holes
Start angle
Tooling

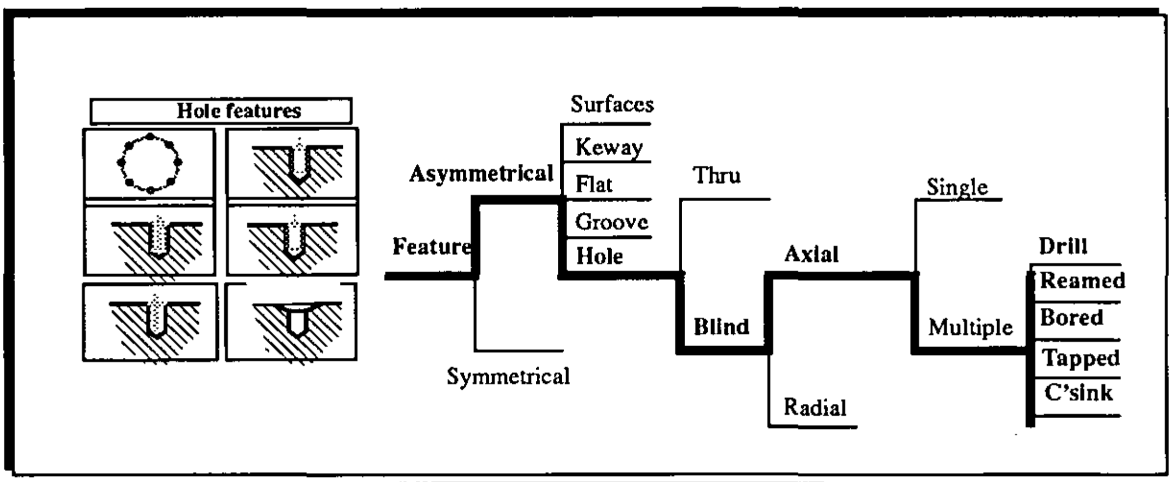

Selection of regions & features
Drill REGIONS
Others
Region
Symmetrical
Asymmetrical
External
Internal
Mill
Millgroove
Drill
Face
Side

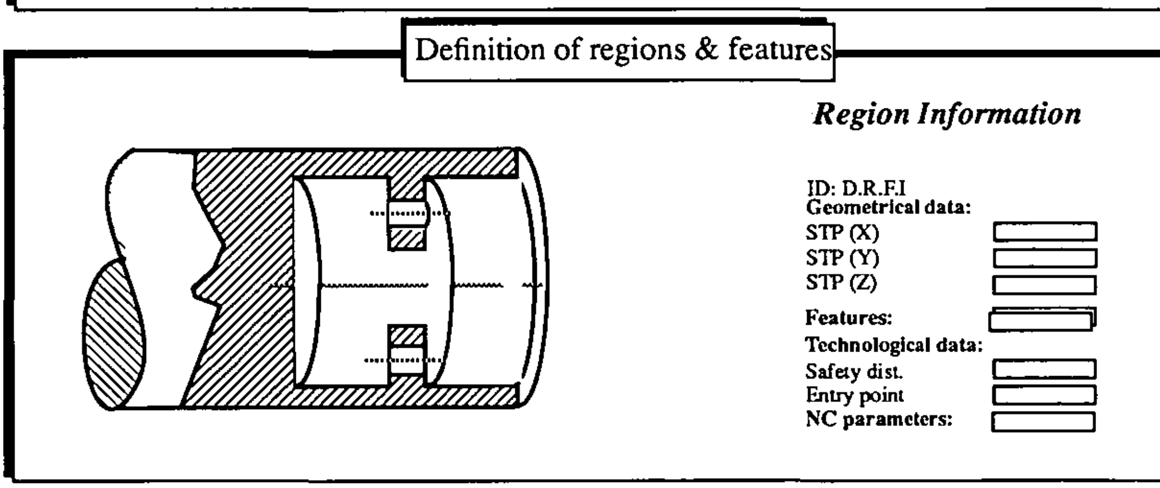

Hole features
Feature
Asymmetrical
Symmetrical
Surfaces
Keway
Flat
Groove
Hole
Thru
Blind
Axial
Radial
Single
Multiple
Drill
Reamed
Bored
Tapped
C'sink

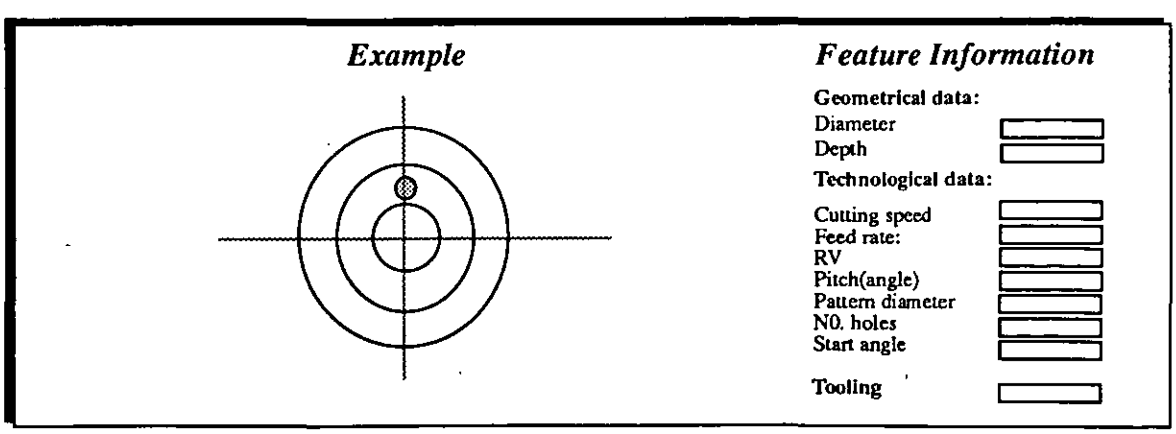

Definition of regions & features
Region Information
ID: D.F
Geometrical data:
STP (X)
STP (Y)
STP (Z)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:

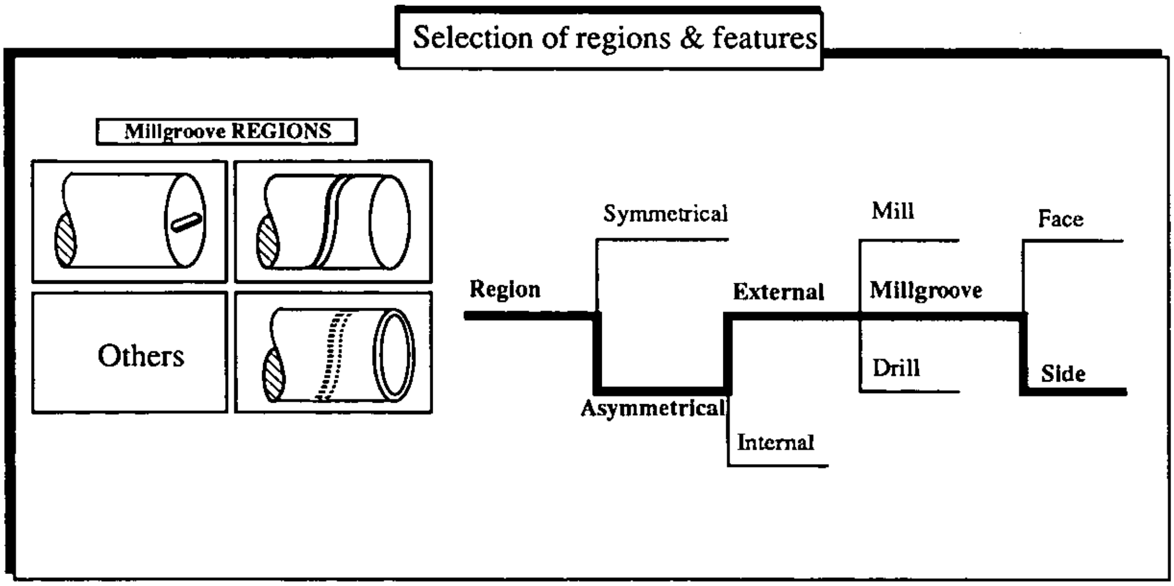

Example
Feature Information
Geometrical data:
Diameter
Depth
Technological data:
Cutting speed
Feed rate:
RV
Pitch(angle)
Pattern diameter
NO. holes
Start angle
Tooling

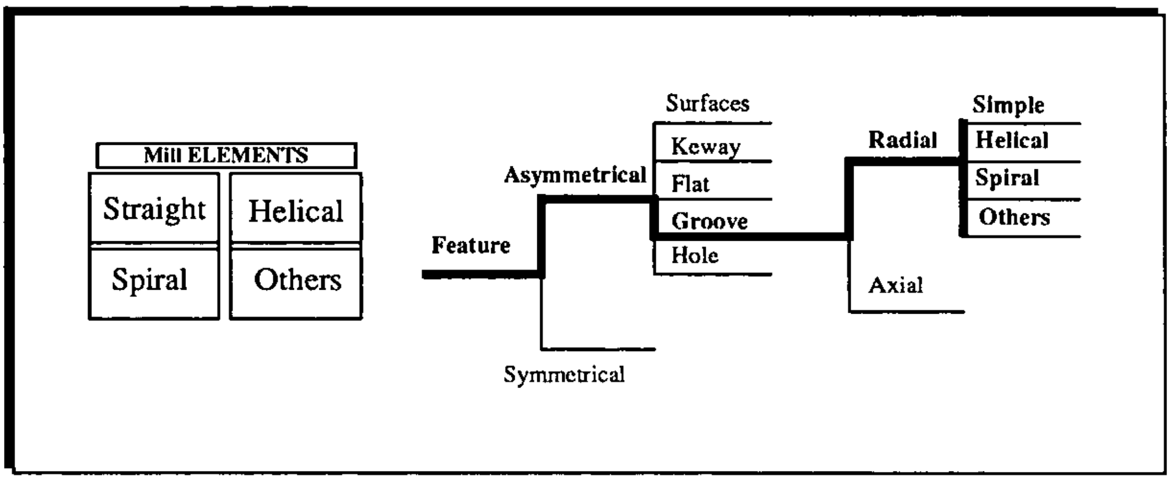

Selection of regions & features
Drill REGIONS
Others
Symmetrical
Region
External
Mill
Asymmetrical
Internal
Millgroove
Drill
Face-in

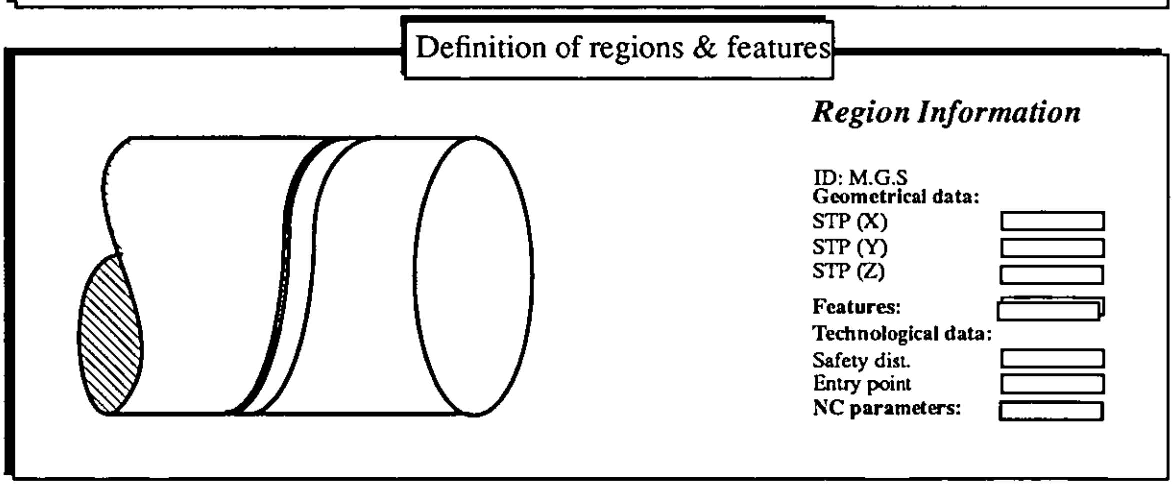

Hole features
Surfaces
Keway
Asymmetrical
Flat
Thru
Single
Groove
Feature
Hole
Axial
Drill
Reamed
Blind
Multiple
Bored
Tapped
Symmetrical
C'sink
Radial

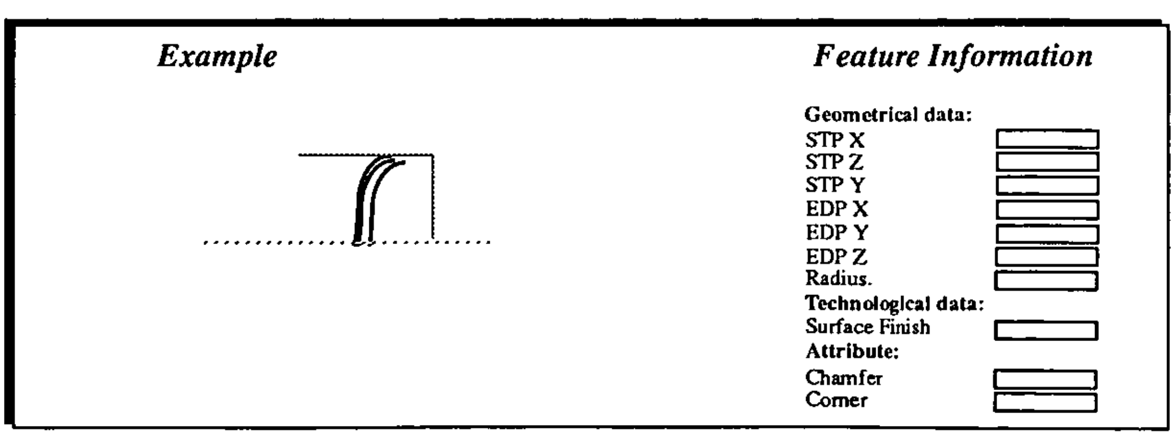

Definition of regions & features
Region Information
ID: D.R.F.I
Geometrical data:
STP (X)
STP (Y)
STP (Z)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:

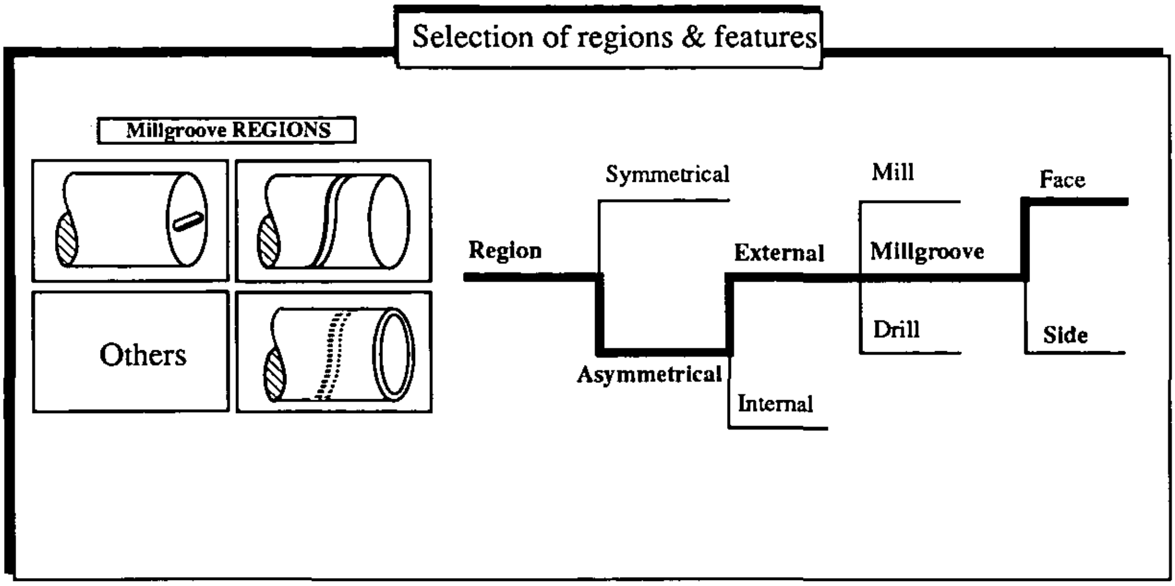

Example
Feature Information
Geometrical data:
Diameter
Depth
Technological data:
Cutting speed
Feed rate:
RV
Pitch(angle)
Pattern diameter
NO. holes
Start angle
Tooling

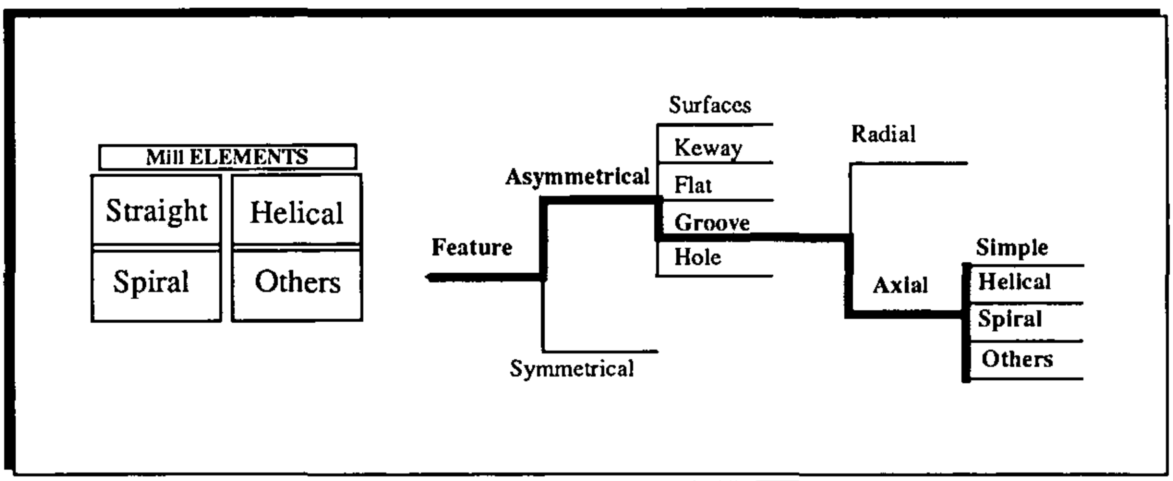

Selection of regions & features
Millgroove REGIONS
Others
Symmetrical
Mill
Face
Region
External
Millgroove
Drill
Side
Asymmetrical
Internal

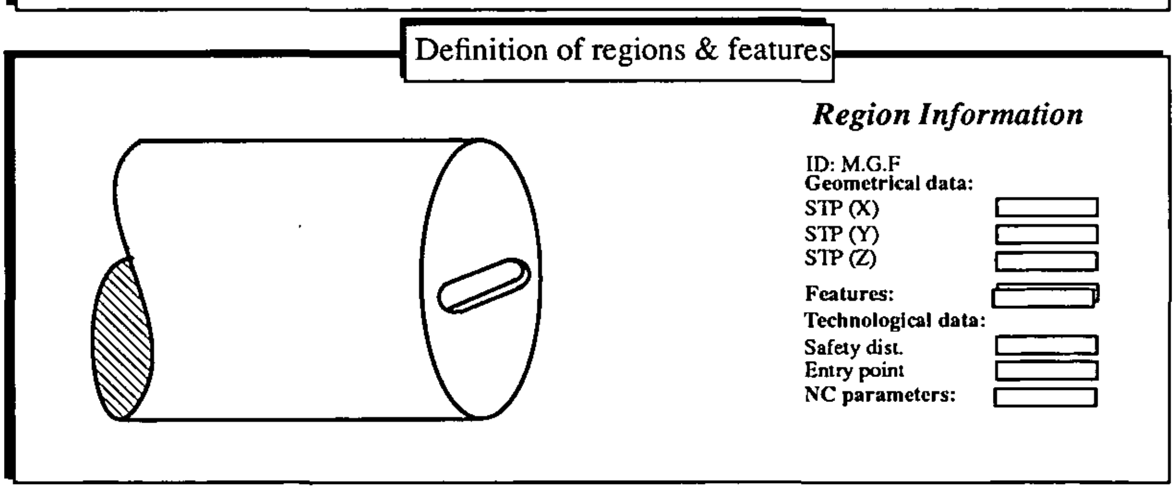

Mill ELEMENTS
Straight
Helical
Spiral
Others
Surfaces
Simple
Keway
Radial
Helical
Asymmetrical
Flat
Spiral
Groove
Others
Feature
Hole
Axial
Symmetrical

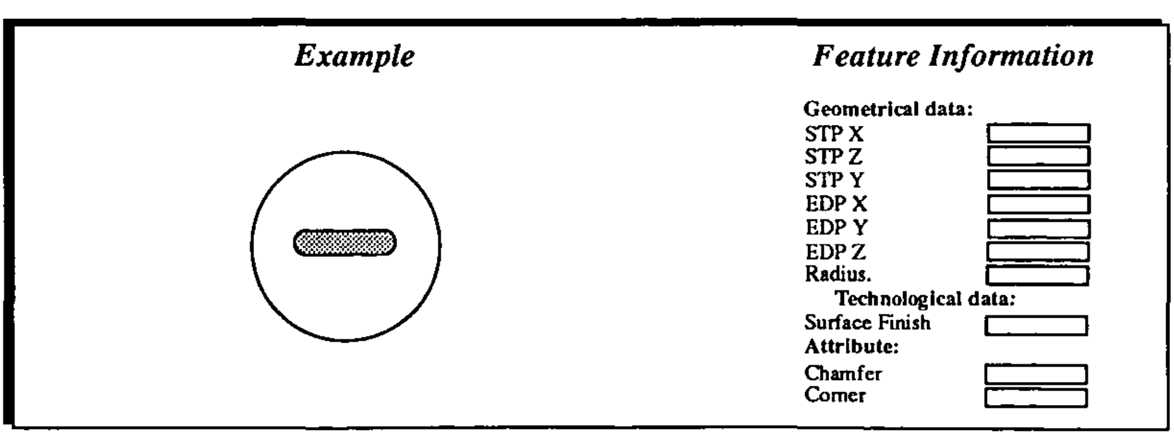

Definition of regions & features
Region Information
ID: M.G.S
Geometrical data:
STP (X)
STP (Y)
STP (Z)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:


Example
Feature Information
Geometrical data:
STP X
STP Z
STP Y
EDP X
EDP Y
EDP Z
Radius.
Technological data:
Surface Finish
Attribute:
Chamfer
Corner

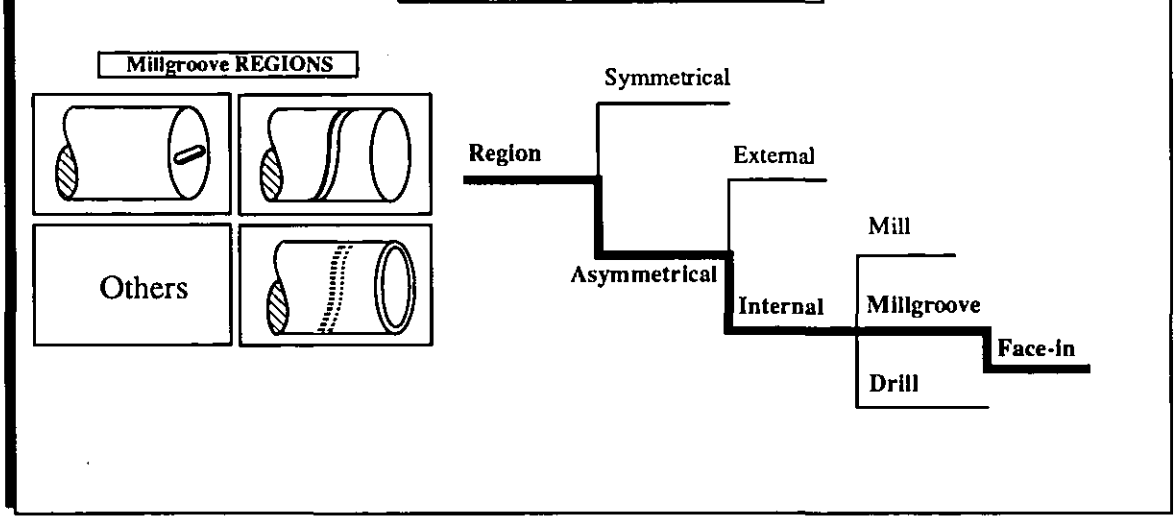

Selection of regions & features
Millgroove REGIONS
Others
Symmetrical
Mill
Face
Region
External
Millgroove
Drill
Side
Asymmetrical
Internal

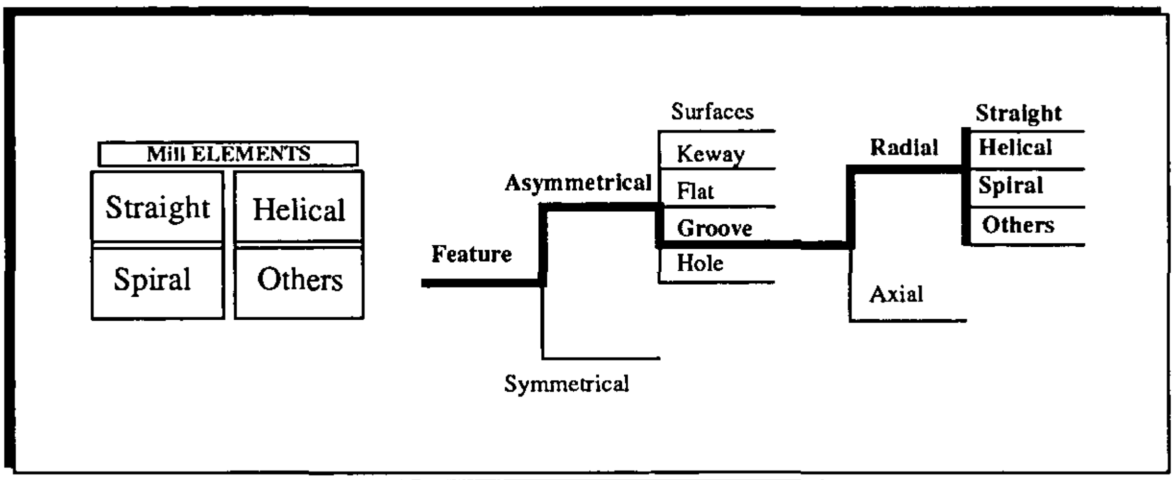

Surfaces
Radial
MIll ELEMENTS
Keway
Straight
Helical
Asymmetrical
Flat
Groove
Feature
Simple
Hole
Spiral
Others
Axial
Helical
Spiral
Others
Symmetrical


Definition of regions & features
Region Information
ID: M.G.F
Geometrical data:
STP (X)
STP (Y)
STP (Z)
Features:
Technological data:
Safety dist.
Entry point
NC parameters:

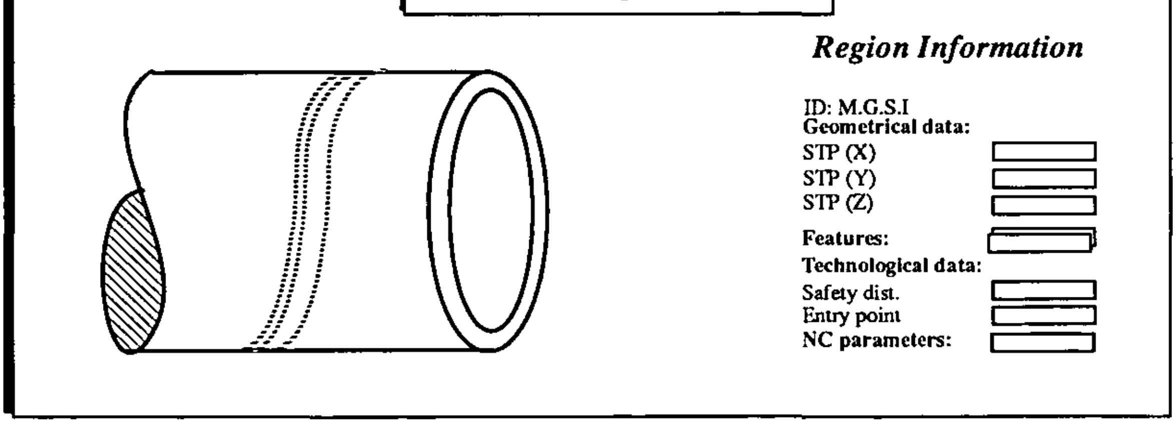

Example
Feature Information
Geometrical data:
STP X
STP Z
STP Y
EDP X
EDP Y
EDP Z
Radius.
Technological data:
Surface Finish
Attribute:
Chamfer
Corner

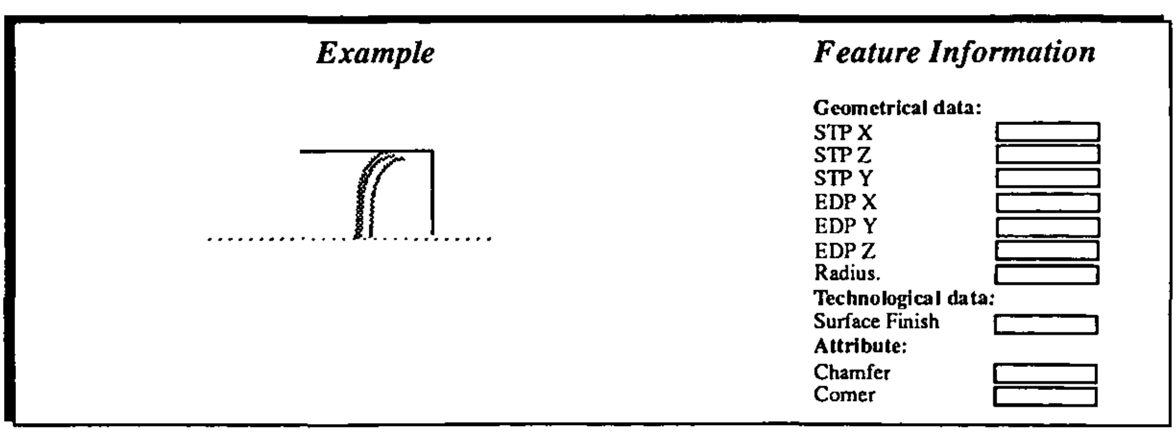
Selection of regions & features





Definition of regions & features





Appendix III

IDEF 0 REPRESENTATION OF THE NC PLANNING SYSTEM

Introduction

IDEF0 was initially created by the U.S airforce under their integrated computer aided manufacturing project, which was devised by D.T Ross. IDEF0 stands for ICAM DEFinition 0 which is applied to describe systems. IDEF0 is used to model the activities and flows in manufacturing systems.

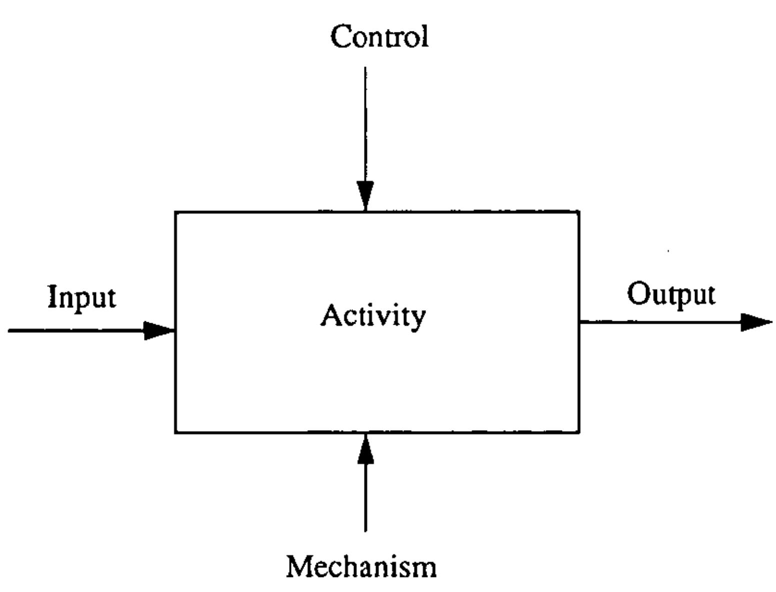
IDEF0 application

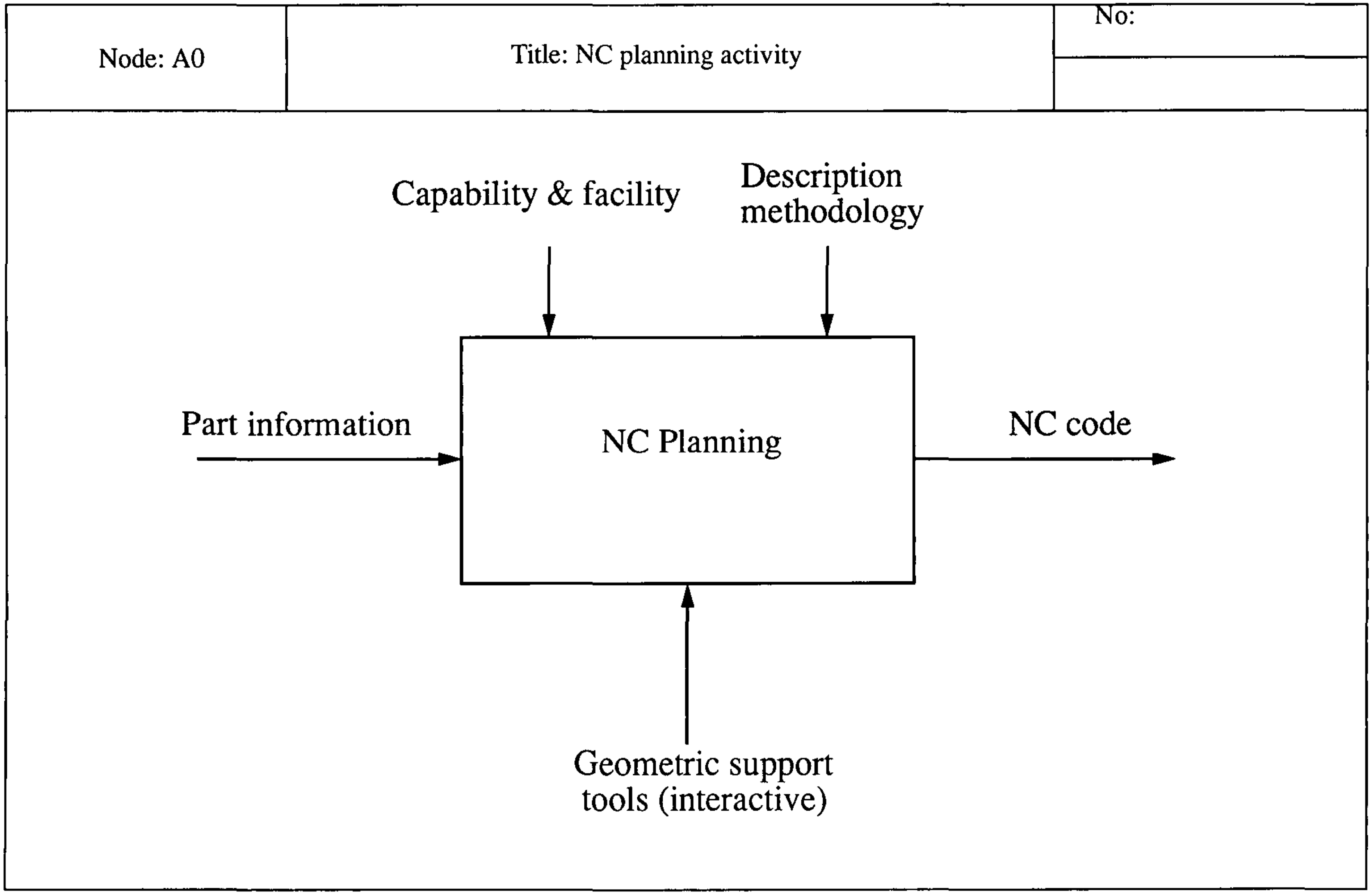
ICAM has classified the uses of IDEF0 into the following categories:

- IDEF0 can be used to describe an existing system.
- IDEF0 can be used in the analysis of the system.
- IDEF0 can be used to design systems.
- IDEF0 can be used to specify statements of requirements.

IDEF0 benefits

IDEF0 is an easy way to model activities and provides the user with systematic method to describe the constituent elements of activities. In short, the technique provides the user with a powerful means of modelling, analysis and development *[Colq 91]*. IDEF0 is used in this research to describe the NC planning system. The notation used for each activity is cited below:

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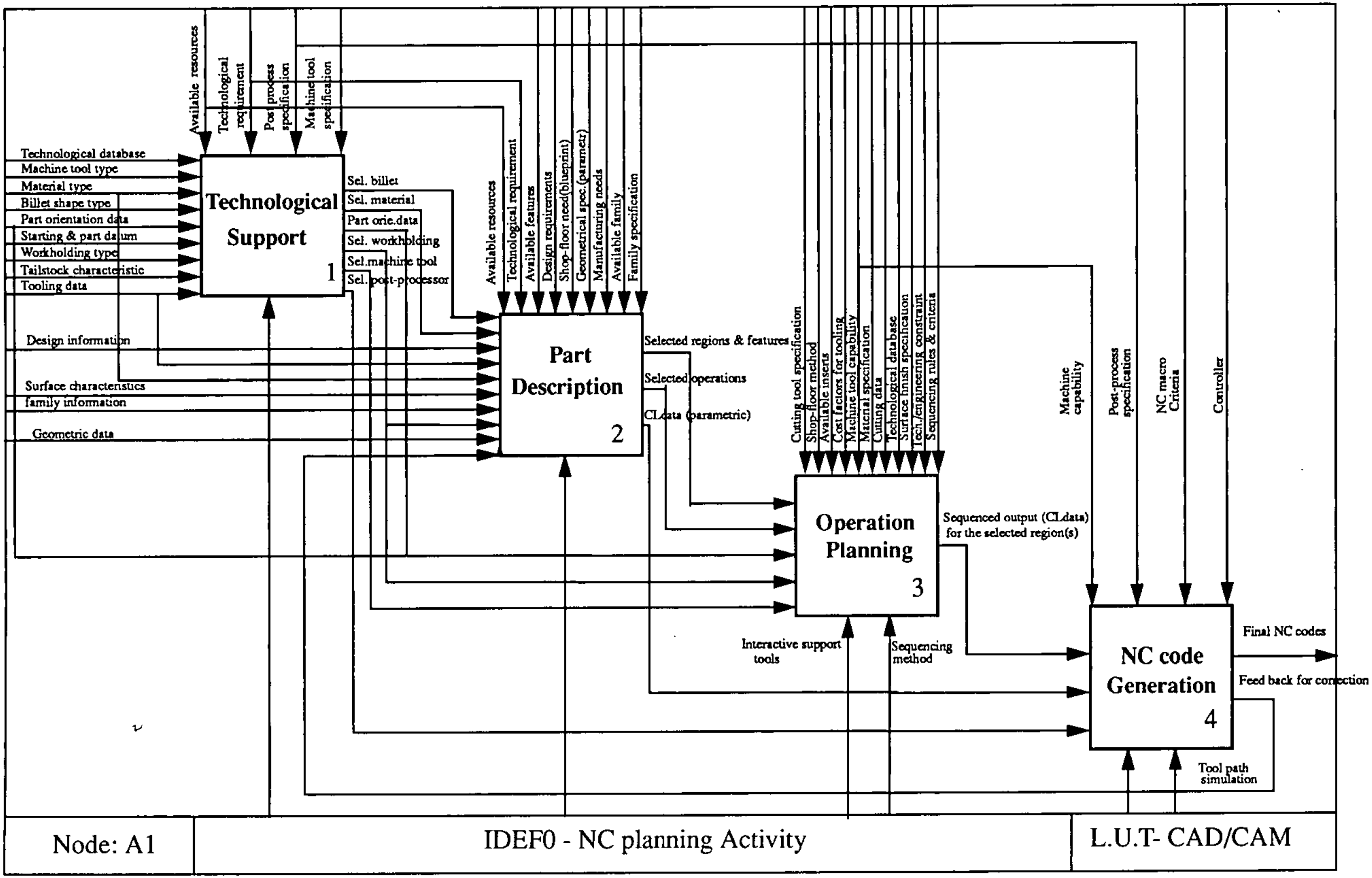
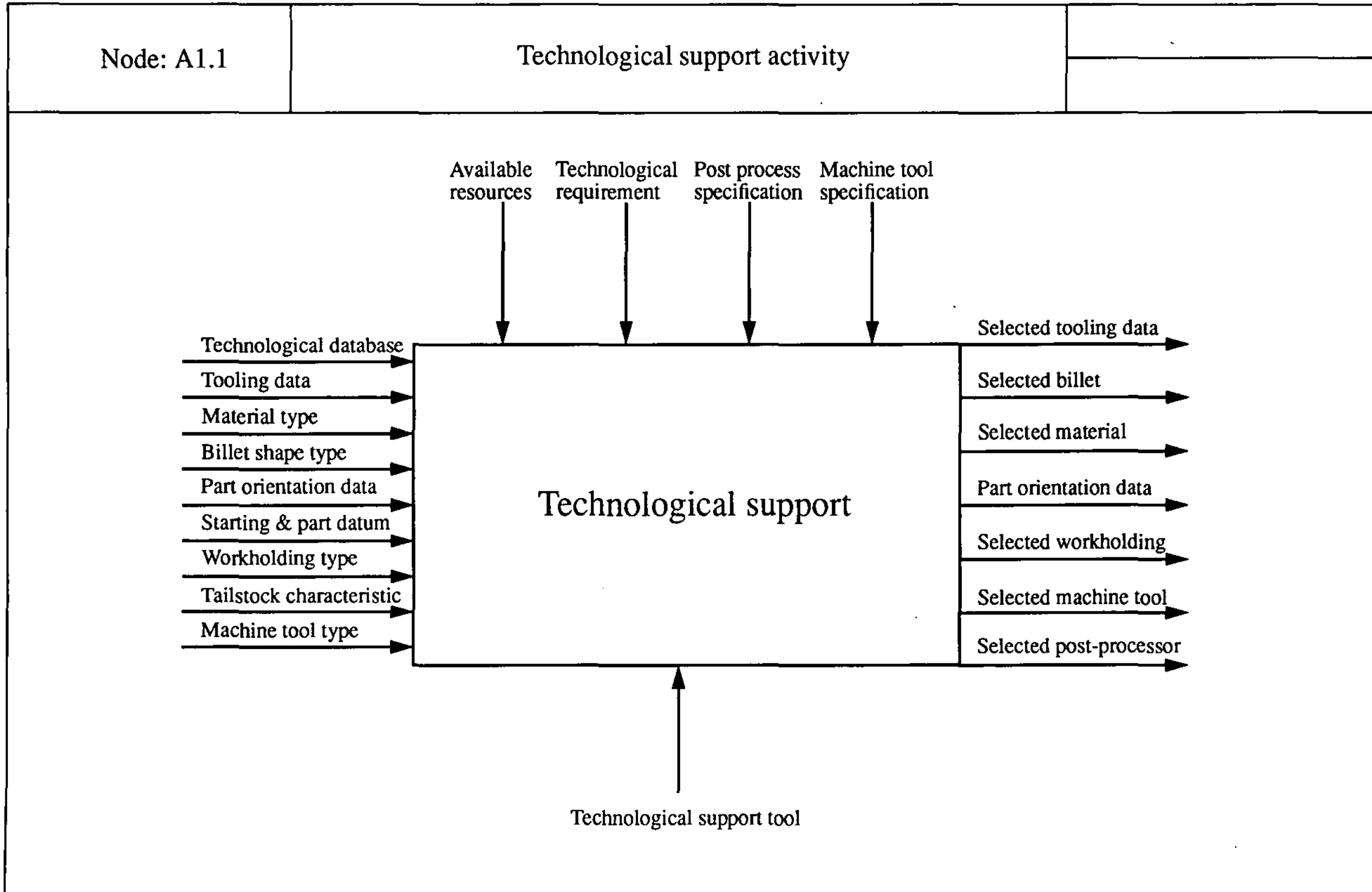
Title: NC planning activity
No:
Capability & facility
Description methodology
Part information
NC Planning
NC code
Geometric support tools (interactive)


Available resources
Technological requirement
Post process specification
Machine tool specification
Technological database
Machine tool type
Material type
Billet shape type
Part orientation data
Starting & part datum
Workholding type
Tailstock characteristic
Tooling data
Technological Support
1
Sel. billet
Sel. material
Part orie.data
Sel. workholding
Sel.machine tool
Sel. post-processor
Design information
Surface characteristics
family information
Geometric data
Available resources
Technological requirement
Available features
Design requirements
Shop-floor need(blueprint)
Geometrical spec.(parametr)
Manufacturing needs
Available family
Family specification
Part Description
2
Selected regions & features
Selected operations
CLdata (parametric)
Cutting tool specification
Shop-floor method
Available inserts
Cost factors for tooling
Machine tool capability
Material specification
Cutting data
Technological database
Surface finish specification
Tech./engineering constraint
Sequencing rules & criteria
Operation Planning
3
Interactive support tools
Sequencing method
Sequenced output (CLdata) for the selected region(s)
Machine capability
Post-process specification
NC macro Criteria
Controller
NC code Generation
4
Final NC codes
Feed back for correction
Tool path simulation
Node: A1
IDEF0 - NC planning Activity
L.U.T- CAD/CAM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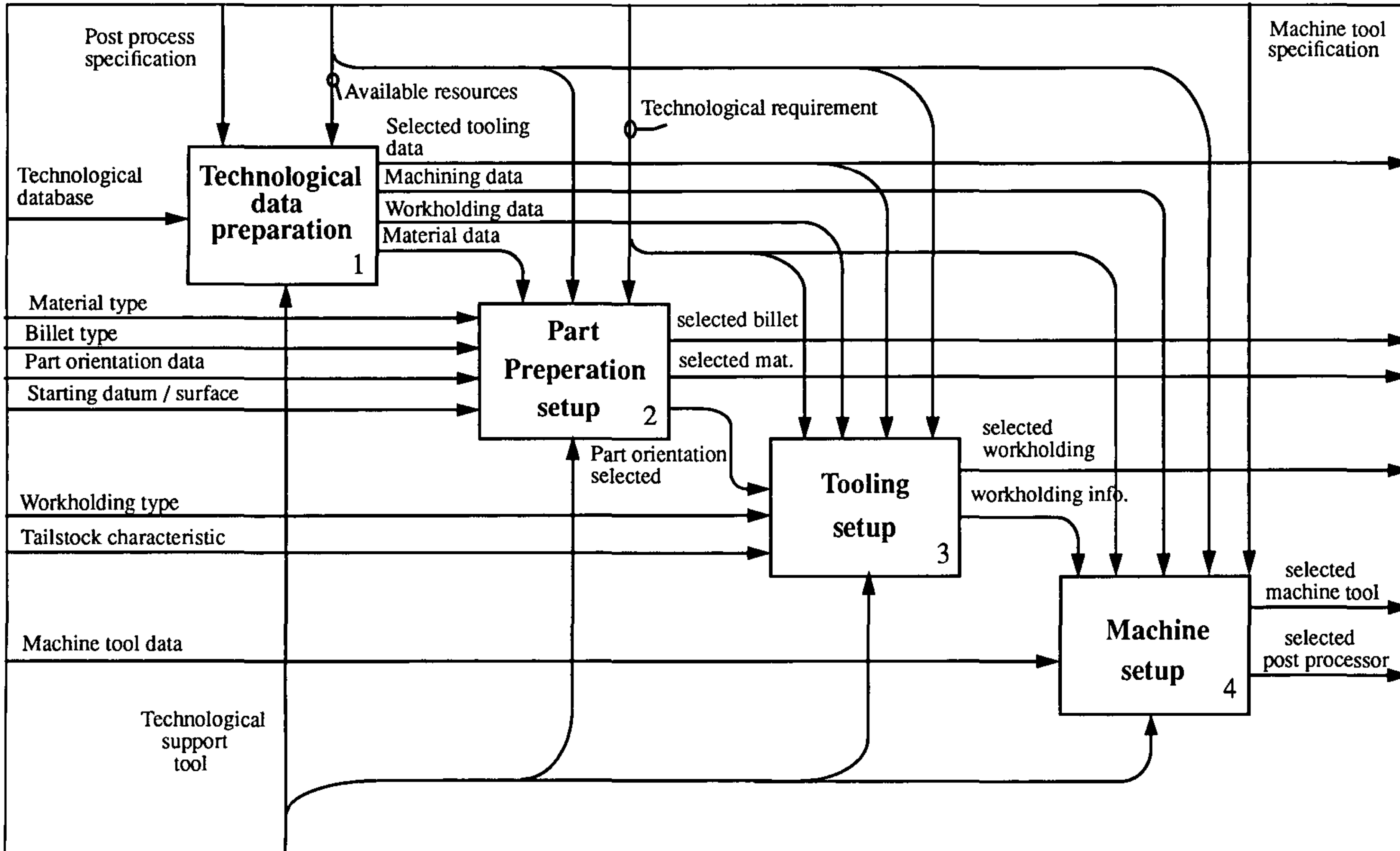
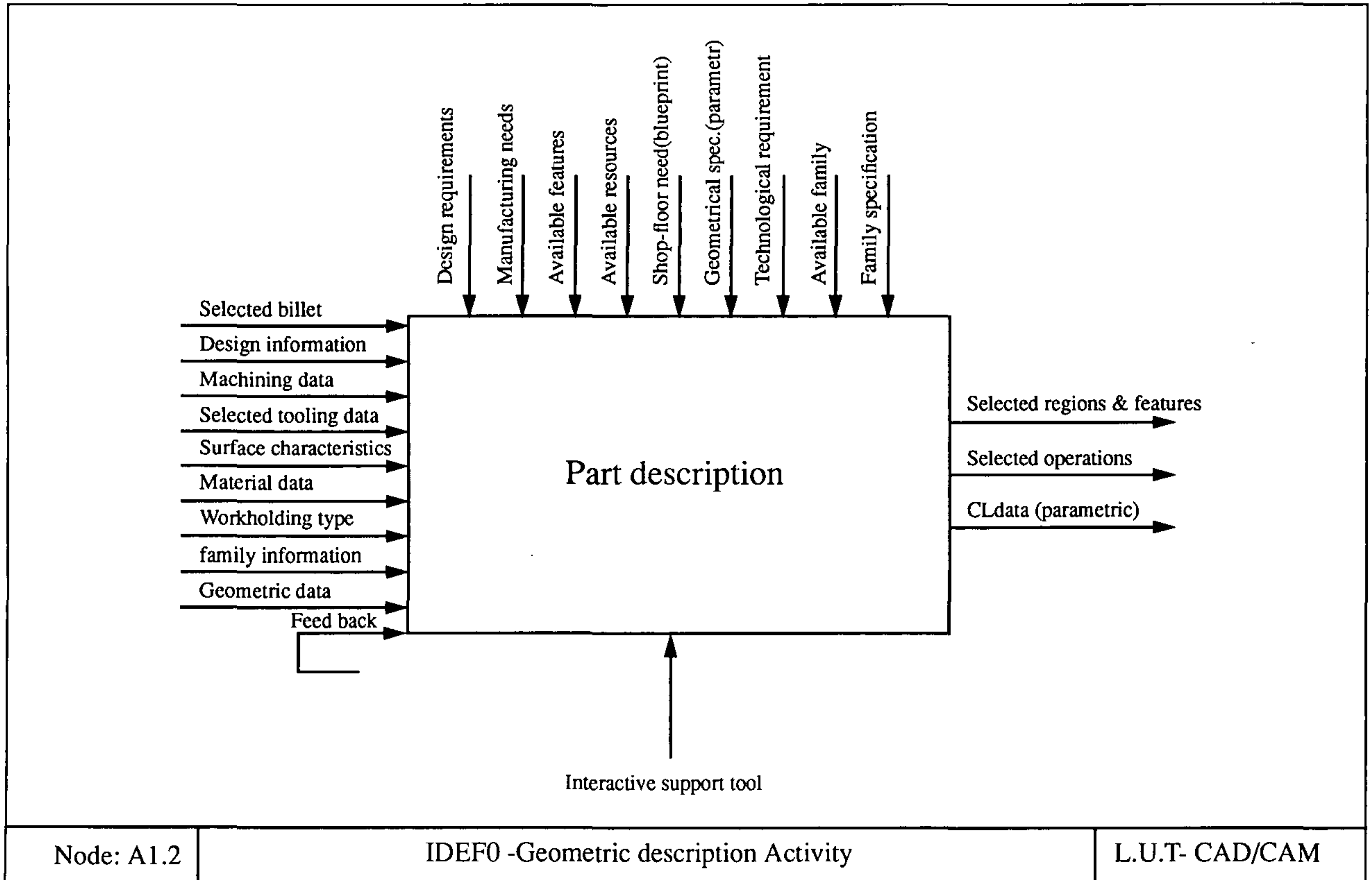
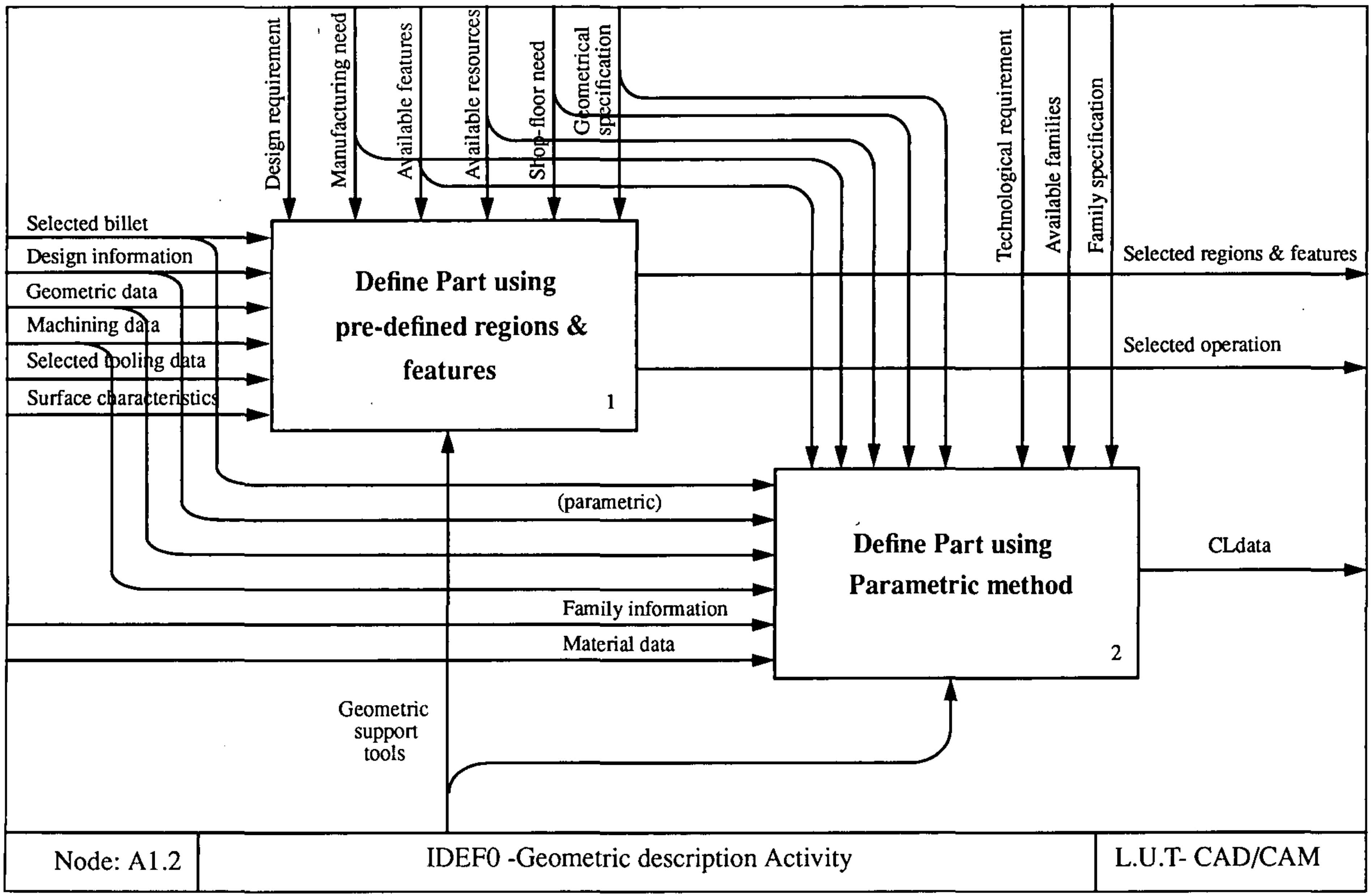
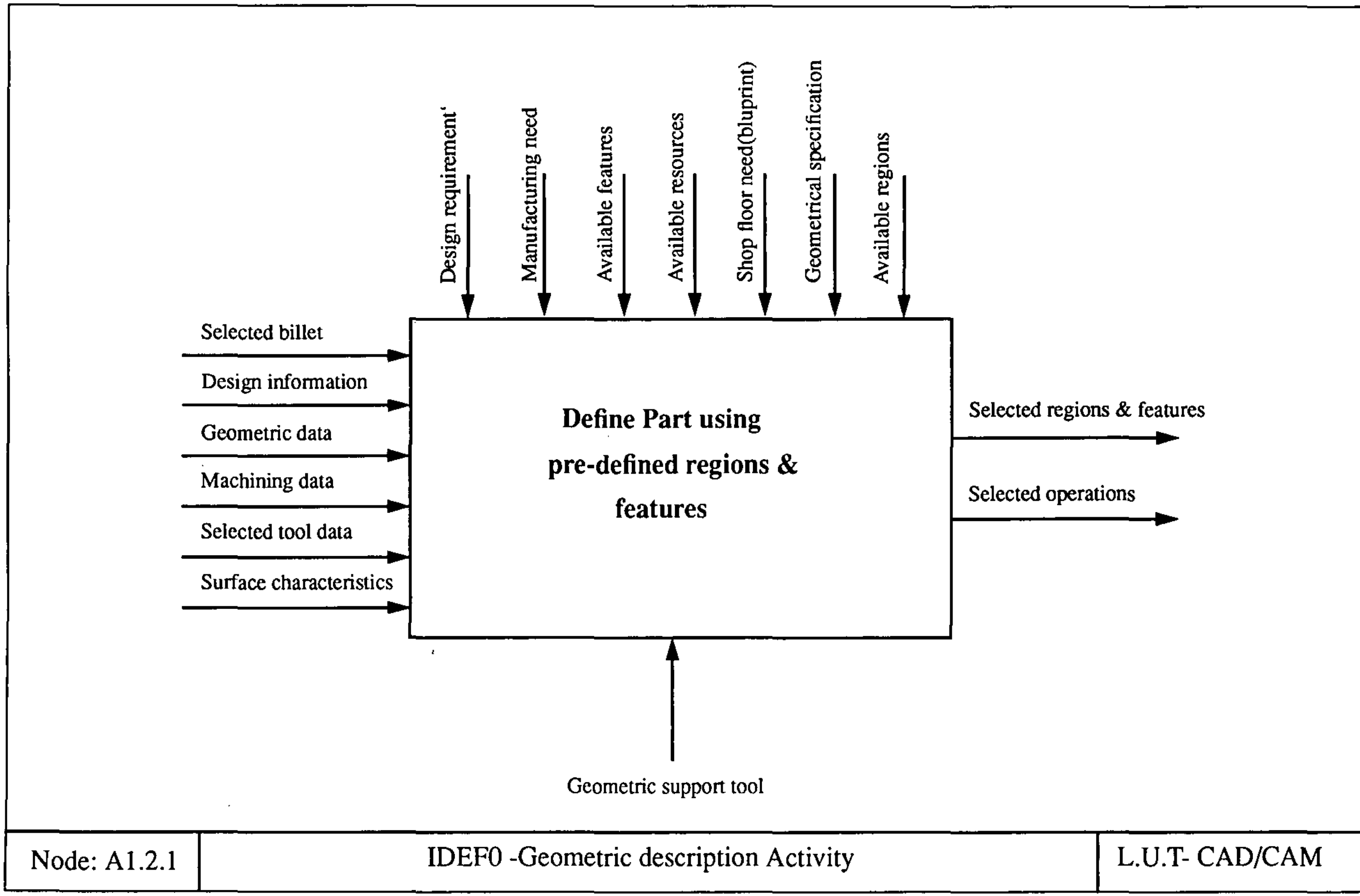
Technological support activity
Available resources
Technological requirement
Post process specification
Machine tool specification
Technological database
Tooling data
Material type
Billet shape type
Part orientation data
Starting & part datum
Workholding type
Tailstock characteristic
Machine tool type
Technological support
Selected tooling data
Selected billet
Selected material
Part orientation data
Selected workholding
Selected machine tool
Selected post-processor
Technological support tool

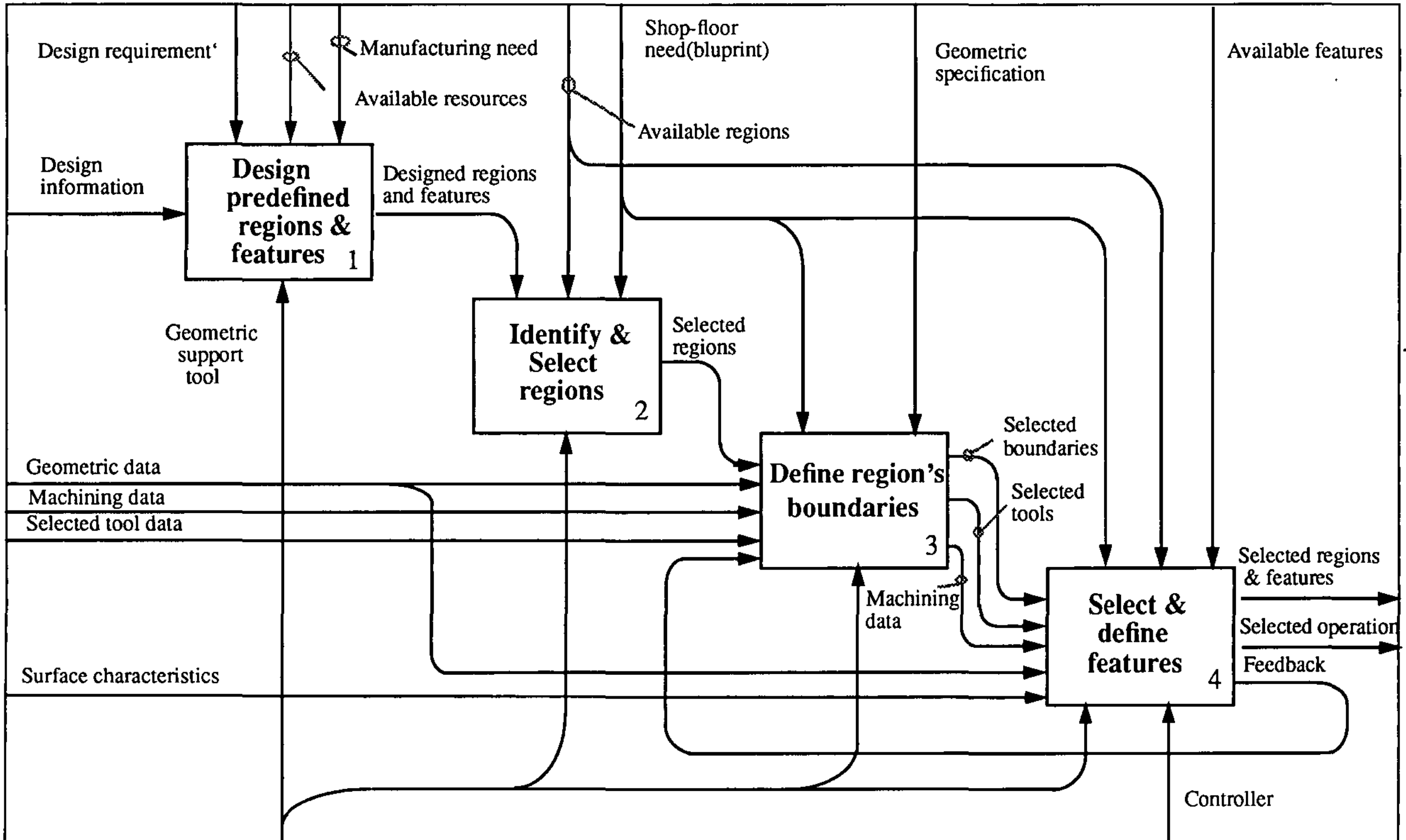


Node: A1.1	IDEF0 -Technological Support Activity	L.U.T- CAD/CAM

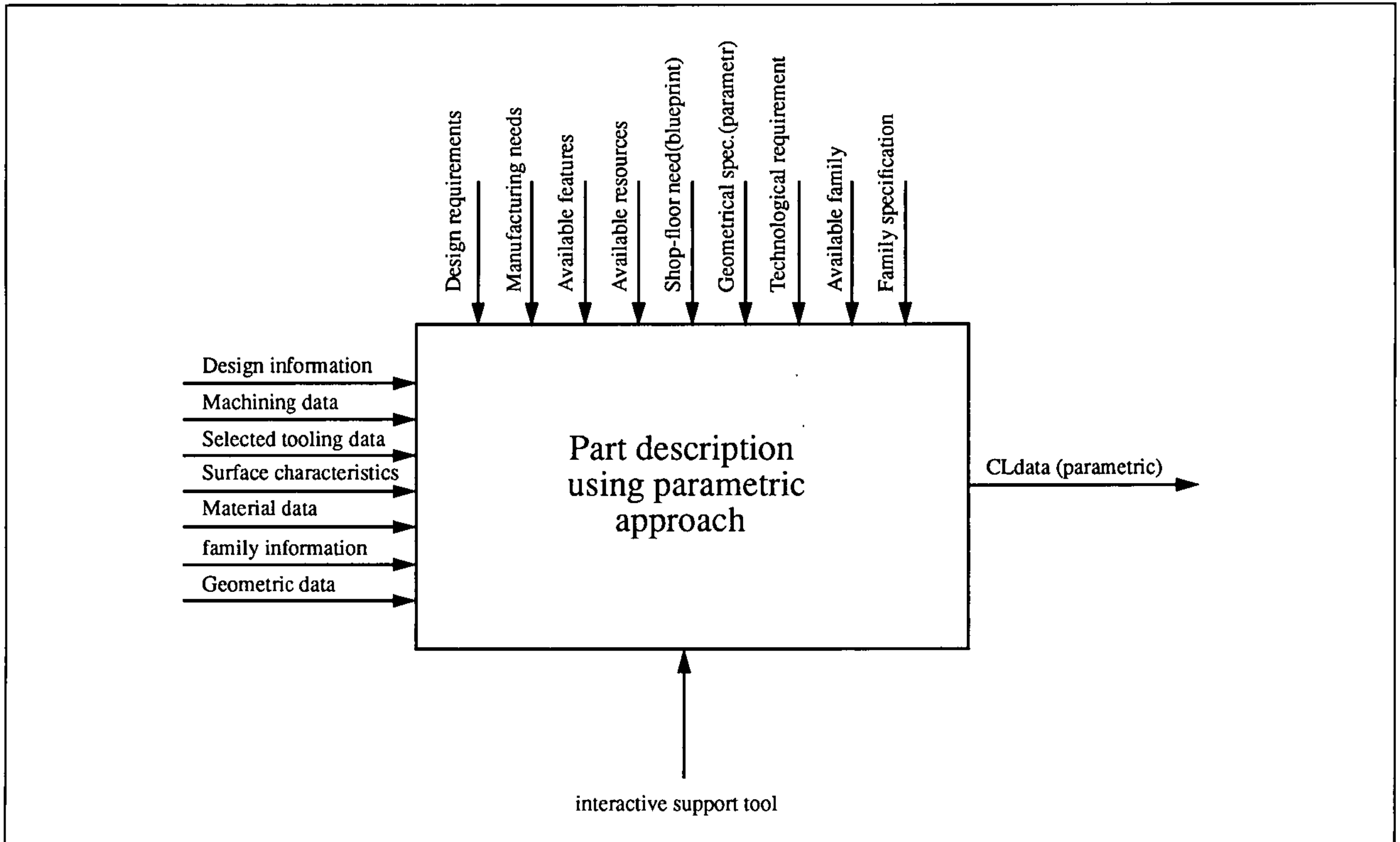

Design requirements
Manufacturing needs
Available features
Available resources
Shop-floor need(blueprint)
Geometrical spec.(parametr)
Technological requirement
Available family
Family specification
Selected billet
Design information
Machining data
Selected tooling data
Surface characteristics
Material data
Workholding type
family information
Geometric data
Feed back
Part description
Selected regions & features
Selected operations
CLdata (parametric)
Interactive support tool
Node: A1.2
IDEF0 -Geometric description Activity
L.U.T- CAD/CAM


Design requirement
Manufacturing need
Available features
Available resources
Shop-floor need
Geometrical specification
Technological requirement
Available families
Family specification
Selected billet
Design information
Geometric data
Machining data
Selected tooling data
Surface characteristics
Define Part using pre-defined regions & features
1
Selected regions & features
Selected operation
(parametric)
Define Part using Parametric method
2
CLdata
Family information
Material data
Geometric support tools
Node: A1.2
IDEF0 -Geometric description Activity
L.U.T- CAD/CAM


Design requirement'
Manufacturing need
Available features
Available resources
Shop floor need(bluprint)
Geometrical specification
Available regions
Selected billet
Design information
Geometric data
Machining data
Selected tool data
Surface characteristics
Define Part using pre-defined regions & features
Selected regions & features
Selected operations
Geometric support tool
Node: A1.2.1
IDEF0 -Geometric description Activity
L.U.T- CAD/CAM



Node: A1.2.1	IDEF0 - Geometric definition Activity	L.U.T- CAD/CAM



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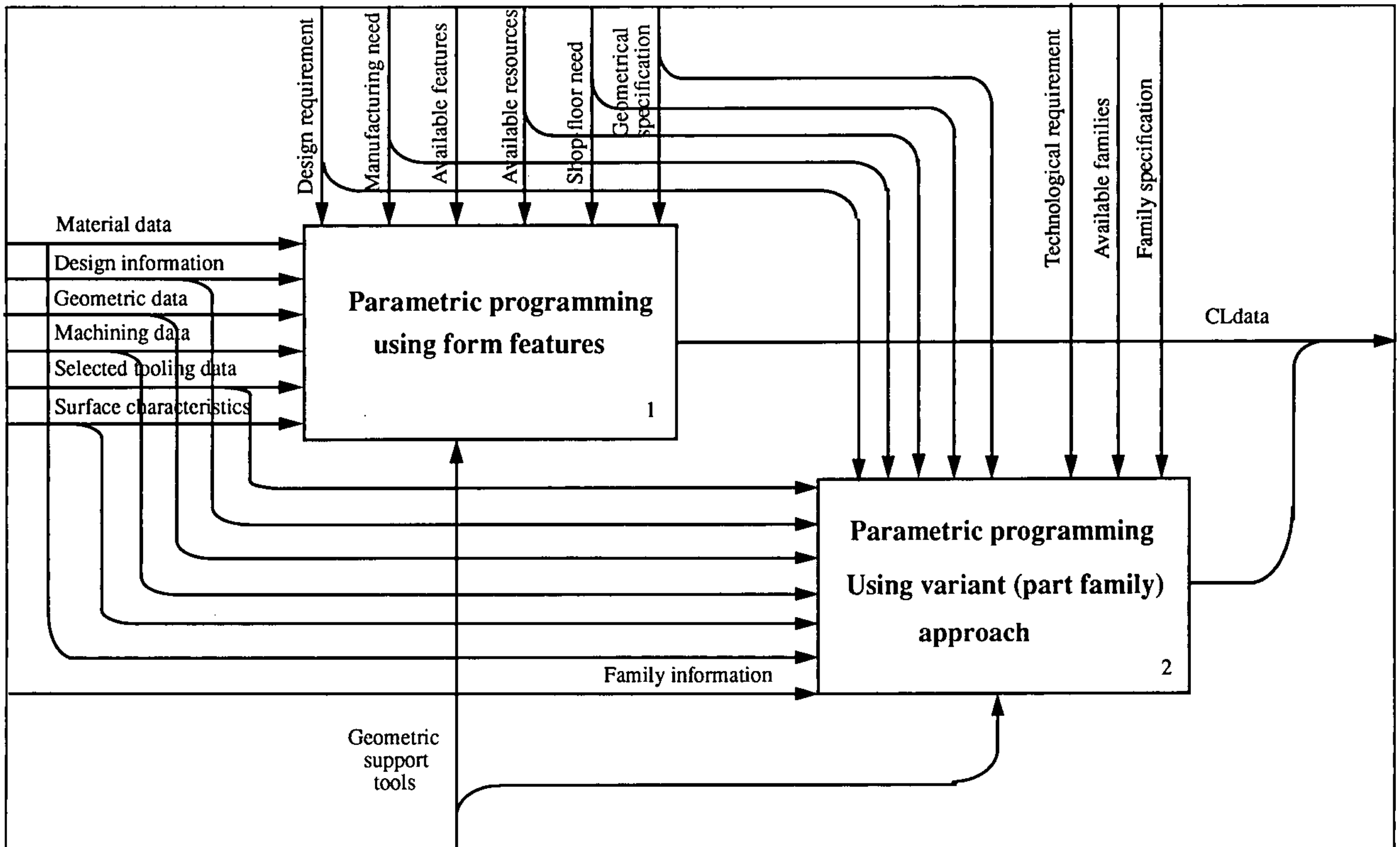
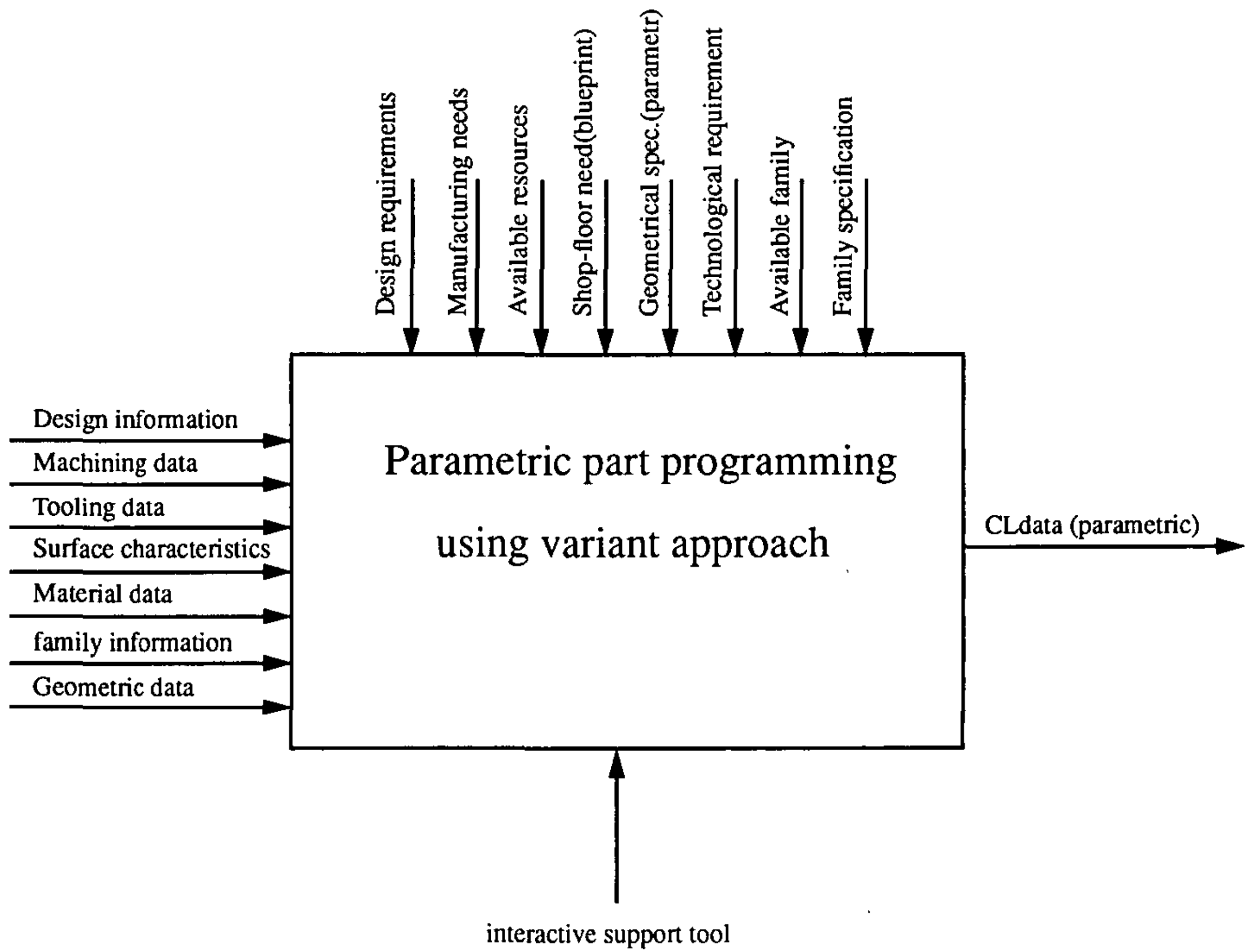
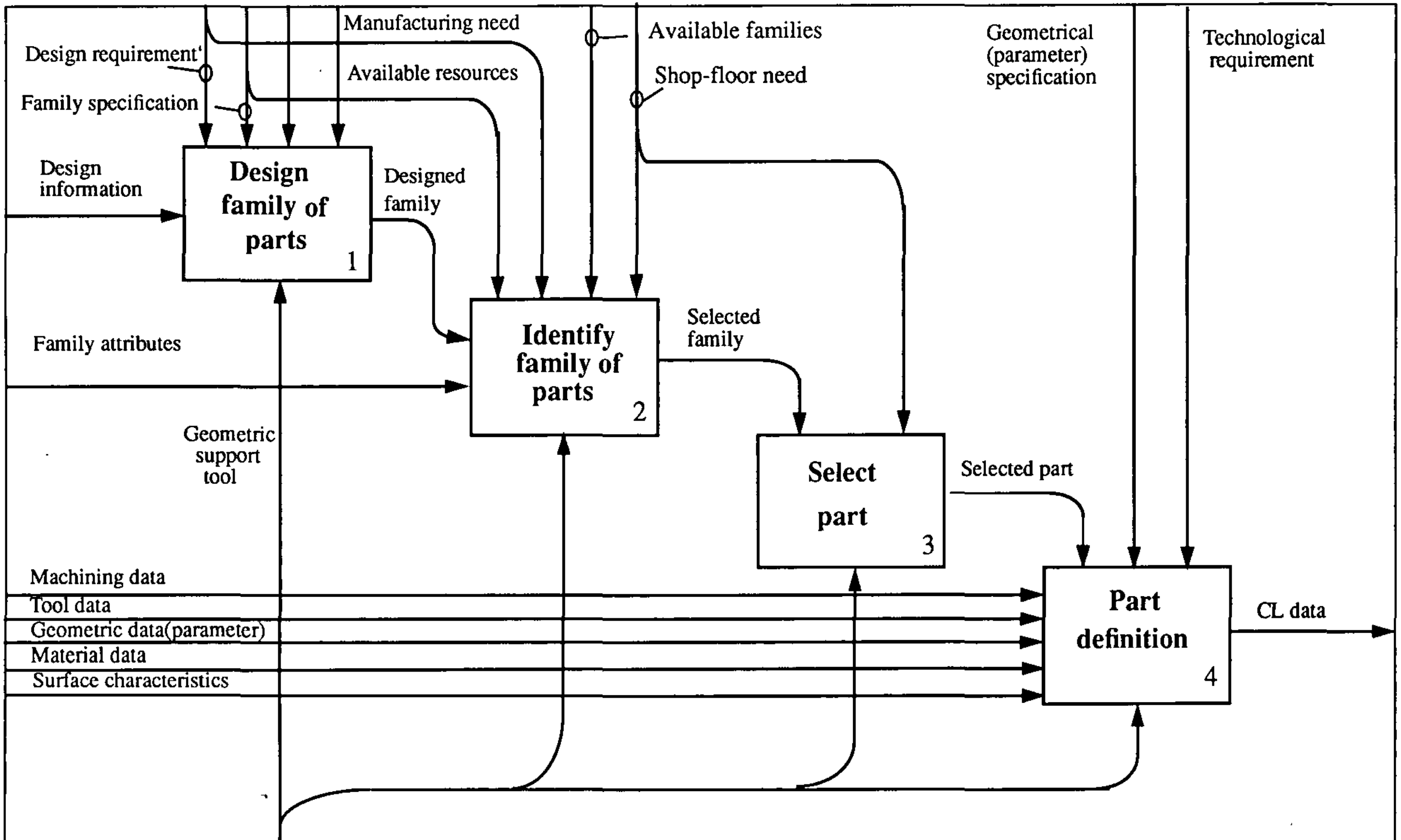


Node: A1.2.2	IDEF0 - Geometric description Activity	L.U.T- CAD/CAM



Node: A1.2.2.1	IDEF0 -Geometric description Activity	L.U.T- CAD/CAM



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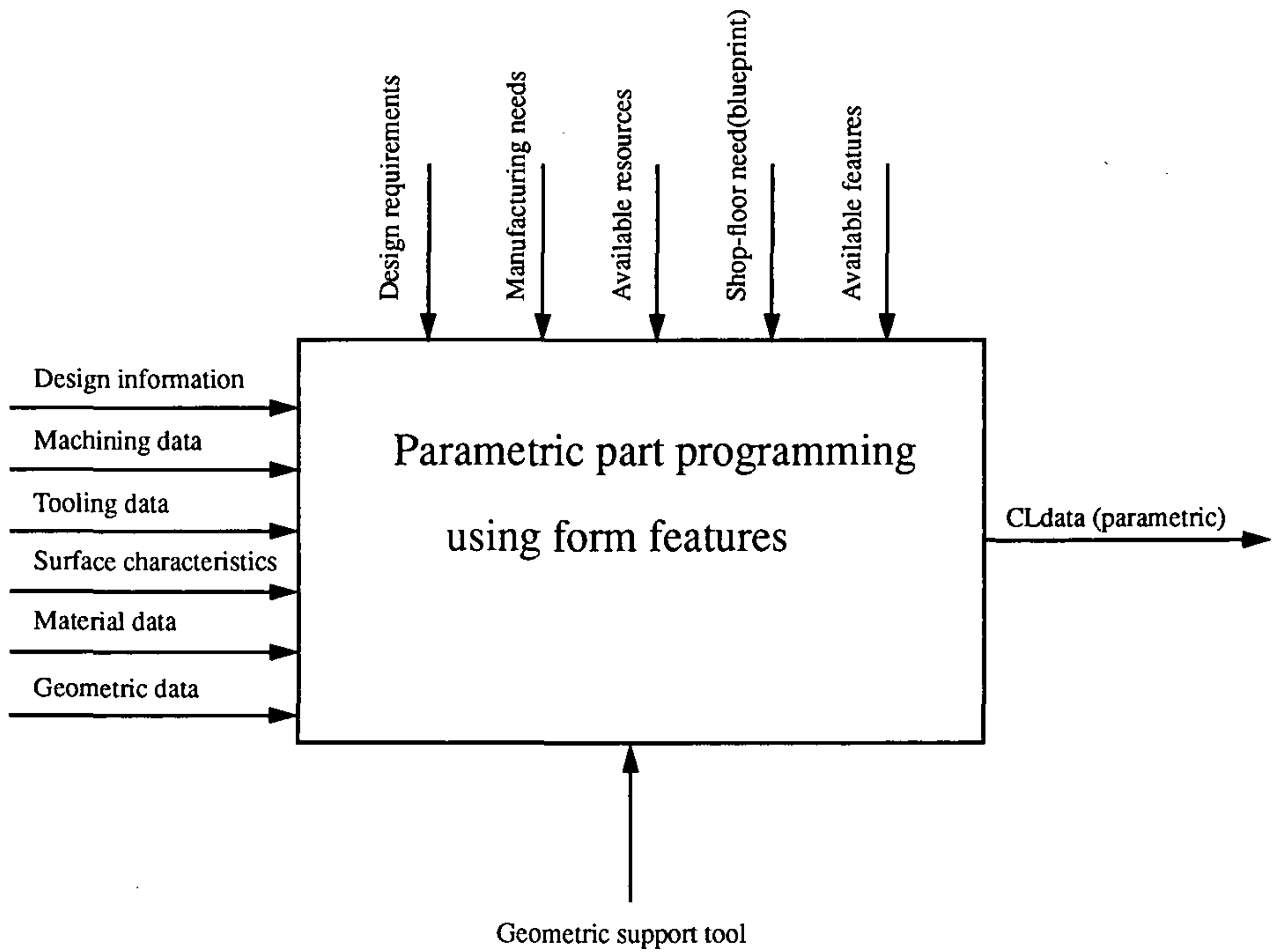
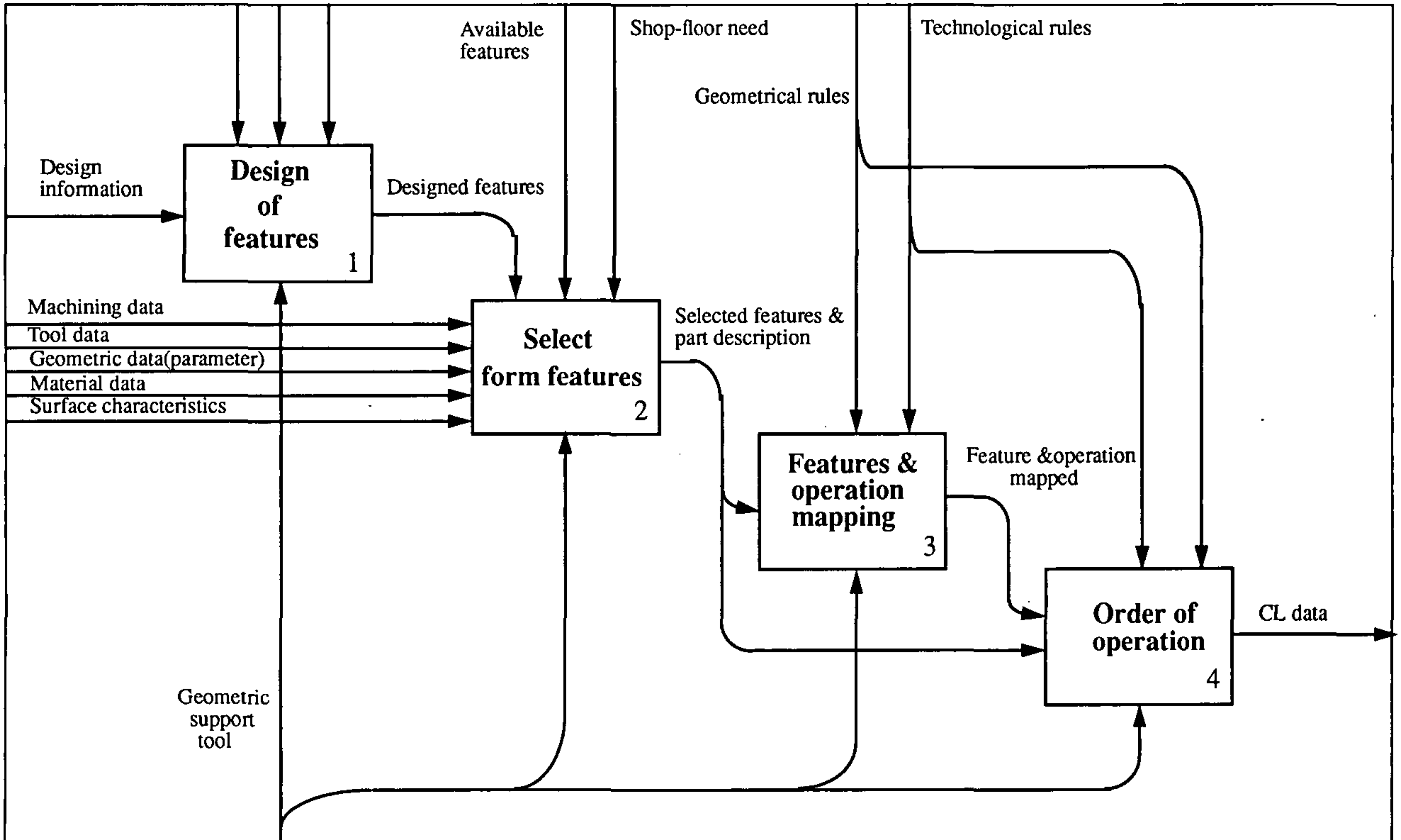
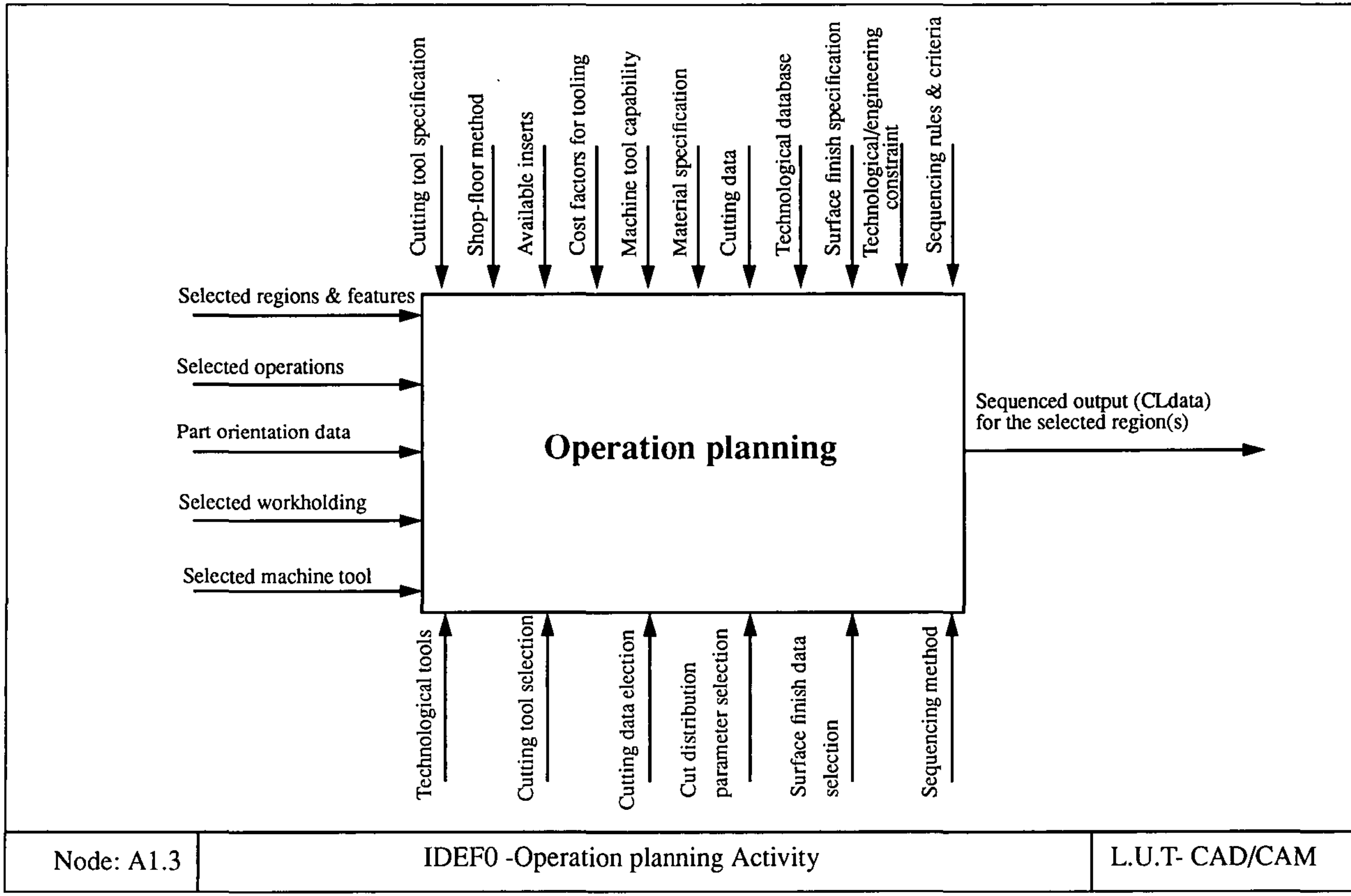
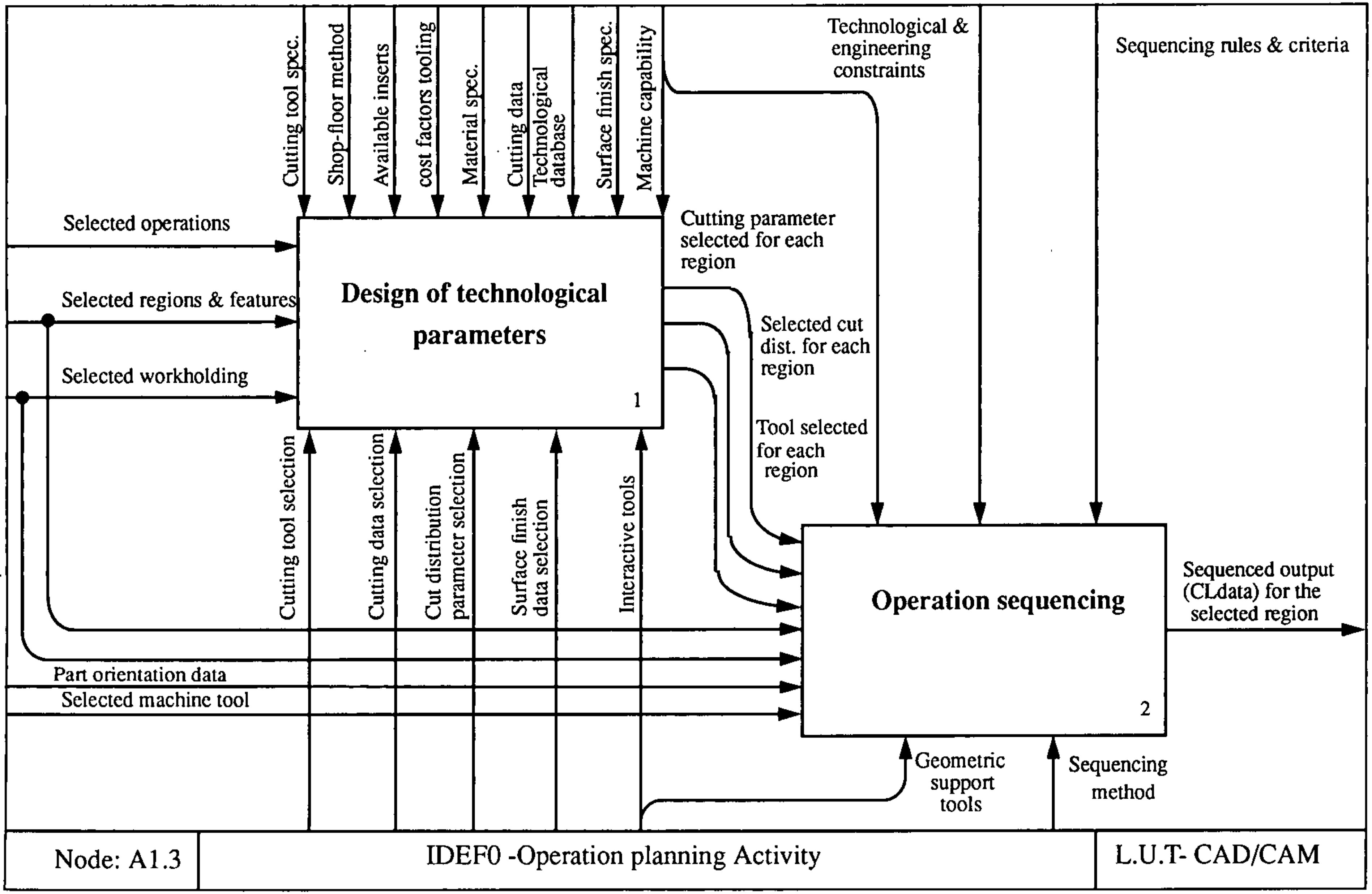


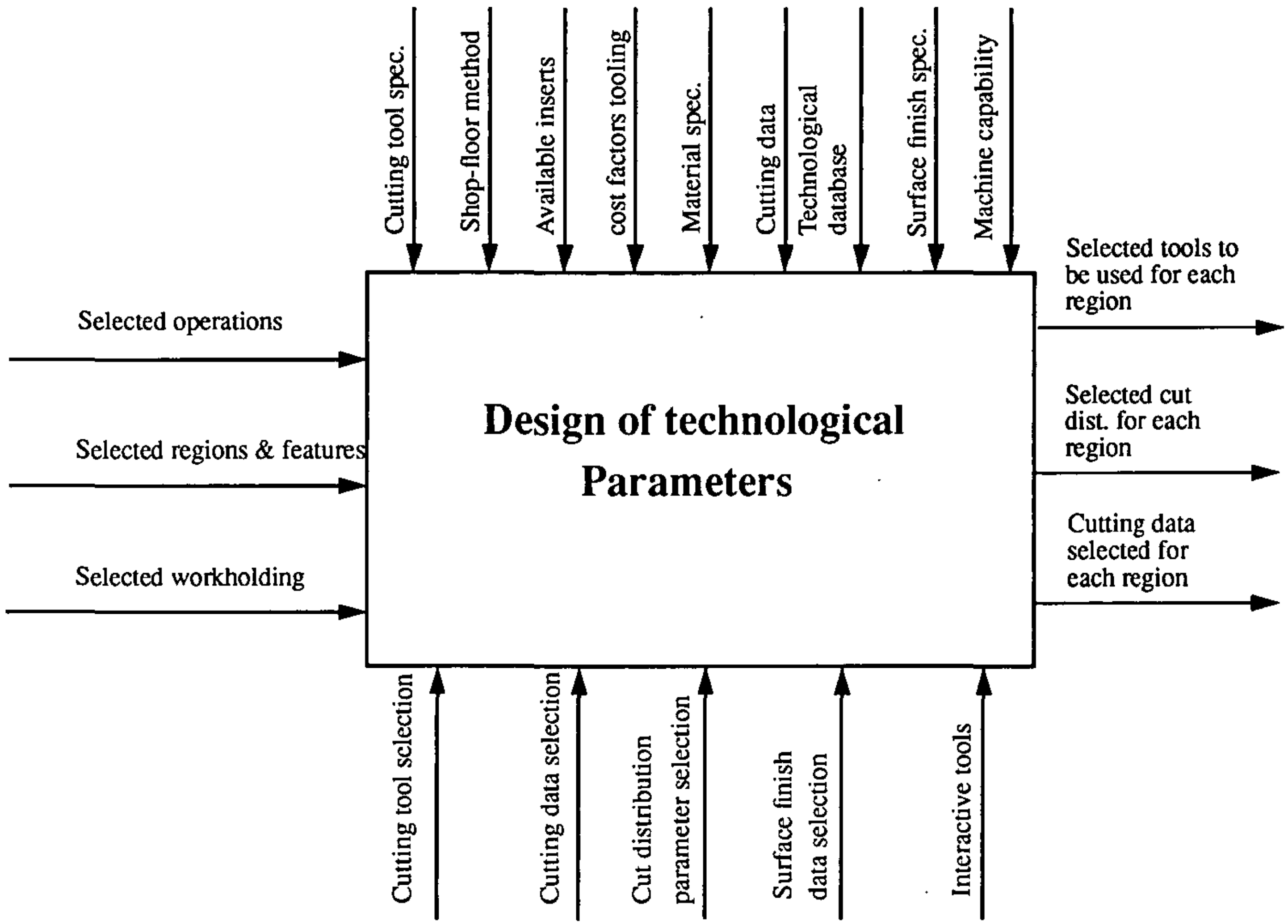
Node: A1.2.2.2	IDEF0 -Geometric description Activity	L.U.T- CAD/CAM



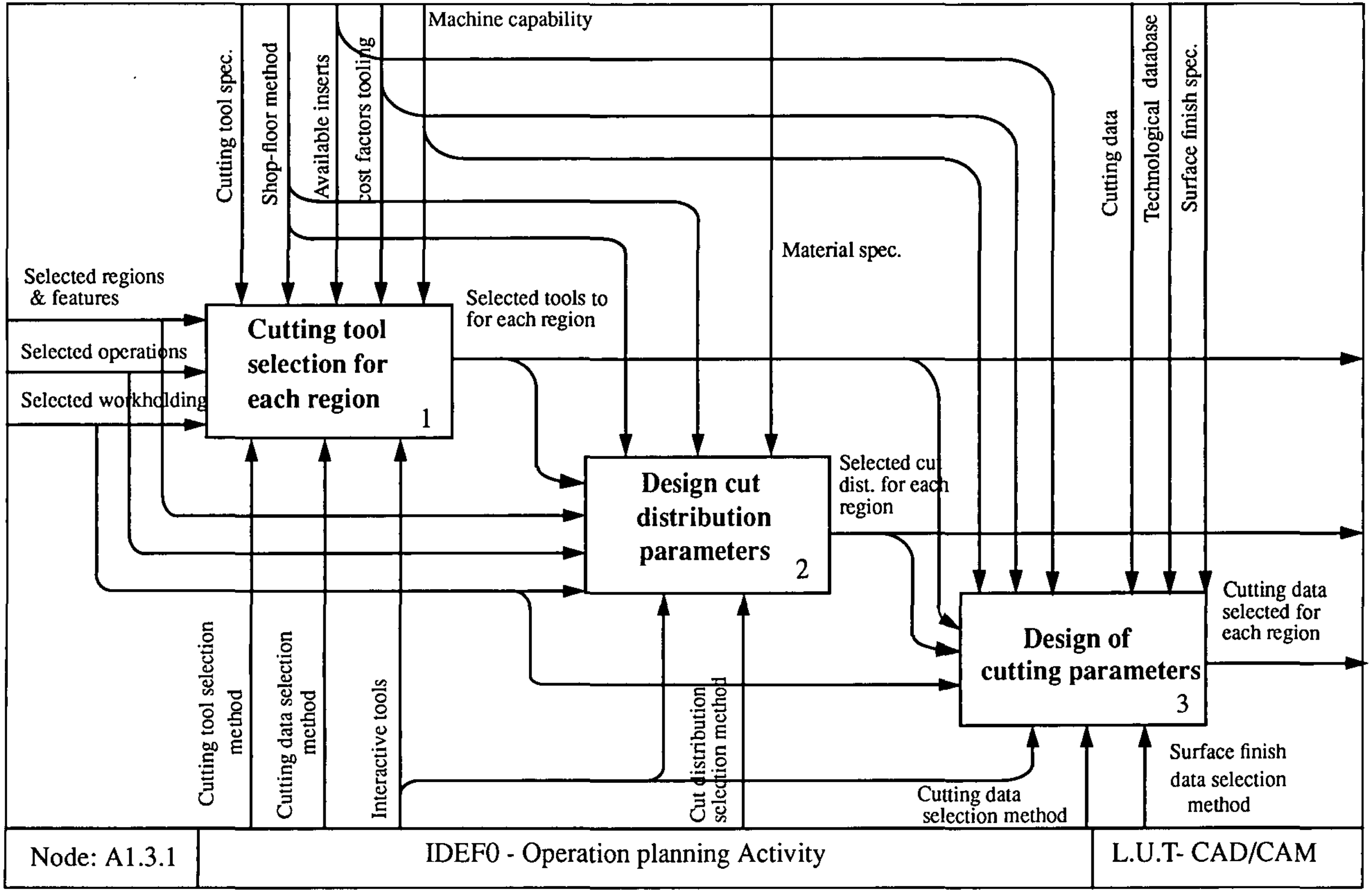
Node: A1.2.2.2 | IDEF0 -Geometric description Activity | L.U.T- CAD/CAM

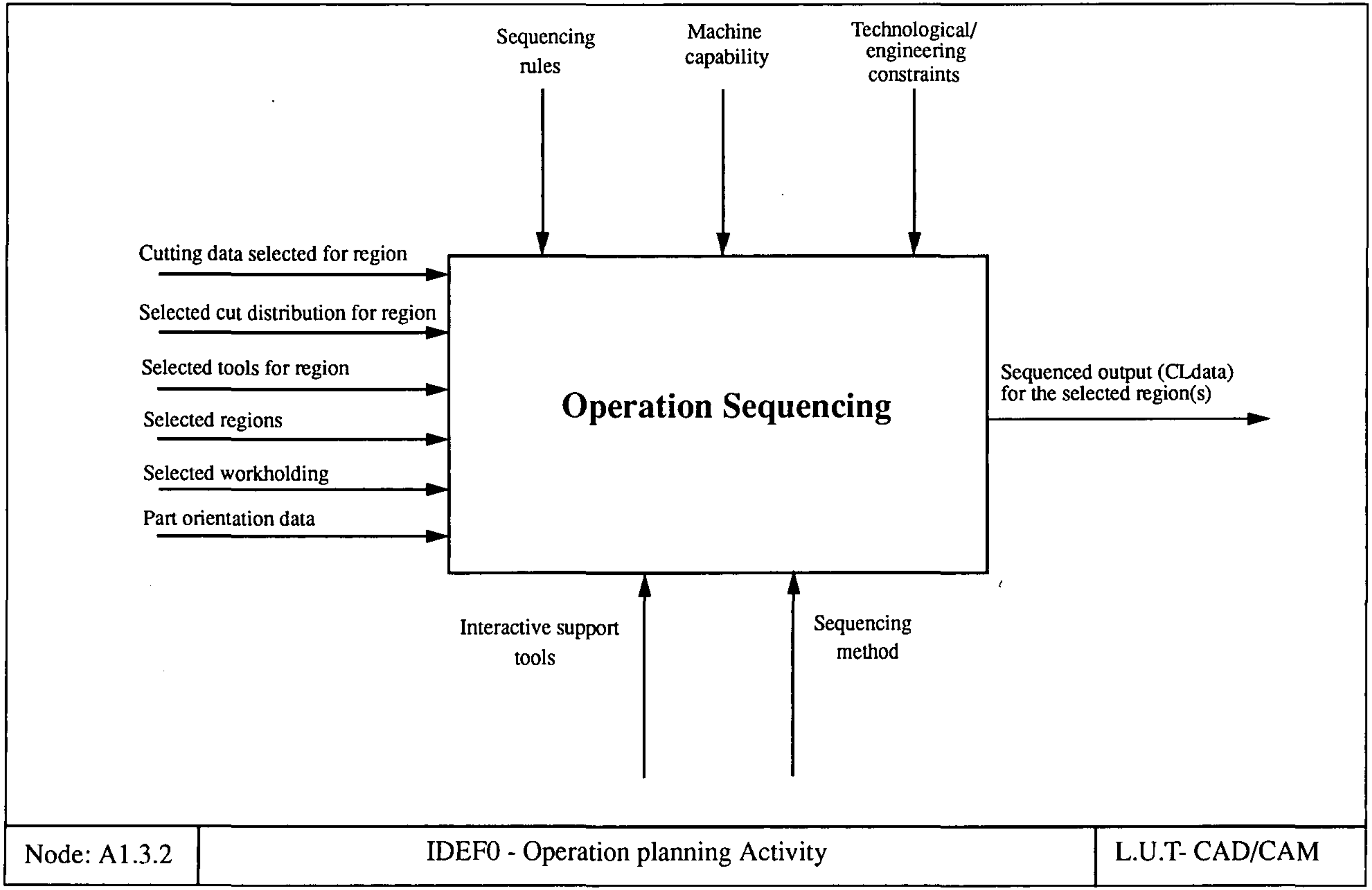

Cutting tool specification
Shop-floor method
Available inserts
Cost factors for tooling
Machine tool capability
Material specification
Cutting data
Technological database
Surface finish specification
Technological/engineering constraint
Sequencing rules & criteria
Selected regions & features
Selected operations
Part orientation data
Selected workholding
Selected machine tool
Operation planning
Sequenced output (CLdata) for the selected region(s)
Technological tools
Cutting tool selection
Cutting data election
Cut distribution parameter selection
Surface finish data selection
Sequencing method
Node: A1.3
IDEF0 -Operation planning Activity
L.U.T- CAD/CAM

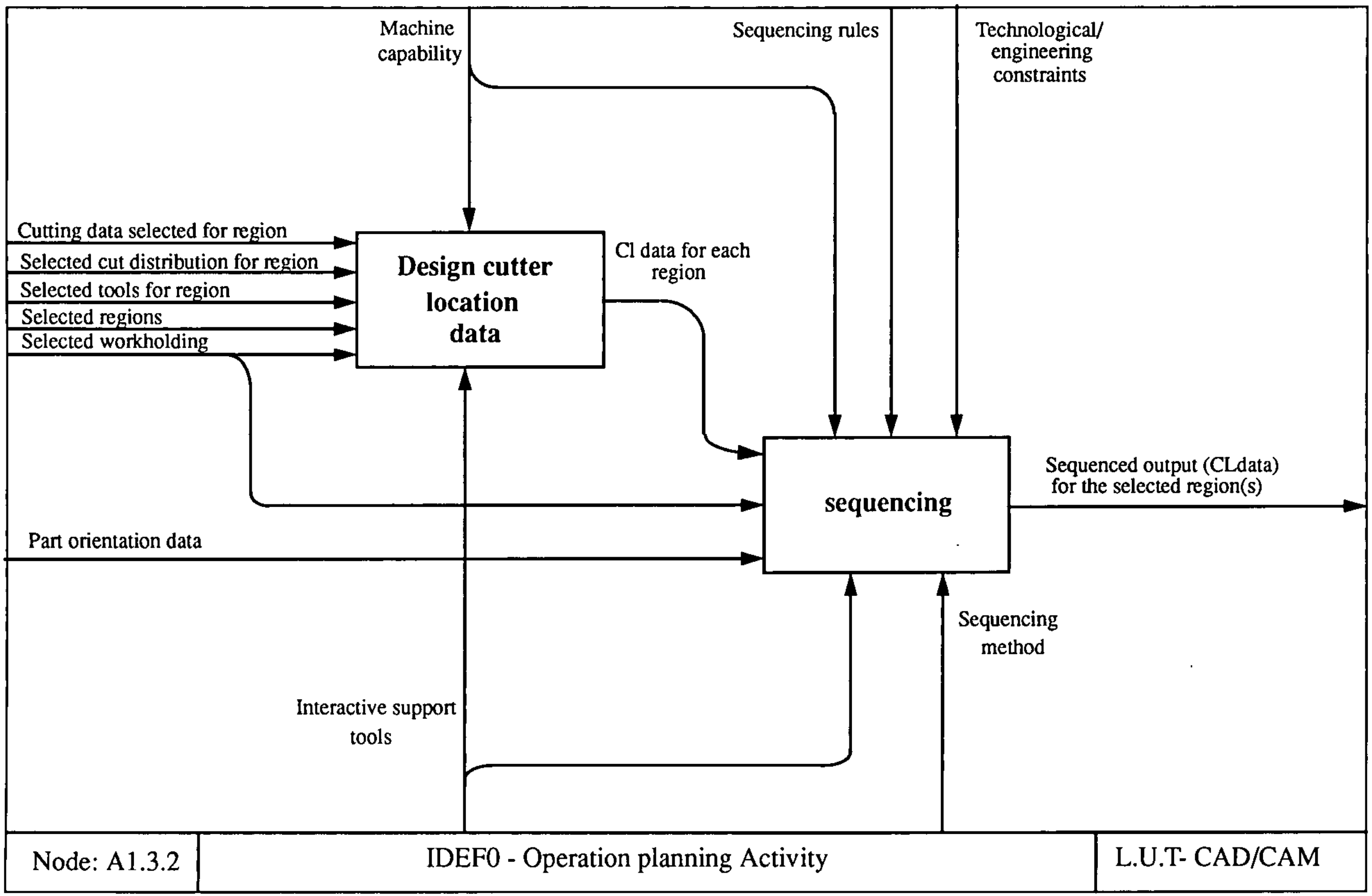

Cutting tool spec.
Shop-floor method
Available inserts
cost factors tooling
Material spec.
Cutting data
Technological database
Surface finish spec.
Machine capability
Technological & engineering constraints
Sequencing rules & criteria
Selected operations
Selected regions & features
Selected workholding
Design of technological parameters
1
Cutting parameter selected for each region
Selected cut dist. for each region
Tool selected for each region
Cutting tool selection
Cutting data selection
Cut distribution parameter selection
Surface finish data selection
Interactive tools
Part orientation data
Selected machine tool
Operation sequencing
2
Sequenced output (CLdata) for the selected region
Geometric support tools
Sequencing method
Node: A1.3
IDEF0 -Operation planning Activity
L.U.T- CAD/CAM

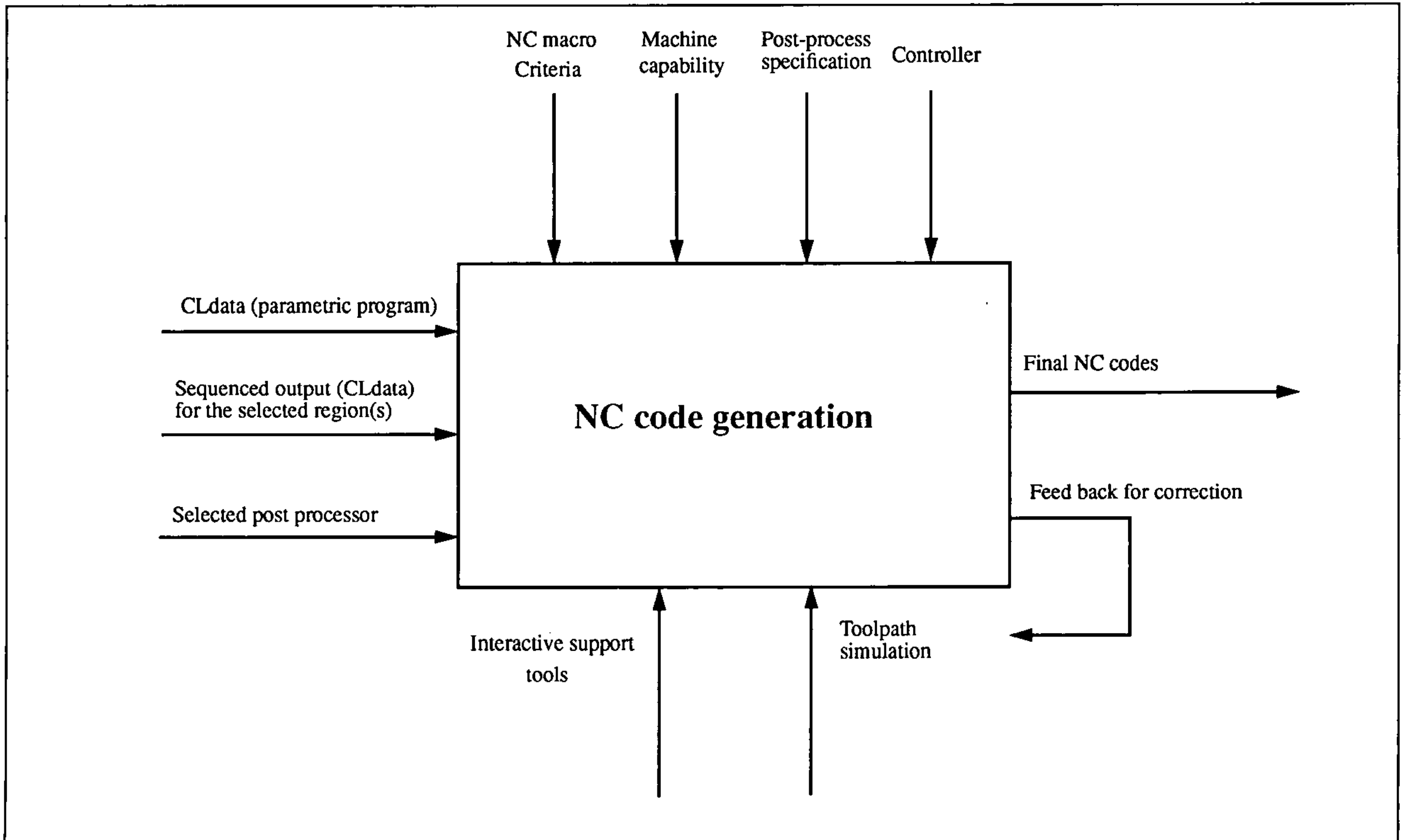


Node: A1.3.1	IDEF0 -Operation planning Activity	L.U.T- CAD/CAM

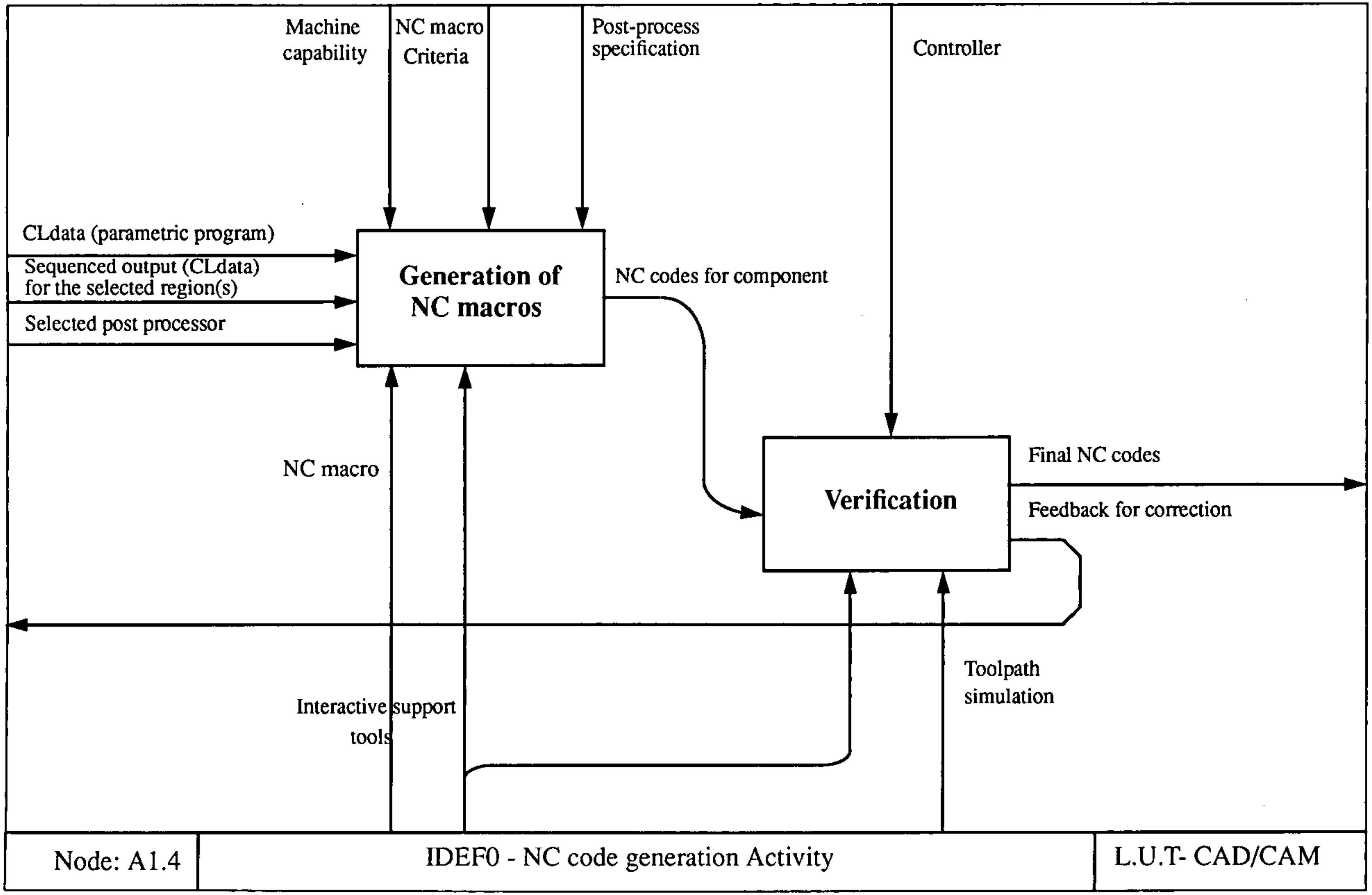

Machine capability
Cutting tool spec.
Shop-floor method
Available inserts
Cost factors tooling
Cutting data
Technological database
Surface finish spec.
Material spec.
Selected regions & features
Selected operations
Selected workholding
Cutting tool selection for each region
1
Selected tools to for each region
Design cut distribution parameters
2
Selected cut dist. for each region
Design of cutting parameters
3
Cutting data selected for each region
Cutting tool selection method
Cutting data selection method
Interactive tools
Cut distribution selection method
Cutting data selection method
Surface finish data selection method
Node: A1.3.1
IDEF0 - Operation planning Activity
L.U.T- CAD/CAM


Sequencing rules
Machine capability
Technological/ engineering constraints
Cutting data selected for region
Selected cut distribution for region
Selected tools for region
Selected regions
Selected workholding
Part orientation data
Operation Sequencing
Sequenced output (CLdata) for the selected region(s)
Interactive support tools
Sequencing method
Node: A1.3.2
IDEF0 - Operation planning Activity
L.U.T- CAD/CAM


Machine capability
Sequencing rules
Technological/ engineering constraints
Cutting data selected for region
Selected cut distribution for region
Selected tools for region
Selected regions
Selected workholding
Design cutter location data
Cl data for each region
sequencing
Sequenced output (CLdata) for the selected region(s)
Part orientation data
Sequencing method
Interactive support tools
Node: A1.3.2
IDEF0 - Operation planning Activity
L.U.T- CAD/CAM



Node: A1.4	IDEF0 - NC code generation Activity	L.U.T- CAD/CAM



Machine capability
NC macro Criteria
Post-process specification
Controller
CLdata (parametric program)
Sequenced output (CLdata) for the selected region(s)
Selected post processor
Generation of NC macros
NC codes for component
NC macro
Verification
Final NC codes
Feedback for correction
Toolpath simulation
Interactive support tools
Node: A1.4
IDEF0 - NC code generation Activity
L.U.T- CAD/CAM

APPENDIX IV

DESCRIPTION OF OPERATIONS & RULES

The description of operations which are associated with each region is presented below. The rules used to initiate the operation planner are cited.

Operation description

The workshop oriented NC system embodies six principal type of operations. In order to clarify operation planning tasks, each operation is listed and briefly described below:

Turning operation:

A machining operation in which the principal motion of the single point cutting tool is parallel to the axis of rotation of the rotating workpiece.

Facing operation:

A machining operation in which the principal motion of a single Point cutting tool is at the right angles to the axis of rotation of the rotating workpiece.

Grooving operation:

A machining operation in which a groove is cut to a specified depth in one pass by a form tool.

Milling operation:

A multi-tool machining operation in which material is removed from a workpiece by the cutter rotating about an axis perpendicular to the surface being produced. The material is usually removed by both the end and periphery of the tool.

Mill grooving operation:

A machining operation in which a groove is produced by a rotating multiple cutting tool.

Threading operation:

A machining operation that uses a single point cutting tool to produces a thread form of uniform section on the internal or external surface of a cylinder or cone.

Drilling operation:

A machining operation in which a hole is produced by means of a multi-point fluted cutting tool (*drill*).

Boring operation:

A machining operation in which a single cutting tool is used to produce an accurate internal cylindrical surface by enlarging an existing hole in a workpiece.

Reaming operation:

A machining operation in which a hole is enlarged and accurately sized by means of a multi-fluted cutting tool.

Tapping operation:

A machining operation in which a tap cutting tool is used to generate a uniform internal threads.

Parting operation:

A machining operation in which a single point cut off tool is used to cut off a section of a workpiece from the raw stock.

Rules for Operation Selection

The rules are basically devised to perform operation assignment. This rules allow the operation planner to be initiated so as to plan the sequence of operations based on the internal decision models or manual sequencing. The rules are divided into two sets. The fist set as depicted overleaf is concerned with basic turning of the profile regions. The second set of rules are concerned with milling, grooving, threading and millgrooving operations. these rules take the form cited overleaf.

If:
(region is profile front)
Then:
(The operation is (rough turn the front profile)
The operation is (finish turn the front profile))

If:
(region is profile back)
Then:
(The operation is (rough turn the back profile)
The operation is (finish turn the back profile))

If:
(region is in profile)
Then:
(The operation is (rough turn the inside diameter profile)
The operation is (finish turn the inside diameter profile))

If:
(region is recess front)
Then:
(The operation is (rough turn the front recess)
The operation is (finish turn the front recess))

If:
(region is recess out)
Then:
(The operation is (turn the recess out))

If:
(region is recess back)
Then:
(The operation is (turn the recess back))

If:
(region is recess in)
Then:
(The operation is (turn the inside recess))

If:
(region is face front)
Then:
(The operation is (rough turn the front face)
The operation is (finish turn the front face))

If:
(region is face back)
Then:
(The operation is (rough turn the face back)
The operation is (finish turn the face back))

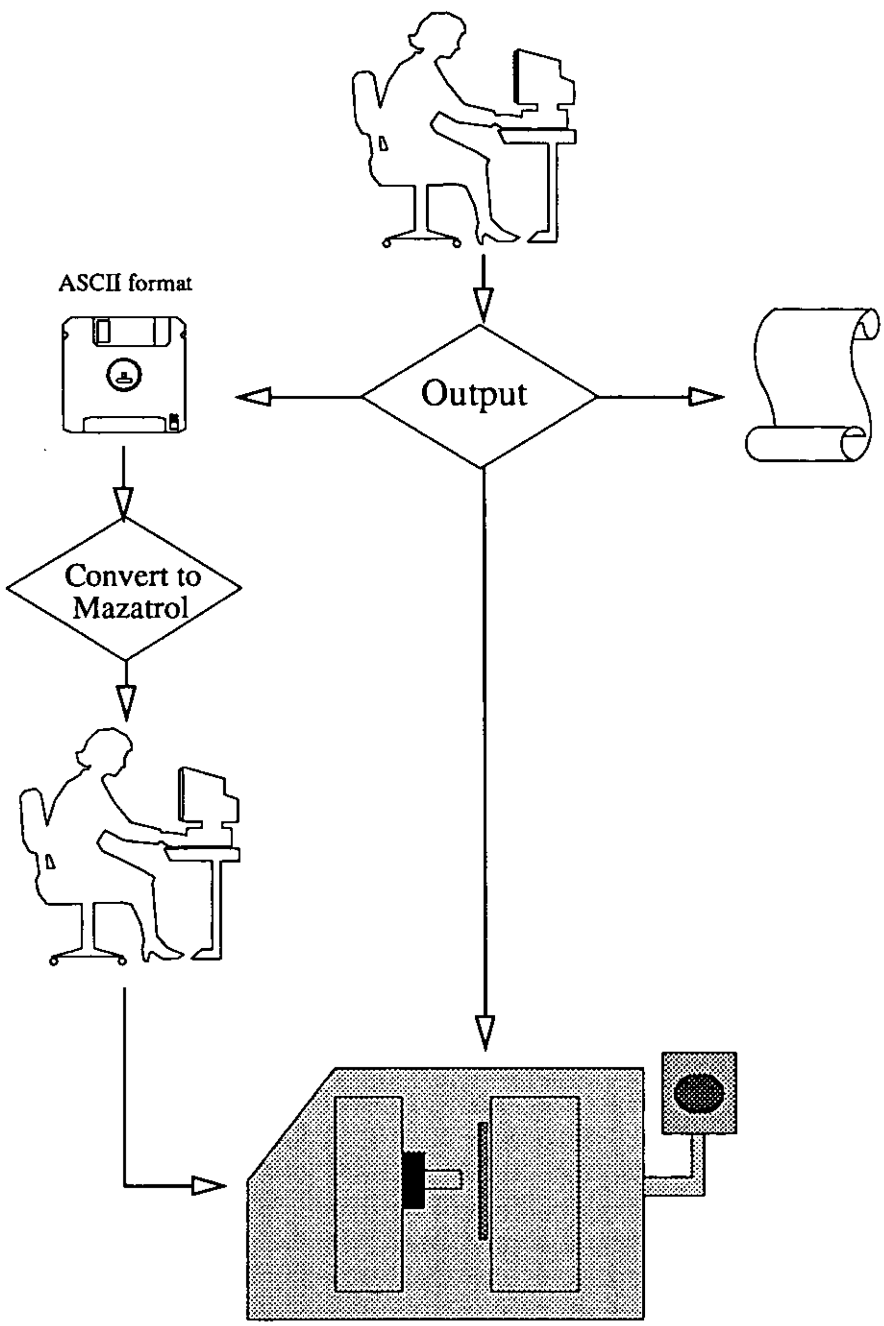
If:
(region is face in)
Then:
(The operation is (rough turn the face in)
The operation is (finish turn the face in))

APPENDIX V

The NC Output For The Case Study

The NC ouput presented in this section has been tested at MAZAK and simulated on MAZATROL T32-2 emulating the *Quick Turn Super 15 turning* centre. The steps for the simulation of the programs are depicted below. The actual tool path print is also provided.

The NC Planning System



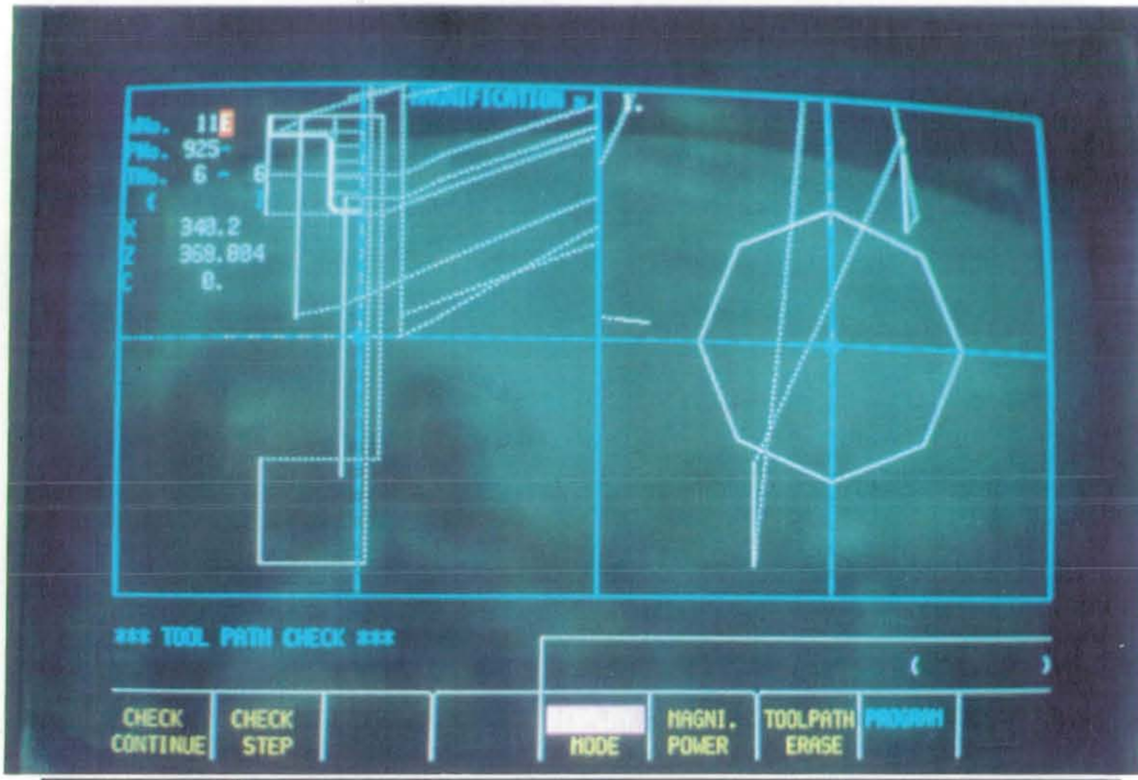


Figure 1 | TOOLPATH FOR COMPONENT B | LUT- CAD/CAM

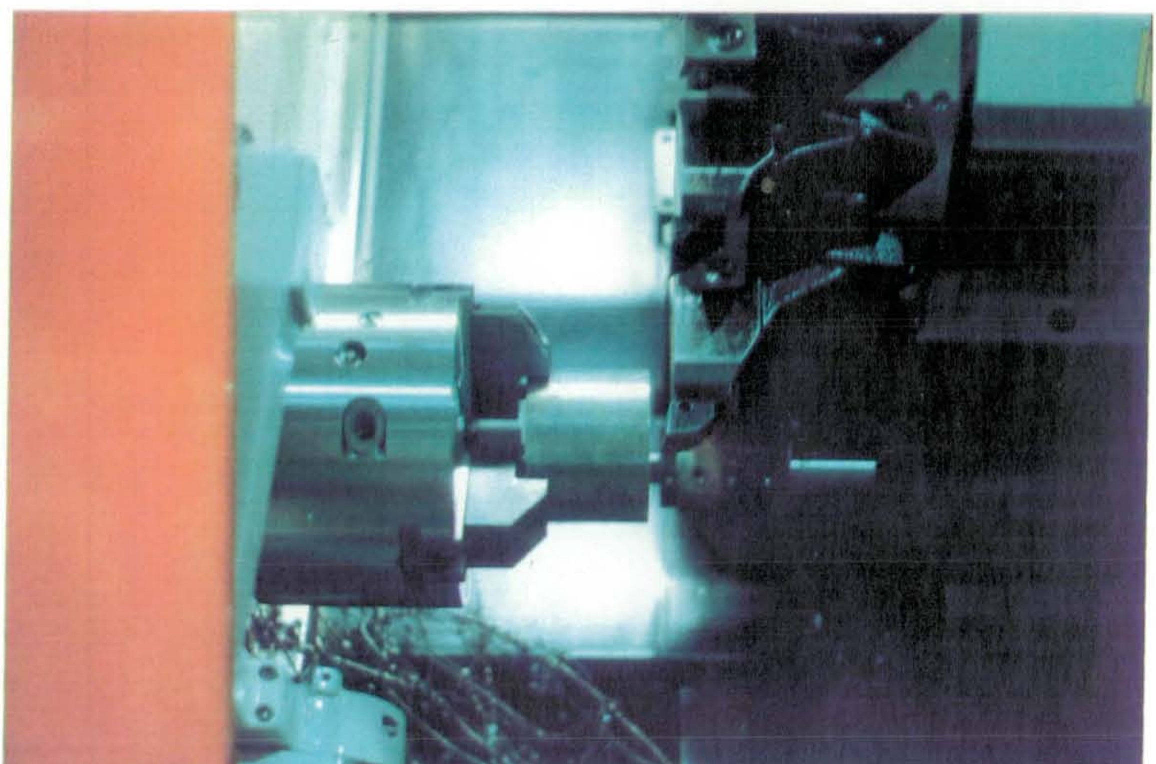
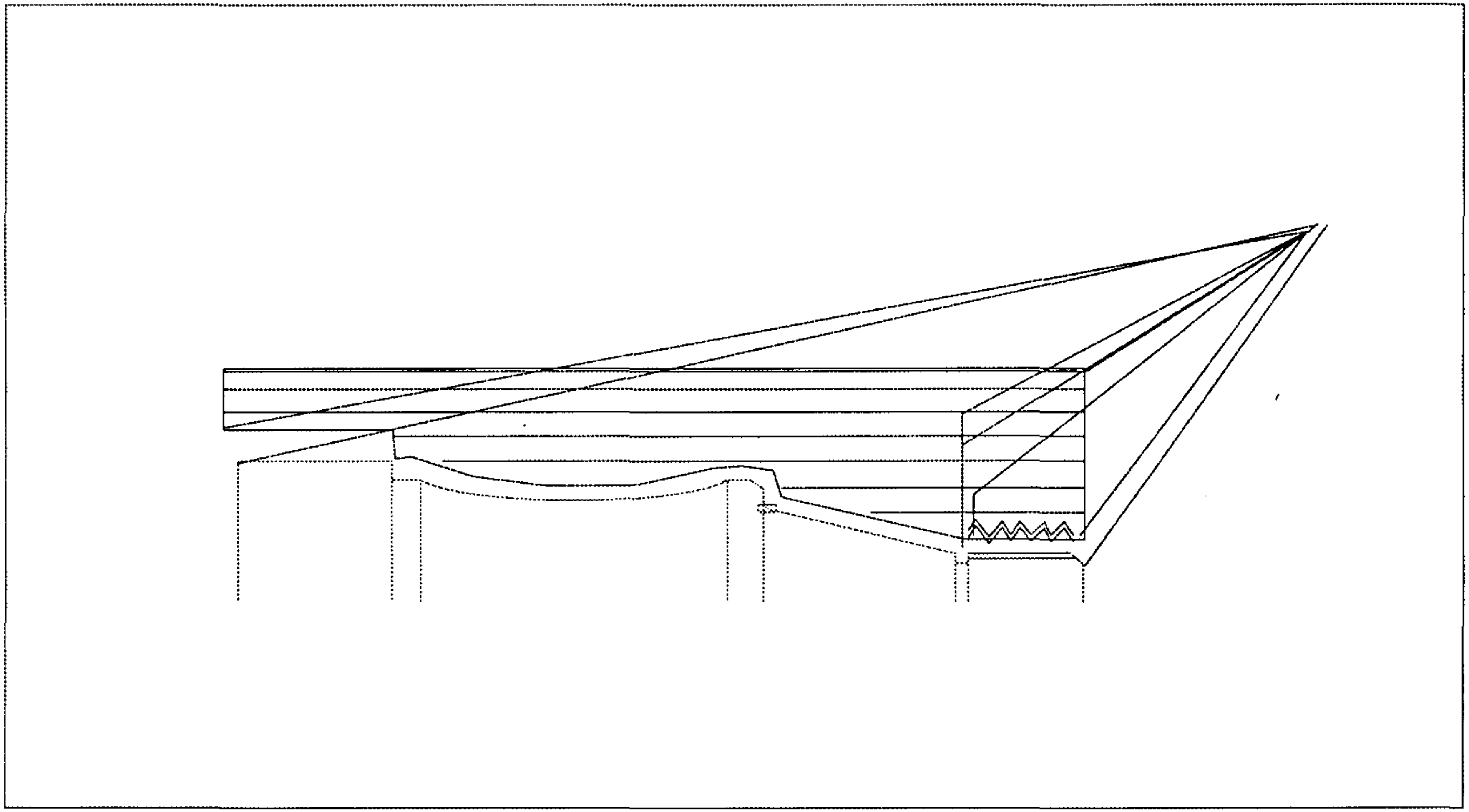
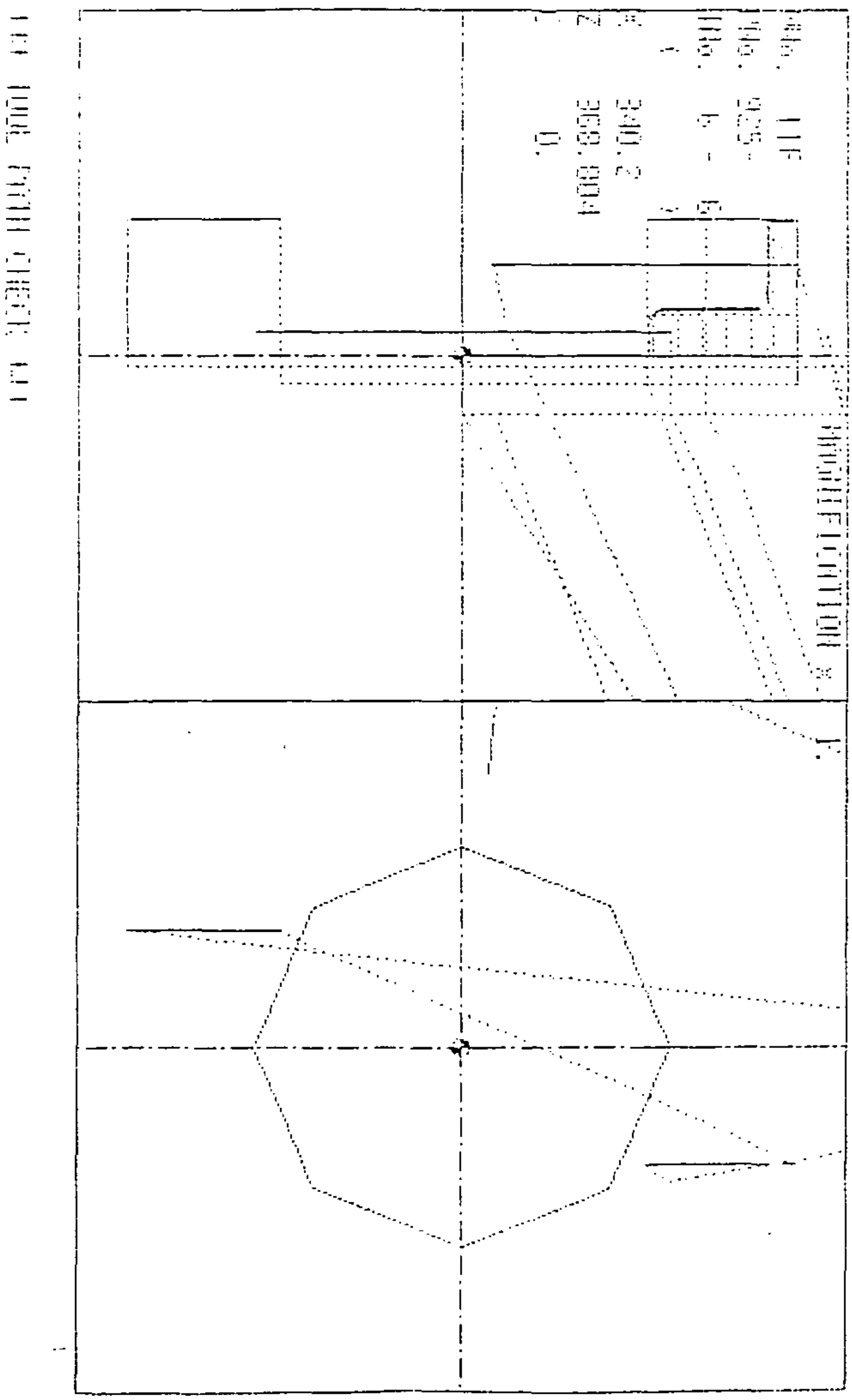


Figure 2 | MAZAK QUICK TURN 15 | LUT- CAD/CAM



TOOL PATH CHECK ***


MAGNIFICATION

EIA/ISO PROGRAM WORK NO. = 0222

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N95;
N100;
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N880X0Y34.0;
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APPENDIX VI

Part Programming Using Parametrised Features

A.1 - Introduction

This appendix reports on the design and implementation of a parametric part programming approach aimed at reducing the complexity of part description by providing a structured and modular method for code generation. The use of a parametric approach and the design of variables intended to rationally describe components is one of the primary objectives of this method. IDEF0 is used to model the activities which describe this approach, see appendix III. The following sections will provide a greater understanding of the work.

A.2 - Scope of Parametric Part Programming Approach

The parametric approach is designed to eliminate the repetitive, complex and cumbersome procedures embedded in traditional part programming systems. Two distinct methods are pursued. The first approach, as discussed in the subsequent sections, is totally independent of the workshop oriented approach presented in the previous chapters *(7, 8, 9, 10, 11, 12, 13)*. This approach offers an alternative method to the one presented in chapter 9. Nonetheless the second parametric approach as described in chapter 13 deals primarily with parametrised components within a part family and it is designed to be an integral part of the workshop oriented NC planning system. However the approach described in this chapter uses predefined features as the optimum medium *[Shah 88]* to be used by a programmer to capture the intent of the design and manufacture. The concept of pre-defined regions as described in chapter 9 is not used in the work discussed in this chapter.

A.3 - Parametric Part Programming Using Features

This research is partially based upon the works of Hinduja *[1989]* and Varvakis *[1991]*. The strength of argument in parametric part programming stems from the importance in any successful manufacturing environment of the role of an NC programmer and the total function of the NC program. Today the NC program represents more than just geometric tool path and machining commands. Therefore, it is essentially a description of the manufacturing process; the culminating effort of various experts who's decisions about the design, quality and manufacturability of the workpiece are concentrated and embedded in the final NC output. It is the author's view that the implementation of a parametric approach can allow the designer, as well as the manufacturing engineer, to incorporate those parameters which can best convey the intention and produce the final product successfully. Features can be used as a medium to embody the parameters designated by various experts to capture the knowledge required in order to machine the geometrical entities efficiently. The primary advantage of parametric part programming is the ability to use variables. Variables are used as arguments that can best represent a rotational component. The type of features and the parameters required to represent them, as well as the arguments suitable for the geometric and process domain are derived by close interaction between the design and manufacturing environment. The arguments and variables are thus defined in a way that allows them to be used throughout the design and manufacturing process. The variables also simplify the description process for the NC programmer. The parametric part programming functions are each described in more detail in the subsequent sections.

A.4 - IDEF0 Representation

IDEF0 is used to model the activities and methods which were developed for the parametric system. As discussed in the previous section, and represented in IDEF0, features for rotational components are designed based on the common needs of both the design and manufacturing activities. In practise, the specification of a feature is determined by the design and manufacturing requirements and the available resources and manufacturing knowledge. However, even if the design of a more global specification might not be feasible, a more dedicated and specific approach (*i.e for part programming*) can be taken which in turn can determine the parameters required for each feature. These decisions are ultimately made when designing each feature. Since a more dedicated approach is chosen (*part programming*), then the designed parameter to some degree controls the selection process meaning that the set of features available in the library can be better used for a specific process. The input to the range of available features is designed to take the essential information regarding the geometric, as well as technological data, in a way that best serves the final aim (*code generation*). It is at this junction where the shop-floor practice plays a vital part, i.e to point out that some of the requirements relating to the shop-floor practice must be taken into consideration at the inception point so that features can be used to maximum effects. Subsequent activities are designed as a central processing unit so that the pertinent information regarding a given component can be interactively entered, analysed and manipulated so as to generate the final manufacturing code. A more detailed and descriptive definition of these activities is provided in the subsequent sections.(*see appendixes iii A1222*)

A.5 - Information Elements for Pre-processing

Several pieces of information are used to convey the necessary data that describes a given component. Each module is designed to provide an efficient description of a particular aspect of a component. As depicted (*figure A.1*) the several layers of information provided can sufficiently generate each and every geometrical feature. Due to the modularity of the design, more layers can be added if needed. These layers consist of a feature library containing and providing the appropriate features, the tooling module, the geometrical module and the technological module, each designed to support the code generation function. The merits of each module are discussed individually in the

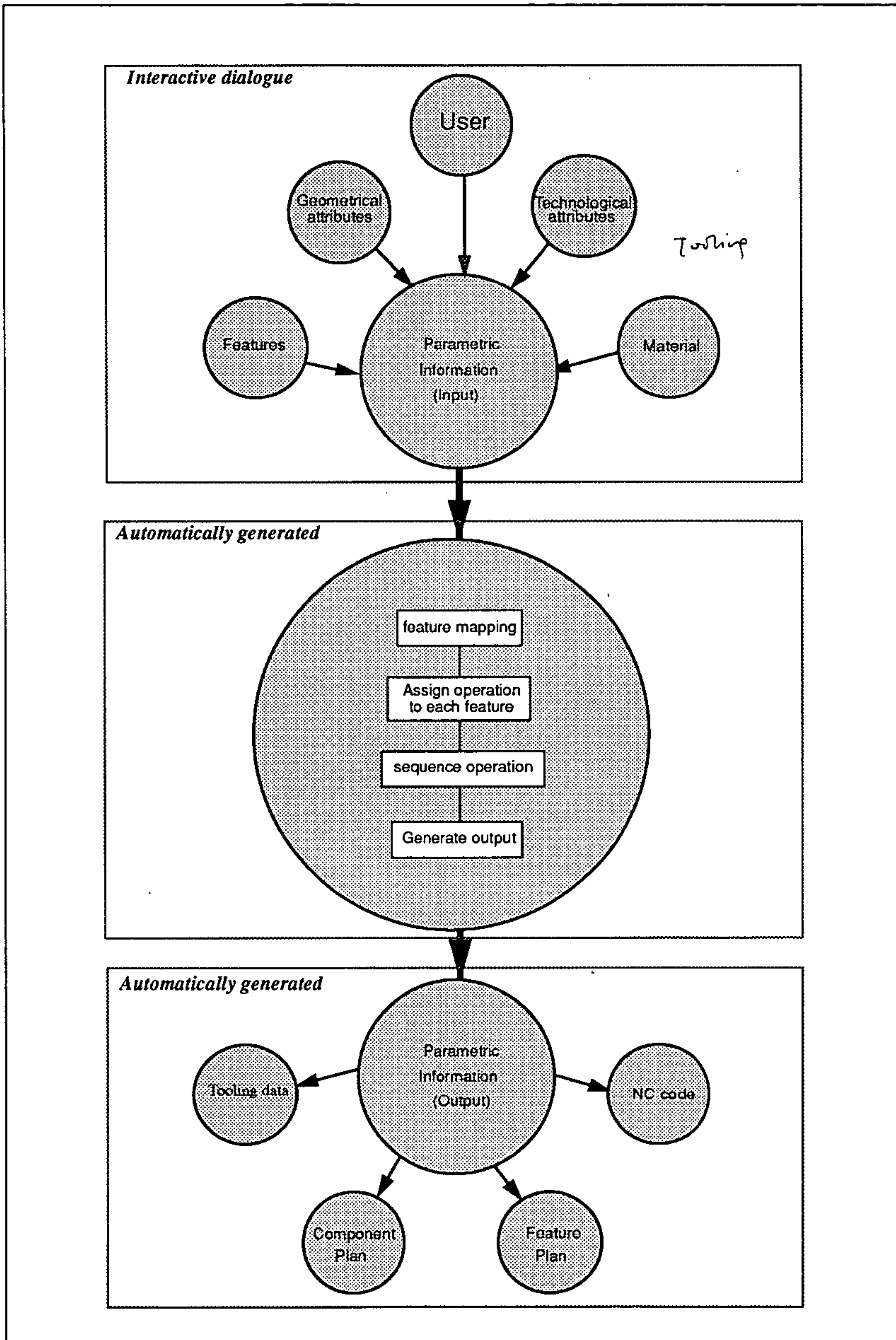


Figure A 1	Program structure	LUT CAD/CAM

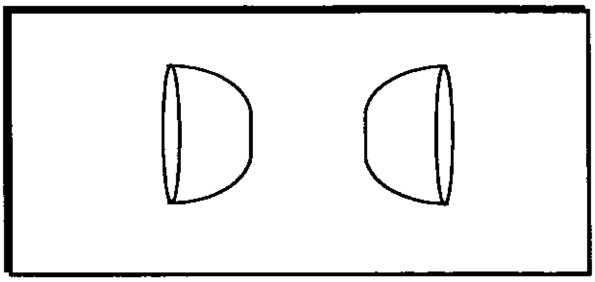
subsequent sections.

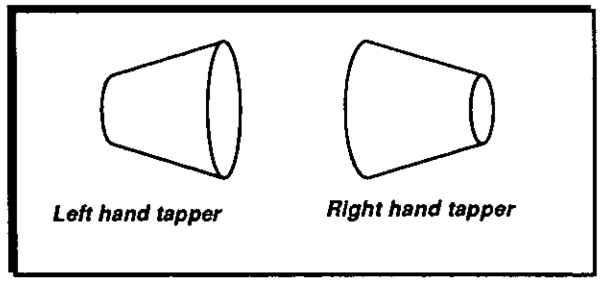
A.5.1 - Features

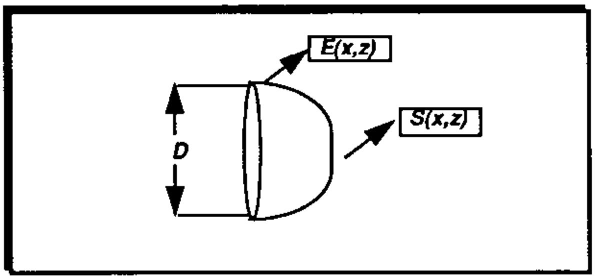
A feature is defined as a recurring geometrical and technological pattern that is designed for a specific geometric and process domain. The objective of the parametric system is to use a set of geometrical patterns that can best describe the rotational workpiece, therefore the library of features designed for the parametric system is aimed at being truly representative of a typical rotational workpiece. These part features are classified into external and internal features, each representing cylindrical, tapered, concave, convex and threads. As shown *(figure 14.2)* each feature is represented by several distinct parameters. These variables are designed to transmit the necessary information so as to assist the generation of NC code. The advantage of using this method is directly related to the fact that less input is required for description. In contrast, the workshop oriented approach requires a greater level of interaction. It is important to note that a disadvantage of using a parametric feature description is that a more complex set of algorithms are required to generate the final output which consequently will exert more pressure on CPU time. A full description of the turning features is depicted overleaf *(figure A.2)*.

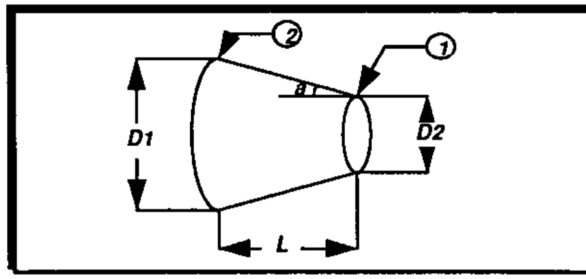
A.5.2 - Geometric Data

Several parameters are assigned to fully describe the geometrical attributes of a feature. For the sake of simplicity each feature is described geometrically with a minimum number of possible parameters. The straight cylinder is defined by its diameter, starting point and ending point. The tapered cylinder is best described by the start and ending diameter and length. The concave and convex features are also described by starting and ending length, diameter and radius (*figure A.2*). These geometric parameters can rapidly describe the outer and inner profile of a given component. In addition the diameter of stock associated with each feature is further described so as to aid the



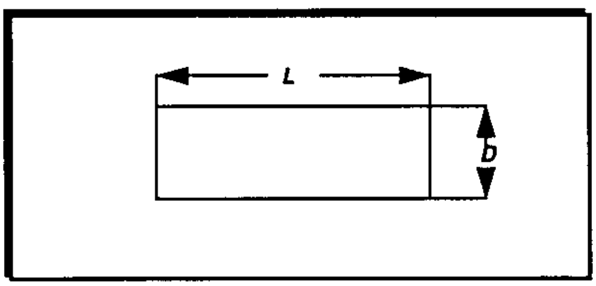


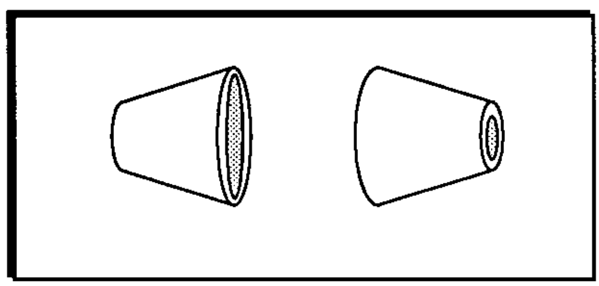


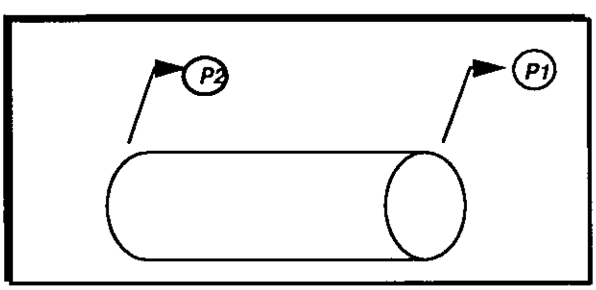


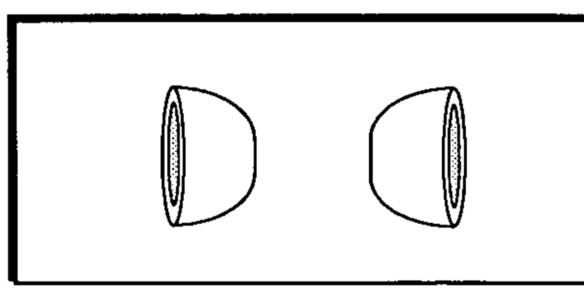
E = x,z coordinate for start of the arc.
S = x,z coordinate for end of arc
D= diameter
R= radius of arc

D1 = The larger diameter of cone or taper
D2 =The smaller diameter of cone or taper
p1 = The first (x,z) point of taper or cone
p2 = The second (x,z) point of taper or cone









P1=First point of feature in z -axis.
P2=Second point of feature in z-axis
L= Length of feature
D = Diameter of feature

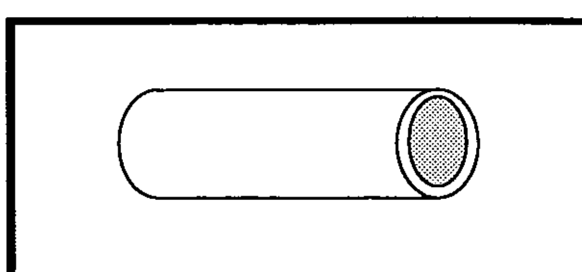


Figure A 2	Feature type	L.U.T CAD/CAM

operation planning decisions (*i.e multi pass decision making*).

A.5.3 - Tooling Information

Tooling is an essential function which provides vital information to operation planning and code generation activities. The geometrical attribute associated with each tool is the variables that determines the technological requirement for the selected features. Each feature is designed in such a way so as to embody the correct cutting tool for both roughing and finishing operations. The user is interactively questioned to input the appropriate cutting tool. Nevertheless, if the tools used for several features are similar then the interaction for tooling could be easily by-passed so as to prevent any redundancy of data. The tool attributes consist of tool position, nose radius, and function.

A.5.3 - Technological Data

The dedicated database is designed to hold the necessary information regarding material type, cutting speed and feedrate. The material choice is directly selected by the user and the cutting speed and feedrate are then automatically calculated. Five categories of materials are provided, therefore the appropriate material can be selected based on the design requirement and consequently the cutting speed and feed rate for both roughing and finishing operations will be determined. The finishing feed rate is determined by both the tool nose radius and the surface finish value assigned for each feature.

A.5.4 - Selection and Planning of Features

The feature based environment provides an easy basis for a part programmer to select the relevant features based on interactive dialogues. The user must then provide the necessary information to describe each feature using geometrical data. A fixed sequence is designed for turning features in which features have to be defined from right to left. Each feature representing a portion of workpiece. The starting and ending point for the length of each feature must be inputted using a negative value in an absolute mode.

A.5.5 - Feature Selection

The parametric part programming system uses a feature based approach *[Hinduja 89]*. Therefore each feature representing a portion of the drawing must be selected from the feature library and described according to the parameters depicted in figure A.2. The burden of selecting the correct features lies with the user. The rest of the decision making is performed automatically by the system to generate the operation plan and NC data. The features represented in the library are limited, nevertheless if more features are required then the feature library can be easily modified to accommodate the changes. As shown (*figure A.3*) the primary features consist of straight cylinder, tapered cylinder, and concave and convex features.

A.5.6 - Operation Mapping

Features are represented in the context of machining, therefore the task of assigning different machining processes to features is relatively straight forward. For example when a cylinder of a smaller diameter is positioned between two larger diameter cylinders then it can only be produced either by grooving or recessing, If the size exceeds the standard groove widths that are commercially available then the segment is recognized as a recess which then must be machined by a turning operation *[Hinduja 89]*. Technological and geometrical constraints are used to limit the number of plausible processes. Three major categories of operation are used to generate the features:

i- Turning
ii-Grooving
iii-Threading

Each area between the stock and the feature is analysed and if the stock thickness

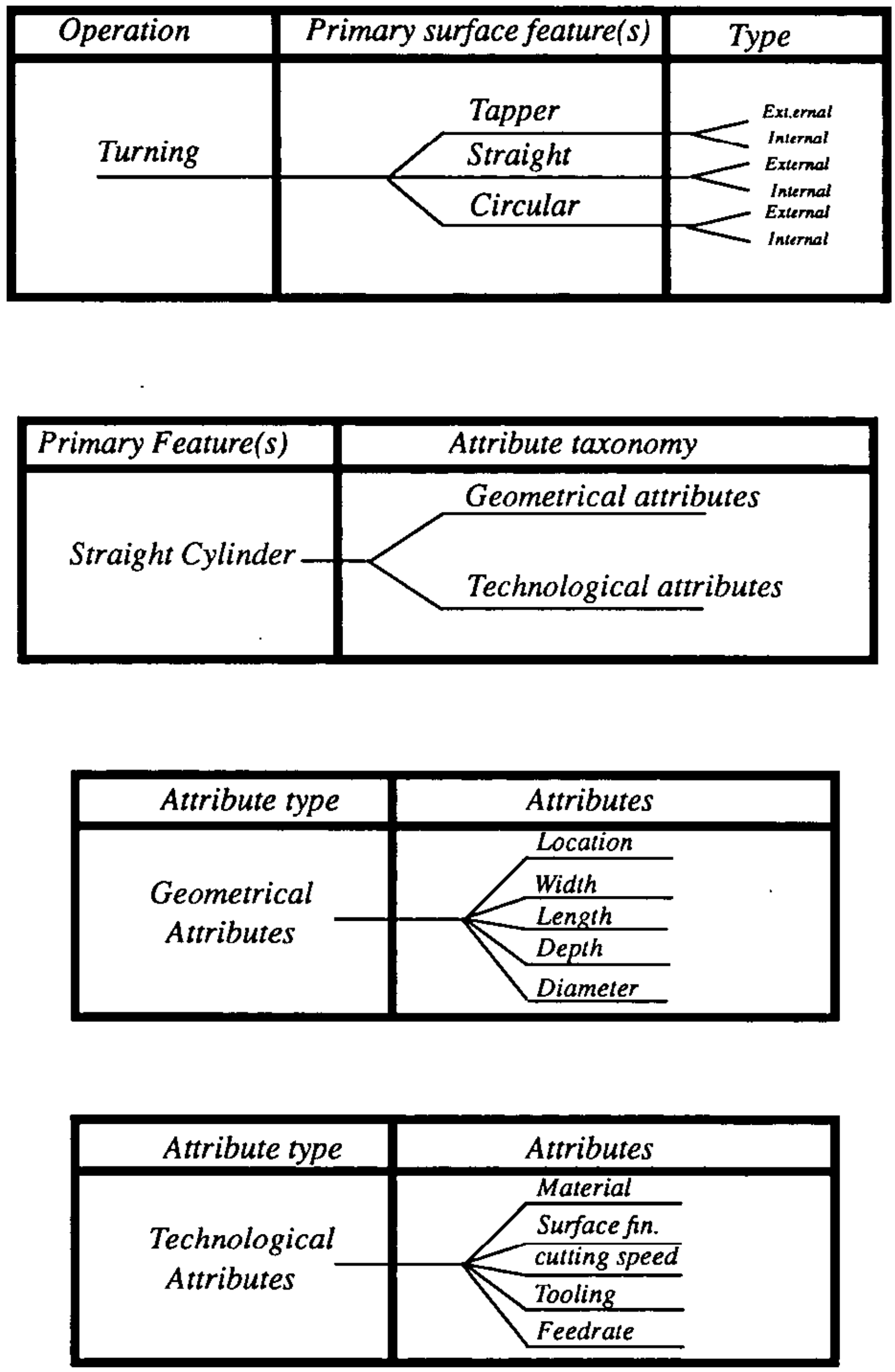


Figure A.3 | Feature description | LUT CAD/CAM exceeds the depth of cut that can be assigned for a finishing operation then a roughing operation takes place before any finishing operation is performed. The intention is to impose those constraints on the sequence of operations which are essential. An internal decision model is used as the basis for planning and decision making (*see chapter 12 for more detail*). The next activity is to perform the grooving and subsequently the threading operations. In order to summarize this activity the system automatically performs the following tasks:

i - Maps the rotational features to the correct machining process (*by turning, grooving, threading, etc.*)

ii -By further analysis the process selected is mapped to the relevant operation (*roughing & finishing*).

At this point the system is quit ready to perform the operation sequencing.

A.5.7 - Operation Sequencing

The sequence of operations for rotational features is based on the principle described in chapter 12. However, the operations that are associated with each feature are analysed and subsequently sequenced based on the following rules: *[Hinduja 89][Eversheim 82]*

i - Machine the surfaces (*rough turning operation for both the O.D & I.D profile*)

ii - Machine the grooves (*grooving operation*)

iii -Machine the threads (*threading operation*)

iv -Machine the surfaces (*finish turning operation for both the O.D & I.D profile*)

A.5.8 - CLDATA Generation

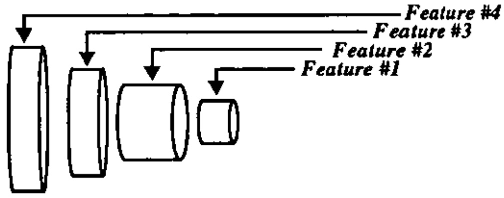
The next event is the generation of cutter location data in order to produce the geometrical features. This activity requires explicit data regarding the boundary of a component. The parameter required to derive the cutter tool path is determined by the depth of rough cut and the number of possible cuts required to produce a component. It is important to point that the technological parameters are automatically generated which consequently assist in generating the CLDATA.

A.6 - Information Output

The information output by the parametric system is designed to assist the user and the system. As is depicted in figure A.4 four separate and distinct outputs are generated which the user can use as a guide. These include a tooling file, a component plan, a feature plan and an NC file. The last file contains the NC code which is used to transmit information and consequently actuate the machine tool. The component plan is used to generate concise planning information for each feature (*the feature plan*), consequently a feature plan is used as the basis for generating the NC output. These output files provide a considerable amount of data which can be used to analyse and examine the component and it's associated features.

A.6.1 - Tooling Data

The system is designed in such away so that the user can interactively input all the relevant information about each tool. The tooling data is then stored in a data file. The tooling file provides valuable information on the tool number used, the tool nose radius, the tool type (*left handle, right handle or neutral*) and the operation it is used for. The concise information embedded in this system provides guidance to the user and this can be helpful when checking the program on the machine (*see figure A.4 - table 1*).



Tool description file

Tool No.	Nose Radius	Type	Tool life	Operation
101 - 102	0.6	L	0.030	S.O turning
101-102	0.6	L	0.061	S.O turning
101 - 102	0.6	L	0.021	S.O turning
101 - 102	0.6	L	0.009	S.O turning

Component operation plan file

Feature	Process	Operation description	Tooling
S.cylinder	Turning	Turn Dia. 10 * length. 10	101 - 102
S.cylinder	Turning	Turn Dia. 15 * length. 20	101 - 102
S.cylinder	Turning	Turn Dia. 30 * length. 7	101 - 102
S.cylinder	Turning	Turn Dia. 40 * length. 3	101 - 102

Feature plan file

Description	Feature #1	Feature #2	Feature #3	Feature #4
Feature type	Straight - OD	Straight - OD	Straight - OD	Straight - OD
Machining ref.	X52, Z 1.0	X52, Z9	X52,Z-29	X52, Z-36
Operation	Ext. Turning	Ext. Turning	Ext. Turning	Ext. Turning
Stock Dia.	50	50	50	50
Feature Dia.	10	15	30	40
Feature length	10	20	7	3
Depth of cut	2.4 mm	2.4 mm	2.4 mm	2.4 mm
Number of R / cut	16	14	8	3
Cutting speed	140	140	140	140
Cutting feed	0.51	0.51	0.51	0.51
tool	101	101	101	101
Cutting time	0.314	0.549	0.110	0.018
Non cutting time	0.0016	0.0028	0.0006	0.0001
Operation	Finishing	Finishing	Finishing	Finishing
Depth of cut	0.33	0.33	0.33	0.33
No. of finish cut	1	1	1	1
Cutting speed	212	212	212	212
Cutting feed	.33	0.33	0.33	0.33
Cutting time	0.0196	0.0392	0.0137	0.006

Figure A.4	The parametric output files	LUT CAD/CAM

A.6.2 - Component Plan

The component plan provides general information regarding the selected features, lists the attributes and features that are interactively selected and specifies the general geometry of each feature. In addition, the sequence of operation is listed. The component plan forms the basis on which the feature plan is generated and the CLDATA is subsequently determined. (*See figure A.4 - table* 2)

A.6.3 - Feature Plan

The feature plan represents more detailed information about the operation planning activity that is associated with each feature. As is depicted in figure A.4 - table 3, the first segment of a feature plan describes the feature name (*i.e. straight O.D*) and specifies the tooling information, as well as the type of operation used to generate a particular feature. The second portion of this file specifies the machine tool reference as it relates to the given feature in terms of starting point and rapid point to the start of the machining boundary. The third type of information represented in the feature plan is concerned with the detailed operation planning activity. The type and the principal operation are listed, in addition the stock diameter above the feature region is fully described and the geometric attributes such as feature diameter and length are also provided. The next portion provides concise information concerning the depth of cut, number of rough cuts, the cutting parameters (*feed and speed*), roughing tool and cutting time & non cutting time. Similar information on the finishing operation is also provided which form the basis on which the CLdata is generated.

A.6.4 - NC Code Generation

The final output created is designed to actuate the CNC lathe. The NC code is directly derived from the operation planning data previously calculated and embedded in the feature plan. All the roughing NC operations are performed first before the finishing operations. The rapid movement, as well as tool direction, are optimised in order to increase the efficiency and decrease the non-cutting time. The final output is in an

ASCII format which can be easily transferred through the RS232 port to machine tools.

A.7 - Concluding Remark

The methodology used for the parametric part programming system has helped the author to understand the differences, demands and the limitations of the parametric approach. The benefit from the user point of view is simplicity and minimum information input. However, from the system's point of view more CPU time and a higher degree of calculation and automation is required to produce the NC code

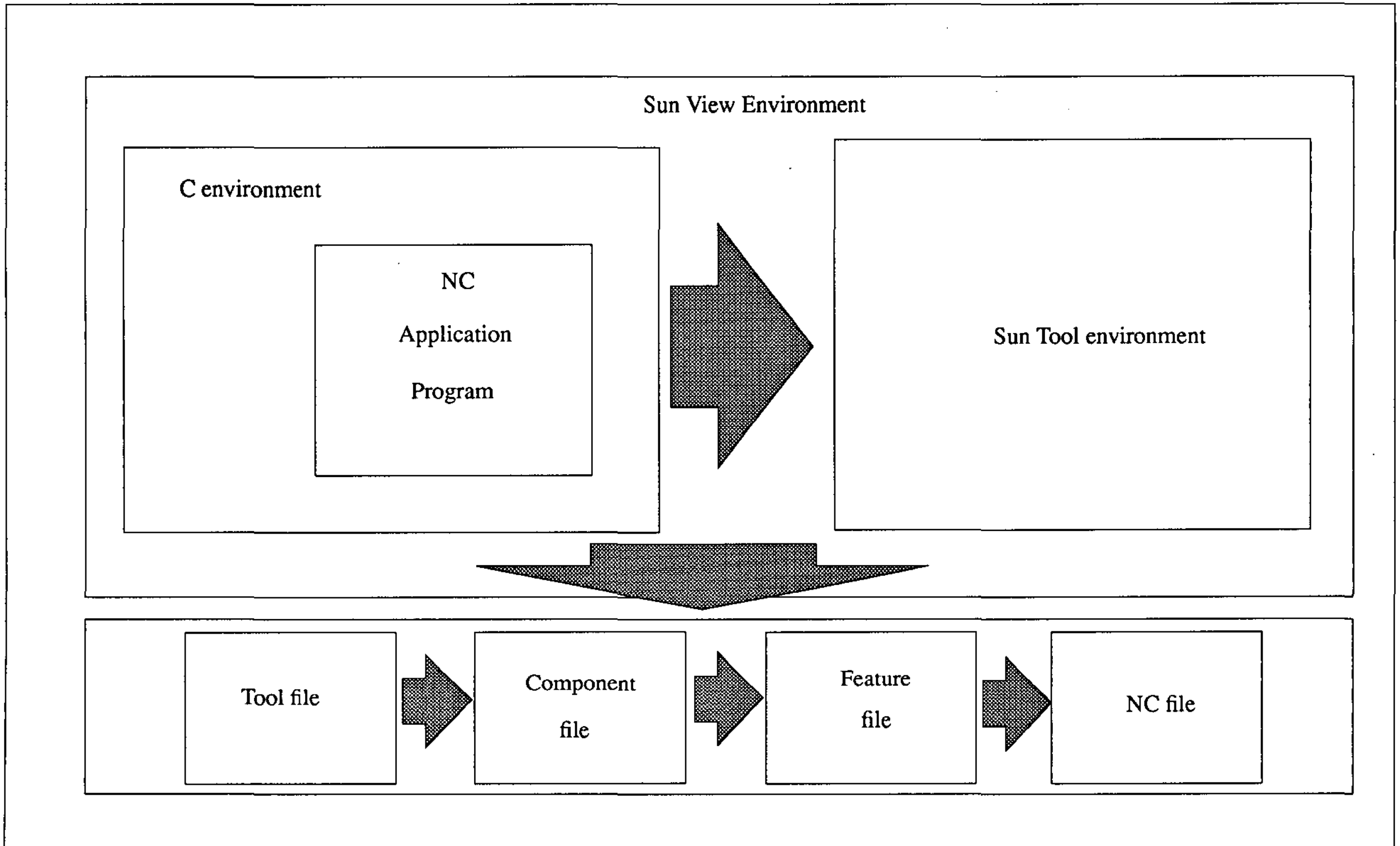
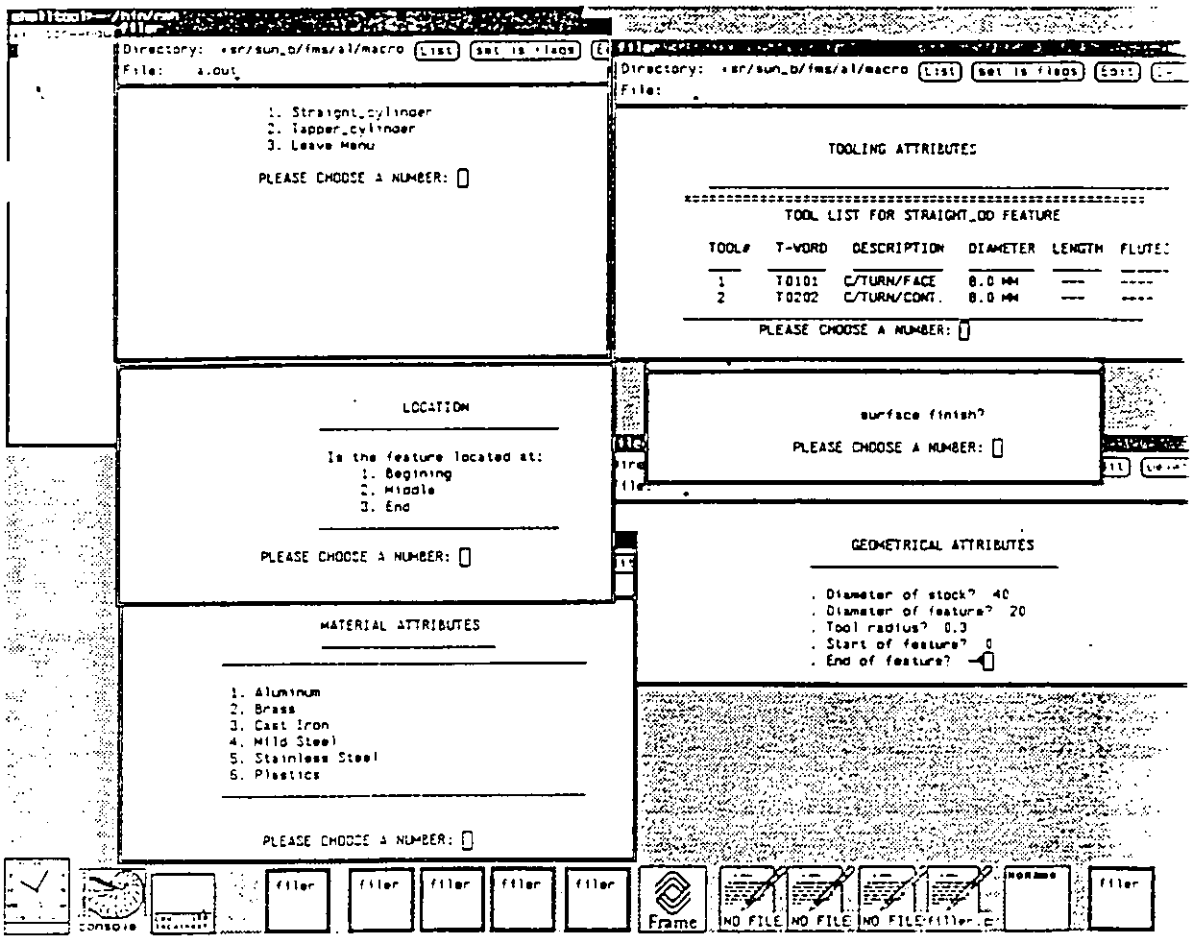


Figure A5	Application software system for parametrised feature	LUT - CAD/CAM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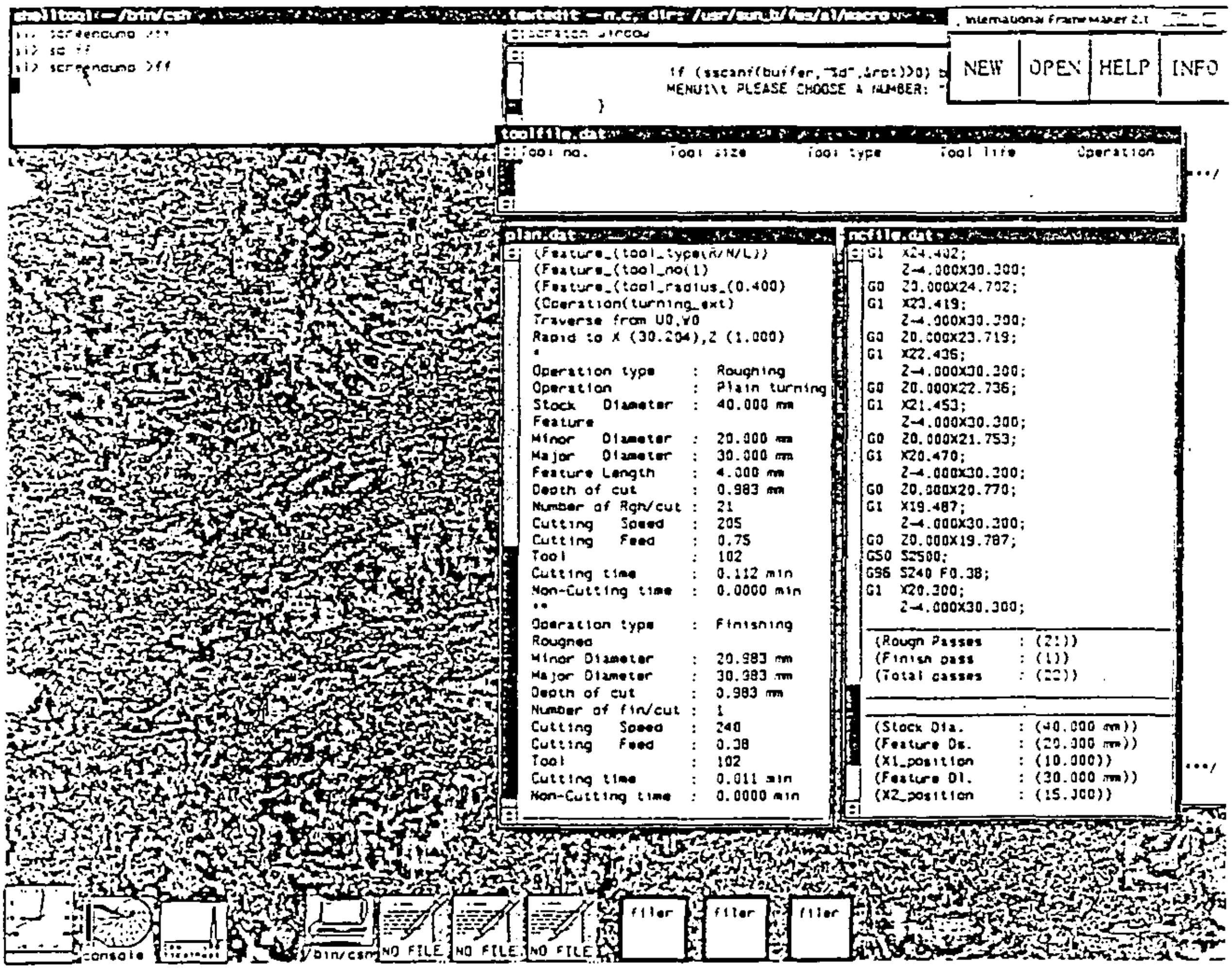
File: a.out
1. Straight_cylinder
2. Tapper_cylinder
3. Leave Menu
PLEASE CHOOSE A NUMBER:
TOOLING ATTRIBUTES
TOOL LIST FOR STRAIGHT_OD FEATURE
TOOL# T-WORD DESCRIPTION DIAMETER LENGTH FLUTES
1 T0101 C/TURN/FACE 8.0 MM
2 T0202 C/TURN/CONT. 8.0 MM
PLEASE CHOOSE A NUMBER:
LOCATION
Is the feature located at:
1. Begining
2. Middle
3. End
PLEASE CHOOSE A NUMBER:
surface finish?
PLEASE CHOOSE A NUMBER:
GEOMETRICAL ATTRIBUTES
. Diameter of stock? 40
. Diameter of feature? 20
. Tool radius? 0.3
. Start of feature? 0
. End of feature?
MATERIAL ATTRIBUTES
1. Aluminum
2. Brass
3. Cast Iron
4. Mild Steel
5. Stainless Steel
6. Plastics
PLEASE CHOOSE A NUMBER:
console
filer
Frame
NO FILE


shelltool - /bin/csh
textedit - n.c; dir: /usr/sun_b/fes/al/macro
International FrameMaker 2.1
NEW
OPEN
HELP
INFO
if (sscanf(buffer,"%d",&rot))0)
MENU1\t PLEASE CHOOSE A NUMBER:
toolfile.dat
Tool no.
Tool size
Tool type
Tool life
Operation
plan.dat
(Feature_(tool_type(R/N/L))
(Feature_(tool_no(1)
(Feature_(tool_radius_(0.400)
(Operation(turning_ext)
Traverse from U0,V0
Rapid to X (30.204),Z (1.000)
Operation type : Roughing
Operation : Plain turning
Stock Diameter : 40.000 mm
Feature
Minor Diameter : 20.000 mm
Major Diameter : 30.000 mm
Feature Length : 4.000 mm
Depth of cut : 0.983 mm
Number of Rgh/cut : 21
Cutting Speed : 205
Cutting Feed : 0.75
Tool : 102
Cutting time : 0.112 min
Non-Cutting time : 0.0000 min
Operation type : Finishing
Roughed
Minor Diameter : 20.983 mm
Major Diameter : 30.983 mm
Depth of cut : 0.983 mm
Number of fin/cut : 1
Cutting Speed : 240
Cutting Feed : 0.38
Tool : 102
Cutting time : 0.011 min
Non-Cutting time : 0.0000 min
ncfile.dat
G1 X24.402;
Z-4.000X30.300;
G0 Z0.000X24.702;
G1 X23.419;
Z-4.000X30.300;
G0 Z0.000X23.719;
G1 X22.436;
Z-4.000X30.300;
G0 Z0.000X22.736;
G1 X21.453;
Z-4.000X30.300;
G0 Z0.000X21.753;
G1 X20.470;
Z-4.000X30.300;
G0 Z0.000X20.770;
G1 X19.487;
Z-4.000X30.300;
G0 Z0.000X19.787;
G50 S2500;
G96 S240 F0.38;
G1 X20.300;
Z-4.000X30.300;
(Rough Passes : (21))
(Finish pass : (1))
(Total passes : (22))
(Stock Dia. : (40.000 mm))
(Feature Ds. : (20.000 mm))
(X1_position : (10.000))
(Feature Dl. : (30.000 mm))
(X2_position : (15.000))
console
/bin/csh
NO FILE
NO FILE
NO FILE
filer
filer
filer

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