UNIT 9 COMPUTER AIDED PROCESS PLANNING (CAPP)

Structure

9.1 INTRODUCTION

Before introduction to the role of computer aided process planning (CAPP), it is worthwhile to understand the role of process planning in the product cycle. Once the design of the product has been evolved from customer’s views, its manufacturing necessitates careful planning and scheduling of the various processes of manufacture. So that, the product is made to right specifications and delivered at the right time at a minimal cost. The cycle from concept to design, planning, production, quality control and feedback to design goes on in which one can easily understand the crucial role of planning. In job/batch manufacture, as an enormous amount of data is needed for planning as well as other activities, data bases are required and the flow of information should be fast for a high performance of the total manufacturing system.

Objectives

After studying this unit, you should be able to

- understand what is process planning and CAPP,
- know the various steps involved in CAPP,
- classify the various methods of CAPP, and
- understand the feature recognition in CAPP.

9.2 INTRODUCTION TO PROCESS PLANNING

In manufacturing, the goal is to produce components that meet the design specifications. The design specification ensures the functionality aspect. Next step to follow is to assemble these components into final product. Process planning acts as a bridge between design and manufacturing by translating design specification into manufacturing process detail. Hence, in general, process planning is a production organization activity that transforms a product design into a set of instruction (sequence, machine tool setup etc.) to manufacture machined part economically and competitively. The information provided in design includes dimensional specification (geometric shape and its feature) and technical specification (tolerance, surface finish etc.)

Now-a-days, process planning is applied to many manufacturing industries like metal cutting, sheet metal forming, composite and ceramic fabrication and other manufacturing processes. Figure 9.1 represents the various steps involved in developing a process plan.

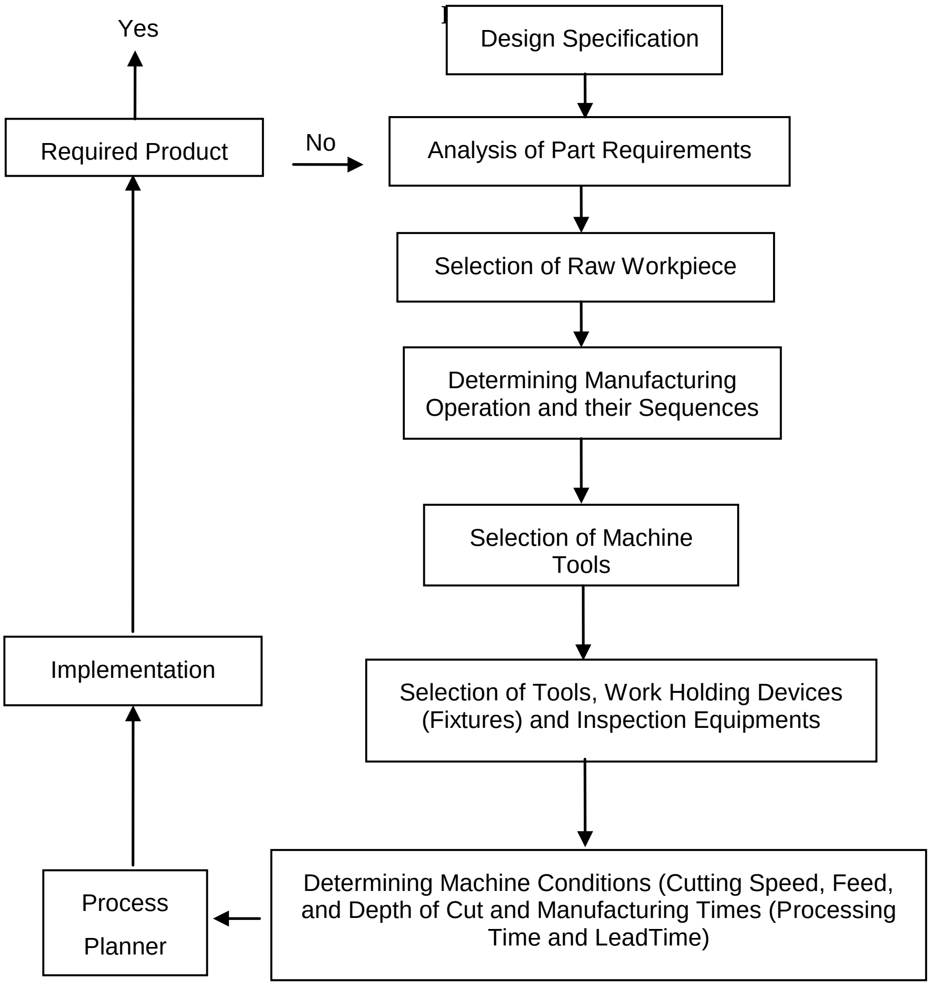


Figure 9.1

Various steps are discussed as follows :

The analysis of finished part requirement is the first step in process planning. Initially the features of parts are analyzed. Examples of geometric feature include plane, cylinder, cone step, edge and include fillet. These common features can be modified by the addition of slots, pockets, grooves, holes and others. The second step is the selection of raw work piece shape, size (dimensions and weight), material and other attributes are determined. Weight and material of the raw part are determined by the functional requirement of plan.

The next logical step in process planning is to determine the appropriate types of processing operations and their sequences to transform the features, dimensions and tolerances of a part from the raw to the finished state. There may be many ways to produce a design some times constraints are also considered like some feature be machined before or after other. Furthermore, the types of machine, available tools as well as batch size influence the process sequence.

Next step to be followed in process planning is the selection of machine tools on which these operations are made.

Some of the factors which influences the selection of machine tool are as follows :

- (i) Attributes related to workpiece, such as desired features, dimensions of workpiece, dimensional tolerances and raw material form.
- (ii) Attributes related to machine tools, e.g. process capability size, mode of operation, tooling capabilities and automatic tool changing capabilities.
- (iii) Attribute related to production volume, e.g. production quantity and order frequency.

Unit cost of production, manufacture lead time and quality are three basic criteria for evaluating the suitability of a machine tool to accomplish an operation.

Next step to be followed is the selection of tools work holding devices and inspection equipments. Features on the workpieces are generated using a combination of machine tool and cutting tools. Work holding devices are used to locate and hold the workpiece to generate features. In order to ensure the dimensional accuracy, tolerance and surface finish on the feature, inspection equipments are required. Part features play a vital role in the selection of machine tools, fixture and inspection equipment.

Now sixth step which has to be performed is the determination of machining condition and manufacturing time. The controllable variables of machine condition are cutting speed (υ), feed (f) and depth of cut (d).

Minimum cost per piece, maximum production rate and manufacture lead time are same for the model to be optimized for high production and less cost.

9.3 APPROACHES TO PROCESS PLANNING

There are basically two approaches to process planning which are as follows :

- (i) Manual experience-based process planning, and
- (ii) Computer-aided process planning method.

9.3.1 Manual Experience-based Process Planning

The steps mentioned in the previous section are essentially same for manual process planning. Following difficulties are associated with manual experienced based process planning method :

- It is time consuming and over a period of time, plan developed are not consistent.
- Feasibility of process planning is dependent on many upstream factors (design and availability of machine tools). Downstream manufacturing activities such as scheduling and machine tool allocation are also influenced by such process plan.

Therefore, in order to generate a proper process plan, the process planner must have sufficient knowledge and experience. Hence, it is very difficult to develop the skill of the successful process planner and also a time consuming issue.

9.3.2 Computer-Aided Process Planning

Computer-aided process planning (CAPP) helps determine the processing steps required to make a part after CAP has been used to define what is to be made. CAPP programs develop a process plan or route sheet by following either a variant or a generative approach. The variant approach uses a file of standard process plans to retrieve the best plan in the file after reviewing the design. The plan can then be revised manually if it is not totally appropriate. The generative approach to CAPP starts with the product design specifications and can generate a detailed process plan complete with machine settings. CAPP systems use design algorithms, a file of machine characteristics, and decision logic to build the plans. Expert systems are based on decision rules and have been used in some generative CAPP systems.

CAPP has recently emerged as the most critical link to integrated CAD/CAM system into inter-organizational flow. Main focus is to optimize the system performance in a global context. The essentiality of computer can easily be understood by taking an example, e.g. if we change the design, we must be able to fall back on a module of CAPP to generate cost estimates for these design changes. Similarly for the case of the breakdown of machines on shop floor. In this case, alternative process plan must be in hand so that the most economical solution for the situation can be adopted. Figure 9.2 is one such representation, where setting of multitude of interaction among various functions of an organization and dynamic changes that takes place in these sub functional areas have been shown. Hence, the use of computer in process planning is essential.

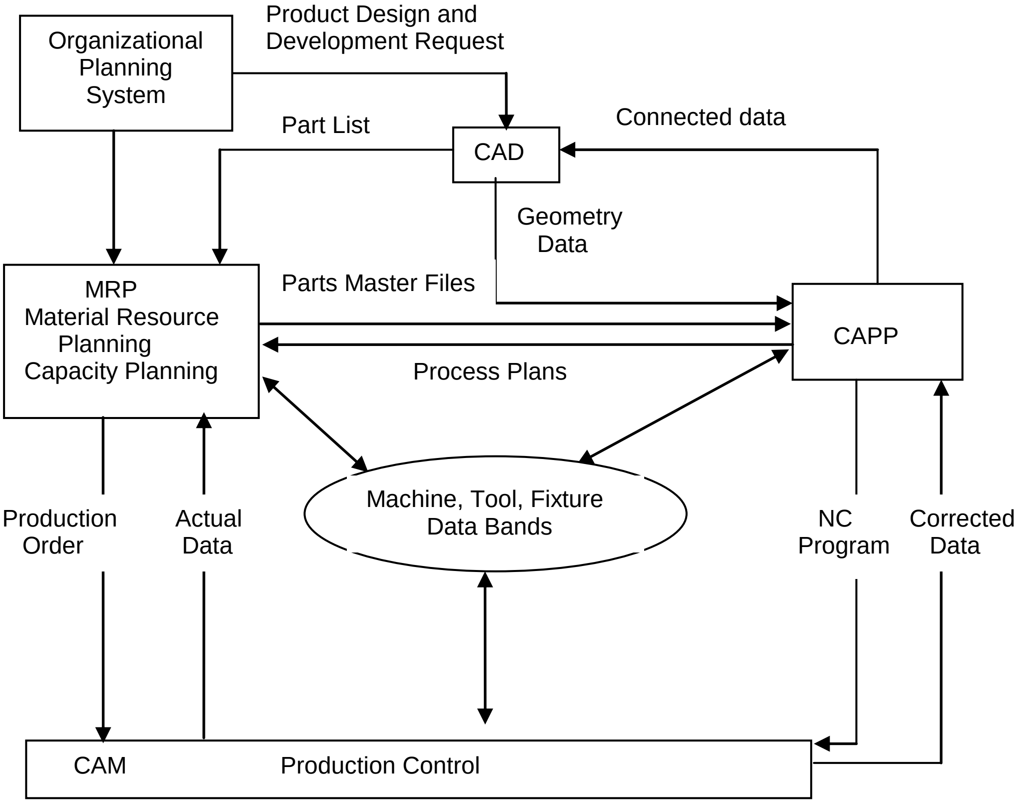


Figure 9.2 : Framework for Computer Aided Process Planning

CAPP is the application of computer to assist the human process planer in the process planning function. In its lowest form it will reduce the time and effort required to prepare process plans and provide more consistent process plan. In its most advanced state, it will provide the automated interface between CAD and CAM and in the process achieve the complete integration with in CAD/CAM.

Advantages Over Manual Experience-based Process Planning

The uses of computers in process plan have following advantages over manual experience-based process planning :

(i) It can systematically produce accurate and consistent process plans.

(ii) It leads to the reduction of cost and lead times of process plan.

(iii) Skill requirement of process planer are reduced to develop feasible process plan.

(iv) Interfacing of software for cost, manufacturing lead time estimation, and work standards can easily be done.

(v) Leads to the increased productivity of process planar.

With the emergence of CIM as predominate thrust area in discrete part industries process planning has received significant attention, because it is the link between CAD and CAM. Hence, computer aided process planning (CAPP) has become a necessary and vital objective of CIM system.

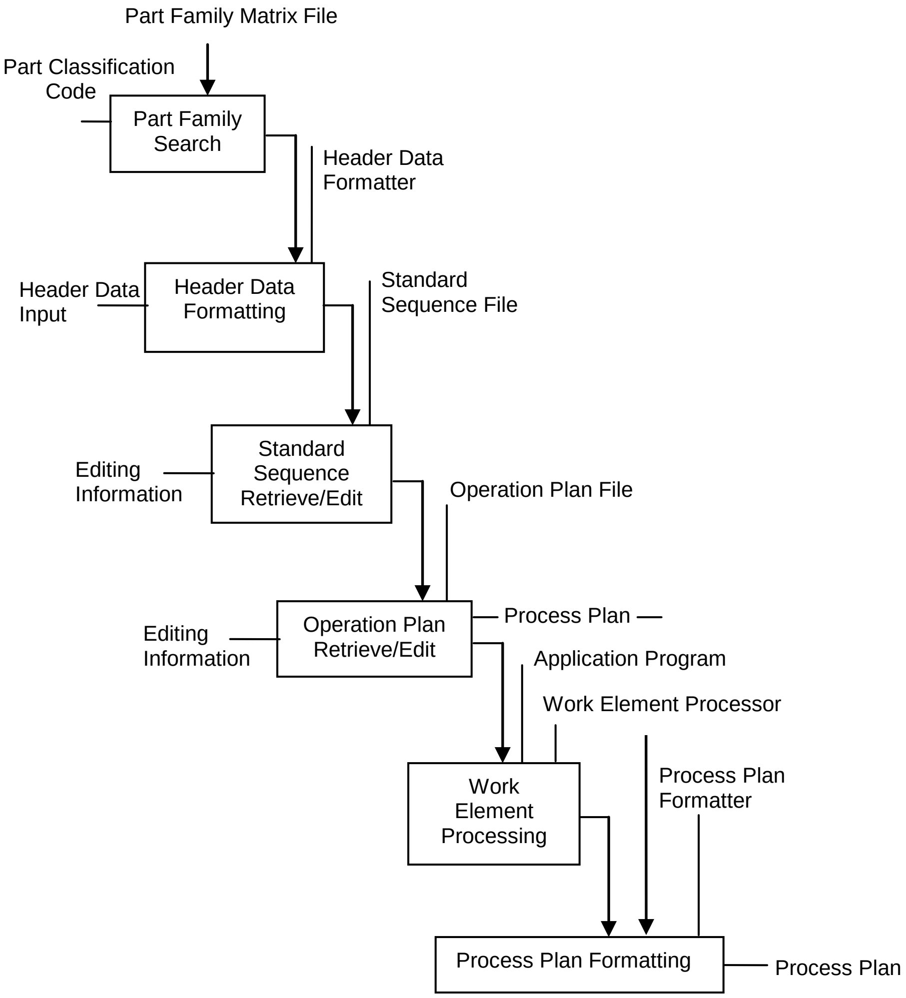


Figure 9.3 : Flow Diagram of the CAPP Process Planning System

Steps Involved in CAPP

Now-a-days, rapid progress is being made in the automation of actual production process and also the product design element. However, the interface between design and production presents the greatest difficulty in accomplishing integration. CAPP has the potential to achieve this integration. In general, a complete CAPP system has following steps :

(i) Design input

(ii) Material selection

(iii) Process selection

(iv) Process sequencing

(v) Machine and tool selection

(vi) Intermediate surface determination

(vii) Fixture selection

(viii) Machining parameter selection

(ix) Cost/time estimation

(x) Plan preparation

(xi) Mc tape image generation.

9.4 APPROACHES TO COMPUTER-AIDED PROCESS PLANNING

In recent days, several computer-aided process planning systems are available for use for a variety of manufacturing operation.

These systems can broadly be clarified into two categories :

(i) Variant computer aided process planning method.

(ii) Generative computer aided process planning method.

The details of these are explained in next subsections.

9.4.1 Variant Process Planning, Advantages and Disadvantages

Variant process planning approach is sometimes referred as a data retrieval method. In this approach, process plan for a new part is generated by recalling, identifying and retrieving an existing plan for a similar part and making necessary modifications for new part. As name suggests a set of standard plans is established and maintained for each part family in a preparatory stage. Such parts are called master part. The similarity in design attributes and manufacturing methods are exploited for the purpose of formation of part families. Using coding and classification schemes of group technology (GT), a number of methods such as coefficient based algorithm and mathematical programming models have been developed for part family formation and plan retrieval. After identifying a new part with a family, the task of developing process plan is simple. It involves retrieving and modifying the process plan of master part of the family.

The general steps for data retrieval modification are as follows :

Establishing the Coding Scheme

A variant system usually begins with building a classification and coding scheme. Because, classification and coding provide a relatively easy way to identify similarity among existing and new parts. Today, several classification and coding systems are commercially available. In some extreme cases, a new coding scheme may be developed. If variant CAPP is preferred than it is useful for a company to look into several commercially available coding and classification systems (e.g. DCLASS, JD-CAPP etc.). Now, it is compared with companies before developing their own coding and classification system. Because using an existing system can save tremendous development time and manpower.

(i) **Form the Part Families by Grouping Parts**

The whole idea of GT lies into group numerous parts into a manageable number of part families. One of the key issues in forming part families is that all parts in the same family should have common and easily identifiable machined features. As a standard process plan are attached with each part family, thereby reducing the total number of standard process plans.

(ii) **Develop Standard Process Plans**

After formation of part families, standard process plan is developed for each part families based on common part features. The standard plan should be as simple as possible but detailed enough to distinguish it from other.

(iii) **Retrieve and Modify the Standard Plans for New Parts**

Step1 to step 3 are often referred as preparatory work. Each time when a new part enters the systems, it is designed and coded based on its feature, using the coding and classification scheme, and than assigned to a part family. The part should be similar to its fellow parts in the same family. Also, family’s standard plan should represent the basic set of processes that the part has to go through. In order to generate detailed process routes and operation sheets to this part, the standard plan is retrieved from the data base and modified. Modification is done by human process planar. After this stage parts are ready for release to the shop.

The success of aforementioned process planning system is dependent on selection of coding scheme, the standard process plan and the modification process, because the system is generally application oriented. It may be possible that one coding scheme is preferable for one company and same is not for other company.

Due to use and advancement of computers, the information management capability of variant process planning is much superior. Otherwise it is quite similar to manual experience-based planning.

Advantages and Disadvantages of Variant CAPP

Following advantages are associated with variant process planning approach:

(i) Processing and evaluation of complicated activities and managerial issues are done in an efficient manner. Hence lead to the reduction of time and labour requirement.

(ii) Structuring manufacturing knowledge of the process plans to company's needs through standardized procedures.

(iii) Reduced development and hardware cost and shorter development time. This is an essential issue for small and medium scale companies, where product variety is not so high and process planner are interested in establishing their own process planning research activities.

Disadvantages of Variant Process Planning Approach

Following disadvantages are associated with variant process planning approach

(i) It is difficult to maintain consistency during editing.

(ii) Proper accommodation of various combinations of attributes such as material, geometry, size, precision, quality, alternate processing sequence and machine loading among many other factors are difficult.

(iii) The quality of the final process plan largely depends on the knowledge and experience of process planner. The dependency on process planner is one of the major shortcomings of variant process planning.

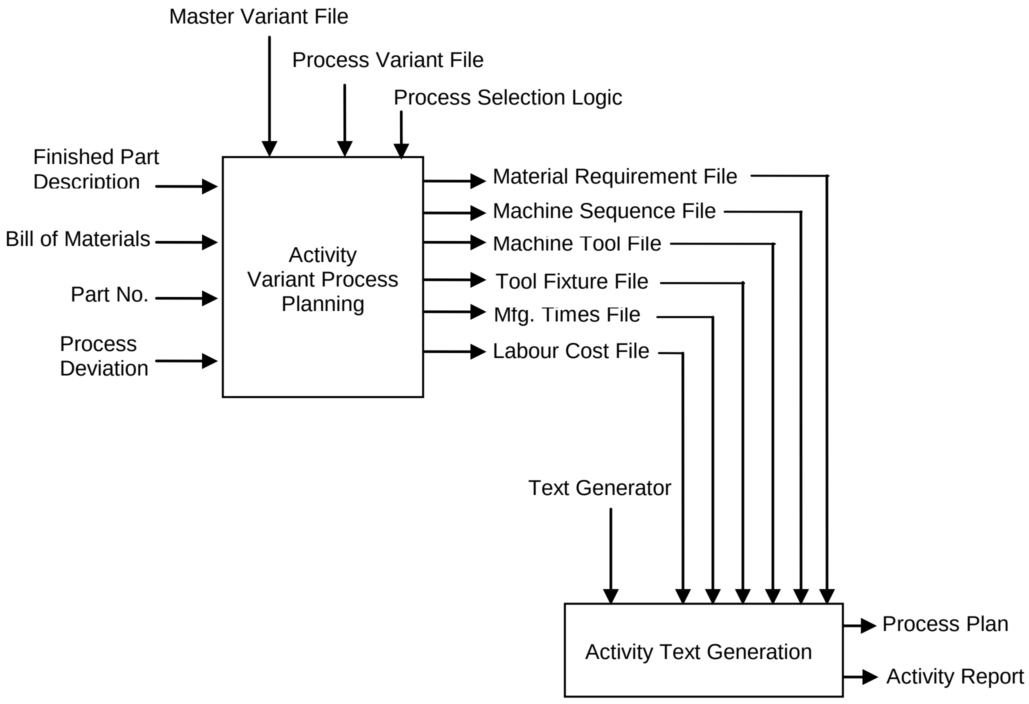


Figure 9.4 : Framework of Variant Process Planning Activity

Some of the most widely used process planning method developed by various company are mentioned as follows :

(i) Mc Donnell-Douglas automation company under the direction and sponsorship of Computer Aided Manufacturing International (CAM-I) developed a system where CAPP can be used to generate process plan for rotational, prismatic and sheet metal part.

(ii) Organization for Industrial Research (OIR) and General Electric Company have developed and another process plan named as MIPLAN. It accommodates both rotational and prismatic part, and is based on MICLASS coding.

9.4.2 Generative Process Planning, Advantages and Disadvantages

In generative process planning, process plans are generated by means of decision logic, formulas, technology algorithms, and geometry based data to perform uniquely processing decisions. Main aim is to convert a part form raw material to finished state. Hence, generative process plan may be defined as a system that synthesizes process information in order to create a process plan for a new component automatically.

Generative process plan mainly consists of two major components :

(i) Geometry based coding scheme.

(ii) Proportional knowledge in the form of decision logic and data.

Geometry-based Coding Scheme

All the geometric features for all process such as related surfaces, feature dimension, locations, on the features are defined by geometry based coding scheme. The level of detail is much greater in generative system than a variant system.

For example, various details such as rough and finished state of the part are provided to transform into desired state.

Proportional Knowledge in the Form of Decision Logic and Data

Process knowledge in the form of decision logic and data are used for matching of part geometry requirement with the manufacturing capabilities. All the methods mentioned above is performed automatically.

Operation instruction sets are automatically generated to help the operators to run the machines in case of manual operation. NC codes are automatically generated, when numerically controlled machines are used.

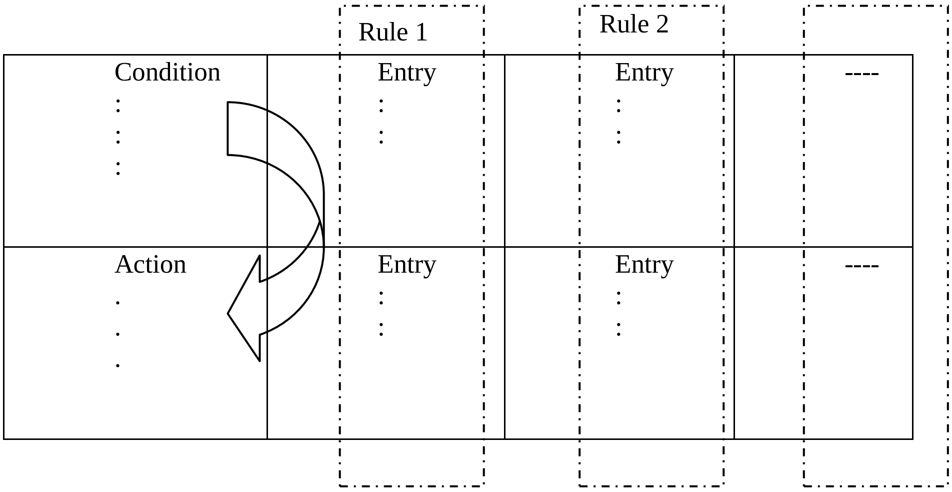


Figure 9.5 : Framework of a Decision Table

Manufacturing knowledge plays a vital role in process planning. The process of acquisition and documentation of manufacturing knowledge is a recurring dynamic phenomenon. In addition, there are various sources of manufacturing knowledge such experience of manufacturing personnel, handbooks, supplier of machine tools, tools, jigs and fixtures materials, inspection equipment and customers etc. Hence, in order to understand manufacturing information, ensuring its clarity and providing a framework for future modification, it is not only necessary but also inevitable to develop a good knowledge structure from wide spectrum of knowledge. Flowchart, decision trees, decision tables, algorithms, concepts of unit machined surfaces, pattern recognition techniques, and artificial intelligent based tools are used to serve the purpose. A brief discussion on decision table is given below.

The basic elements of decision tables are condition, action and rules. They are represented in the form of allocation matrix. Figure 9.4 is one such representation where condition states the goal that we want to achieve and action states the operation that we have to perform. On the basis of experience the expert rules are formed by entry values to establish the relationship between condition and action.

Table 9.1 is one such representation where entry are of Boolean-types (true, false, don't care). Similarly, in Table 9.2, continuous value type entries are shown.

Table 9.1 : Boolean Value-Type Entries

Length of bar $\geq$ 8 in.	T*	F	
Diameter of bar $\leq$ 1 in.			
Diameter of bar $\geq$ 1 in.	T		T
-	-	-	-
Extra Support	T		

* T : *True;* F : *False;* blank : *don't care.*

Table 9.2 : Continuous Value-type Entries

Length of bar (in)		$\leq$ 4	$\geq$ 4	$\leq$ 16	$\geq$ 16
Diameter of bar (in.)	$\leq$ 0.2	> 0.2	1>diameter>0.2	$\geq$ 1	
Extra support	T		T		T

* T : *true*; blank : *do not care*

The decision making process works as follow.

For a particular set of condition entries, look for its corresponding rule from that rule determine the action.

Advantages of Generative Process Plan

Generative process plans have a number of advantages. Among the major ones are the following :

(i) They rely less on group technology code numbers since the process, usually uses decision tree to categorize parts into families.

(ii) Maintenance and updating of stored process plans are largely unnecessary. Since, any plan may be quickly regenerated by processing through the tree. Indeed, many argue that with generable systems, process plans should not be stored since if the process is changed, and out-of-dated process plan might find its way back into the system.

(iii) The process logic rules however must be maintained up to dated and ready for use. This provides the process planner with an assurance that the processes generated will reflect state-of-the-art technology.

Description of various generative and variant and generative CAPP systems is mentioned Table 9.3.

Table 9.3 : Some of the Variant and Generative CAPP Systems

CAPP System	Part Shapes	Process Planning Approaches	Characteristics and Commercial Situation	Programming Languages Used	Developers
CMPP	Rotational	Generative	Uses English like language(COPPL)	FORTRAN 77	UTRC (USA)
GENPLAN	All	Variant and Generative	Interfaced with CAD\CAM		Lockheed-Georgia(USA)
GT-CAPP	All	Generative	Part family code used		Rockwell Inc (USA)
KAPPS	Rotational and Prismatic	Generative	Part family numbers used	LISP	Kobe Univ. (JAPAN)
MIPLAN	Rotational and Prismatic	Variant	Expert system based on MICLASS		OIR and GE Co.(USA)
RTCAPP	Prismatic	Generative	Generic shell		USC (USA)
TURBO-CAPP	Rotational	Generative	Knowledge based interfaced with CAD	PROLOG	Penn. State Univ (USA)
XPLAN	All	Generative	Expert system based on DCLASS	FORTRAN 77	Tech. Univ. of DK (Denmark)
XPLAN-R	Rotational	Generative	Expert system based on DCLASS	FORTRAN 77	Tech. Univ. of DK (Denmark)
XPLANE	Rotational	Generative	Knowledge based	FORTRAN	Twente Univ. Tech. (Netherland)
XPS-1	All	Variant and Generative	COPPL used	FORTRAN	UTRC and CAM-I (USA)

(***Source*** **:** Alting and Jhang (1989))

9.4.3 Knowledge-based Process Planning

The main forces behind to apply knowledge-based (KB) techniques for CAPP is the requirement of large amount of human expertise in CAPP. Based on the previous discussion, one realizes that a productive CAPP system must contain tremendous amount of knowledge – facts about the machine and shop environment as well as rules about sequencing machining operations must be included. A traditional CAPP program cannot learn new knowledge without a programmer explicitly rewriting it. The rigidity of traditional methodology endangers the implementation of CAPP systems. A KB system stores knowledge in a special manner so that it is possible to add, delete and modify facts and rules in the knowledge base without rewriting the program, i.e. it learns new things according to embedded learning procedures.

A complete set of manufacturing knowledge is not equipped by any existing knowledge-based process planning system. Most of these systems focus on a small portion of the issues in the domain of automated process planning using an expert systems approach. Some of them are :

EXCAP Family of Process Planning Systems

EXCAP, EXpert Computer-Aided Process Planning, developed by Davies and Darbyshire, is a knowledge-based system for rotational part process planning.

EXCAP-A and EXCAP-Y are previous generations of the current member of the EXCAP family of process planning systems.

GARI

GARI is the first AI-based CAPP program to appear in the literature. It is implemented in MACLISP and operates on CII-Honeywell Bull HB-68 computer under the MULTICS operating system. GARI utilizes production rules in its knowledge representation and generates a process plan from a model of the part. It emphasizes the “conflict resolution”. The knowledge is rather subjective and specialized. As a result, in the planning process, “compromises are often necessary.”

TOM : Technostructure of Manufacturing

TOM is another production rule-based CAPP system written in PASCAL and runs on VAX computer. TOM was designed to accept input in two ways: (1) directly entering part desecration by the user, and (2) translating design data from COMPAC CAD system. TOM can deal with “holes” exclusively.

SIPP : Semi-Intelligent Process Planner

SIPP is an AI-based CAPP system for the creation of metal parts using chip metal removal operations. It is written in PROLOG and utilizes “frames” as its knowledge representation scheme instead of using production rules. Frames are used to represent two types of knowledge: (1) information about the characteristics of various kinds of machinable surfaces, and (2) the capabilities of various machining processes.

SIPS

SIPS, another AI-based CAPP system which selects machining operations for the creation of metal parts, is a successor to SIPP. It is written in LISP and is currently being integrated into the AMRF (Automated Manufacturing Research Facility) project, where it is used to select machining operations on a feature by feature basis.

Like SIPP, SIPS also employs branch and bound search strategy for the least-cost-first solution in its inference engine. The basic difference between SIPP and SIPS is that SIPS used a new knowledge representation technique, called hierarchical knowledge clustering, instead of “flat” frames to represent problem-solving knowledge.

TOLTEC

TOLTEC is a system equipped with some learning capability. It takes input as feature-based part description interactively. The features are represented in a frame structure. It generates output in a form of operations and their sequence.

Turbo-CAPP

Turbo-CAPP is a knowledge-based CAPP system written in PROLOG and capable of :

- extracting and interpreting surface features from a 2&1/2-D CAD data base.
- performing intelligent reason for process planning.
- learning new process and machining capabilities.
- generating alternative process plans (based on the current status of the knowledge base).
- creating generic NC part programs for automated.

Turbo-CAPP is designed to handle strictly symmetric rotational parts. It employs a backward chining inference mechanism for plan generation. In the process of creating process plan and NC codes, the system must acquire knowledge from the user from time to time.

XPS-2 Family of CAPP Systems

CAM-I started the first structured development of process planning systems. It then embarked on a form-feature based, generative planning project, XPS and accomplished with the completion of XPS-2 in 1987. The form feature used to implement XPS-2 were taken from a "feature taxonomy" developed by CAM-I.

Other Knowledge-Based CAPP Systems

Rather than aforementioned Knowledge-Based CAPP System some other KB process planning systems are in existence :

(i) CMPP (Austin, 1996) is a planning system for planning cylindrical parts (also for some non-cylindrical features). It performs dimension, tolerance, and stock removal analysis based on a sophisticated algorithm with the objective of optimizing tolerance capabilities of shop equipment.

(ii) Hi-MAPP developed by Brenfi and Khoshnevis.

(iii) Wolfe and Kung in 1984 developed a CAPP system, which reads part geometry from a PADL model and generates process plans automatically.

9.4.4 Variant or Generative, Which to Use?

What CAPP approach (Variant or Generative) is better? This question has been constantly asked but, there is no definite answer to it.

Generally speaking, a variant system is better for manufacturing setting where similar parts are manufactured repetitively. Because parts are similar, Group Technology can easily be implemented and shows quick and significant return on investment (ROI). Because similar parts are produced repetitively, process plan can be retrieved, slightly modified and used, without going through too much trouble. On the other hand, generative process planning is better suited for a manufacturing environment in which part does not exhibit too much similarity and new part are introduced on a regular basis. In this case, benefits cannot be gained from Group Technology due to dissimilarity of parts. Because, new parts are regularly introduced, historical data does not have too much value to the process planner. However, aforementioned approach is a rough guideline for selecting the appropriate CAPP approach.

SAQ 1

(a) What is process planning?

(b) What are the various steps in developing a process plan?

(c) Why the need for CAPP arises?

(d) What are different approaches to CAPP? Describe briefly.

(e) Briefly describe the "Knowledge based Process Planning".

(f) Write short notes on following :

  (i) Manual experience based process plan.

  (ii) Computer Aided Process Plan.

9.5 FEATURE RECOGNITION IN CAPP

As we have seen that CAPP system usually serve as link in integrating the CAD and CAM. However, it is only the partial link due to lack of part feature information provided by existing CAD/ Drafting system. Part feature information is an essential data for CAPP. In other words, it is a tedious job for CAPP to understand the three dimensional geometry of the designed part from CAD system in terms of their engineering meaning related to assembly and manufacturing. Generally, all CAPP planning method and systems suffered from such type of problem and is referred as feature recognition in CAPP.

Hence, objective of feature recognition is to bridge the gap between the database and automated process planning systems by automatically distinguishing the feature of a part from the geometry and topological data stored in the CAD system. The essence of feature recognition can easily be understood by taking an example as shown in Figure 9.6. This figure is defined by a constructive solid geometry tree that represents a block primitive and a cylinder primitive combined by the Boolean operator "-". Shape and dimension can easily be identified by these schemes but, some higher level information is not provided by this scheme such as, whether the hole is blind hole or through hole. Such types of information are called as feature. Hence, features play a vital role in CAPP. In order to identify features and to solve CAD / CAPP interface problem, feature recognition is one of the most efficient technique.

Feature recognition transforms a general CAD model into an application specific feature model. In general, a generic part feature recognition system must be able to resolve following issues.

(i) Extract design information of a part.

(ii) Identify all surfaces of part.

(iii) Recognize reasons about\and\or interpret these surfaces in terms of Part features.

Once the features are classified, the automated planning system could develop the required process plan to make the part and hence, eliminate the need for a human to translate the CAD data into something that process planning system can understand.

Here, it is pertinent to mention that feature recognition is not only applicable to CAPP system but it can also be applied to various other engineering applications that require information about feature of parts classification and automated coding in GT.

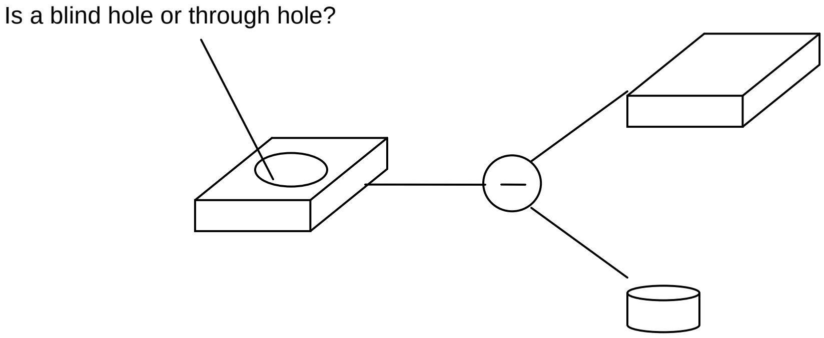


Figure 9.6 : Advance Level Information

9.5.1 Approaches to Part Feature Recognition

The most robust description of any part is provided through solid modelling. Therefore, these appear to be a logical starting point for developing a feature recognition system. Henderson and Anderson developed a system called **FEATURES** to perform automatic feature recognition using data from solid modelling system. A FEATURE simulates the human interpretation of part features. The system consists of a feature recognizer, extractor, and organizer. For objects containing swept features, this system performs well. This approach is encouraging because, conceptually, it can be applied for more complex parts. The FEATURES system uses the boundary representation (BREP) of a part, which denotes the faces, edges and vertices (FEV). Thus, features such as holes must be derived from more primitive data.

Table 9.4 : A Brief Review and Recent Trends in Feature Recognition Research

Author	**Part Feature-recognition System**	**Recognizable Features**
CAM-1	From feature taxonomy	--
Choi	CAD/CAM-compatible, toll-oriented process planning system.	Holes, Slots, Pockets
Henderson and Anderson	Extraction of feature information from 3-D CAD data.	Holes, Slots, Pockets
Jalubowski	Syntactic characterization of machine part shapes.	Rotational part family
Kakazu and Okino	Pattern-recognition approaches to GT code generation.	Rotational GT code
Kakino et.al.	A method of parts description for computer-aided production planning.	Grooves, steps, flanges
Kung	Feature-recognition and expert process planning system	Holes, Slots, Pockets
Kyprianou	Shape features in geometric modelling	Rotational part family
Lee	Integration of solid modelling and data base management for CAD/CAM	--
Liu	Generative process planning using syntactic pattern recognition.	--
Srinrasan, Liu and Fu	Extraction on manufacturing details from geometric models	Rotational part family
Woo	Computer-aided recognition of volumetric designs	--

Representing FEV contained in a BREP graph. As a result a hole may be present as a collection of faces that must be recognized from the part data.

A number of approaches to part feature recognition for rotational as well as prismatic parts have been developed. These different approaches are enlisted as follows :

(i) Syntactic Pattern Recognition

(ii) State Transition Diagram and Automata

(iii) Geometry Decomposition Approach

(iv) Expert System Rule Logic

(v) CSG (Set Theoretic) Approach

(vi) Graph Based Approaches

The syntactic pattern recognition and/or expert logic approach are mainly applied for feature extraction of rotational part feature recognition. The complexity increases in case for prismatic parts due to lack of rotational property. In this case, the difficulty of both representation of a generic object and recognition of its feature increases extensively. A brief review and recent trends in feature recognition research has been enumerated in Table 9.4.

In next subsection, we have discussed the graph based approach to feature recognition.

9.5.2 Attributed Adjacency Graph Based Approach for Feature Recognition

Following three steps are involved in Graph based feature recognition

(i) Generating graph based representation of the object to be recognized.

(ii) Defining part features.

(iii) Matching part features in the graph representation.

Generating Graph Based Representation of the Object to be Recognized

During first step graphs are used for representation of the object. This step is necessary because data extracted from the data base are usually in the form of boundary representation (BREP) and can not be used for feature recognition. Information regarding the type of face adjacency and relationship between the sets of faces should be expressed explicitly to recognize a feature. Here, attribute adjacency graph (AAG) has been used to demonstrate the recognition process.

Attributed Adjacency Graph

An AAG can be defined as a graph $G = (N, A, T)$, where N is the set of nodes, A is the set of arcs, T is the set of attributes to arcs in A such that :

- For every face f in F, there exists a unique node n in N.
- For every edge e in E, there exists a unique arc a in A, connecting nodes n_i and n_j, corresponding to face f_i and face f_j, which share the common edge e.
- "t" is an attribute assigned to every arc a in A, where :

  $t = 0$ if the faces sharing the edge form a concave angle (or " inside" edge)

  $t = 1$ if the faces haring the edge form a convex angle (or "outside" edge).

The AAG is represented in the form of matrix as follows :

$$\begin{array}{c|ccccc|}
 & F_1 & F_2 & \ldots & \ldots & F_n \\
\hline
F_1 & E_{1,1} & E_{1,2} & E_{1,3} & \ldots & E_{1,n} \\
F_2 & : & : & : & : & : \\
: & : & : & : & : & : \\
: & : & : & : & : & : \\
F_n & E_{n,1} & E_{n,2} & \ldots & \ldots & E_{n,n}
\end{array}$$

where
$$E_{ij} = \begin{cases} 0 & \text{if } F_i \text{ forms a concave angle with } F_j \\ 1 & \text{if } F_i \text{ forms a convex angle with } F_j \\ \phi & \text{if } F_i \text{ is not adjacent to } F_j \end{cases}$$

Hence it can easily be understood from above observation that AAG defines the shape of a part uniquely up to its topology, if and only if the faces are cut orthogonally.

Definition of Part Feature

First we have to define what actually feature is? In general any shape can be feature if their manufacturing meanings are defined. There are mainly six features which are commonly used in manufacturing. These are step, slot, three side pocket, four side pocket, pocket (or blind hole) and through hole. Figures 9.7(a-f) represent some of the features and their surfaces are labeled.

Four-side Pocket

F_1 is adjacent to F_2 and F_4

F_3 is adjacent to F_2 and F_4

F_2 is adjacent to F_1, F_3, and F_4

F_4 is adjacent to F_1, F_3 and F_2

F_1 forms concave (90^o) angles with F_2 and F_4

F_2 forms concave (90^o) angles with F_3, F_1 and F_4

F_3 forms concave (90^o) angles with F_2 and F_4

F_4 forms concave (90^o) angles with F_1, F_2 and F_3

Blind Hole (Pocket)

F_1 is adjacent to F_2, F_4 and F_5

F_2 is adjacent to F_1, F_3 and F_5

F_3 is adjacent to F_2, F_4, and F_5

F_4 is adjacent to F_1, F_3, and F_5

F_5 is adjacent to all other surfaces of the pocket

F_1 forms concave (90^o) angles with F_2, F_4 and F_5

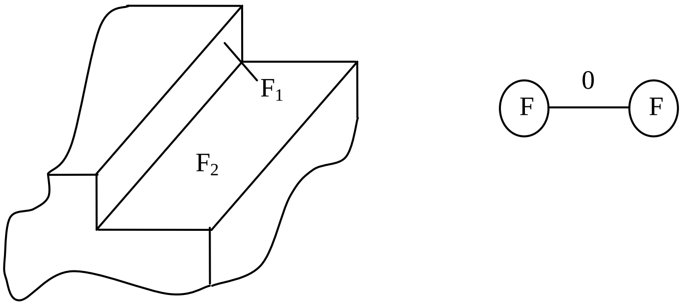
F_2 forms concave (90^o) angles with F_3, F_1 and F_5

F_3 forms concave (90^o) angles with F_2 and F_4 and F_5

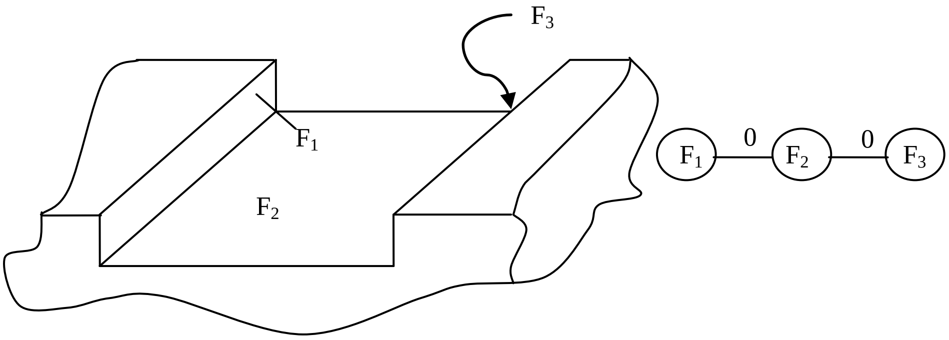
F_4 forms concave (90^o) angles F_3, F_1 and F_5

F_5 forms concave angle (90^o) with all other surfaces of the pocket

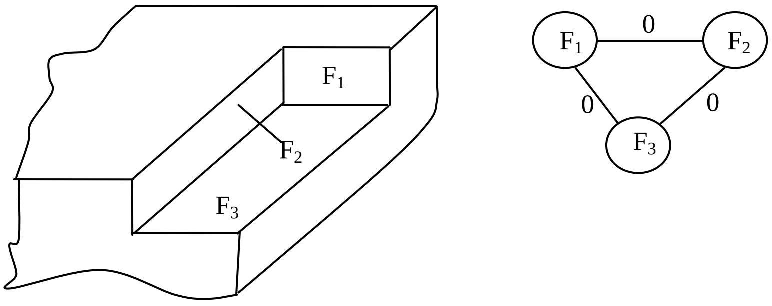
(a)



(b)



(c)



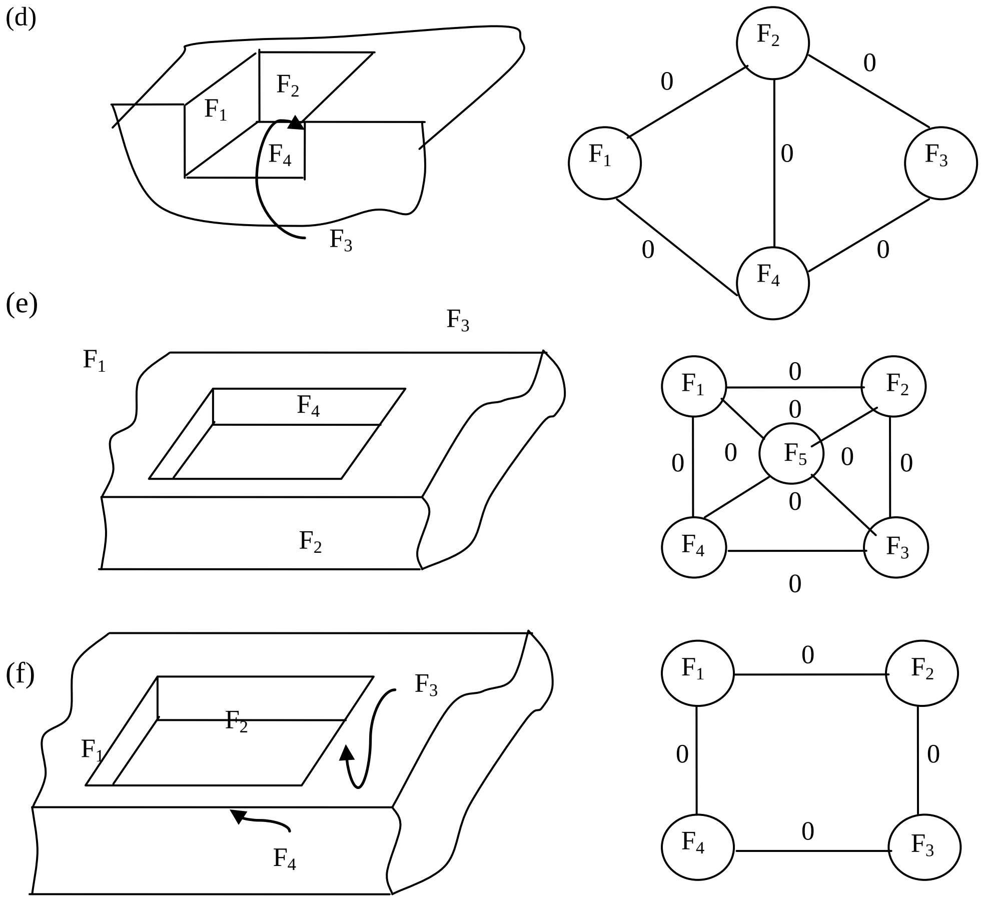


Figure 9.7(a-f) : Various Features

Matching the Features

After execution of step 1 and 2, the main task is to recognize AAG subgraph instead of recognizing machining features in parts. Because, complete AAG graph represents the part and subgraphs represent the features. It is computationally complex task to identify subgraphs in a graph. Although, there is no general way or algorithm to solve the problem.

Joshi and Chang, 1988 used an algorithm to identify the components of the graph that could form a feature. The algorithm is based on the following observations :

A face that is adjacent to all its neighbouring faces with a convex angle 270^o does not form part of a feature. This observation is used as a basis for separating the original graph into subgraphs that could corresponds to features. The separation is done by deleting some nodes of the graph. The delete node rule follow *IF THEN* rule and given as follows. For all nodes :

If (all incident arcs of a node have attribute “1”)

Then (delete this node (and all the incident arcs at the node) from AAG)

Delete node rule actually delete rows and column that represent the nodes in the matrix. Now feature recognition rule are applied to identify that whether or not a sub-graph represent a feature. On the basis of feature definition some rules are written. In order to identify features some rules are given as follows :

For a Given AAG

It is a four side feature if

(The AAG subgraph has four nodes) *and* (The number of arcs with attribute “0” is the number of nodes plus one).

It is a pocket feature *if*

(The AAG subgraphs have five nodes) *and* (The number of arcs with attribute”0” is the number of attributes plus three).

In some of the cases, delete node rule fails. This is due to the intersection of features. Delete node rule cannot separate complete AAG graph into subgraphs, particularly for the case when features intersects. Hence, only for those cases when features are disjoint, delete node rule can be applied.

Following procedures are used to separate the subgraphs for intersecting features.

- Delete all 1 arcs
- Form the subgraphs that may or may not represent the features.
- If not all the subgraphs, represent features, restore the one arc deleted within the subgraph.

The main task of this procedure is to separate the graphs into subgraphs. If the procedure is successful, it greatly reduces the computational effort otherwise graph remains unchanged.

9.5.3 An Illustrative Example

An example is taken from Li (1992), which is illustrated as follows

Example 9.1

It is easy for human to recognize that the part shown in Figure 5.14(a) has a slot and a pocket feature. In this example, however, we simulate the computer to apply the feature recognition algorithm discussed earlier. We, therefore, want to solve the following problem :

(i) Develop the AAG of the object, (ii) Give the matrix representation of the AAG, and (iii) Recognize the features in this object.

Solution

(i) First, we have to label each surface of the part. Given that the part is labeled as shown in Figure 9.8(a), we develop the AAG as shown in Figure 9.8(b) from the definition of AAG. By the definition of AAG we mean that each surface of this part is represented by a node and each edge by an arc with attribute 1 or 0.

(ii) For propose of inputting the AAG graph into the computer, we have to convert the graph to matrix form. The matrix representation of AAG is given as follows.

$$\begin{array}{c|ccccccccccccccc|}
F_1 & F_1 & F_2 & F_3 & F_4 & F_5 & F_6 & F_7 & F_8 & F_9 & F_{10} & F_{11} & F_{12} & F_{13} & F_{14} & F_{15} \\
\hline
F_2 & 9 & 0 & 9 & 0 & 0 & 1 & 9 & 9 & 9 & 9 & 9 & 9 & 9 & 9 & 9 \\
F_3 & . & 9 & 0 & 9 & 0 & 1 & 9 & 9 & 9 & 9 & 9 & 9 & 9 & 9 & 9 \\
F_4 & . & . & 9 & 0 & 0 & 1 & 9 & 9 & 9 & 9 & 9 & 9 & 9 & 9 & 9 \\
F_5 & . & . & . & 9 & 9 & 1 & 9 & 9 & 9 & 9 & 9 & 9 & 9 & 9 & 9 \\
F_6 & . & . & . & . & 9 & 9 & 9 & 9 & 9 & 9 & 9 & 9 & 9 & 9 & 9 \\
F_7 & . & . & . & . & . & 9 & 1 & 9 & 9 & 9 & 9 & 9 & 1 & 1 & 1 \\
F_8 & . & . & . & . & . & . & 9 & 1 & 9 & 9 & 9 & 9 & 9 & 1 & 1 \\
F_9 & . & . & . & . & . & . & . & 9 & 1 & 9 & 9 & 9 & 9 & 1 & 1 \\
F_{10} & . & . & . & . & . & . & . & . & 9 & 1 & 9 & 9 & 9 & 1 & 1 \\
F_{11} & . & . & . & . & . & . & . & . & . & 9 & 1 & 9 & 9 & 1 & 1 \\
F_{12} & s & y & m & m & e & t & r & y & . & . & 9 & 0 & 9 & 1 & 1 \\
F_{13} & . & . & . & . & . & . & . & . & . & . & . & 9 & 0 & 1 & 1 \\
F_{14} & . & . & . & . & . & . & . & . & . & . & . & . & 9 & 1 & 1 \\
F_{15} & . & . & . & . & . & . & . & . & . & . & . & . & . & 9 & 9 \\
 & . & . & . & . & . & . & . & . & . & . & . & . & . & . & 9
\end{array}$$

(iii) Apply the delete node rule of the algorithm; that is delete the nodes connected with all "1" attributer arcs. Also delete these "1" arcs. Doing this on the adjacent matrix, we remove the rows and columns without 0 elements. For example, row 15 and column 15 represent this type of arc and can be deleted. After all such arcs are deleted, the present matrix will result into two unrelated sub-matrices. Each sub-matrix represents a sub-graph. We find that "0" in column 12, which is $F_{12.}$ We find that two disjoint subgraphs are generated (from Figure 9.8(d)). Figure 9.8(c) gives the same structure as the one shown in Figure 9.8(b), which corresponds to the slot feature. Thus the first feature that is recognized is the slot feature. In the computer this matching is achieved by applying the identifying rules. That is, if AAG subgroup has three nodes and the number of arcs with attribute "0" is 2, and then it is a slot. Also, because Figure 9.8(d) has the same structure as the one shown is Figure 9.7(e), it is a pocket. As there are no more features to be recognized. We conclude that there are two features in this part, a slot and a pocket.

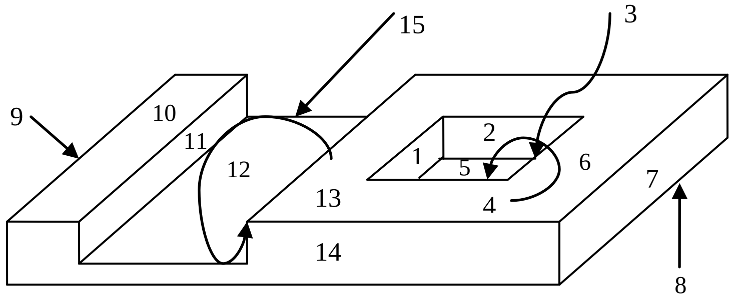


Figure 9.8(a)

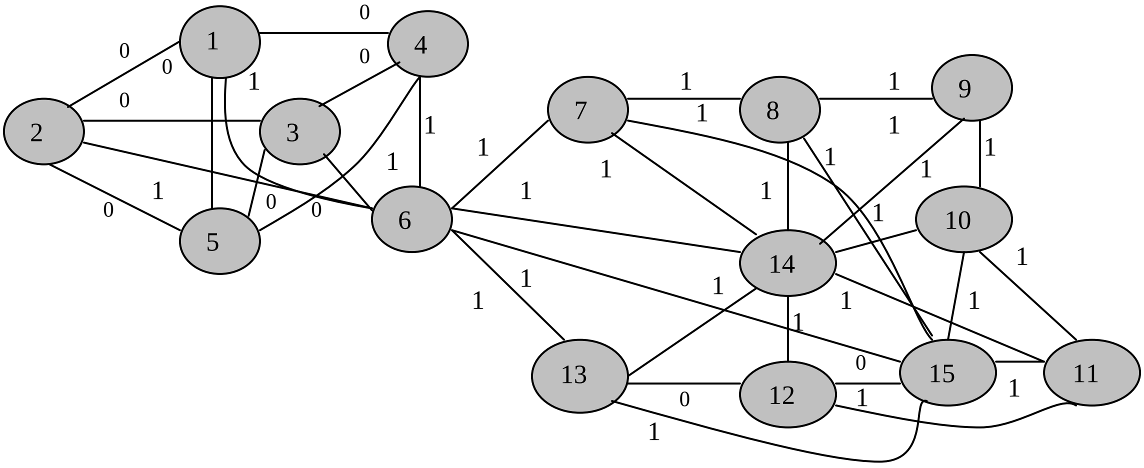
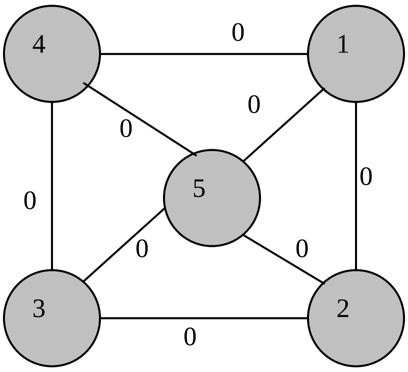


Figure 9.8(b) : AAG for the Example Part



(c) AAG for Slot Features

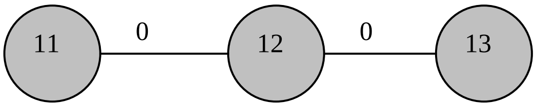


Figure (d) : AAG for Pocket Feature

9.6 RECENT TRENDS IN CAPP

In the global competitive market, various areas such as design process planning, manufacturing and inspection plays a vital role in reducing cost and lead time. In the various areas, different kind of interference mechanism has been developed. A lot of difficulty arises while integrating the goal in CIM environment. For example, all functional areas have its own standalone relational database and associated database management system. One of the main difficulties posed in CIM environment is the incompatibility of software and hardware incompatibility. Hence, it is not only desirable but also inevitable to develop a single database technology to address these problems. The major challenges of and research areas are to make CAPP system affordable to the medium and small scale manufacturing industries. Hence recent trends in CAPP systems include :

- Automated translation of the design dimensions.
- Tolerances into manufacturing dimensions.
- Tolerances considering process capabilities.
- Dimensional chains.
- And to make CAPP system affordable for small and medium scale manufacturing industries.

SAQ 2

(a) What do you mean by Feature Recognition?

(b) What are different steps of Graph based approach?

(c) Mathematically define AAG.

(d) Discuss about future trends in CAPP.

(e) What are the achievements of CIM?

9.7 SUMMARY

In the early 1970s, the function of process planning received very little attention. Today, manufacturing environment has become more complex and competition has become more intense. Hence, process planning has been accepted as critical to the success of many companies. Process planning bridges the gap between design and manufacturing. In addition, it has been acknowledged to be the link between CAD and CAM. As a result process planning is recognized as a vital element in CIM environment.

This unit dealt with process planning where more focus was concentrated on CAPP. It begins with the introduction of process planning and its various components. We discussed and illustrated with examples the element of process planning, such as analysis of part requirement; selection of the raw workpiece; determining manufacturing operation and their sequences; selection of machine tools; selection of tools, jigs or fixtures and inspection equipment; and determining machining condition and manufacturing times (setup time, processing time and lead time). After that Computer Aided Process Planning is discussed by explaining the reason why Computer Aided Process Planning has recently received much attention both in industry and academia. It follows by an overview of basic approaches for building Computer Aided Process Planning system : variant and generative. It then discusses the basic component required in a variant or generative system. A few existing knowledge based Computer Aided Process Planning systems are reviewed. After that, principles of making decisions for using either variant or generative approaches are discussed. Feature recognition in Computer Aided Process Planning has been discussed with a brief review of part feature recognition approaches. In this unit, we limit our exposition to the graph based approach to feature recognition. And finally focuses are made on recent trends in Computer Aided Process Planning.

9.8 KEY WORDS

Process Planning	**:**	Process planning is a production organization activity that transforms a product design into a set of instruction (Machine tool setup etc.) to manufacture market part or produced economically and competitively.
Computer-Aided Process Planning	**:**	Computer aided process planning has recently emerged as the most critical link to integrate CAD/CAM system into inter-organizational flow.
Variant Process Planning	**:**	In this approach, process plan for a new part is generated by recalling, identifying and retrieving an existing plan for a similar part and making necessary modifications for new part.
Generative Process Planning	**:**	In Generative Process Planning, process plans are generated by means of decision logic, formulas, technology algorithms, and geometry based data to perform uniquely processing decisions.
Feature Recognition	**:**	Objective of feature recognition is to bridge the gap between the database and automated process planning systems by automatically distinguishing the feature of a part from the geometry and topological data stored in the CAD system.

9.9 ANSWERS TO SAQS

Refer the relevant text in this unit for Answer to SAQs.