**Computer aided process planning**

**Process planning:**
Process planning is concerned with determining the sequence of individual manufacturing operations needed to produce a given part or product. The resulting operation sequence is documented on a form typically referred to as operation sheet. The operation sheet is a listing of the production operations and associated machine tools for a work part or assembly. Process planning is an important stage of product development since production tooling like jigs, fixtures, special tools etc. can be designed only after the process is finalized.

Process planning is that function within a manufacturing facility, that establishes which machining process and process parameters are to be used to convert a work material (blank) from its initial form (raw material) to a final form defined by an engineering drawing. Process planning is a common task in small batch, discrete parts metal working industries. The process planning activity can be divided into the following steps:

- Selection of processes and tools
- Selection of machine tools/Manufacturing equipment
- Sequencing the operations
- Grouping of operations
- Selection of work piece holding devices and datum surfaces (Set ups)
- Selection of inspection instruments
- Determination of production tolerances
- Determination of the proper cutting conditions.
- Determination of the cutting times and non-machining Times (setting time, inspection time) for each operation

Editing the process sheets. All the information determined by the process planning function is recorded on a sheet called Process plan. The process plan is frequently called an operation sheet, route sheet or operation-planning sheet. This provides the instructions for the production of the part. It contains - operation sequence, processes, process parameters and machine tools used.

**CAPP**

Computer aided process planning (CAPP) is a means of implementing the planning function by computer.

The primary purpose of process planning is to translate the design requirements into manufacturing process details. Thus a system was developed in which design information is processed by the process planning system to generate manufacturing process details. CAPP is usually considered to be part of CAM, however this results CAM as a stand alone system. Synergy of CAM can be achieved by integrating it with CAD system and CAPP acts as a connection between the two.
Readymade CAPP systems are available today to prepare route Sheets. CAPP integrates and optimizes system performance into the inter organizational flow. For example, when one changes the design, it must be able to fall back on CAPP module to generate manufacturing process and cost estimates for these design changes. Similarly, in case of machine breakdown on the shop floor, CAPP must generate the alternative actions so that most economical solution can be adopted in the given situation. Because of the problems encountered with manual process planning, attempts have been made in recent years to capture the logic, judgment and experience required for this important function (Process planning) and incorporates them into computer programmes. Based on the features of a given part, the program automatically generates the sequence of manufacturing operations. The automated process planning provides the opportunity to generate production routings, which are rational, consistent and perhaps even optimal. It has the following advantages:

- reduces the skill required of a planner
- reduces the planning time
- reduces the process planning and manufacturing cost
- creates more consistent plans
- produces more accurate plans
- increases productivity

**Group technology:**

Group technology is a manufacturing philosophy in which similar parts are identified and grouped together to take advantage of their similarities in design and production. Similar parts are arranged into part families, where each part family possesses similar design and/or manufacturing characteristics. For example, a plant producing 10,000 different part numbers may be able to group vast majority of these parts into 30-40 distinct families. It is reasonable to believe that the processing of each member of a given family is similar, and this should result in manufacturing efficiencies. The efficiencies are generally achieved by arranging the production equipment into machine groups, or cells, to facilitate workflow. Grouping the production equipment into machine cells, where each cell specializes in the production of a part family is called cellular manufacturing (CM). Cellular manufacturing is an example of mixed model production.

**PART FAMILIES:**

- A part family is a collection of parts that are similar either because of geometric shape and size or because similar processing steps are required in their manufacture.
- The parts with in a family are different, but their similarities are close enough to merit their inclusion as members of the part family.
The below two figure shows two different part families. The two parts in fig 15.1 are very similar in terms of geometric design, but quite different in terms of manufacturing because of differences in tolerances, production quantities and material. The ten parts shown in fig 15.2 constitute a part family in manufacturing, but their different geometries make them appear quite different from a design viewpoint.

**THE PARTS CLASSIFICATION AND CODING:** It is one of the important methods used in grouping the part into families. In this method, similarities among parts are identified and these similarities are related in a coding system. Two categories of part similarities can be distinguished:

- **Design attributes**—which is concerned with part characteristics such as geometry, size and material.
- **Manufacturing attributes**—which consider the sequence of processing steps required to make a part. While the design and manufacturing attributes of a part are usually correlated, the correlation is less than perfect.
Accordingly, classification and coding systems are devised to include both a parts design attributes and its manufacturing attributes. **Reasons for using a coding scheme include:**

- **Design retrieval:** A designer faces with the task of developing a new plant can use a design retrieval system to determine if a similar part already exists. A simple change in an existing part would take much less time than designing a whole new part from scratch.

- **Automated process planning:** The part code for a new part can be used to search for process plans for existing parts with identical or similar codes.

- **Machine cell design:** The part can be used to design machine cells capable of producing all members of a particular part family, using the composite part concept. (See cellular manufacturing section).

### Table 15.1 Design and Manufacturing Attributes Typically Included in a Group Technology Classification and Coding System

<table>
<thead>
<tr>
<th>Part Design Attributes</th>
<th>Part Manufacturing Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic external shape</td>
<td>Major processes</td>
</tr>
<tr>
<td>Basic internal shape</td>
<td>Minor operations</td>
</tr>
<tr>
<td>Rotational or rectangular shape</td>
<td>Operation sequence</td>
</tr>
<tr>
<td>Length-to-diameter ratio (rotational parts)</td>
<td>Major dimension</td>
</tr>
<tr>
<td>Aspect ratio (rectangular parts)</td>
<td>Surface finish</td>
</tr>
<tr>
<td>Material type</td>
<td>Machine tool</td>
</tr>
<tr>
<td>Part function</td>
<td>Production cycle time</td>
</tr>
<tr>
<td>Major dimensions</td>
<td>Batch size</td>
</tr>
<tr>
<td>Minor dimensions</td>
<td>Annual production</td>
</tr>
<tr>
<td>Tolerances</td>
<td>Fixtures required</td>
</tr>
<tr>
<td>Surface finish</td>
<td>Cutting tools</td>
</tr>
</tbody>
</table>
To accomplish parts classification and coding requires examination and analysis of the design and/or manufacturing attributes of each part. The examination is sometimes done by looking in tables to match the subject part against the feature described and diagrammed in the tables. An alternative and more-productive approach involves interaction with a computerized classification and coding system, in which the user responds to question asked by the computer. On the basis of the responses, the computer assigns the code number to the part. Whatever method is used, the classification results in a code number that uniquely identifies the parts attributes.

The classification and coding procedure may be carried out on the entire list of active parts produced by the firm, or some sort of sampling procedure may be used to establish part families. For example, parts produced in the shop during a certain time period could be examined to identify part family categories. The trouble with any sampling procedure is the risk that the sample may be unrepresentative of the population.

A number of classification and coding systems are described in the literature and there are a number of commercially available coding packages. However, none of the systems has been universally adopted. One of the reasons for this is that a classification and coding system should be customized for a given company or industry. A system that is best for one company may not be best for another company.

Methods of computer aided process planning:
There are two approaches to CAPP:
1. Variant or Retrieval type process planning
2. Generative approach

**Variant or Retrieval type Process Planning**
A variant process planning system uses the similarity among Components to retrieve the existing process plans. A process plan that can be used by a family of components is called a Standard plan. A standard plan is stored permanently with a family number as its key. A family is represented by a family matrix, which includes all possible members. The variant process planning system has two operational stages:
1. preparatory stage
2. Production stage.

During the preparatory stage, existing components are coded, classified, and subsequently grouped into families. The process begins by summarizing process plans already prepared for components in the family. Standard plans are then stored in a database and indexed by family matrices.

The production stage occurs when the system is ready for production. An incoming part is first coded. The code is then input to a part family search routine to find the family to which the component belongs. The family number is then used to retrieve a standard plan. Some other functions, such as parameter selection and standard time calculations, can also be added to make the system more complete. This system is used in a machine shop that produces a variety of small components.
Design of Variable Process Planning System:
The following are the sequences in the design of a variant Process planning system:
1. Family formation
2. Data base structure design
3. Search algorithm development and implementation Plan editing
4. Process parameter selection/updating

Family Formation
Part family classification and coding were discussed earlier. This is based on the manufacturing features of a part. Components requiring similar processes are grouped into the same family. A general rule for part family formation is that all parts must be related. Then, the entire family can share a standard process plan. Minimum modification on the standard plan will be required for such family members.

Data Base Structure Design
The database contains all the necessary information for an application, and can be accessed by several programs for specific application. There are three approaches to construct a database: hierarchical, network, and relational.

Search Procedure
The principle of a variant system is to retrieve process plans for similar components. The search for a process plan is based on the search of a part family to which the component belongs. When, the part family is found, the associated standard plan can then be retrieved. A family matrix search can be seen as the matching of the family with a given code. Family matrices can be considered as masks. Whenever a code can pass through a mask successfully, the family is found.

Plan Editing and Parameter Selection
Before a process plan can be issued to the shop, some modification of the standard plan may be necessary, and process parameters must be added to the plan. There are two types of plan editing: One is the editing of the
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standard plan itself in the database, and the other is editing of the plan for the component. For editing a standard plan, the structure of the database must be flexible enough for expansion, additions, and deletions of the data records. A complete process plan includes not only operations but also process parameters. The data in the process parameter files are linked so that we can go through the tree to find the speed and feed for an operation. The parameter file can be integrated into variant planning to select process parameters automatically.

Problems associated with the variant approach:

- The components to be planned are limited to similar components previously planned.
- Experienced process planners are still required to modify the standard plan for the specific component.
- Details of the plan cannot be generated.
- Variant planning cannot be used in an entirely automated manufacturing system, without additional process planning.

Advantages of the variant approach

- Once a standard plan has been written, a variety of components can be planned.
- Comparatively simple programming and installation (compared with generative systems) is required to implement a planning system.
- The system is understandable, and the planner has control of the final plan.
- It is easy to learn, and easy to use.

Generative Process Planning
Generative process planning is a system that synthesizes process information in order to create a process plan for a new component automatically. In a generative planning system, process plans are created from information available in manufacturing database without human intervention. Upon receiving the design model, the system can generate the required operations and operation sequences for the component. Knowledge of manufacturing must be captured and encoded into efficient software. By applying decision logic, a process planner’s decision making can be imitated. Other planning functions, such as machine selection, tool selection, process optimization, and so on, can also be automated using generative planning techniques. The generative planning has the following advantages:

1. It can generate consistent process plans rapidly.
2. New components can be planned as easily as existing components.
3. It can be interfaced with an automated manufacturing facility - to provide detailed and up-to-date control information

The generative part consists of:
- Component representation module
- Feature extraction module
- Feature process correlation module
- Operation selection and sequencing module
- Machine tool selection module
- Standard time / cost computation module
- Report generation module

In order to generate a more universal process planning system, variables such as process limitations, and capabilities, process costs and so on, must be defined to the production stage. A wide range of methods have been used and can be used for generative process planning. A few methods that have been implemented successfully are:
- Forward and backward planning
- The input format.
- CAD models
- Decision logic
  - Decision trees
  - Decision tables
- Artificial intelligence

**Forward and Backward-Planning**

In generative process planning, when process plans are generated, the system must define an initial state in order to reach the final state (goal). The path taken represents the sequence of processes. For example, the initial state is the raw material and the final state is the component design. Then a planner works in modifying the raw work piece until it takes on the final design qualities. This is called forward planning. Backward planning uses a reverse procedure. Assuming that we have a finished component, the goal is to go back to the unmachined work piece. Each machining process is considered a filling process. Forward and backward planning may seem similar; however, they affect the programming of the system significantly. Planning each process can be characterized by a precondition of the surface to be machined and a post condition of the
machining (it results). For forward planning, we must know the successor surface before we select a process, because the post condition of the first process becomes the precondition for Second process. Backward planning eliminates this conditioning Problem since it begins with the final surfaces and processes are selected to satisfy the initial requirements. In forward planning, the objective surface must be taken to guarantee the result. On the other hand, backward planning starts with the final requirements and searches for the initial condition.

The Input Format
The input format of a process planning system affects the ease with which a system can be used, and the capability of the system. The transitional form from the original design (either engineering drawing or CAD model) to a specific input format may be tedious and difficult to automate. However, such input can provide more complete information about a component, and more planning functions can be accomplished using the input. Many different input formats have been used in process planning systems. Some of the few input formats used are:

**Code**
Some generative systems such as APPAS use GT codes as input. Codes used are in generative system are more detailed.

**Description Language**
Specially designed part description languages can provide detailed information for process planning system. For example AUTAP system uses a language similar to a solid modeling language. The union of some primitives and modifiers describes a component. Material, processes, machine selection, and time estimates can be selected by the system using the input model. Another system CIMS/PRO uses an input language called CIMS/DEC. CAPP system uses its own special language.

**CAD Models**
Using a CAD model as input to a process planning system can eliminate the human effort of translating a design into code and other descriptive form. A CAD model contains all the details about a design. However, an algorithm is necessary to identify a general machined surface from a CAD model. Additional code is needed to convert the machined surface shape from raw material shape. CAD/CAM system uses a CAD model as its input. Several other systems such as GENPLAN, AUTO PLAN, etc., also use a CAD database interactively for Tool and fixture selection.

**Decision Logic**
The decision logic determines how a process or processes are selected. The major function of the decision logic is to match the process capabilities with the design specification. The different techniques in decision logic are:

- Decision trees
- Decision tables

These two techniques are methods of describing or specifying the various actions associated with the combination of input conditions.

**Artificial Intelligence**
AI can be defined as the ability of a device to perform functions that are normally associated with the human intelligence. These functions include reasoning, planning, and
problem solving applications for AI have been in natural language processing, intelligent data base retrieval, expert consulting systems, theorem proving, robotics, scheduling, and perception Problems. Process planning applications have been considered as part of an expert consulting system.

There are two types of knowledge involved in process planning systems: Component knowledge, and process knowledge. The component knowledge defines the current state of the problem to be solved (declarative knowledge). On the other hand, the knowledge of processes defines how the component can be changed by processes (procedural knowledge).

There are several methods to represent declarative knowledge:

- First order predicate calculus
- Frames and semantic networks

Procedural knowledge can be represented by IF (condition), THEN (action) statements which are similar to decision trees or decision tables. In AI such rules can be called production rules. Even after the descriptive and procedural knowledge have been represented, conclusions cannot be deduced, because we do not have mechanism to apply the appropriate rule to the problem.

Control knowledge is similar to human knowledge in reasoning, which deduces certain facts from the knowledge base concerning problem. This can be a difficult task to program on a computer.

Computer Aided Process Planning has been an active area of research works in AI for many years. Feature recognition, feature process correlation, process sequencing, blank selection, cutting parameter selection, tool selection etc. are the segments of CAPP where AI can contribute to improve the quality of process plans.

**Implementation considerations**

The process planning function is manufacturing system dependent. This implies that no one single process planning system can satisfy all of the different manufacturing systems needs. There are several factors that must be considered when one attempts to implement a process planning -system. These include:

i. Manufacturing system components
ii. Production volume batch size
iii. Number of different production families

For a moderate number of component families and many similar components in each family, a variant process planning system is usually the most economical automated planning alternative. Fig illustrates the economic regions for the different planning alternatives.
### Process Planning Systems

The majority of existing processes planning systems are variant in nature. Some of them are: CAPP, MIPLAN, MITURN, MIAPP, UNIVATION, CINTURN, COMCAPPV, etc. However there are some generative system, such as METCAPP, CPPP, AUTAP, and APPAS. Some of the planning systems are discussed in the following paragraph. These are systems continuously evolving in many cases. The descriptions are therefore only approximate.

**CAM-I CAPP**

- It is a type of variant type of CAPP.
- The CAM-I (Computer Aided Manufacturing-International)
- Automated process planning system (CAPP) is perhaps the most widely used of all process planning systems.
- CAPP is a database management system written in ANSI standard FORTRAN.
- It provides a structure for a database, retrieval logic, and interactive editing capability.
- The user adds the coding scheme for part classification and the output format.

**MIPLAN and MULTICAPP**

Both MIPLAN and MULTICAPP were developed in conjunction with OIR (Organization for Industrial Research). They are both variant systems that use the MICLASS coding system for part description. They are data retrieval systems, which retrieve process plans based on part code, part number, family matrix, and code range. By inputting a part code, parts with a similar code are retrieved. The process plan for each part is then displayed and edited by the user.
APPAS and CADCAM
APPAS (an acronym for Automated Process Planning and Selection) is a generative system for detailed process selection. CADCAM is an example of APPAS. CADCAM operates using a CAD “front end” to interface with APPAS. APPAS describes the detailed technological information of each machined surface by means of a special code. CADCAM provides an interactive graphics interface to APPAS. Components can be modeled graphically and edited interactively.

AUTO PLAN and RPO
Auto Plan is generative only in the detailing of the part. The process selection and process sequencing level does not differ significantly from CAPP or MIPLAN. The four major modules of the system are:
1. Group technology retrieval-process plan retrieval
3. Generative process planning

AUTAP System
The AUTAP system is one of the most complete planning systems in use today AUTAP uses primitives to construct a part similar to a constructive solid geometry (CSG). AUTAP is a system designed especially to interface with a CAD system. It can be installed as part of an integrated CAD/CAM system.
CPPP

CPPP (computerized production process planning) was designed for planning cylindrical parts. CPPP is capable of generating a summary of operations and the detailed operation sheets required for production. The principle behind CPPP is a composite-component concept. A composite component can be thought of as an imaginary component, which contains all the features of components in one part family. CPPP incorporates a special language, COPPL, to describe the process model. CPPP allows an interactive mode whereby the planner can interact with the system at several fixed interaction points.
GARI
GARI is an experimental problem solver, which uses artificial intelligence (AI) techniques. The unique feature of the GARI is the representation of planning knowledge. GARI employs a production rule knowledge base to store process capabilities.

TIPPS
Although the process planning steps have been discussed, an integrated approach to generative process planning has yet to be presented. TIPPS is acronym for Totally Integrated process planning. TIPPS is generative process planning system that has evolved from the APPAS and CAD/CAM systems. In TIPPS, the logical divisions of process planning are broken into functional modules. The TIPPS has the following features:

- It has a modular structure
- It can interact with a CAD system
- It allows, for interactive surface identification
- It contains a process/knowledge description language