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NPTEL ONLINE CERTIFICATION COURSES

NPTEL

AUTOMATION IN PRODUCTION SYSTEMS AND MANAGEMENT

Automated CAPP (Part-I)

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Automated CAPP (Part-I)

- **Lecture-1:** Definitions of Process Planning, Functions of Process Plan
- **Lecture-2:** Basic Steps in Process Plan Development
- **Lecture-3:** Processing Planning Approaches: Manual Experience-based Process Planning
- **Lecture-4:** Process Planning Approaches: Computer-aided Process Planning Method
- **Lecture-5:** CIM and CAPP, Process Optimization and CAPP

Automated CAPP (Part-I)

- ✓ **Definitions of Process Planning,**
- ✓ **Functions of Process Plan**

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Definitions of Process Planning

- The task of process planning is to translate design data to work instructions to produce a part or a product.
- Process planning should interact directly with the information presented on the work piece drawing and the bill of materials.
- The information rendered by process planning leads the work piece through individual manufacturing stages. It starts with the selection of raw material and ends with the completion of the part.

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Definitions of Process Planning

- The form of the raw material used depends on the part and the manufacturing process.
- Typical materials are metal sheets, rods, bar stock, forgings and blanks or slabs of metal.
- It is usually designed such that the metal cutting or forming operations to produce the part are kept to a minimum.

Definitions of Process Planning

- The most common production process are turning, boring, chilling, milling, grinding, broaching, punching, bonding, forging, sintering, electro discharge machining, and chemical milling.
- With a conventional manual system the planner relies heavily on personal manufacturing experience.
- One must know possible machining operations and sequences to produce a part, and the available cutting tools, machining tools, and measuring instruments.

Definitions of Process Planning

- In addition, one needs tables and handbooks to determine obtainable tolerances and surface finishes as well as the depth of cut, optimal speeds and feeds for machining.
- A planner usually tries to minimize the manufacturing cost or time. However, this may not be possible in every case, since there are many parts completing for the same machining resources.
- Thus the planner has the additional burden of investigating manufacturing alternatives to utilize idle machine tools and to search for short material flow routes.

Definitions of Process Planning

- With a wide part spectrum or intricate parts, the planning process is very tedious and demands much skill and endurance.
- It is usually very difficult to find good manufacturing experts who are willing to do this type of repetitive work. For this reason selected processes and machining sequences are often impractical, time consuming, and expensive.
- With computerized process planning an attempt is made to automate the planning function and to reduce the nonproductive residence time for a part in the factory.

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Definitions of Process Planning

- With an automated planning system the computer can be given decision rules to generate the process plan.
- For this purpose it must have access to the central manufacturing data base, containing information on customer orders, engineering specification, available machine tools, and manufacturing processes.
- It may also contain optimization rules to utilize the plant resources fully. The particular asset of the computer is its high speed, which allows investigation of many different manufacturing alternatives.

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Definitions of Process Planning

- The twenty-first century engineering response to world competition is Concurrent Engineering (CE).
- CE requires the integration of all aspects of the product life cycle, that is, design, manufacturing, assembly, distribution, service, and disposal.
- Two important areas in the life cycle of a product are design and manufacturing.
- Process planning serves as an integration link between design and manufacturing.
- Process planning is one of the most important activities in concurrent engineering to help translate the product design into a final product.

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Definitions of Process Planning

- Process Planning acts as a bridge between design and manufacturing by translating design specifications into manufacturing process details.

- Process Planning refers to a set of instructions that are used to make a component or a part so that the design specifications are met.

- Process Planning essentially determines how a component will be manufactured. Therefore, it is the major determinant of manufacturing cost and profitability of products.

Definitions of Process Planning

- The question is: what information is required and what activities are involved in transforming a raw part into a finished component, starting with the selection of raw material and ending with completion of the part.

- The answer to this question essentially defines the information and set of activities required to develop a process plan(s).

Functions of the Process Plan

1. Selection of raw material or blank
    a. Shape
    b. Dimension
    c. Weight
    d. Material
2. Selection of process and sequence of machining operations
    a. Global operations
    b. Local operations at a given work places.
3. Machine Tool selection

Functions of the Process Plan

4. Auxiliary functions
    a. Fixtures
    b. Tools
    c. Manufacturing specifications
    d. Measuring Instruments
5. Manufacturing times
    a. Set-up time
    b. Processing time
    c. Speeds and feeds
    d. Lead time

Functions of the Process Plan

6. Text Generation
7. Process Plan Output
   a. Process plan header
   b. Process plan parameters

- The product designer (most often) has a specific process in mind, and this affects the geometry of the part.
- Process planners are bound by the part drawing and therefore, are forced to consider a particular process.

Functions of the Process Plan

- However, they are still free to define any process that they consider appropriate. The available processes usually overlap to some extent, and thus, for example, it is almost always possible to replace a forming process by a metal-cutting and corresponding production process.

- A general equation for the direct part cost is as follows :

$$C = \frac{C_T}{Q_1} + \frac{C_S t_S}{Q_2} + C_L . T$$

Functions of the Process Plan

Where, C = overall cost per part

C_T = overall tooling cost

C_L = hourly rate for direct labour

C_S = hourly rate for set-up labour

Q_1 = total quantity to be produced by the tool

Q_2 = batch – size quantity

t_S = set-up time

T = direct manufacturing time

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Functions of the Process Plan

- If we assume a continuous process and include the set-up cost as part of the tooling cost.
- The previous cost equation becomes

$$C = \frac{C_T}{Q} + C_L . \mathrm{T} = \frac{C_T}{Q} + C_L - f(C_T)$$

- The optimum tooling cost can be derived from this equation.
- Even in a predefined process, the process planner has the freedom to specify tool design and thereby affect the cost of parts.

Functions of the Process Plan

- An Example.

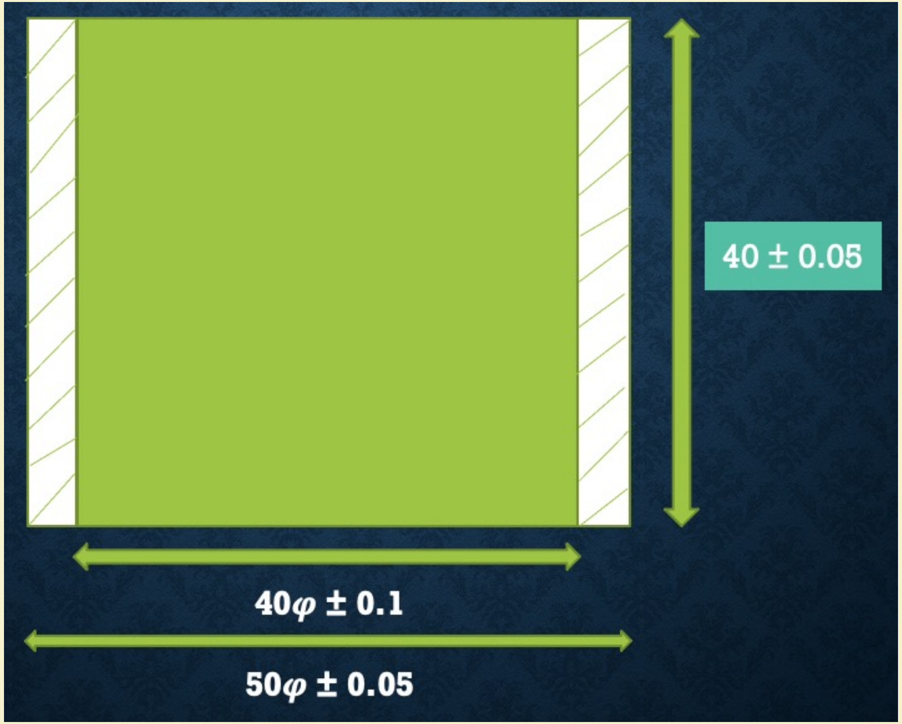

Fig. Process plan of the same part by different planners

Operation number	One	Two	Three	Four
1	Machine first face	Hole drilled in two steps,	Outside surface 50 mm dia turned	Hole drilled to finish in two steps
		a. 20 mm dia		a. 30 mm dia
		b. 38 mm dia		b. 40 mm dia
2	Hole finished in three steps; a. Drill 10 mm b. Drill 38 mm c. Drill 40 mm	Machine first face	Hole drilled to finish in one step with drill of 40mm dia	Outside surface 50 mm dia turned
3	Outside surface 50 mm dia turned	Cutoff	Machine first face	Machine first face
4	Cut off	Machine second face	Cutoff	Cutoff
5	Machine second face	Outside surface 50 mm dia turned	Machine second face`	Machine second face
6	-	Hole finished to 40 mm dia by boring	-	-

Automated CAPP (Part-I)

✓ **Basic Steps in Process Plan Development**

Basic Steps in Developing a Process Plan

The development of process plans involves a number of activities.

i. Analysis of part requirements
ii. Selection of raw work piece
iii. Determining manufacturing operations and their sequences.
iv. Selection of machine tools
v. Selection of tools, work holding devices, and inspection equipment
vi. Determining machining conditions (cutting speed, feed and depth of cut) and manufacturing times (setup time, processing time, and lead time).

Analysis of Part Requirements

- The primary purpose of process planning is to translate the design requirements for parts into manufacturing process details.
- The question is, what are the part design requirements? At the engineering design level, the part requirements can be defined as the part features, dimensions, and tolerance specifications.
- First, the features of the parts are analyzed. Examples of geometric features are a plane, cylindrical, cone, step, edge, and fillet.
- These common features can be modified by the addition of slots, pockets, grooves, and holes, among others.

Selection of Raw Workpiece

- Selection of the raw work piece is an important element of process planning.
- It involves such attributes as shapes, size (dimensions and weight), and material.
- For example, a raw part may be in the shape of a rod, a slab, a blank, or just a rough forging.
- It is important to determine the required oversize of the raw part.
- The weight and the material of the raw part are dictated by the functional requirement of the parts.

Determining Manufacturing Operations and Their Sequences

- The next logical step in process planning is to determine the appropriate types of processing operations and their sequence to transform the features, dimensions, and tolerances of a part from the raw to the finished state.

- Sometimes constraints such as accessibility and setup may require that some features be machined before or after others.

- The types of machines and tools available as well as the batch sizes influence the process sequence.

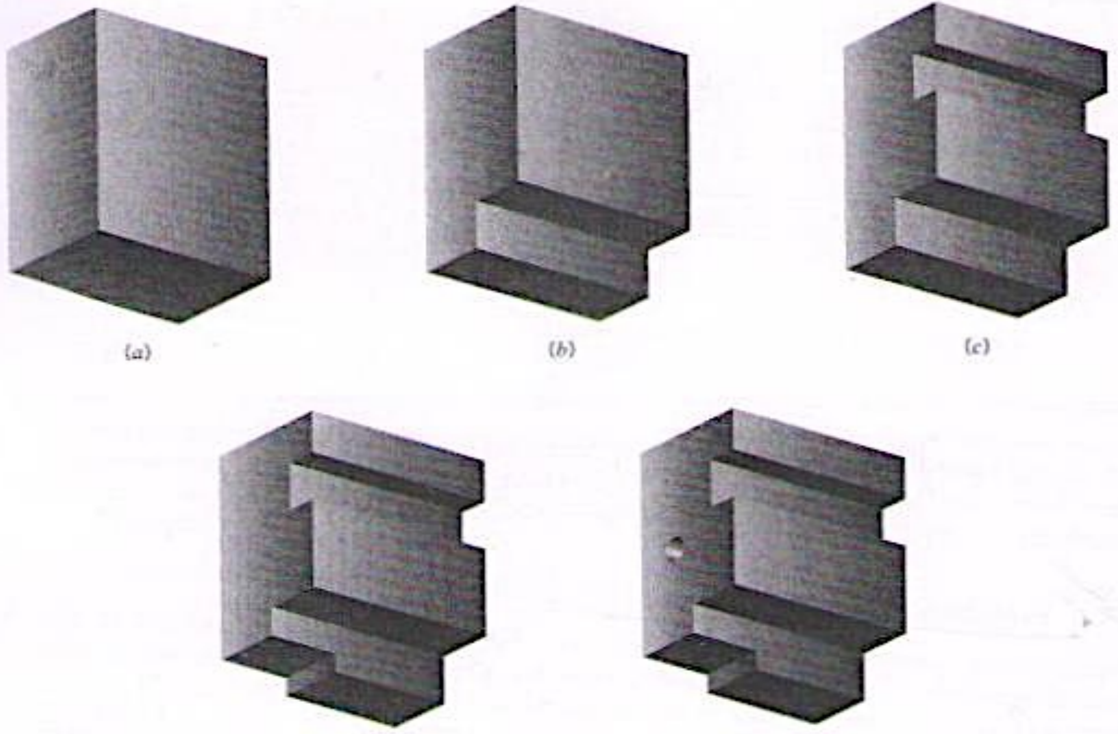

FIGURE 5.7 Successive modification of a part: (*a*) part with plane geometric features; (*b*) step addition; (*c*) slot addition; (*d*) side step addition; (*e*) a blind cylindrical hole addition.

Determining Manufacturing Operations and Their Sequences

- For example, a process plan that is optimal on a three-or four-axis machine may not be optimal on a five-axis machine because of the greater flexibility of higher-axis machines.

- Similarly, the tools that are available and the tools that can be loaded onto a particular machine might change the sequence.

Determining Manufacturing Operations and Their Sequences

- Surface roughness and tolerances requirements also influence the operation sequence.

- For example, a part requiring a hole with low tolerance and surface roughness specification would require a simple drilling operation. The same part with much finer surface finish and closer tolerance requirements would require first a drilling operation and then a boring operation to obtain the desired surface roughness and the tolerance on the hole feature of the part.

Determining Manufacturing Operations and Their Sequences

- Sometimes operations are dependent on one another (Ssemakula and Rangachar, 1989).

- The holes must be drilled before milling the inclined surface because the holes cannot be drilled accurately on an inclined surface.

- However, if the inclined surface has to be finished before drilling, an end mill should be used to obtain a flat surface perpendicular to the axis of the drill before drilling the hole.

Determining Manufacturing Operations and Their Sequences

- Cutting forces and rigidity of the work piece-tool machine tool also influence the operation sequence.

- For example, consider the part shown in figure Hole H2 must be produced before machining the slot. If the hole is machined after finishing the slot, it may bend.

Determining Manufacturing Operations and Their Sequences

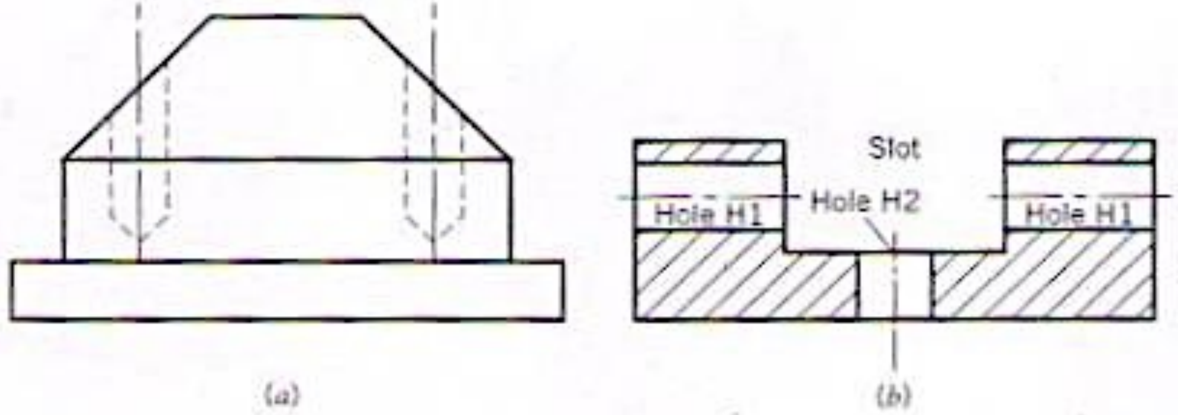

FIGURE 5.8 (*a*) Dependent operations—holes on inclined surfaces; (*b*) a part with interdependent features.

Selection of Machine Tools

A large number of factors influence the selection of machine tools :

1. Work-piece related attributes such as the kinds of features desired, the dimensions of the work-piece, its dimensional tolerance, and the raw material form.
2. Machine tool related attributes such as process capability, size, mode of operation (e.g. manual, semiautomatic, automatic, numerically controlled), tooling capabilities (e.g. size and type of the tool magazine), and automatic tool-changing capabilities.
3. Production volume related information such as the production quantity and order frequency.

Selection of Machine Tools

A simple analytical framework for the selection of machine tools as follows:

$$Y^i = k^i Y^0$$

$$Y^S = k^s Y^0$$

$$X^0 = k^i X^i - k^s X^S + k^i f\left(Y^i\right)$$

Where X^i, X^o, and X^s represent the unit cost of input, output, and scrap, respectively; Y^i, Y^o, and Y^s represent input, output, and scrap units, respectively; k^i and k^s represent the technological coefficients of input and scrap, respectively; and $f(Y^i)$ is the unit processing cost as a function of input.

Selection of Machine Tools

$$k^S = \frac{SC}{1 - SC}$$

Where SC is the fraction of scrap generated and

$$k^i = 1 + k^S$$

Selection of Tools, Work-holding Devices, and Inspection Equipment

- A combination of machine tool and cutting tool is required to generate a feature(s) on the work-piece.

- Work-holding devices are used to locate and hold the work-pieces to help generate the features.

- Inspection equipment is necessary to ensure the dimensional accuracy, tolerances, and surface finish on the features. The major categories include on-line and off-line inspection equipment.

Selection of Tools, Work-holding Devices, and Inspection Equipment

- The selection of machine tools, cutting tools, fixtures, and inspection equipment is based primarily on part features.

- For example, if tolerances are to be specified in the range of ± 0.0002 to ± 0.0005 in./in. and surface finishes in the range of 16 to 32 µin., Swiss Automatics as a machine tool and a high speed steel (HSS) single point cutting tool may be recommended.

- Cutting tool specifications may include various angles such as rakes, clearances, cutting edge, and nose radius.

Selection of Tools, Work-holding Devices, and Inspection Equipment

- The primary purpose of a work-holding device is to hold the work-piece securely. These devices include clamps, jigs, and fixtures, which are often used interchangeably in manufacturing operations.

- Jigs, however, are designed to have various reference surfaces and points for accurate alignment of parts and tools.

Selection of Tools, Work-holding Devices, and Inspection Equipment

- Common examples of work-holding devices:

1. Manually operated devices such as collets, chucks, mandrels, faceplates, and various kinds of fixtures.
2. Designed devices such as power chucks.
3. Flexible fixtures used in flexible manufacturing systems. The objective is to accommodate a range of part shapes and dimensions with the least need for changes and adjustment requiring operator interventions.

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Selection of Tools, Work-holding Devices, and Inspection Equipment

- The shapes, dimensions, accuracy production rate and variety of parts essentially determine the types of work-holding devices required.

- For example, a four-jaw chuck can accommodate prismatic parts, faceplates are used for clamping irregularly shaped workpiece, and collets are used to hold round bars only (and only those within a certain range of diameters.

- The fixtures are, however, designed for specific shapes and dimensions of parts.

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Determining Machining Conditions and Manufacturing Times

- Having specified the work-piece material, machine tool, and cutting tool, the question is what can be controlled to reduce cost and increase production rate.
- The controllable variables are cutting speed (v), feed (f), and depth of cut (d).
- Jointly, v, f, and d are referred to as machining conditions.
- There are a number of models for determining the optimal machining conditions.

Automated CAPP (Part-I)

- ✓ **Processing Planning Approaches: Manual Experience-based Process Planning**

Processing Planning Approaches

- Principal approaches to process planning:

  1. Manual experience-based method

  2. Computer-aided process planning method

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Manual Experience-Based Planning Method

- The manual experience-based process planning method is most widely used.
- The biggest problem with this approach is that it is time consuming and the plans developed over a period of time may not be consistent.
- Feasibility of process planning is dependent on many upstream factors such as the design and the availability of machine tools.

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Manual Experience-Based Planning Method

- A process plan has a great influence on many downstream manufacturing activities such as scheduling and machine tool allocation.
- Therefore, to develop a proper process plan (not to mention an optimal one), process planners must have sufficient knowledge and experience.
- It may take a relatively long time and is usually costly to develop the skill of a successful planner. Computer-aided process planning has been developed to overcome these problems to a certain extent.

Bill of Materials (BOM)

- The bill of materials and the drawing are the principal documents needed to produce a part.
- Each part contained in the final product is represented in the bill of materials.
- There are several preservatives.
  a. Each part is to be identified uniquely, including raw materials and sub assemblies.
  b. The contents of an item must be defined uniquely.
  c. The state of the completion of a product should be reflected by the structure of the bill of materials.

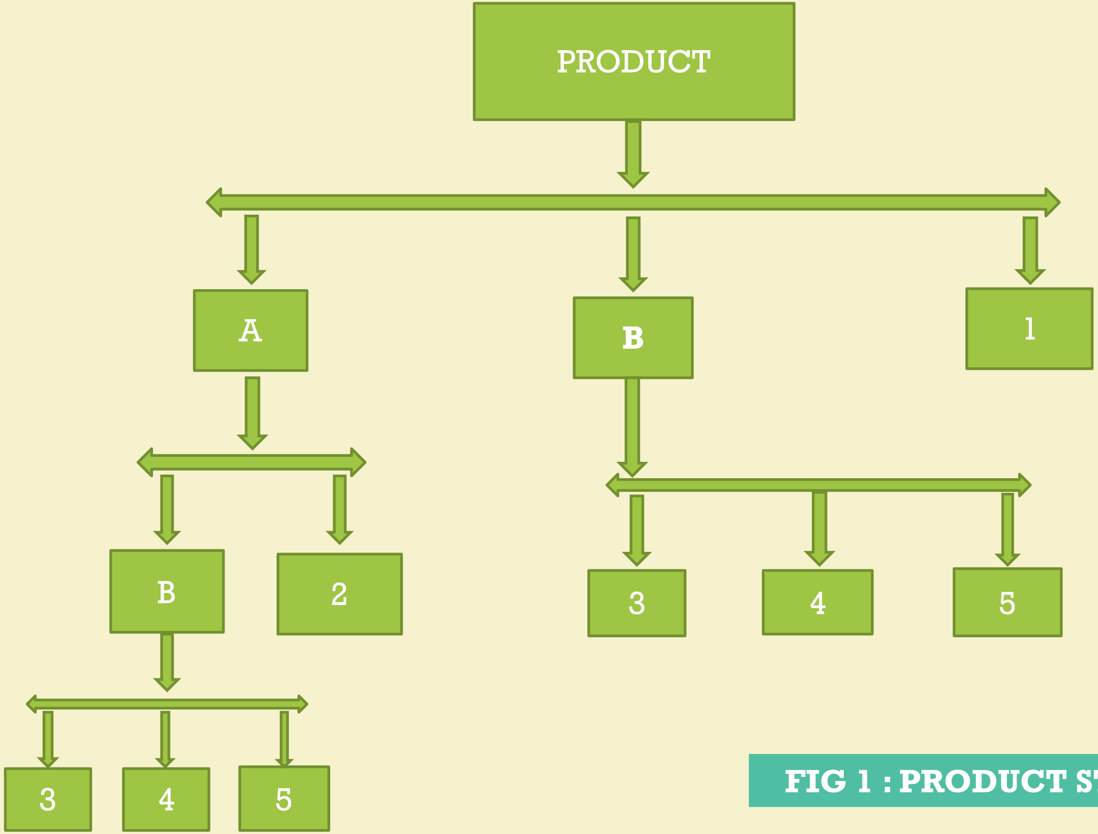

FIG 1 : PRODUCT STRUCTURE

PRODUCT	
PART	**QUANTITY**
1	1
2	1
3	2
4	2
5	2

FIG 2: BOM FOR PARTS

PRODUCT	
PART	QUANTITY
A	1
2	1
B	1
3	1
4	1
5	1
B	1
3	1
4	1
5	1
1	1

FIG 3: INTENTED FULL OF MATERIALS

PRODUCT		
ITEM	QUANTITY	
A	1	X
B	1	X
1	1	

ITEM A		
ITEM	QUANTITY	
B	1	X
2	1	

ITEM B		
ITEM	QUANTITY	
3	1	
4	1	
5	1	

(X = POINTER TO FURTHER EXPLODED LIST)
FIG 4: BLOCK – TYPE BILL OF MATERIALS

Bill of Materials (BOM)

- In this block-type bill of materials the information on each sub-group of the product has to be stored only once.
- The required memory space in the computer is minimized.
- Moreover, additions/deletions can easily be performed since they have to be done only once.
- However, this structure makes it difficult to calculate total quantity required. Also, the product structure cannot readily be seen.
- Despite these difficulties, many computer users prefer this structure for implementing a bill of materials in the computer.

Simplified Manual Operation Sheet

Operation Sheet No				Date		
Part No		Part Name		Drawing No		
Plan Rev	Divg Rev		Planner		Checked Approved	
Pieces	Matl		Weight		Next Assy	

OP.NO	OPERATION	MACHINE TOOL	TOOLS	FIXTURES	SET-UP TIME Hr.	OP.TIME Hr.
10	ROUGH TURNING	LATHE 1	T1	CHUCK	0.1	0.15
20	FINE TURNING	LATHE 2	T2	CHUCK	0.05	0.15
30	DRILLING	D'PRESS 1	D1	DRILL JIG	0.15	0.10
40	C'SUNK CHAMFER	D'PRESS 1	Ch.1	-	0.05	0.05
50	COUNTERBURE	D'PRESS 1	D2	DRILL JIG	0.05	0.08
60	HEAT-TREATMENT	FURNACE			0.1	0.5
70	GRIND	GRIND 5			0.1	0.05

Automated CAPP (Part-I)

- ✓ **Process Planning Approaches: Computer-aided Process Planning Method**

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Features of an Automated Process Planning System

1. It should operate as an integrated planning aid that obtains input data automatically from engineering and sales to generate a complete set of process plans to be used by production planning as well as production, material and quality control.

2. It should render basic data for work order routing, production schedules, payroll accounting, and material release.

3. It should be of generalized design to accommodate different types of parts.

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Computer-Aided Process Planning Method

- **Why Computer-Aided Process Planning?**

- To translate the design requirements into manufacturing process details, a feedforward system is needed in which design information is processed by the process planning system to generate manufacturing process details.

- We want to optimize the system performance in a global context. Therefore, we have to integrate the CAPP system into the interorganizational flow.

Computer-Aided Process Planning Method

- For example, if we change a design, we must be able to fall back on a module of CAPP to generate cost estimates for these design changes.

- If there is a breakdown of a machine(s) on the shop floor, the CAPP system must be able to generate alternative process plans so that the most economical solution for the situation can be adopted.

Computer-Aided Process Planning Method

The use of computers in process planning also helps to achieve the following:

1. It can systematically produce accurate and consistent process plans.
2. It can reduce the cost and lead time of process planning.
3. The skill requirements of process planners are reduced.
4. It results in increased productivity of process planners.
5. The application programs such as cost and manufacturing lead time estimation and work standards can easily be interfaced.

Computer-Aided Process Planning Method

Two major methods are used in computer-aided process planning:

- **Variant CAPP method**
- **Generative CAPP method**

Variant CAPP Method

- In the variant process planning approach, a process plan for a new part is created by recalling, identifying, and retrieving an existing plan for a similar part and making necessary modifications for the new part.

- Quite often, process plan are developed for parts representing a family of parts. Such parts are called master parts.

- Once a new part is identified with the family, the task of developing a process plan is simple. It involves retrieving and modifying the process plan of the master part of that family.

Variant CAPP Method

A variant process planning approach can be realized as a four-step process:

1. **Define the coding scheme:** Adopt existing coding or classification schemes to label parts for the purpose of classification. In some extreme cases, a new coding scheme may be developed.
2. **Group the parts into part families:** Group the parts into part families using the coding scheme defined in step 1 based on some common part features. A standard process plan is attached to each part family (see step 3). Often, a number of part types are associated with a family, thereby reducing the total number of standard process plans.

Variant CAPP Method

3. **Develop a standard process plan:** Develop a standard process plan for each part family based on the common features of the part types. This process plan can be used for every part type within the family with suitable modifications.

4. **Retrieve and modify the standard plan:** When a new part enters the system, it is assigned to a part family based on the coding and classification scheme. Then the corresponding standard process plan is retrieved and modified to accommodate the unique features of the new part.

Variant CAPP Method

- Variant process planning is quite similar to manual experience-based planning.

- However, its information management capabilities are much superior because of the use of computers.

Variant CAPP Method

- Advantages of the variant process planning approach:

- Efficient processing and evaluation of complicated activities and decisions, thus reducing the time and labor requirements.
- Standardized procedures by structuring manufacturing knowledge of the process planners to company's needs.
- Lower development and hardware costs and shorter development times. This is especially important for small and medium-sized companies whose product variety is not high, who have process planners and are interested in establishing their own process planning research activities.

Variant CAPP Method

- Disadvantages of the variant process planning approach:

- Maintaining consistency in editing is difficult.
- Adequately accommodating various combinations of material, geometry, size, precision, quality, alternative processing sequences, and machine loading, among many other factors, is difficult.
- The quality of the final process plan generated depends to a large extent on the knowledge and experience of the process planners. This dependence on the process planners is one of the major shortcomings of the variant process planning approach.

Variant CAPP Method

- One of the most widely used systems is computer-aided process planning, developed by McDonnell-Douglas Automation Company under the direction and sponsorship of Computer-Aided Manufacturing-International (CAM-I).

- CAPP can be used to generate process plans for rotational, prismatic, and sheet metal parts.

Generative CAPP Method

- In the generative approach, process plans are generated by means of decision logic, formulas, technology algorithms, and geometry-based data to perform uniquely the many processing decisions for converting a part from raw material to a finished state.
- There are essentially two major components of a generative process planning system:
  i. A geometry-based coding scheme
  ii. Process knowledge in the form of decision logic and data.

Generative CAPP Method

- Geometry-Based Coding Scheme:

- The objective is to define all geometric features for all process-related surfaces together with feature dimensions, locations, and tolerances and the surface finish desired on the features.
- The level of detail is much greater in a generative system than a variant system. For example, such details as rough and finished states of the parts and process capability of machine tools to transform these parts to the desired states are provided.

Generative CAPP Method

- Process Knowledge in the Form of Decision Logic and Data:
- The matching of part geometry requirements with the manufacturing capabilities is accomplished in this phase using process knowledge in the form of decision logic and data.
- Examples include the selection of processes, machine tools, tools, jigs, or fixtures, inspection equipment, and sequencing of operations.
- Setup and machining times are calculated.
- Operations instructions sheets are generated to help the operators run the machines in the case of manual operations.
- If the machines are numerically controlled, the NC codes are automatically generated.

Generative CAPP Method

- Manufacturing knowledge is the backbone of process planning.

- The sources of manufacturing knowledge are many and diverse, such as the experience of manufacturing personnel; handbooks; suppliers of major machine tools, tools, jigs, or fixtures, materials, and inspection equipment; and customers.

Generative CAPP Method

- To use this wide spectrum of knowledge ranging from qualitative and narrative to quantitative, it is necessary to develop a good knowledge structure to help provide a common denominator for understanding manufacturing information, ensuring its clarity, and providing a framework for future modifications.

- Tools available for the purpose include flowcharts, decision trees, decision tables, iterative algorithms, concepts of unit-machined surfaces, pattern recognition techniques, and artificial intelligence tools such as expert system shells.

Knowledge-Based Process Planning

- A knowledge-based system refers to a computer program that can store knowledge of a particular domain and use that knowledge to solve problems from that domain in an intelligent way (Hayes-Ruth, 1983).
- In a knowledge-based process planning system, we use a computer to simulate the decision process of a human expert.
- Usually, human process planners develop process planning based on their experience, knowledge, and inference.

Knowledge-Based Process Planning

- A computer, to some extent, can also be used to perform these functions.
- In a knowledge-based system, two major problems need to be solved: the knowledge representation and the inference mechanism.
- The knowledge representation is a scheme by which a real-world problem can be represented in such a way that the computer can manipulate the information.

Knowledge-Based Process Planning

- For example, to define a part, we need to define whether there is a hole in it. Given that there is a hole, we next have to define the attributes of the hole, such as the type of the hole, the length, and the diameter.

- The reason for this is that the computer is not capable of reading the design from blueprints or databases as humans are.

- The inference mechanism is the way in which the computer finds the solution.

Knowledge-Based Process Planning

- One approach is based on IF – THEN structured knowledge. For example, IF there is a hole, THEN a drill may be used.

- Through this type of knowledge, the computer can infer what operations are needed. Once the operations are known, it is easy to calculate other details and the process plan can be developed.

- Other aspects of a knowledge-based system include the interface, which contains the user interface, the interface with the computer-aided design (CAD) database, and the inquiry facility, which explains why a decision is made.

Automated CAPP (Part-I)

- ✓ **CIM and CAPP,**
- ✓ **Process Optimization and CAPP**

CIM and CAPP

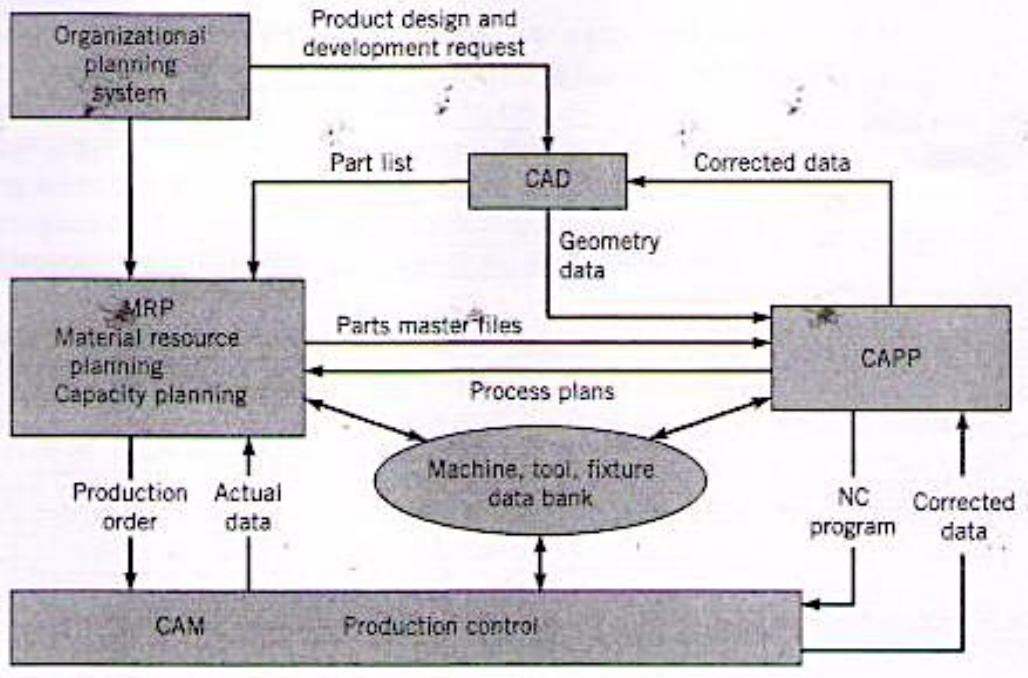

FIGURE 5.9 A computer-aided process planning framework.

Decision Tables

- Decision tables provide a convenient way to document manufacturing knowledge. They are the principal elements of all decision table-based process planning systems.
- The elements of a decision table are conditions, actions, and rules.

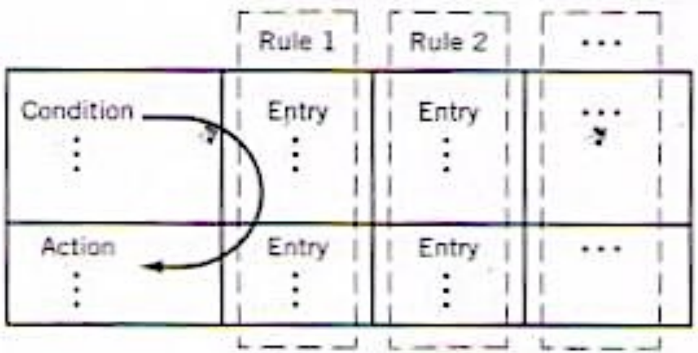

FIGURE 5.10 Format of a decision table.

Decision Tables

- Entries can be either Boolean-type values (true, false, and do not care) or continuous values.

TABLE 5.3 **Boolean Value–type Entries**

Length of bar ≥ 8 in.	T*	F	
Diameter of bar < 1 in.	T		
Diameter of bar ≥ 1 in.			T
Extra support	T		

* T, true; F, false; blank, do not care.

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Decision Tables

TABLE 5.4 **Continuous Value-type Entries**

Length of bar (in.)		≤ 4	≥ 4	≤ 16	≥ 16
Diameter of bar (in.)	≤ 0.2	> 0.2	$1 > \text{diameter} > 0.2$	≥ 1	
Extra support	T		T		T

* T, true; blank, do not care.

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Decision Tables

❑ Example

Consider the problem of the selection of lathes or grinding machines for jobs involving turning or grinding operations. Data on conditions such as lot size, diameter, surface finish, and tolerance desired are available. They are compiled in the form of a decision table as shown in Table 5.5. Make a machine selection recommendation if

a) The lot size of the job is 70 units; diameter is relatively small; the surface roughness desired is 30µm; and the tolerance range required is ±0.003 in.

Decision Tables

b) The lot size of the job is less than 10 units; diameter is relatively small; the surface roughness desired is 45µm; and the tolerance range required is ±0.004 in.

c) The lot size is greater than 50 units; diameter is relatively small; surface roughness is 20µm; and the tolerance is less than 0.0008 in.

Decision Tables

- **Solution:**

a) From the set of conditions given in the problem, it is easy to see from Table 5.5 that rule 3 is suitable for this situation. The action, therefore is obviously turret lathe; that is, the operation is performed on a turret lathe.

b) Similarly, the solution is engine lathe.

c) From the conditions given in the problem, we find that rule 2 is most suitable. Therefore, the recommended actions are to finish parts on an engine lathe and subsequently on a centerless grinding machine to achieve the desired specifications.

TABLE 5.5 **Decision Table for the Selection of a Machine(s) for Turning Operation**

*Conditions**	*Rule 1*	*Rule 2*	*Rule 3*	*Rule 4*
LS ≤ 10	X			
LS ≥ 50		X	X	
LS ≥ 4000				X
Relatively large diameters				
Relatively small diameters	X	X	X	X
SF in the range 40–60 min.	X			
SF in the range 16–32 min.		X	X	X
±0.003 ≤ Tol ≤ ±0.005	X			
±0.001 ≤ Tol ≤ ±0.003			X	
±0.0005 ≤ Tol ≤ ±0.001		X		X
Engine lathe	X	1		
Turret lathe			X	
Automatic screw machine				X
Centerless grinding machine		2		

* LS, lot size; SF, surface finish; Tol, tolerance.

Determining Machining Conditions and Manufacturing Times

- Mathematically, this can be expressed as

$$C_u = c_o t_1 + c_o t_c + c_o t_d \left(\frac{t_{ac}}{d}\right) + c_t \left(\frac{t_{ac}}{T}\right)$$

- The tool life equation as a function of cutting speed (v) is expressed as

$$VT^n = C$$

Determining Machining Conditions and Manufacturing Times

Where

c_o = cost rate including labor and overhead cost rates ($/min)

c_t = tool cost per cutting edge, which depends on the type of tool used

C = constant in the tool life equation, $VT^n = C$

v = cutting speed in meters/minute

f = feed rate (mm/rev)

d = depth of cut (mm)

Determining Machining Conditions and Manufacturing Times

n = exponent in the tool life equation
t_1 = nonproductive time consisting of loading and unloading the part and other idle time (min)
t_c = machining time per piece (min/piece)
t_d = time to change a cutting edge (min)
t_{ac} = actual cutting time per piece, which is approximately equal to t_c (min/piece)
T = tool life (min)

Determining Machining Conditions and Manufacturing Times

- Consider a single-pass turning operation. If *L*, *D*, and *f* are the length of cut (mm), diameter of the work-piece (mm), and feed rate (mm/rev), respectively, then the cutting time per piece for a single-pass operation is

$$t_c = t_{ac} = \frac{\pi L D}{1000 v f}$$

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Determining Machining Conditions and Manufacturing Times

- Upon substituting these values as well as the tool life equation in the cost per piece equation, we obtain the following equation.

$$C_u = c_o t_1 + c_o \left(\frac{\pi LD}{1000vf}\right) + c_o \left(\frac{\pi LD}{1000vf}\right) \left(\frac{v}{C}\right)^{\frac{1}{n}} t_d + c_t \left(\frac{\pi LD}{1000vf}\right) \left(\frac{v}{C}\right)^{\frac{1}{n}}$$

Determining Machining Conditions and Manufacturing Times

- The feed rate and depth of cut are normally fixed to their allowable values. Therefore, the cutting speed *v* is the decision variable.

- Differentiating C_u with respect to *v*, equating to zero, and solving, We obtain the minimum unit cost cutting speed (v_{min}) as follows:

$$v_{min} = \frac{C}{\left[\left(\frac{1}{n-1}\right) \cdot \left(c_o t_d + \frac{c_t}{c_o}\right)\right]^n}$$

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Determining Machining Conditions and Manufacturing Times

- Upon substituting the value of cutting speed in the tool life equation, we obtain the optimal tool life (T_{min}) for minimum unit cost as follows:

$$T_{min} = \left(\frac{1}{n-1}\right) \cdot \left(c_o t_d + \frac{c_t}{c_o}\right)$$

Maximum Production Rate Model

- Another criterion used to determine the optimal machining conditions is maximum production rate.
- The production rate is inversely proportional to the production time per piece, which is given by,
- Time per piece, T_u = nonproductive time per piece + machining time per piece + tool changing time per piece

Maximum Production Rate Model

- Mathematically, this can be expressed as

$$T_u = t_1 + t_c + t_d\left(\frac{t_{ac}}{T}\right)$$

- Upon substituting the values of T, t_c, and t_{ac} in equation we obtain

$$T_u = t_1 + \left(\frac{\pi LD}{1000vf}\right) + \left(\frac{\pi LD}{1000vf}\right) \cdot \left(\frac{v}{C}\right)^{\frac{1}{n}} t_d$$

Maximum Production Rate Model

- Upon partially differentiating T_u with respect to v, equating to zero, and solving for v, we obtain

$$v_{max} = \frac{C}{\left[\left(\frac{1}{n-1}\right) t_d\right]^n}$$

- And hence,

$$T_{max} = \left[\left(\frac{1}{n-1}\right) t_d\right]$$

Manufacturing Lead Time

- Assuming that the lot size is Q units, then the average lead time to process these units will be

$$\text{Lead Time} = \text{Major Setup Time} + T_u . Q$$

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Thank You!!