

Unit I: Process Planning and Process Engineering

1. Introduction

Process planning is deciding how a product will be manufactured. After design is done, process planning translates the drawing into a step-by-step manufacturing plan.

Output: Process sheet / Route sheet / Operation sheet listing machines, tools, sequence, time, cost.

2. Function of Process Planning

Select process: Forging or casting? Milling or shaping?

Select machines & tools: Which lathe, which jig/fixture, which cutting tool.

Sequence operations: Turning → Milling → Drilling → Grinding

Determine setup: How to hold the work, datums, clamping

Estimate time & cost: Machining time, setup time, labor cost

Prepare documents: Route sheet for shop floor

3. Pre-requisites for Process Planning

Part drawing: Dimensions, tolerances, material, surface finish.

Production quantity: 10 pieces vs 10,000 pieces — affects process choice

Delivery schedule: How urgent is it?

Available facilities: What machines/tools are in your plant

Quality standards: ISO, company specs

Cost data: Machine hour rate, labor rate

4. Steps in Process Planning

Study the part drawing → Understand all features, tolerances, material

List basic processes → For a hole: drill, bore, ream. For flat surface: mill, grind

Select best sequence → Roughing first, finishing last. Avoid re-clamping

Select machines → Based on size, accuracy, availability

Select tools, jigs, fixtures → Special tooling needed?

Calculate machining parameters → Speed, feed, depth of cut

Estimate time & cost → Setup time + operation time

Document → Prepare process sheet and submit for approval

5. Factors Affecting Process Planning

Product factors: Material, size, shape, tolerance, surface finish

Quantity: Job production vs batch vs mass — affects automation level

Plant factors: Available machines, capacity, worker skill

Cost factors: Cheapest process that meets quality

Time factors: Delivery date, lead time

Management policy: Make in-house or subcontract

6. Make or Buy Decision

Deciding whether to manufacture a component in-house or purchase from vendor.

Make if: Idle capacity exists, proprietary tech, quality critical, cheaper long term

Buy if: Small quantity, no expertise, vendor is cheaper, urgent need

Analysis: Compare Cost to Make vs Cost to Buy. Break-even quantity formula used.

7. Plant Capacity & Machine Capacity

Plant Capacity: Max output a factory can produce in given time.

Machine Capacity: Max output of one machine = 60 / cycle time per piece.

Utilization = Actual output / Capacity. Important for process selection and scheduling.

B. Process Engineering

1. Preliminary Part Print Analysis

First step in process engineering. Engineer studies drawing to understand:

- a. General Characteristics of Work Piece: Size, weight, material, hardness, raw material form — bar, casting, forging
- b. Principal Process: What main process gives basic shape? Casting for engine block, forging for crankshaft
- c. Functional Surfaces: Which surfaces are critical? Mating surfaces, bearing surfaces need tight tolerance. Non-functional surfaces can be rough.
- d. Nature of Work to be Performed: List all operations needed: Turning, facing, drilling, tapping, heat treatment, grinding
- e. Finishing & Identifying Operations: Which operations give final size & finish? Grinding, lapping, honing. Also marking part numbers.

2. Dimensional Analysis

Study of dimensions on drawing to plan manufacturing.

- a. Types of Dimensions: Functional: Critical for assembly, e.g., bearing diameter Non-functional: Not critical, e.g., outer body size Auxiliary: For reference only
- b. Geometry of Form: Understand shape — flatness, roundness, cylindricity, parallelism, perpendicularity
- c. Baselines: Reference surfaces/edges from which all dimensions are taken. Important for setup. Choose baselines that match datums for machining.
- d. Direction of Specific Dimensions: Dimensions should be given in direction easy for measurement and machining to reduce tolerance stack-up.

3. Tolerance Analysis

- a. Causes of Work Piece Variation: Machine vibration, tool wear, operator error, temperature, material variation
- b. Terms in Work Piece Dimensions:
Nominal size: Basic size on drawing
Tolerance: Permissible variation, e.g., 25 ± 0.05
Limits: Max and Min size
Allowance: Difference between hole and shaft for fit
Fit: Clearance, interference, transition
- c. Tolerance Stacks:
When multiple dimensions add up, errors add up. E.g., 3 parts of 10 ± 0.1 assembled = 30 ± 0.3 . Can cause assembly problem. Use tolerance charting to control.

4. Work Piece Control

How to hold and locate the part during machining so dimensions are achieved.

- a. Theories:
3-2-1 Principle: 6-point location. 3 points on primary plane, 2 on secondary, 1 on tertiary. Removes all 6 degrees of freedom.
- b. Concept of Location:
Fixing position of work piece wrt tool. Use pins, V-blocks, rests.
- c. Geometric Control:
Control of form, orientation, location using GD&T symbols — flatness, parallelism, position

d. Dimensional Control:

Achieving size within tolerance using proper machine, tool, measurement

e. Mechanical Control:

Clamping force, fixture rigidity, cutting force control so part doesn't move during cutting

f. Equilibrium Control:

Cutting forces + clamping forces should balance. If not, part deflects → dimension error.

Tolerance Stack:

When multiple parts or dimensions are assembled, individual tolerances add up. This total variation is called tolerance stack or tolerance accumulation. If not controlled, the assembly may not fit or function.

Why it matters: A shaft of 25 ± 0.1 and a hole of 25 ± 0.1 can give clearance from 0 to 0.4 mm. If you need max 0.2 mm clearance, the design fails.

Types of Stack-up

Type	Formula	When Used
Worst Case / Arithmetic	$T_{total} = \pm(t_1 + t_2 + t_3 + \dots)$	When 100% assembly must work. Conservative, costly
Statistical / RSS	$T_{total} = \pm\sqrt{t_1^2 + t_2^2 + t_3^2 + \dots}$	For mass production. Assumes random variation. Less tolerance, cheaper

t_1, t_2 = individual tolerances

Example 1 – Simple Linear Stack

Problem: A shaft must fit in two bushings placed 100 ± 0.3 mm apart. Shaft length = 99.5 ± 0.2 mm. Will it always assemble? What clearance range?

Solution - Worst Case:

Nominal $H = 20 + 15 + 10 = 45$ mm

Total tolerance = $\pm(0.2 + 0.1 + 0.05) = \pm 0.35$ mm

So, $H = 45 \pm 0.35$ mm → Max = 45.35, Min = 44.65 mm

Solution - Statistical:

$$\begin{aligned}\text{Total tolerance} &= \pm\sqrt{0.2^2 + 0.1^2 + 0.05^2} = \pm\sqrt{0.04 + 0.01 + 0.0025} \\ &= \pm\sqrt{0.0525} = \pm 0.229 \text{ mm}\end{aligned}$$

So, $H = 45 \pm 0.23$ mm → Much tighter than worst case.

Example 2 – Assembly Fit Problem

Problem: A shaft must fit in two bushings placed 100 ± 0.3 mm apart. Shaft length = 99.5 ± 0.2 mm. Will it always assemble? What clearance range?

Solution:

Gap = Distance between bushings – Shaft length

Nominal gap = $100 - 99.5 = 0.5$ mm

Worst Case Stack:

Max gap = Max distance – Min shaft = $100.3 - 99.3 = 1.0$ mm

Min gap = Min distance – Max shaft = $99.7 - 99.7 = 0.0$ mm Result: Gap varies 0 to 1.0 mm. Since min gap = 0, there is a chance of interference. Design fails.

Fix: Tighten tolerances or change nominal to 99.2 ± 0.2 to ensure min gap = 0.3 mm.

Notes: Production Forecasting and Scheduling

1. Production Forecasting

1.1 Introduction

Production forecasting is the process of estimating the future production requirements of an organization for a specified period. It helps management determine **what to produce, how much to produce, when to produce, and what resources will be required.**

Production forecasting is generally based on:

- Past production and sales data
- Market demand
- Customer requirements
- Economic conditions
- Seasonal variations
- Production capacity
- Availability of materials and manpower
- Technological and competitive changes

Importance of Production Forecasting

1. Helps in production planning.
 2. Determines future material requirements.
 3. Helps utilize machines and manpower effectively.
 4. Reduces excess inventory and shortages.
 5. Supports purchasing and supply-chain decisions.
 6. Helps in financial and manpower planning.
 7. Improves customer service by ensuring product availability.
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2. Strategic Role of Forecasting in Supply Chain

Forecasting is an important input for almost every decision in a **supply chain**.

Major roles

1. Procurement planning

Forecasts help determine the quantity and timing of raw materials to be purchased.

2. Inventory management

Accurate forecasts help maintain optimum inventory and reduce carrying costs.

3. Production planning

Manufacturers can plan production quantities according to expected demand.

4. Capacity planning

Forecasts help determine future requirements for:

- Machines
- Factory space
- Labour
- Equipment

5. Transportation planning

Expected demand helps organizations plan transportation capacity and distribution.

6. Workforce planning

Forecasts help determine the number of employees required.

7. Financial planning

Sales and production forecasts provide a basis for budgeting and cash-flow planning.

Supply-chain relationship

**Demand Forecast → Production Plan → Material Requirement →
Inventory Plan → Purchasing → Distribution**

3. Time Frame of Forecasting

Forecasts can be classified according to the time horizon.

A. Short-Term Forecast

Generally covers **a few days to several months**.

Uses:

- Daily/weekly production scheduling
- Workforce allocation
- Inventory control
- Purchasing
- Machine loading

B. Medium-Term Forecast

Generally covers **several months to about 2 years**.

Uses:

- Aggregate production planning
- Workforce planning
- Capacity adjustment
- Subcontracting decisions
- Inventory planning

C. Long-Term Forecast

Generally covers **more than 2 years**.

Uses:

- Plant expansion
- New product development
- New machinery
- Location decisions
- Major capital investment
- Strategic capacity planning

Forecast	Typical horizon	Main purpose
Short-term	Days to months	Operations and scheduling
Medium-term	Months to ~2 years	Production and capacity planning
Long-term	More than ~2 years	Strategic planning

4. Demand Behaviour

Demand behaviour describes how demand changes with time.

Major components of demand

1. Level

The average value around which demand fluctuates.

2. Trend

A long-term upward or downward movement in demand.

Example: Increasing demand for electric vehicles over several years.

3. Seasonality

A regular pattern that repeats over a specific period.

Example:

- Increased demand for cooling equipment during summer.
- Increased demand for certain products during festivals.

4. Cyclic variation

Long-term fluctuations associated with economic or business cycles.

5. Random variation

Unpredictable fluctuations caused by unexpected events.

Demand pattern

Observed Demand = Level + Trend + Seasonal Effect + Cyclical Effect + Random Variation

5. Forecasting Methods

Forecasting methods are broadly classified into:

1. Qualitative methods
 2. Quantitative methods
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5.1 Qualitative Forecasting Methods

Qualitative methods depend mainly on **expert judgment, experience, opinions and market knowledge** rather than numerical historical data.

1. Jury of Executive Opinion

A group of experienced managers provides their opinions about future demand.

Advantages:

- Simple
- Quick
- Useful when data is limited

Limitation:

Results may be affected by personal bias.

2. Sales Force Composite Method

Salespersons estimate future demand based on their knowledge of customers and markets.

Advantages:

- Salespersons are close to customers.
- Useful for regional forecasting.

Limitation:

Estimates may be influenced by individual sales targets.

3. Consumer Survey

Customers are directly asked about their future purchasing intentions.

Useful for:

New products and market research.

4. Delphi Method

A panel of experts independently provides forecasts. Their opinions are collected and refined through several rounds until a reasonable consensus is obtained.

Advantages:

- Reduces direct group pressure.
- Useful for long-term forecasting.

5. Market Research

Information is collected about:

- Customers
- Competitors
- Market conditions
- Product preferences

6. Quantitative Forecasting Methods

Quantitative methods use **historical numerical data and mathematical/statistical techniques**.

They can be broadly classified into:

A. Time-Series Methods

These use past demand patterns to predict future demand.

Common methods include:

1. Moving Average

The forecast is calculated from the average demand of previous periods.

$$F_{t+1} = \frac{D_t + D_{t-1} + \cdots + D_{t-n+1}}{n}$$

Where:

- F_{t+1} = forecast for next period
- D = actual demand
- n = number of periods

2. Weighted Moving Average

Different weights are assigned to previous observations.

$$F_{t+1} = w_1 D_t + w_2 D_{t-1} + \cdots + w_n D_{t-n+1}$$

where:

$$w_1 + w_2 + \cdots + w_n = 1$$

3. Exponential Smoothing

A commonly used forecasting technique.

$$F_{t+1} = \alpha D_t + (1 - \alpha) F_t$$

where:

- α = smoothing constant, $0 < \alpha < 1$
- D_t = actual demand
- F_t = previous forecast

B. Causal/Associative Methods

These assume that demand is related to one or more independent variables.

Examples:

- Regression analysis
- Econometric models

For example, demand for a product may depend on **price, income, population and advertising expenditure**.

7. Forecast Accuracy

Forecast accuracy indicates how closely the forecast corresponds to the actual demand.

A forecast is considered more accurate when the difference between forecast demand and actual demand is small.

Forecast Error

$$e_t = A_t - F_t$$

Where:

- A_t = actual demand
- F_t = forecast demand

Common measures

1. Mean Absolute Deviation (MAD)

$$MAD = \frac{\sum |A_t - F_t|}{n}$$

Lower MAD indicates better accuracy.

2. Mean Squared Error (MSE)

$$MSE = \frac{\sum (A_t - F_t)^2}{n}$$

Large errors receive greater importance because errors are squared.

3. Mean Absolute Percentage Error (MAPE)

$$MAPE = \frac{100}{n} \sum \left| \frac{A_t - F_t}{A_t} \right|$$

It expresses forecast error as a percentage.

Importance of Forecast Accuracy

High forecast accuracy helps:

- Reduce inventory costs

- Avoid stock-outs
 - Improve production planning
 - Improve capacity utilization
 - Reduce overtime
 - Improve customer satisfaction
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8. Scheduling

8.1 Introduction

Scheduling is the process of deciding **when and in what sequence jobs, operations, machines and workers should be utilized**.

It converts the production plan into a detailed time-based operating plan.

Example

If three jobs A, B and C have to be processed on one machine, scheduling determines:

Which job first → Which job second → Which job third → Starting and completion times

9. Objectives of Scheduling

The main objectives are:

1. Maximum utilization of machines.
 2. Maximum utilization of manpower.
 3. Minimum production time.
 4. Minimum machine idle time.
 5. Minimum work-in-process inventory.
 6. Minimum production cost.
 7. Meeting delivery dates.
 8. Reducing waiting time.
 9. Maintaining smooth production flow.
 10. Improving customer satisfaction.
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10. Loading

Loading means assigning jobs or work to machines, work centres or workers according to their available capacity.

Objectives of Loading

- Utilize available capacity efficiently.
- Avoid machine overloading.
- Reduce idle time.
- Balance workload among machines.
- Meet production deadlines.

Types of Loading

1. Machine loading:

Assigning jobs to machines.

2. Labour loading:

Assigning work to employees.

Example

Suppose Machine A has 8 hours available and Machine B has 8 hours available. If jobs require 10 hours on A and 6 hours on B, the scheduler may redistribute suitable work to prevent **overloading of A** and **under-utilization of B**.

11. Sequencing

Sequencing determines the **order in which jobs are processed** on machines or work centres.

Common sequencing rules

1. FCFS - First Come First Served

Jobs are processed in the order in which they arrive.

2. SPT - Shortest Processing Time

The job requiring the shortest processing time is processed first.

Advantage: Generally reduces average flow time.

3. LPT - Longest Processing Time

The job requiring the longest processing time is processed first.

4. EDD - Earliest Due Date

The job with the earliest due date is processed first.

Useful for: Meeting delivery deadlines.

5. Critical Ratio

$$CR = \frac{\text{Time remaining until due date}}{\text{Processing time remaining}}$$

A lower critical ratio generally indicates greater urgency.

12. Monitoring

Production monitoring is the continuous observation and control of production activities to determine whether actual performance agrees with the schedule.

Main activities

1. Track production progress.
2. Compare actual output with planned output.
3. Identify delays.
4. Monitor machine utilization.
5. Monitor material availability.
6. Identify bottlenecks.
7. Take corrective action.
8. Update schedules when necessary.

Important monitoring information

- Production quantity
- Machine status
- Labour availability
- Material availability
- Work-in-process
- Quality performance
- Delivery status

Feedback process

Plan → Schedule → Execute → Monitor → Compare → Correct → Reschedule

13. Advanced Planning and Scheduling Systems (APS)

Advanced Planning and Scheduling (APS) systems are computer-based systems that use advanced algorithms and optimization techniques to plan and schedule production considering various constraints.

APS considers:

- Demand
- Available capacity
- Raw materials
- Machine availability
- Labour
- Delivery dates
- Production constraints
- Inventory
- Set-up times

Main functions

1. Demand planning
2. Supply planning
3. Capacity planning
4. Production planning
5. Detailed scheduling
6. Material planning
7. Resource allocation

Advantages

- Better utilization of resources
- Faster scheduling
- Improved delivery performance
- Reduced inventory
- Better response to demand changes
- Identification of capacity constraints
- Improved coordination between departments

APS vs traditional scheduling

Traditional scheduling	APS
Often manual	Computer-based

Traditional scheduling	APS
Limited data	Integrates large amounts of data
Difficult to handle many constraints	Handles multiple constraints
Slower response	Faster rescheduling
Less flexible	Highly flexible

14. Theory of Constraints (TOC)

Theory of Constraints (TOC) is a management approach that states that the performance of a system is limited by one or a few **constraints or bottlenecks**.

A **constraint** is anything that prevents a system from achieving higher performance.

Example

A factory has:

- Machine A: 100 units/day
- Machine B: 50 units/day
- Machine C: 100 units/day

Machine B is the **bottleneck** because its capacity is only 50 units/day.

Increasing the capacity of A or C alone will not significantly increase total system output unless the constraint at B is addressed.

Five Focusing Steps of TOC

Step 1: Identify the Constraint

Find the process that limits overall performance.

Step 2: Exploit the Constraint

Use the existing constraint as efficiently as possible.

Step 3: Subordinate Everything Else

Align other activities with the capacity of the constraint.

Step 4: Elevate the Constraint

Increase the capacity of the constraint by:

- Adding machines
- Adding workers
- Overtime
- Outsourcing
- Process improvement

Step 5: Repeat

Once one constraint is removed, identify the next constraint.

Main objective

Increase throughput while controlling inventory and operating expenses.

15. Employee Scheduling

Employee scheduling is the process of assigning employees to specific jobs, shifts and working hours according to organizational requirements.

Objectives

1. Ensure adequate staffing.
2. Match employee skills with jobs.
3. Maintain required production levels.
4. Minimize labour cost.
5. Distribute workload fairly.
6. Meet legal and organizational working-hour requirements.
7. Provide appropriate rest and leave.
8. Improve employee productivity.

Factors affecting employee scheduling

- Number of employees
- Skill and qualification
- Shift requirements
- Working hours
- Leave and absenteeism
- Production demand
- Labour regulations
- Overtime
- Employee preferences

Types of employee schedules

1. Fixed shift:

Employees work the same shift regularly.

2. Rotating shift:

Employees rotate between different shifts.

3. Flexible scheduling:

Working hours can vary within defined limits.

4. Part-time scheduling:

Employees work fewer hours than full-time employees.

Quick Revision Summary

Topic	Key point
Production Forecasting	Predicting future production/demand requirements
Forecasting role	Supports production, inventory, purchasing and capacity decisions
Short-term	Scheduling and operational decisions
Medium-term	Aggregate production and capacity planning
Long-term	Strategic investment and expansion
Demand behaviour	Level, trend, seasonality, cycles and random variation
Qualitative forecasting	Based on expert judgment and market information
Quantitative forecasting	Based on numerical data and mathematical models
Forecast accuracy	Measures how close forecasts are to actual demand
Scheduling	Deciding when and in what order work is performed
Loading	Assigning jobs to machines/work centres

Topic	Key point
Sequencing	Determining order of jobs
Monitoring	Comparing actual production with planned production
APS	Computer-based advanced planning and scheduling
TOC	Improves system performance by managing constraints
Employee scheduling	Assigning workers to jobs and shifts

Important formulas for examination

$$F_{t+1} = \frac{\sum D}{n}$$

Moving Average

$$F_{t+1} = \alpha D_t + (1 - \alpha)F_t$$

Exponential Smoothing

$$e_t = A_t - F_t$$

Forecast Error

$$MAD = \frac{\sum |A_t - F_t|}{n}$$

Mean Absolute Deviation

$$MAPE = \frac{100}{n} \sum \left| \frac{A_t - F_t}{A_t} \right|$$

Mean Absolute Percentage Error

$$CR = \frac{\text{Time remaining until due date}}{\text{Processing time remaining}}$$

Critical Ratio

