Learning Objectives:
By the end of the lecture the student should be able to:

- Apply mathematical models of production performance problems.
- Explain the concepts of fixed and variable manufacturing costs.
Production Concepts and Mathematical Models

- Production rate $R_p$
- Production capacity $PC$
- Utilization $U$
- Availability $A$
- Manufacturing lead time $MLT$
- Work-in-progress $WIP$
Operation Cycle Time

Typical cycle time for a production operation:

\[ T_c = T_o + T_h + T_{th} \]

where \( T_c = \) cycle time, \( T_o = \) processing time for the operation, \( T_h = \) handling time (e.g., loading and unloading the production machine), and \( T_{th} = \) tool handling time (e.g., time to change tools)
Production Rate

Batch production: batch time $T_b = T_{su} + QT_c$
Average production time per work unit $T_p = T_b / Q$
Production rate $R_p = 1/T_p$

Job shop production:
For $Q = 1$, $T_p = T_{su} + T_c$

For quantity high production:
$R_p = R_c = 60/T_p$ since $T_{su}/Q \to 0$
Production Capacity

Plant capacity for facility in which parts are made in one operation ($n_o = 1$):

$$PC_w = n \cdot S_w \cdot H_s \cdot R_p$$

where $PC_w = \text{weekly plant capacity, units/wk}$

Plant capacity for facility in which parts require multiple operations ($n_o > 1$):

$$PC_w = \frac{nS_wH_sR_p}{n_o}$$

where $n_o = \text{number of operations in the routing}$
Utilization and Availability

Utilization: \[ U = \frac{Q}{PC} \]

where \( Q \) = quantity actually produced, and \( PC \) = plant capacity

Availability: \[ A = \frac{MTBF - MTTR}{MTBF} \]

where \( MTBF \) = mean time between failures, and \( MTTR \) = mean time to repair
Availability -

*MTBF* and *MTTR* Defined

![Diagram showing MTBF and MTTR]

- **MTBF**: Time between breakdowns.
- **MTTR**: Time to repair.

**Breakdown**

**Repairs completed**

**Equipment operating**

**Time**
Manufacturing Lead Time (Batch)

\[ MLT = n_o (T_{su} + QT_c + T_{no}) \]

where \( MLT \) = manufacturing lead time, \( n_o \) = number of operations, \( T_{su} \) = setup time, \( Q \) = batch quantity, \( T_c \) = cycle time per part, and \( T_{no} \) = non-operation time
Work-In-Process

\[
WIP = \frac{AU(PC)(MLT)}{S_w H_{sh}}
\]

where \( WIP \) = work-in-process, pc; \( A \) = availability, \( U \) = utilization, \( PC \) = plant capacity, pc/wk; \( MLT \) = manufacturing lead time, hr; \( S_w \) = shifts per week, \( H_{sh} \) = hours per shift, hr/shift
Costs of Manufacturing Operations

- Two major categories of manufacturing costs:
  1. Fixed costs - remain constant for any output level
  2. Variable costs - vary in proportion to production output level

- Adding fixed and variable costs

\[ TC = FC + VC(Q) \]

where \( TC \) = total costs, \( FC \) = fixed costs (e.g., building, equipment, taxes), \( VC \) = variable costs (e.g., labor, materials, utilities), \( Q \) = output level.
Fixed and Variable Costs

\[ TC_2 = FC_2 + VC_2(Q) \]

\[ TC_1 = FC_1 + VC_1(Q) \]

Production quality, \( Q \)

Method 1: manual

Method 2: automated

Break-even point
Manufacturing Costs

- Alternative classification of manufacturing costs:
  1. Direct labor - wages and benefits paid to workers
  2. Materials - costs of raw materials
  3. Overhead - all of the other expenses associated with running the manufacturing firm
    - Factory overhead
    - Corporate overhead
Typical Manufacturing Costs

- Selling price:
  - Manufacturing cost: 40%
  - Engineering: 15%
  - Research and development: 5%
  - Administration, sales, marketing: 25%
  - Profit: 15%

- Manufacturing cost:
  - Direct labor: 12%
  - Plant and machinery depreciation, energy: 26%
  - Indirect labor: 12%
  - Parts and materials: 50%
Overhead Rates

Factory overhead rate:

\[ FOHR = \frac{FOHC}{DLC} \]

Corporate overhead rate:

\[ COHR = \frac{COHC}{DLC} \]

where \( DLC = \) direct labor costs