Chapter 3 - DESIGN OF THE OPERATION SYSTEM

- 3.1 Product and service design
  3.2 Process selection
  3.3 Strategic Capacity Planning
  3.4 Facility Location & layout
  3.5 Job Design and Work Measurement

At the end of this unit, students will be able to:

- Discuss Product and service design
- Discuss Process selection
- Discuss Strategic Capacity Planning
- Discuss Facility Location & layout
- Discuss Job Design and Work Measurement

Product and service design

- The process of deciding on and defining the **unique characteristics** of a company's product & service offerings in terms of

  - appearance,
  - materials,
  - dimensions,
  - tolerances,
  - Performance
  - standards.

- Serves to define a company's customer base, image, competition and future growth

- Major factors in design strategy
  - Cost
  - Quality
  - Time-to-market
  - Customer satisfaction
  - Competitive advantage

Activities of Product or Service Design

- Translate customer wants and needs into product and service requirements
- Refine existing products and services
- Develop new products and services
- Formulate
  - quality goals
  - cost targets
- Construct and test prototypes
- Document specifications

Product Vs Service Design

Service design

- Is an activity of organizing and planning people, communication and material components in order to deliver better service quality.
- It is the interaction between the service provider and customers and the customers' experience.
- A service is anything that is done to or for a client and is **created and delivered simultaneously**.
- The two most important issues in service design are the **degree of variation** in requirements and the **degree of customer contact** in which determines how standardized the service can be. The greater the degree of customer contact, the greater the opportunity for selling.

- **concepts and ideas generated are captured in sketches or in service prototypes.** The strong visual element, combined with the opportunity to test and rapidly change services and interfaces, delivers real value in today's competitive markets.

Product Design:

- combines **ergonomics** with **product and business knowledge** to generate ideas and concepts and convert them into physical and usable objects or services.
- The discipline covers the entire range of activities from concept, manufacturing, testing to product launch.
- Product Designers conceptualize and evaluate ideas and themes they find profitable. **The designers make these ideas tangible through products using a systematic approach.**

Difference between service design and product design:

- Service design is an **intangible** aspect while product design is **tangible**.
- Services are generally created and delivered at the **same time** and can not be held in inventory like actual products. Also, services (especially quality one) are highly visible to customers.

Reasons for Product or Service Design

- Economic
    - Low demand, excessive warranty claims
- Social and demographic
    - Changing tastes, aging population
- Political, liability, or legal
    - Safety issues, new regulations, government changes
- Competitive
    - New products and services in the market, promotions
- Cost or availability
    - Raw materials, components, labor
- Technological
    - Components, production processes

Objectives of Product and Service Design

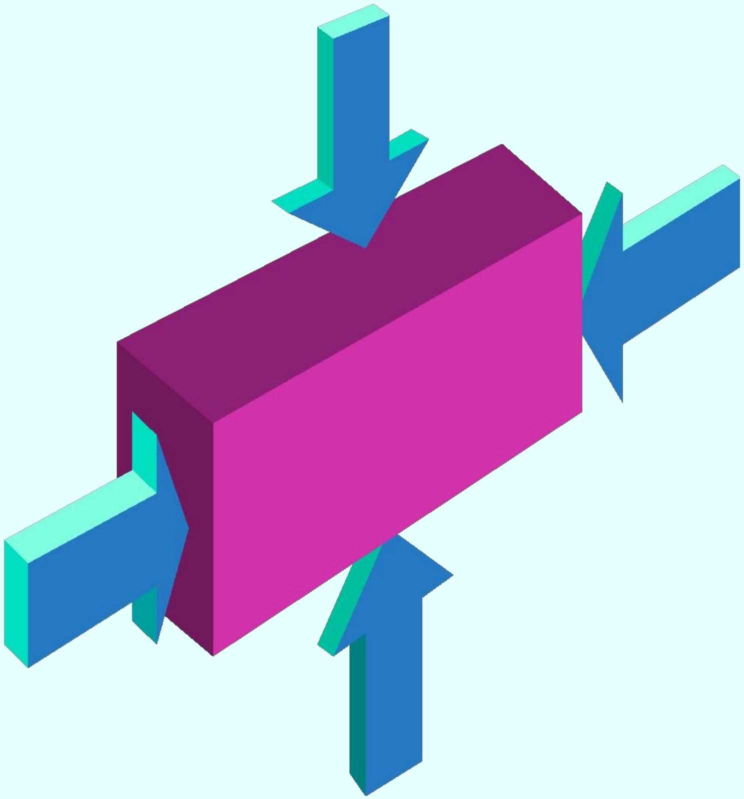
- Main focus
  - Customer satisfaction
- Secondary focus
  - Function of product/service
  - Cost/profit
  - Quality
  - Appearance
  - Ease of production/assembly
  - Ease of maintenance/service

Design For Operations

- Taking into account the capabilities of the organization in designing goods and services
    - Location of facilities
    - Suppliers
    - Transportation fleet
    - Current workforce
    - Current technology
    - Standing contracts
  - All can limit the implementation of a new design

Forthcoming Aspects of Product Design

- Product Life Cycles
- Standardization
- Mass Customization
- Modular Design
- Robust Design
- Concurrent Engineering
- Computer-Aided Design



Product and Service Life Cycle

During their useful life, many services and products go through four stages. Since the demand can vary for each of these 4 stages, different strategies should be applied to achieve optimum product/service performance during each stage.

Product Life Cycle

- **Product life cycle stages**
  - **Introduction**
  - **Growth**
  - **Maturity**
  - **Decline**
- **Facility & process investment depends on life cycle**

The Product/Service Life Cycle

- **Introduction Stage**
- When a product or service is introduced, it is likely to be offering something new in terms of its design or performance, with few competitors offering the same product or service. The needs of customers are unlikely to be well understood, so the operations management needs to develop the flexibility to cope with any changes and be able to give the quality to maintain product/service performance.

The Product/Service Life Cycle

- **Growth Stage**
- As volume grows, competitors may enter the growing market. Keeping up with demand could prove to be the main operations preoccupation. Rapid and dependable response to demand will help to keep demand buoyant, while quality levels must ensure that the company keeps its share of the market as competition starts to increase.

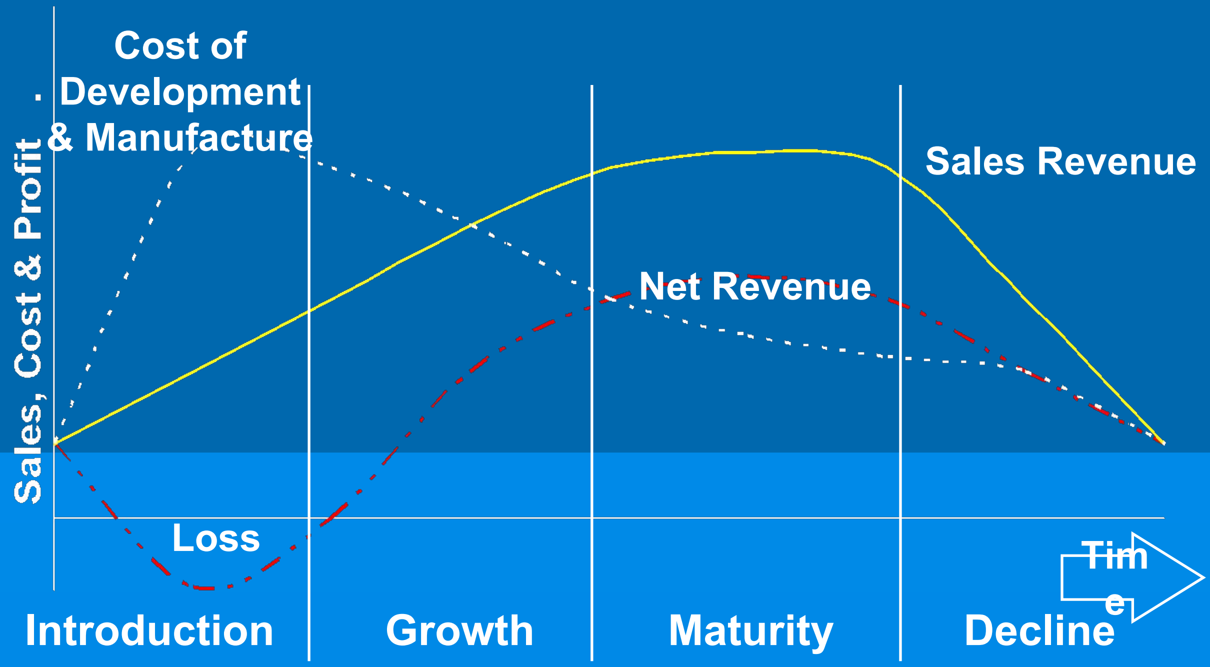
The Product/Service Life Cycle

- **Maturity Stage**
- Demand starts to level off. Some early competitors may have left the market and the industry will probably be dominated by a few larger companies. So operations will be expected to get the costs down in order to maintain profits or to allow price cutting, or both. Because of this, cost and productivity issues, together with dependable supply, are likely to be the operation's main concerns.

The Product/Service Life Cycle

- **Decline Stage**
- After time, sales will decline, with more competitors dropping out of the market. There might be a residual market, but unless a shortage of capacity develops the market will continue to be dominated by price competition. Operations objectives continue to be dominated by cost.

Product Life Cycle, Sales, Cost, and Profit



Standardization

- Standardization
  - Extent to which there is an absence of variety in a product, service or process
- The degree of Standardization?
- Standardized products are immediately available to customers

Mass Customization

Mass customization:

- A strategy of producing standardized goods or services, but incorporating some degree of customization
  - Delayed differentiation
  - Modular design

Delayed Differentiation

- Delayed differentiation is a postponement tactic
  - Producing but not quite completing a product or service until customer preferences or specifications are known
- Postponing the completion until customer specification are known
- Examples: Wheeled loaders

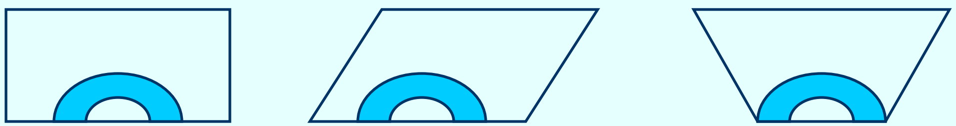
Modular Design

Modular design is a form of standardization in which component parts are subdivided into modules that are easily replaced or interchanged. It allows:

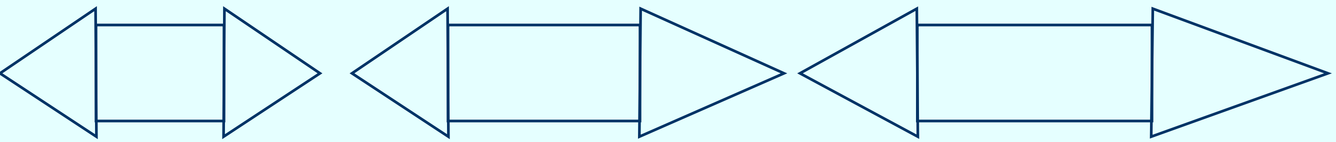
- easier diagnosis and remedy of failures
- easier repair and replacement
- simplification of manufacturing and assembly

Disadvantage: variety decreases

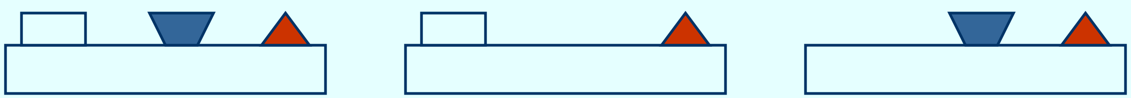
Types of Modularity for Mass Customization



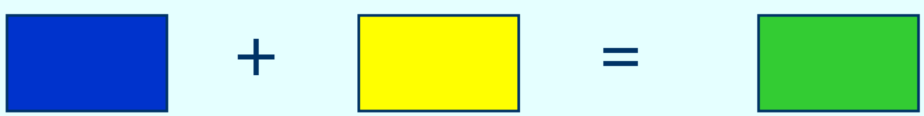
Component Sharing Modularity



Cut-to-Fit Modularity,
Gutters that do not require seams

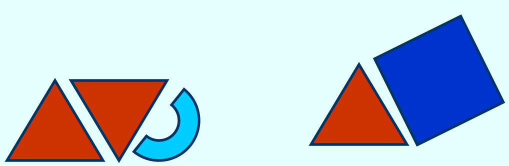


Bus Modularity,
E-books



Mix Modularity,
Paints

Sectional Modularity, LEGO



Robust Design

- Design that can function over a **broad** range of conditions

Concurrent Engineering

Concurrent engineering: **Bringing engineering design and manufacturing and other personnel together early in the design phase.**

- Manufacturing personnel helps to identify production capabilities, selecting suitable materials and process, the conflicts during production can be reduced.
- Early consideration of technical feasibility.
- Shortening the product development process.

- Design for manufacturing (DFM)
- Design for assembly (DFA)

  number of parts, methods, sequence.
- Design for recycling (DFR)
- Remanufacturing
- Design for disassembly (DFD)

Computer-Aided Design

- Computer-Aided Design (CAD) is product design using computer graphics.
  - increases **productivity** of designers, 3 to 10 times
  - creates a **database** for manufacturing information on product specifications
  - Simplifies **communication** of a design. Design teams at various locations can work together.
  - provides possibility of **engineering and cost analysis** on proposed designs

STEPS IN PRODUCT DESIGN

STEP 1 IDEA DEVELOPMENT.

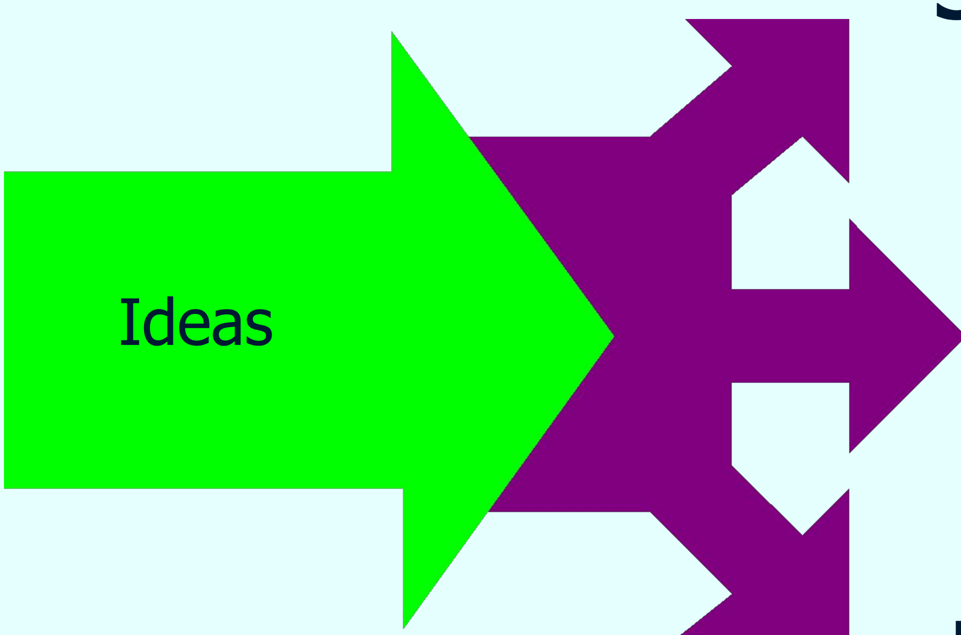
STEP 2 PRODUCT SCREENING.

STEP 3 PRELIMINARY DESIGN AND TESTING.

STEP 4 FINAL DESIGN.

Idea Generation

A need is identified & a product idea to satisfy it is put together



Supply chain based

- **suppliers**
- **Company members**
- **Customers**

Competitor based

- **Reverse engineering**

Research based

- Basic research
- Applied research

Product Screening

- Initial ideas are evaluated for difficulty & likelihood of success
  - Operations:
    - Are production requirements consistent with existing capacity?
    - Are the necessary labor skills & raw materials available?
  - Marketing:
    - How large is the market position?
    - What is the long-term potential for the product?
  - Finance:
    - What is the expected return on investment?

Every business needs a formal/structured evaluation process:

- Fit with facility and labor skills,
- Size of market,
- Contribution margin,
- Break-even analysis,
- Return on sales

are the parameters trough which products are to be evaluated.

Preliminary Design & prototype Testing

- General performance characteristics are translated into technical specifications
- Prototypes are built & tested (maybe offered for sale on a small scale)
- Bugs are worked out & designs are refined

Final Design

- Specifications are set & then used to:
  - Develop processing and service delivery instructions
  - Guide equipment selection
  - Outline jobs to be performed
  - Outline contracts formats with suppliers and distributors

Process Selection

- **Process selection is based on five considerations**
  - Type of process; range from intermittent to continuous
  - Degree of vertical integration
  - Flexibility of resources
  - Mix between capital & human resources
  - Degree of customer contact

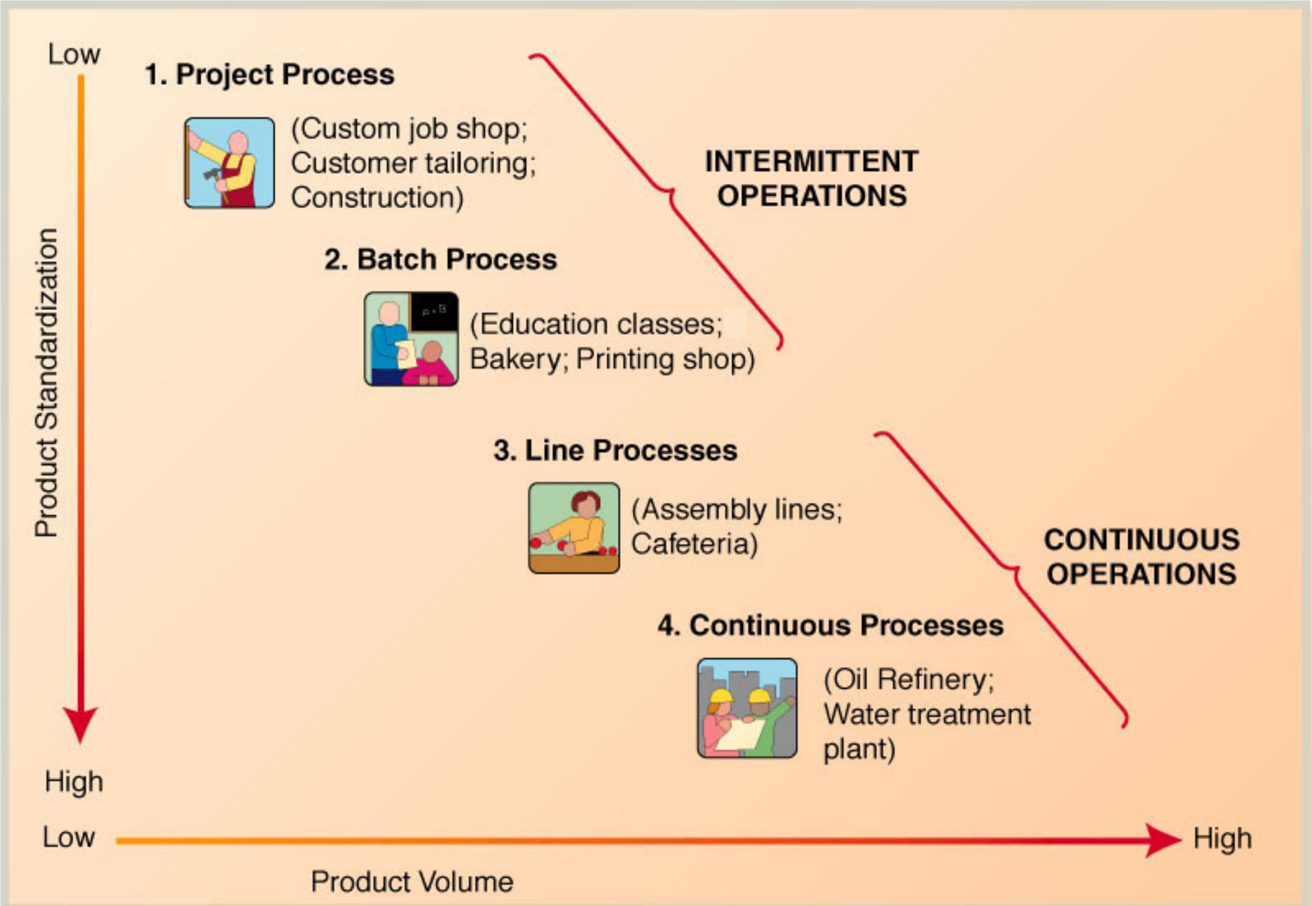
- **<u>Process types</u> can be:**
  - Project Process
  - Batch Process
  - Line Process
  - Continuous Process

Types of Processes

- Intermittent operations:
  - Capable of producing **a large variety of product** designs in relatively **low volumes**
- Continuous operations:
  - Capable of producing **one** (or a **few**) standardized designs in **very high volumes**

Intermittent operations

Continuum of Process Types



Differences between Intermittent and Continuous Operations

Decision	Intermittent	Continuous
Product Variety	Large	Small
Degree of Standardization	Low	High
Path through Facility	Varied pattern	Line Flow
Critical Resource	Labor	Equipment
Importance of Work Skills	High	Low
Type of Equipment	General Purpose	Specialized
Degree of Automation	Low	High
Throughput Time	Longer	Shorter
Work-in-Process Inventory	More	Less

Process Decisions

1. Vertical integration

- Refers to the segments in the **chain from acquisition of raw materials to final delivery of finished products**
- Refers to the degree a firm chooses to do processes itself- **raw material to sales**
- **Backward Integration** means where a company owns or acquires sources of supply, raw materials, or subassemblies.
- **Forward Integration** means where a company owns facilities closer to the customer, such as distribution channels, warehouses, and retail locations.

2. Make-or-Buy decision

- is a type of backward integration decision, where the company decides whether to purchase certain materials or tasks or perform the operations itself. Often this is called ***outsourcing***. *Many companies routinely outsource* certain services, such as janitorial services, repair, security, payroll, or records management.
- factors must be considered in the make-or-buy decision**:**
  - Strategic impact
  - Available capacity
  - Expertise
  - Quality considerations
  - Speed
  - Cost (fixed cost + variable cost)make = Cost (fixed cost + Variable cost)buy

Strategic Capacity Planning

- **Capacity** is the upper limit or ceiling on the load that an operating system can handle.

- The objective of capacity management *(i.e. planning and control of capacity)* is **to match the level of operations to the level of demand.**
  - Overcapacity □ operating costs that are too high
  - Under capacity □ strained resources and possible loss of customers
- Capacity needs include
  - Equipment
  - Space
  - Employee skills

Capacity Planning Horizons

- Capacity planning can be classified into three planning horizons:

Long range

- planning horizons of **one year or longer**
- to build a new facility, to expand the existing facility or to move to a new facility due to expected changes in demand.

Medium range

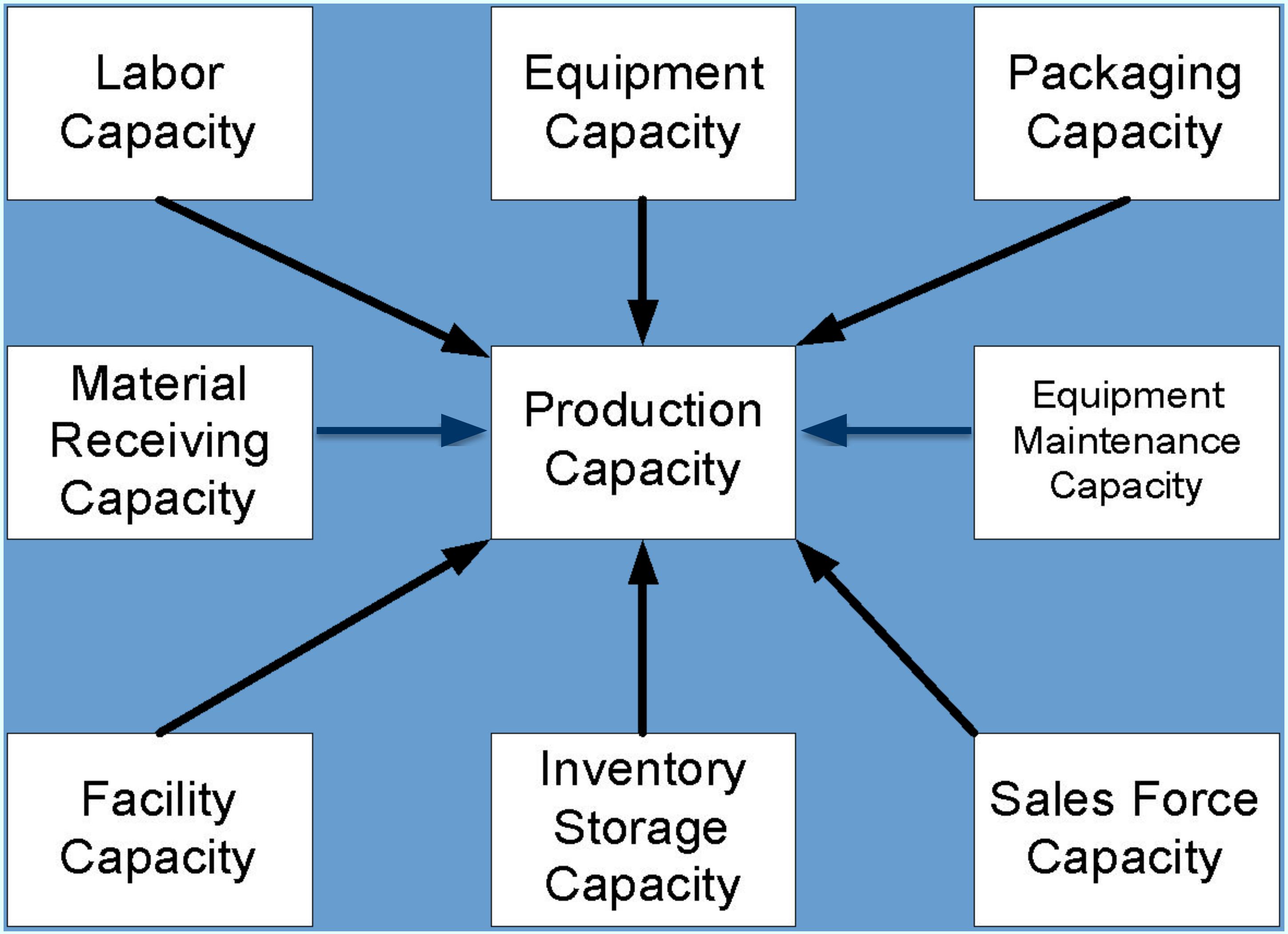
- planning horizon ranges approximately from **one month and less than a year.**
- Decisions include acquisition of a major piece of machinery and subcontracting.

Short range

- planning horizon **daily or a weekly**
- These activities include like machine loading and detailed production scheduling.

Capacity Planning Questions

- Key Questions:
  - **What kind** of capacity is needed?
  - **How much** is needed to match demand?
  - **When** is it needed?
- Related Questions:
  - How much will it cost?
  - What are the potential benefits and risks?
  - Are there sustainability issues?
  - Should capacity be changed all at once, or through several smaller changes
  - Can the supply chain handle the necessary changes?


Labor Capacity
Equipment Capacity
Packaging Capacity
Material Receiving Capacity
Production Capacity
Equipment Maintenance Capacity
Facility Capacity
Inventory Storage Capacity
Sales Force Capacity

Capacity Decisions Are Strategic

- Capacity decisions
  1. impact the ability of the organization to meet future demands
  2. affect operating costs
  3. are a major determinant of initial cost
  4. often involve long-term commitment of resources
  5. can affect competitiveness
  6. affect the ease of management
  7. have become more important and complex due to globalization
  8. need to be planned for in advance due to their consumption of financial and other resources

Measures of Capacity

- We measure the capacity of a plant, machine department, worker, hospital, etc., either
  - in terms of **output** (number of units or number of pounds manufactured) or
  - in terms of **input** (e.g. number of machine hours, labor hours, …).

Design capacity

- Maximum output rate or service capacity an operation, process, or facility is designed for

Effective capacity

- Design capacity minus allowances such as personal time, maintenance, and scrap etc.

Actual output

- Rate of output actually achieved--cannot exceed effective capacity.

We measure the capacity in terms of

- *Efficiency : the ratio of actual output to effective capacity. In contrast,*

$$\text{Efficiency} = \frac{\text{actual output}}{\text{effective capacity}}$$

- *Utilization :the ratio of actual output to design capacity.*

$$\text{Utilization} = \frac{\text{actual output}}{\text{design capacity}}$$

Example– Efficiency and Utilization

- Design Capacity = 50 trucks per day
- Effective Capacity = 40 trucks per day
- Actual Output = 36 trucks per day

$$\text{Efficiency} = \frac{\text{actual output}}{\text{effective capacity}} = \frac{36}{40} = 90\%$$

$$\text{Utilization} = \frac{\text{actual output}}{\text{design capacity}} = \frac{36}{50} = 72\%$$

Expected output = (Effective capacity)(Efficiency)

Exercise

The design capacity for engine repair in our company is 80 engines per day. The effective capacity is 40 engines per day and the actual output is 36 engines per day. Calculate the utilization and efficiency of the operation. If the efficiency for next month is expected to be 82%, what is the expected output?

Steps in Capacity Planning

Step1. Determine service/product level requirements

a. Define workloads

b. Determine the unit of work

c. Identify product/service levels for each workload

Step 2. Analyze current system capacity

a. Measure actual capacity and compare to objectives

b. Measure overall resource usage

c. Measure resource usage by workload

d. Identify components of response time

step 3. Plan for the future capacity

a. Determine future processing requirements

b. Plan future system configuration

Facility Location & layout

- **Facility Location**
- **Where should a plant or service facility be located?**
- This is a top question on the strategic agendas of contemporary manufacturing and service firms particularly, in this age of global markets and global production.
- **Plant location or the facilities** location problem is an important strategic level decision making for an organization.
- One of the key features of a conversion process (manufacturing system) is the efficiency with **which the products (services) are transferred to the customers.** This fact will include the determination of where to place the plant or facility.

Facility Location

- **The selection of location is a key-decision as large investment is made in building plant and machinery.** It is not advisable or not possible to change the location very often.
- **So an improper location of plant may lead to waste of all the investments made in building and machinery, equipment.**
- Before a location for a plant is selected, long range **forecasts** should be made anticipating future needs of the company.
- The plant location should be based on the company's expansion plan and policy, diversification plan for the products, changing market conditions, the changing sources of raw materials and many other factors that influence the choice of the location decision.

Need for Selecting a Suitable Location

- The need for selecting a suitable location arises because of three situations.
  - I. When **starting a new organization**, i.e., location choice for the first time.
  - II. **In case of existing organization**.
  - III. **In case of Global Location**.

Facility Location

- **Need for Selecting a Suitable Location**
- The need for selecting a suitable location arises because of three situations.

1. **When starting a new organization**, i.e., location choice for the first time.
   - Identification of region:
   - Choice of a site within a region:
   - Dimensional analysis:
2. **In case of existing organization.**
   - Plant manufacturing distinct products.
   - Manufacturing plant supplying to specific market area.
   - Plant divided on the basis of the process or stages in manufacturing.
   - Plants emphasizing flexibility.
4. **In case of Global Location.**
   - Virtual Proximity
   - Virtual Factory

Reasons for a Global/Foreign Location

- **Tangible Reasons:**
  - Reaching the customer:
  - cost and case of logistics:
  - The host country may offer substantial tax advantages compared to the home country.
  - The costs of manufacturing and running operations may be substantially less in that foreign country.
  - The company may overcome the tariff barriers by setting up a manufacturing plant in a foreign country rather than exporting the items to that country.

- **Intangible Reasons:**

1. **Customer-related Reasons**
   - With an operations facility in the foreign country, the firm’s customers may feel secure that the firm is more accessible.
   - The firm may be able to give a personal tough.
   - The firm may interact more intimately with its customers and may thus understand their requirements better.
   - It may also discover other potential customers in the foreign location.

2. Organizational Learning-related Reasons:

- The firm can learn **advanced technology**.
- The firm can learn from its **customers** abroad.
- It can also learn from its **competitors** operating in that country.
- The firm may also learn from its **suppliers** abroad.

3. Other Strategic Reasons

- The firm by being physically present in the host country may gain some ‘local boy’ kind of **psychological advantage**.
- The firm may **avoid ‘political risk’** by having operations in multiple countries.
- By being in the foreign country, the firm can build alternative sources of supply. The firm could, thus, **reduce its supply risks.**
- The firm could hunt for human capital in different countries by having operations in those countries. Thus, the firm can **gather the best of people from across the globe.**
- Foreign locations in addition to the domestic locations would **lower the market risks for the firm.** If one market goes slow the other may be doing well, thus lowering the overall risk.

Factors Influencing Plant Location/Facility Location

- It is appropriate to divide the factors, which influence the plant location or facility location on the basis of the nature of the organization as:

1. **General locational factors**, which include controllable and uncontrollable factors for all type of organizations.
2. **Specific locational factors** specifically required for manufacturing and service organizations. Location factors can be further divided into two categories:

General factors

- Following are the general factors required for location of plant in case of all types of organizations.

- **Controllable Factors**
  - Proximity to markets
  - Supply of materials
  - Transportation facilities
  - Infrastructure availability
  - Labor and wages
  - External economies
  - Capital.

- **Uncontrollable Factors**
  - Government policy
  - Climate conditions
  - Supporting industries and services
  - Community and labor attitudes
  - Community Infrastructure.

Specific Locational Factors

- Favorable labor climate
- Proximity to markets
- Quality of life
- Proximity to suppliers and resources
- Utilities, taxes, and real estate costs

Specific Locational Factors for Service Organization

- **Dominant Factors:**
  - **Proximity to Customers**
  - **Transportation Costs and Proximity to Markets**
  - **Location of Competitors**

Facility layout

- **Layout decisions** entail determining the placement of:
  - Departments,
  - Work groups within the departments,
  - Workstations,
  - Machines, and
  - Stock-holding points within a production facility.
- The objective is to arrange these elements in a way that ensures:
  - **a smooth work flow** (in a factory) or **a particular traffic pattern** (in a service organization).

Inputs to the layout decision

- **Specification** of objectives of the system in output and flexibility.
- **Estimation** of product or service demand on the system.
- **Processing** requirements in number of operations and amount of flow between departments and work centers.
- **Space requirements** for the elements in the layout.
- **Space availability** within the facility itself, or if this is a new facility, possible building configurations.

Strategic Importance of Layout Decisions

- Layout is one of the decisions that determine **the long-run efficiency of operations.** Layout has numerous strategic implications because **it establishes a firm competitive priority in regard to capacity, processes, flexibility, and cost, as well as quality work life.**
- An effective layout can help a firm to achieve the following:
  - Higher utilization of space, equipment, and people.
  - Improve flow of information, materials, or people.
  - More convenience to the customer.
  - Improved employee morale and safer working conditions.

Types of Layout

- Layout decisions include the **best placement** of:
  - Machines (in a production setting),
  - Offices and desks (in an office setting), or
  - Service centers (in settings such as hospitals or department stores).
- **An effective layout facilitates the flow of materials, people, and information, within and between areas.**
- Management's goal is to arrange (layout) the system so that it operates at peak **effectiveness and efficiency**. To achieve these layout objectives, a variety of approaches have been developed. Among them are the following:

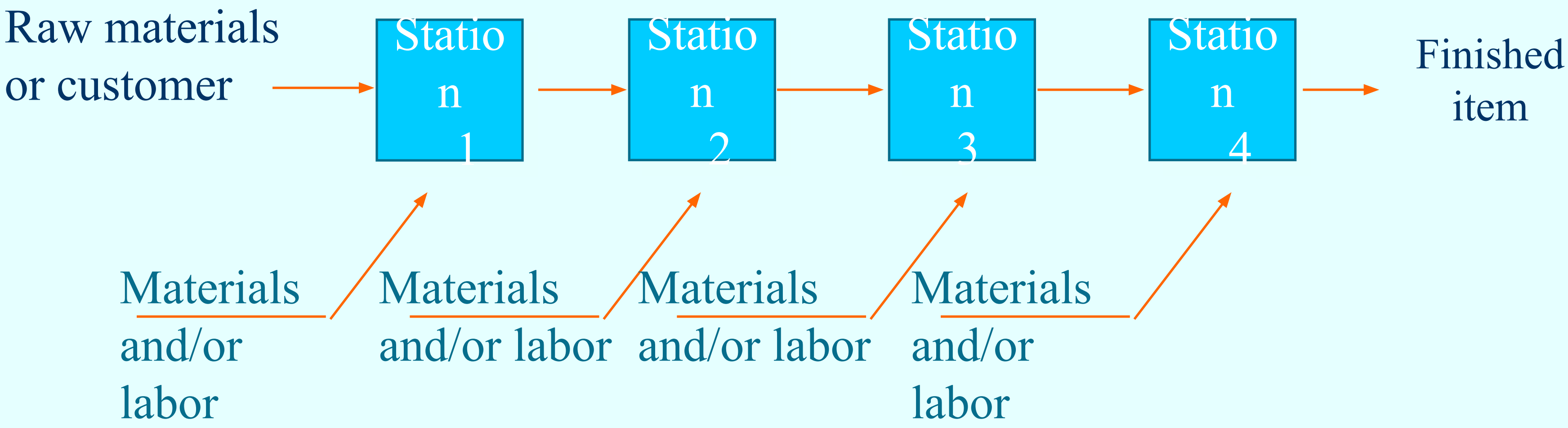
Types of Layout

- **Fixed-position layout:**
  - Addresses the layout requirements of large, bulky projects such as ships and buildings.
  - A fixed-position layout is one in which the **project remains stationary** and **require workers and equipment to come to one work area**. Examples of this of project are a ship, a highway, a bridge, a house, and a burning oil well.
- **Process-Oriented layout:**
  - Deals with low-volume, high-variety production (also called “job shop” or intermittent production).
  - **The process-oriented layout can simultaneously handle a wide variety of products or services.** In fact, it is most efficient when making products that have different requirements or when handling customers who have different needs.

Types of Layout

- **Office layout:**
  - positions workers, their equipment, and spaces/offices to provide for movement of information.
  - The criteria for a rational approach to office layouts in terms of workflow are the same as those for manufacturing tangible goods. That is, we can organize around either processes or products.
- **Retail/service layout:** allocates shelf space and responds to customer behavior.
- **Warehouse layout:** addresses trade-offs between space and material handling.
- **Product-oriented layout:**
  - Seeks the best personnel and machine utilization in repetitive or continuous production.
  - Product-oriented layouts are organized around a product or a family of similar high volume, low-variety products.

▪ Production/Assembly Line

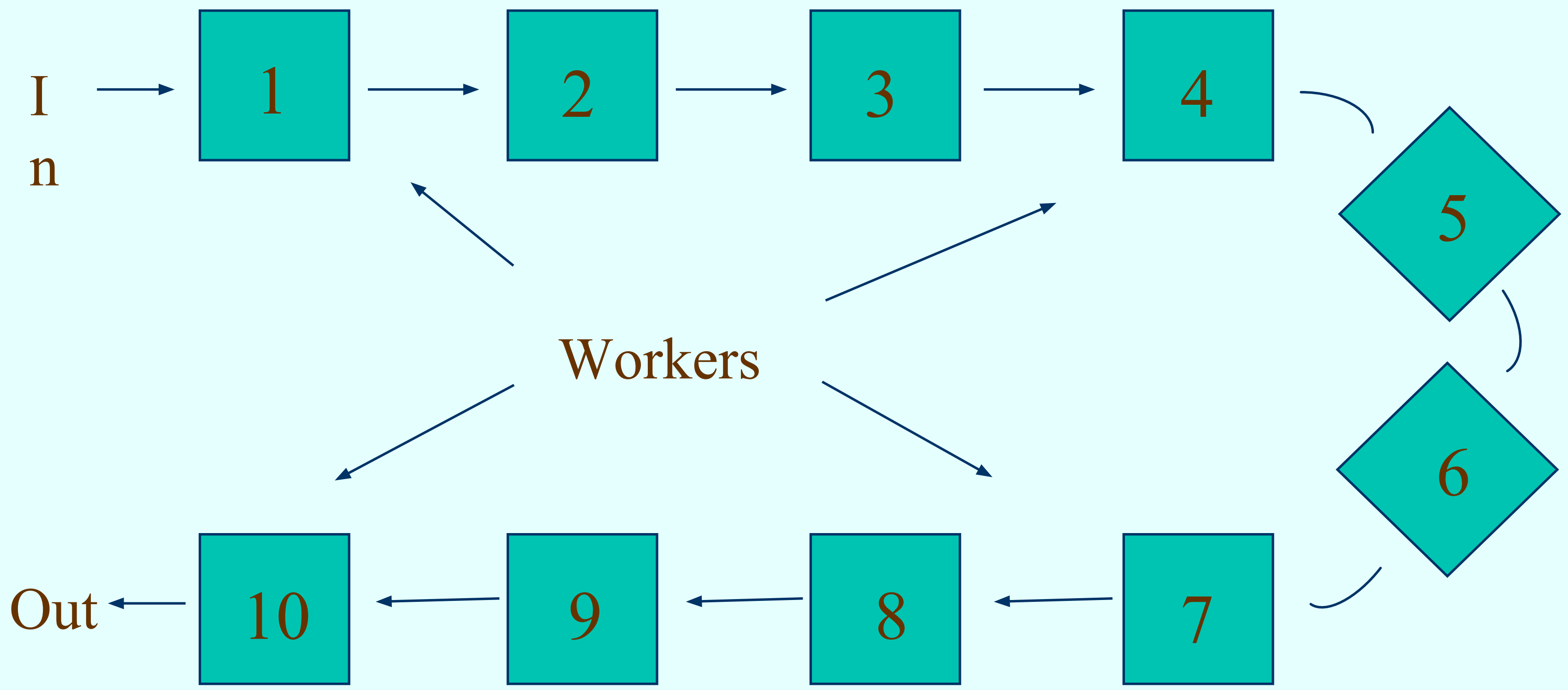


Used for Repetitive or Continuous Processing

Example: automobile assembly lines, cafeteria serving line

Bisheftu Automotive Industry

U-Shaped Production Line



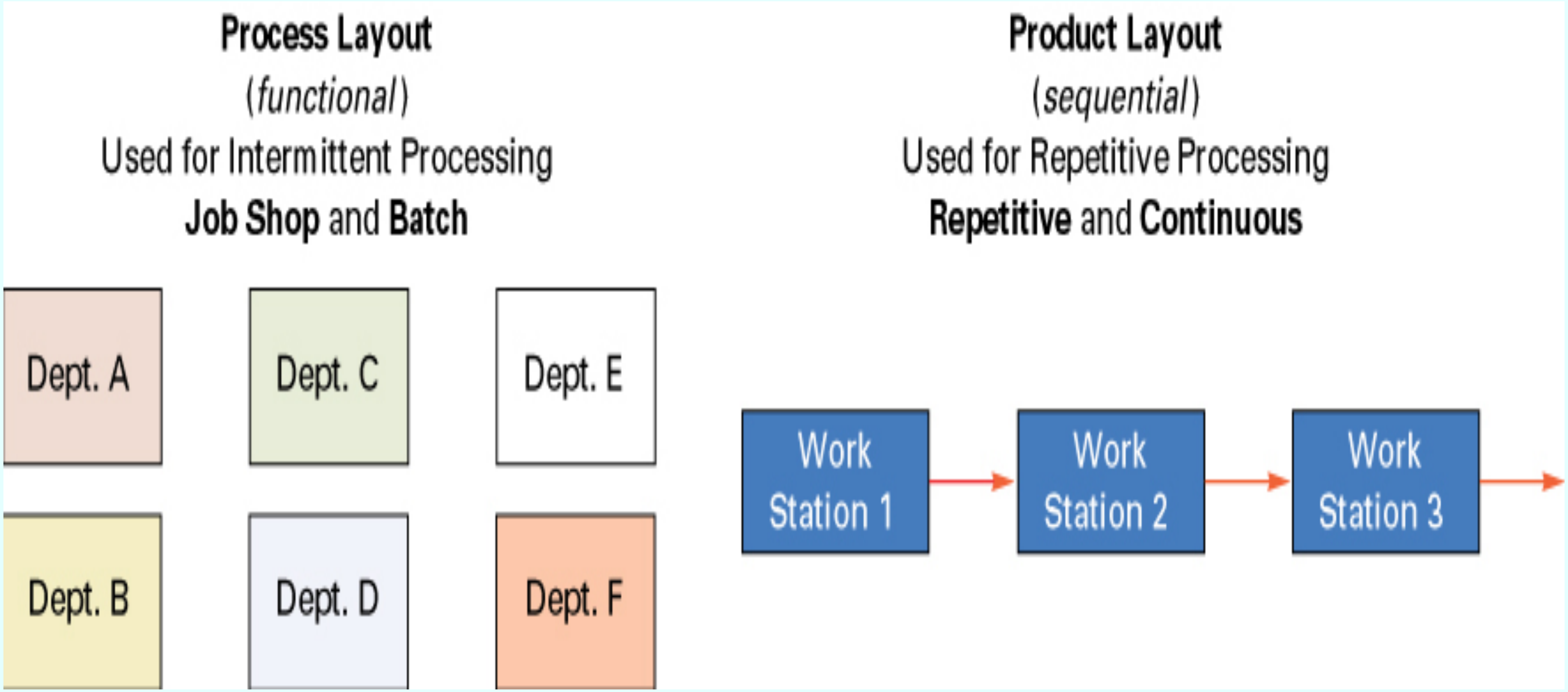
Advantages of Product Layouts

- High rate of output
- Low unit cost
- Labor specialization
- Low material handling cost
- High utilization of labor and equipment
- Established routing and scheduling
- Routine accounting, purchasing and inventory control

Disadvantages of Product Layouts

- Creates boring, repetitive jobs
- Poorly skilled workers may not maintain equipment or quality of output
- Fairly inflexible to changes in volume
- Highly inclined to shutdowns
- Needs preventive maintenance
- Individual incentive plans are impractical

Comparison of Process and Product Layout



Process vs. Product Layouts

Process Layouts	Product Layouts
Able to produce a large number of different products.	Able to produce a small number of products efficiently.
Resources used are general purpose.	Resources used are specialized.
Facilities are more labor intensive.	Facilities are more capital intensive.
Greater flexibility relative to the market.	Low flexibility relative to the market.
Slower processing rates.	Processing rates are faster.
High material handling costs.	Lower material handling costs.
Higher space requirements.	Lower space requirements.

Designing Product Layouts

- Designing product layouts requires consideration of:
  - **Sequence** of tasks to be performed by each workstation
  - **Logical order**
  - **Speed considerations** – line balancing

Designing Product Layouts

Step 1: Identify tasks & immediate predecessors

Step 2: Determine the required workstation cycle time (*C*),

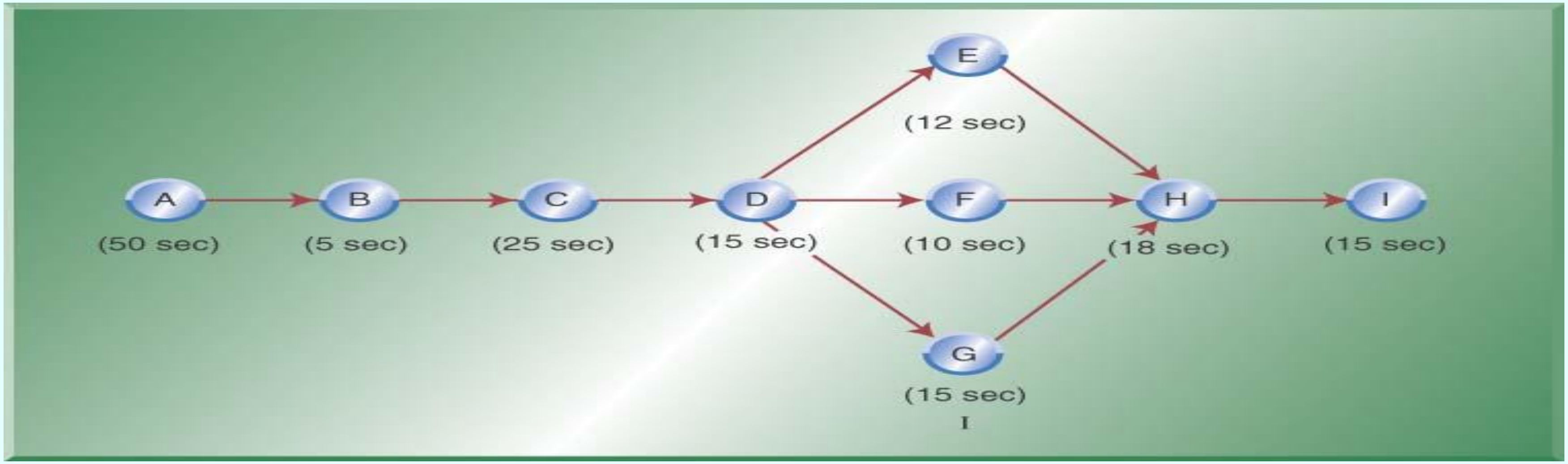
Step 3: Compute the Theoretical Minimum number of Stations

Step 4: Assign tasks to workstations (balance the line)

Step 5: Compute efficiency, idle time & balance delay

Step 1: Identify Tasks & Immediate Predecessors

Example 10.4 Vicki's Pizzeria and the Precedence Diagram			
		Immediate	Task Time
Work Element	Task Description	Predecessor	(seconds
A	Roll dough	None	50
B	Place on cardboard backing	A	5
C	Sprinkle cheese	B	25
D	Spread Sauce	C	15
E	Add pepperoni	D	12
F	Add sausage	D	10
G	Add mushrooms	D	15
H	Shrinkwrap pizza	E,F,G	18
I	Pack in box	H	15
		Total task time	165



Layout Calculations

- **Step 2: Determine cycle time**
  - The amount of time each workstation is allowed to complete its tasks
  - Considering
    - **Vicki needs to produce 60 pizzas per hour** and the task time is in second
    - there are a 8 working hrs per day

$$\text{Cycle time (sec./unit)} = \frac{\text{available time}\left(\text{sec./day}\right)}{\text{desired output}\left(\text{units/hr}\right) * 8hrs} = \frac{\text{60 min/hr x 60 sec/min * 8hrs}}{\text{60 units/hr * 8hrs}} = \text{60 sec./unit}$$

Layout Calculations con't

- **Step 3**: Compute the theoretical minimum number of stations
  - **TMN = number of stations needed to achieve 100% efficiency (every second is used)**

$$\text{TMN} = \frac{\sum(\text{task times})}{\text{cycle time}} = \frac{165 \text{ seconds}}{60 \text{ sec/station}} = 2.75, \text{ or } 3 \text{ st}$$

  - **Always round up (no partial workstations)**
  - **Serves as a lower bound for our analysis**

Layout Calculations con't

- **Step 4: Assign tasks to workstations**
  - Start at the first station & choose the **longest eligible task** following precedence relationships
  - Continue adding the longest eligible task that fits without going over the desired cycle time
  - When no additional tasks can be added within the desired cycle time, begin assigning tasks to the next workstation until finished

Work station	Task	Task time	Remaining tasks	Idle time (sec)
1	A B	50 5	B no	 5
2	C D G	25 15 15	D,G G no	 5
3	E F H I	12 10 18 15	F,H,I H,I I No	 5

Last Layout Calculation

- **Step 5**: Compute efficiency and balance delay
  - **Efficiency (%) is the ratio of total productive time divided by total time**

$$\text{Efficiency } (\%) = \frac{\sum t}{NC} = \frac{165 \text{ sec.}}{3 \text{ stations } \times \ 60 \text{ sec.}}(100) = 91.7\%$$

  - Where: t is task time and N is actual number of work stations
  - **Balance delay (%) is the amount by which the line falls short of 100%**

$$\text{Balance delay} = 100\% - 91.7\% = 8.3\%$$

Exercise

- The Model J Wagon is to be assembled on a conveyor belt. Five hundred wagons are required per day. Production time per day is 420 minutes, and the assembly steps and times for the wagon are given below. Find the balance that minimizes the number of workstations, subject to cycle time and precedence constraints.

Task	Task time in sec	Predecessor task
A	45	-
B	11	A
C	9	B
D	50	-
E	15	D
F	12	C
G	12	C
H	12	E
I	12	E
J	8	F,G,H,I
K	9	J