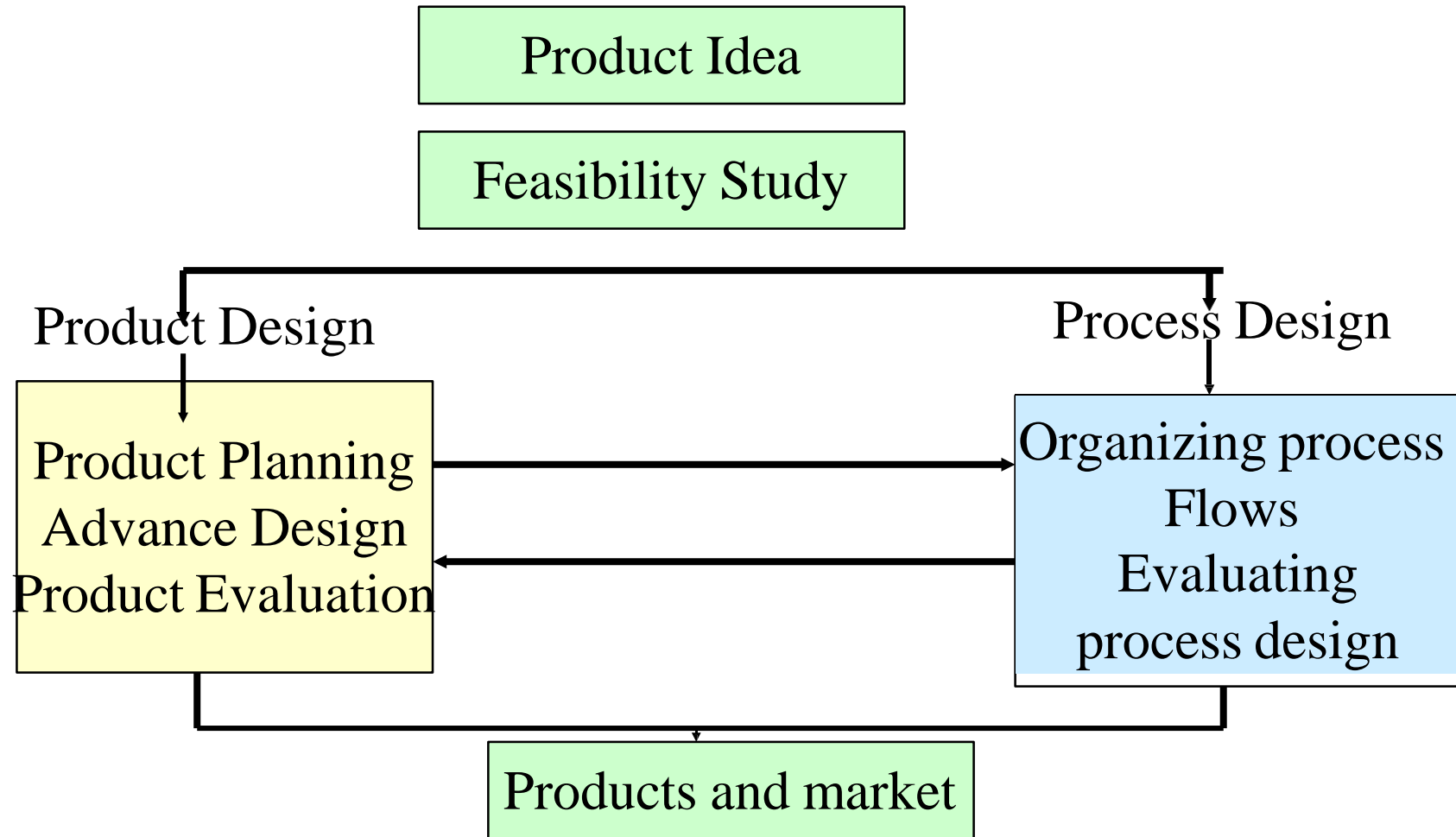


Process and Operations Analytics



Interrelation between Product & Process Design



Key Decisions in Process Design

- Key decisions relating to Process design is related to organizing the process flows necessary to manufacture new products.
- **Organizing process flow**
 - ❖ Five types of Processes are distinguished
 - ❖ Project
 - ❖ Job Shop
 - ❖ Batch
 - ❖ Assembly line
 - ❖ Continuous

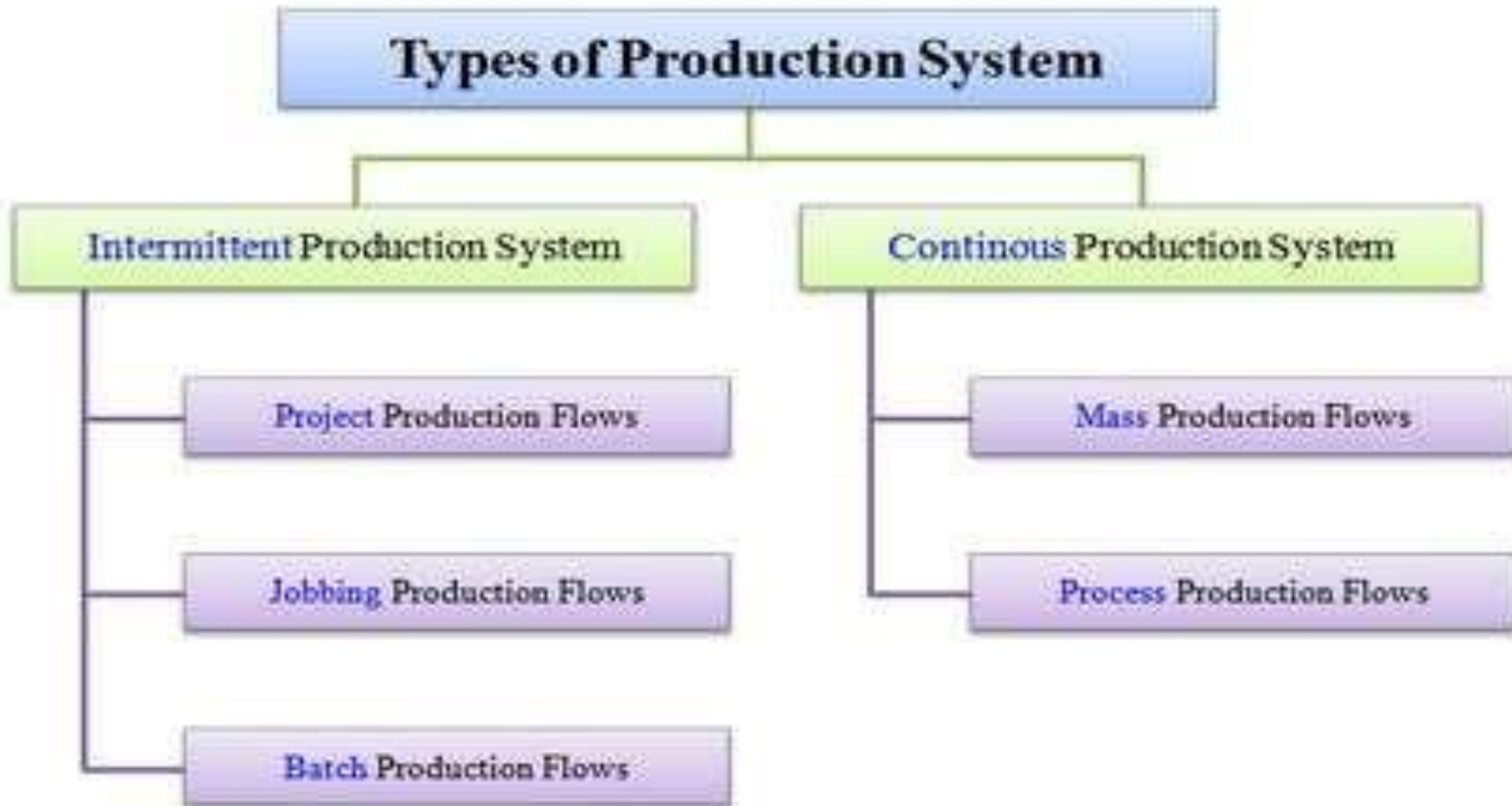
Relations of process Design to types of process flow

- ❖ There is a definite relation between **Production** process and process flow. For continuous manufacturing the methods and processes are determined before the line set up.
- ❖ The process design is built into the line
- ❖ Changes usually require that the line be shut down with consequent loss of production
- ❖ For intermittent process no lines are set up. process engineer is usually adapt the methods to the types of equipment available.
- ❖ Changes in methods can easily be effected without affecting the overall productive capacity of the plant.

Evaluation of process Design

- ❖ The major objectives of designing a **Process** flow is to ensure that the goods and services are produced at the minimum cost.
- ❖ Process design is a dynamic activity
- ❖ A process engineer should be alert to changes to which of the below mentioned factors
 - 1) Volume.
 - 2) Product quality.
 - 3) Equipments.
- ❖ Careful Planning ensures a complete coverage of all operations in manufacturing a product and the costs involved.

Types of production system



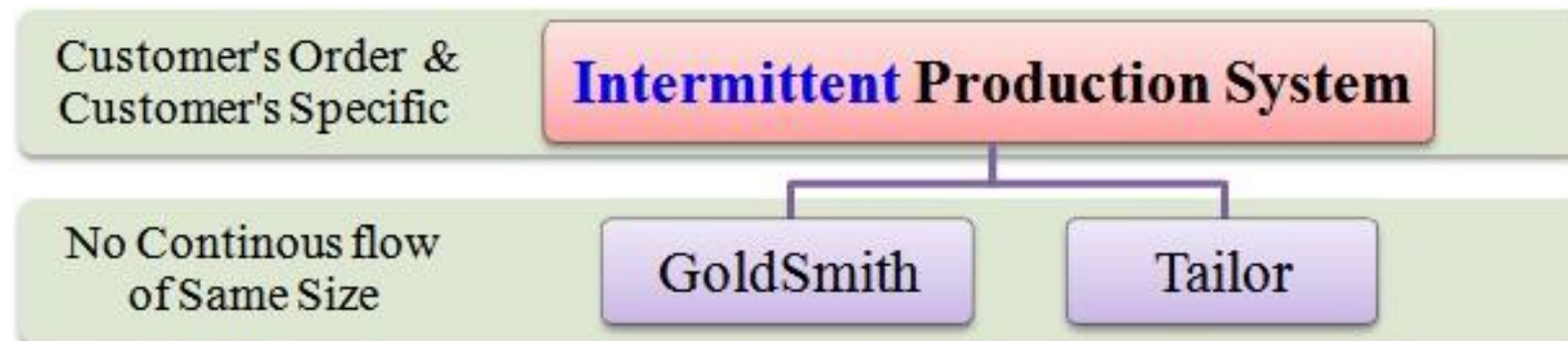
Types of production system

The types of production system are grouped under two categories viz.,

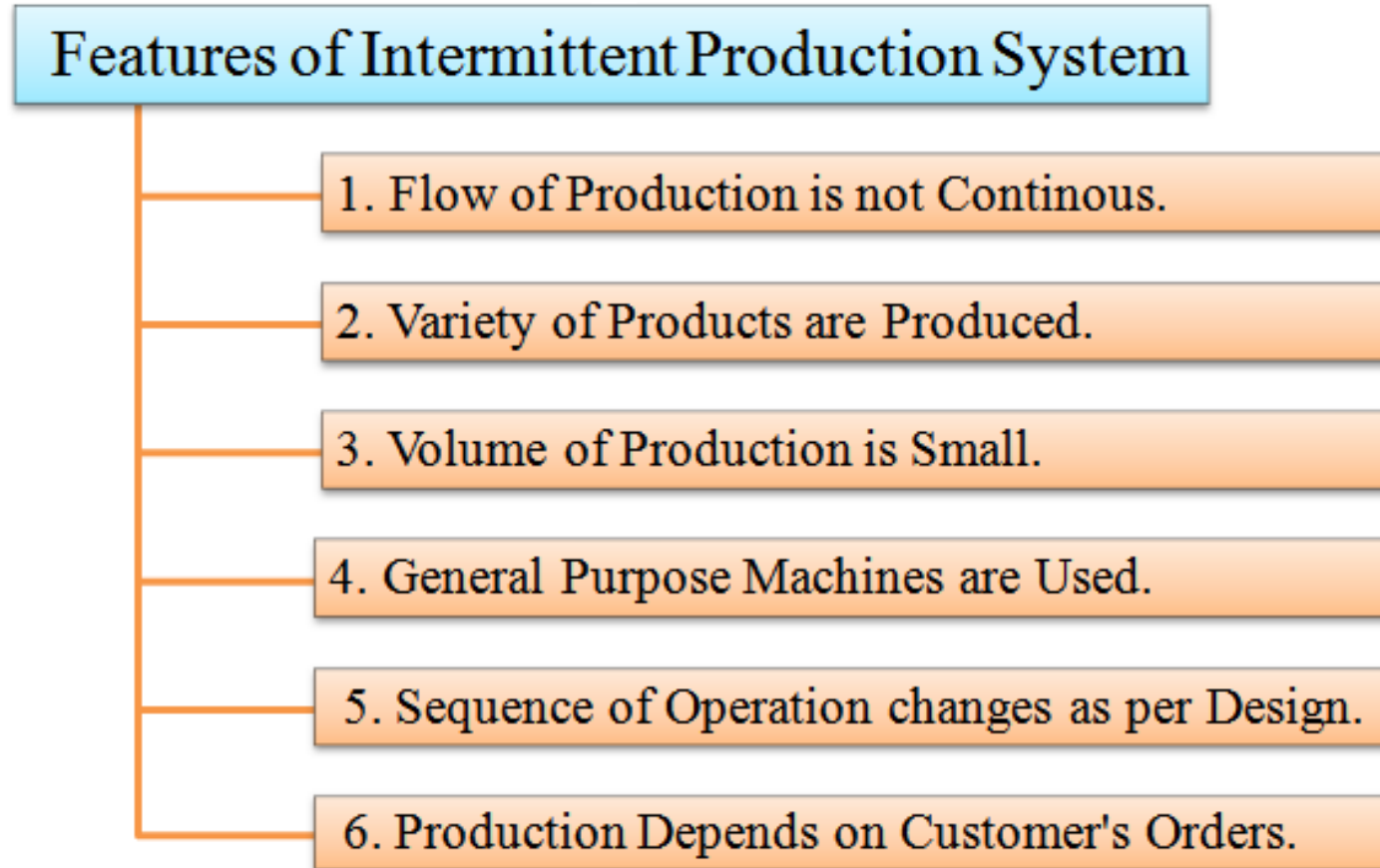
- Intermittent production system, and
- Continuous production system.

Intermittent production system

- Intermittent means something that starts (**initiates**) and stops (**halts**) at irregular (**unfixed**) intervals (time gaps).
- In the intermittent production system, goods are produced based on customer's orders.
- These goods are produced on a small scale.
- The flow of **production** is intermittent (irregular)
- These products are of different sizes.
- The design of these products goes on changing. It keeps changing according to the design and size of the product. Therefore, this system is very flexible.

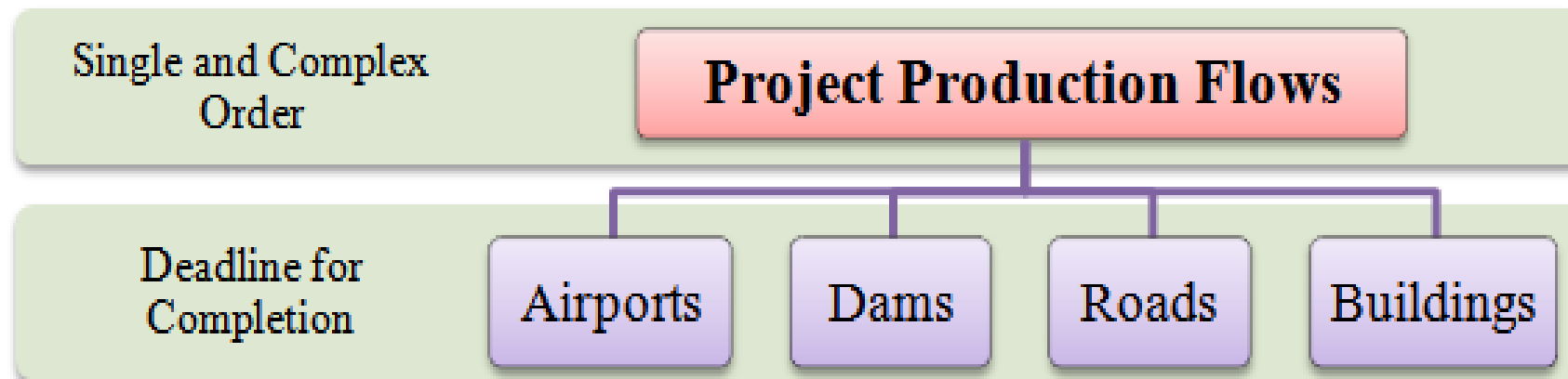


Features of an intermittent production system



Project production flows

- Here, in project production flows, company accepts a single, complex order or contract. The order must be completed within a given period of time and at an estimated cost.
- Examples of project production flows mainly include, construction of airports, dams, roads, buildings, shipbuilding, etc.

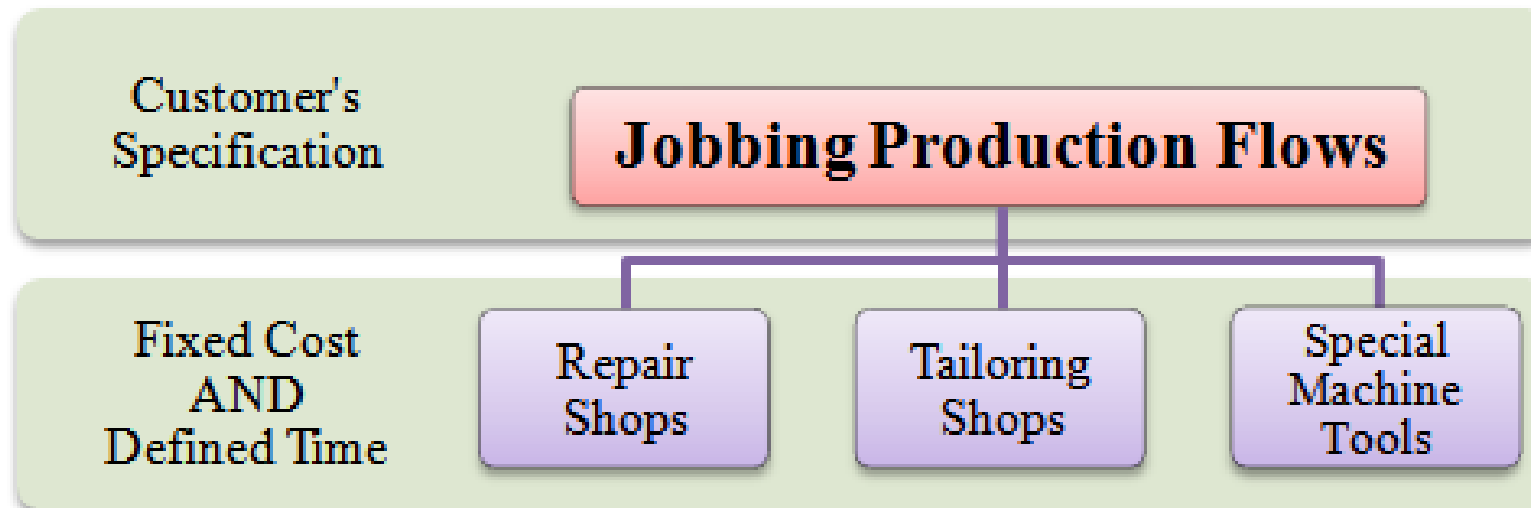


Characteristics project production

- The requirement of resources is not same (it varies).
- Generally, the resource requirement at the beginning is low. Then in mid of production, the requirement increases. Finally, it slows down when the project is near its completion phase.
- Many agencies are involved in the project. Each agency performs specialized jobs. Here, coordination between agencies is important because all jobs are interrelated.
- Delays take place in completion of projects due to its complexity and massiveness.
- As routing and scheduling changes with fresh orders, proper inspection is required at each stage of production.

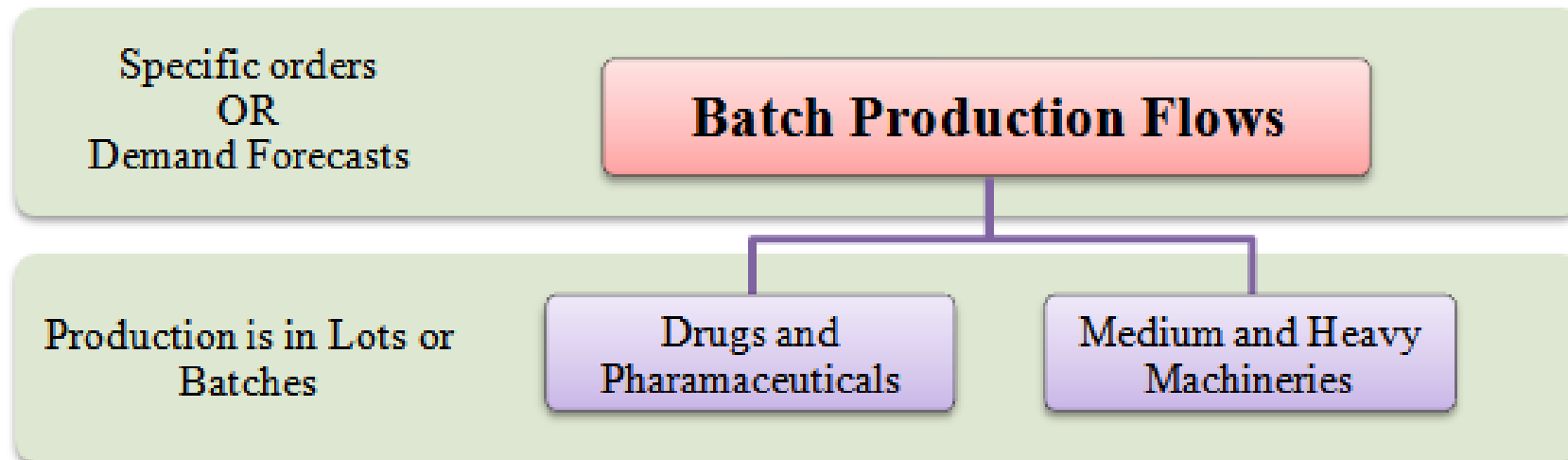
Job production

- Here, in jobbing production flows, company accepts a contract to produce either one or few units of a product strictly as per specifications given by the customer.
- The product is produced within a given period and at a fixed cost. This cost is fixed at the time of signing the contract.
- Examples of such jobbing production flows include, services given by **repair shops, tailoring shops, manufacturer of special machine tools**, etc.



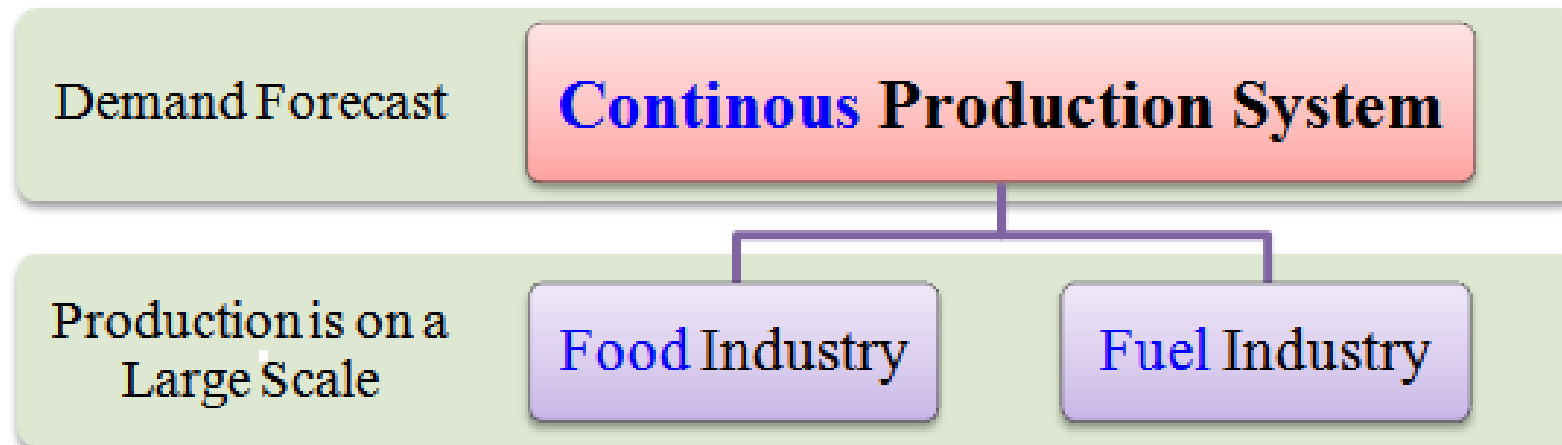
Batch production

- In batch production flows, the production schedule is decided according to specific orders or are based on the demand forecasts.
- Here, the production of items takes place in lots or batches. A product is divided into different jobs.
- All jobs of one batch of production must be completed before starting the next batch of production.
- Examples of batch production flows include, **manufacturing of drugs and pharmaceuticals, medium and heavy machineries**, etc.



Continuous production system

- Continuous means something that operates constantly without any irregularities or frequent halts.
- In the continuous production system, goods are produced constantly as per demand forecast.
- Goods are produced on a large scale for stocking and selling.
- They are not produced on customer's orders.
- Here, the inputs and outputs are standardized along with the production process and sequence.



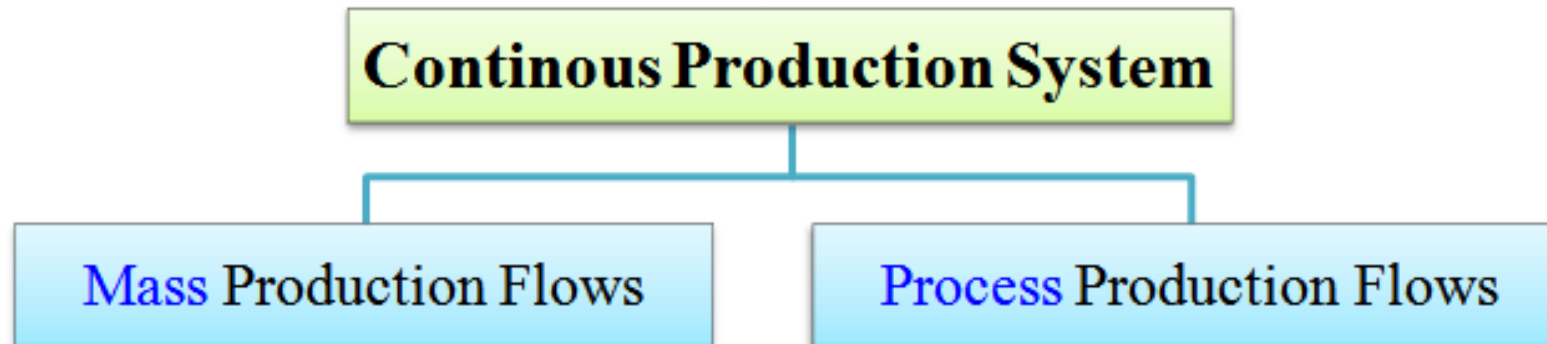
Continuous production system

Features of Continuous Production System

1. Flow of Production is Continuous and not intermittent.
2. Products are Standardized.
3. Products are produced as per Quality Standards.
4. Products are produced in Anticipation of Demand.
5. Standardized routing sheets and schedules are prepared.

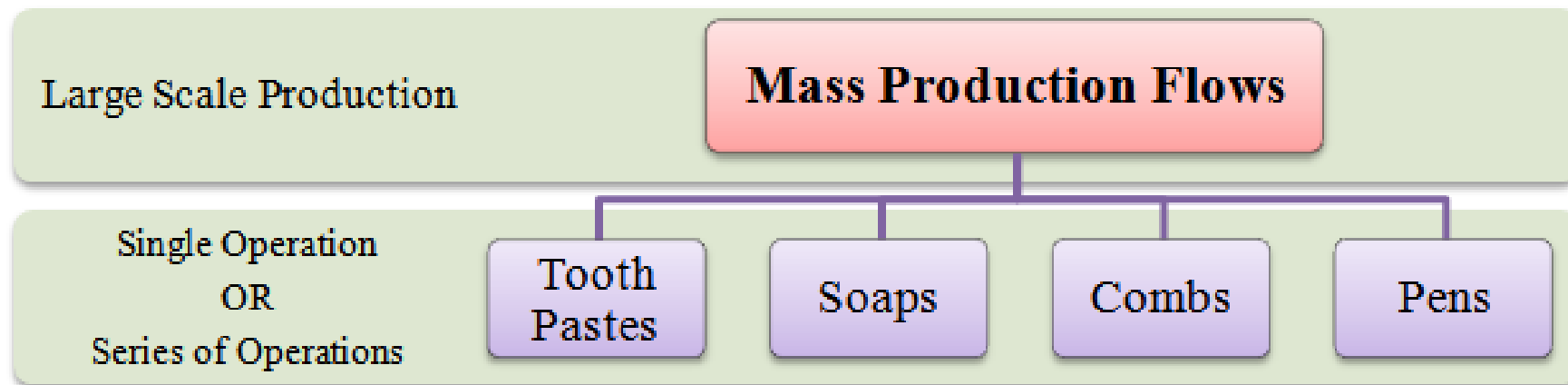
Characteristics of a CPS

- The flow of production is continuous. It is not intermittent.
- The products are **standardized**.
- The products are produced on **predetermined quality standards**.
- The products are produced in **anticipation**(An expectation) of demand.
- Standardized routing sheets and schedules are prepared



Mass production flows

- Here, company produces different types of products on a large-scale and stock them in warehouses until they are demanded in the market.
- The goods are produced either with the help of a single operation or uses a series of operations.
- E.g. of mass production is the production of toothpastes, soaps, pens, etc.

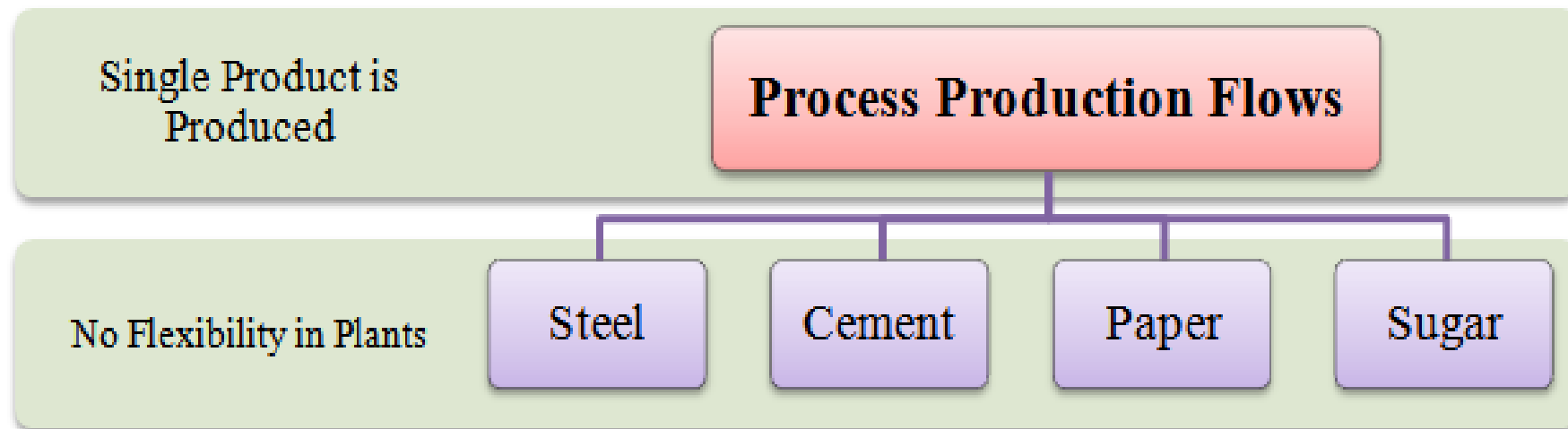


Characteristics mass production flows

- There is a continuous flow of production. However, this depends on the demand in the market.
- Here, there is limited work-in-progress.
- Supervision is easy because only few instructions are necessary.
- The material handling is done mostly by machines, i.e. conveyors and automatic transfer machines.
- The flow of materials is continuous. There is little or no queuing at any stage of production.

Process production flows

- Here, a **single product is produced** and stocked in **warehouses** until it is demanded in the market. The flexibility of these plants is almost zero because only **one product** can be produced.
- Examples of these plants include, steel, cement, paper, sugar, etc.

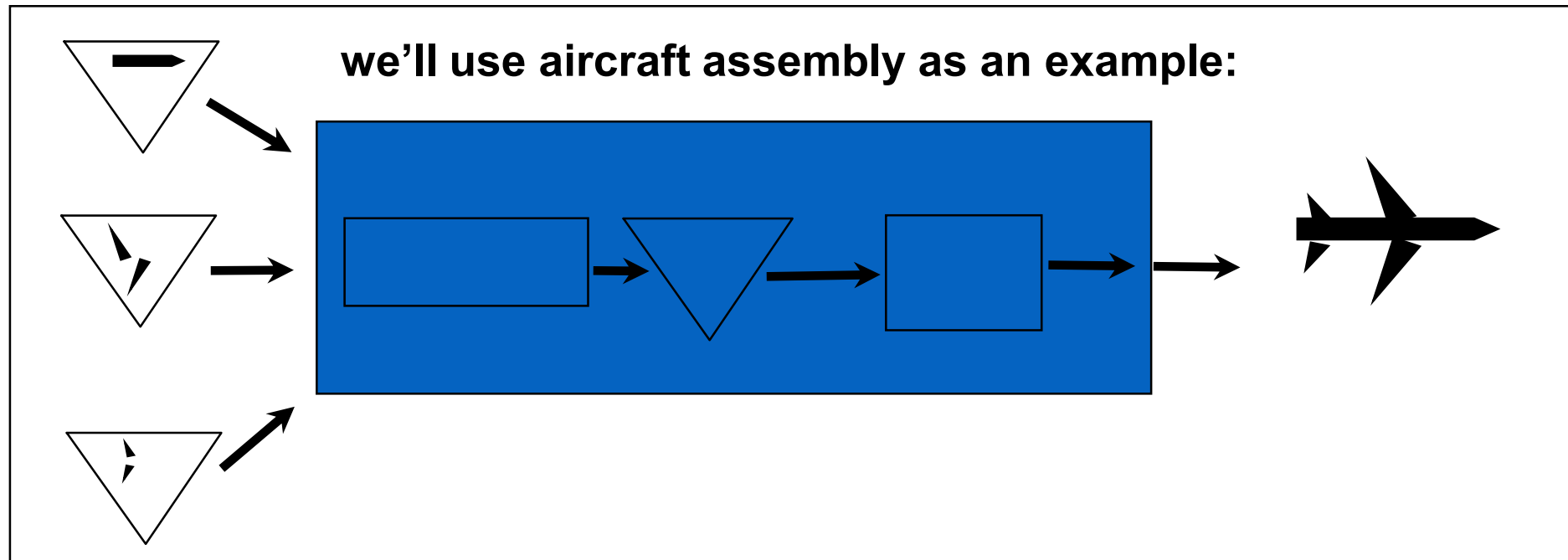


Process Analysis

- Process Analysis
- **Types of Processes**

Process Flowcharting

Process Performance Metrics



Process Diagram: Define Material Flow

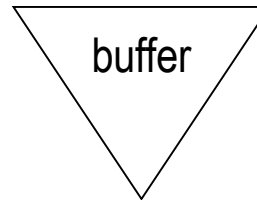
Task: value added



Sub-assemblies installed

Flow: geographical or virtual movement 

Storage: time spent doing neither of the above



note: level of detail will depend on the purpose of the diagram!

Designing Processes

Process design tools include

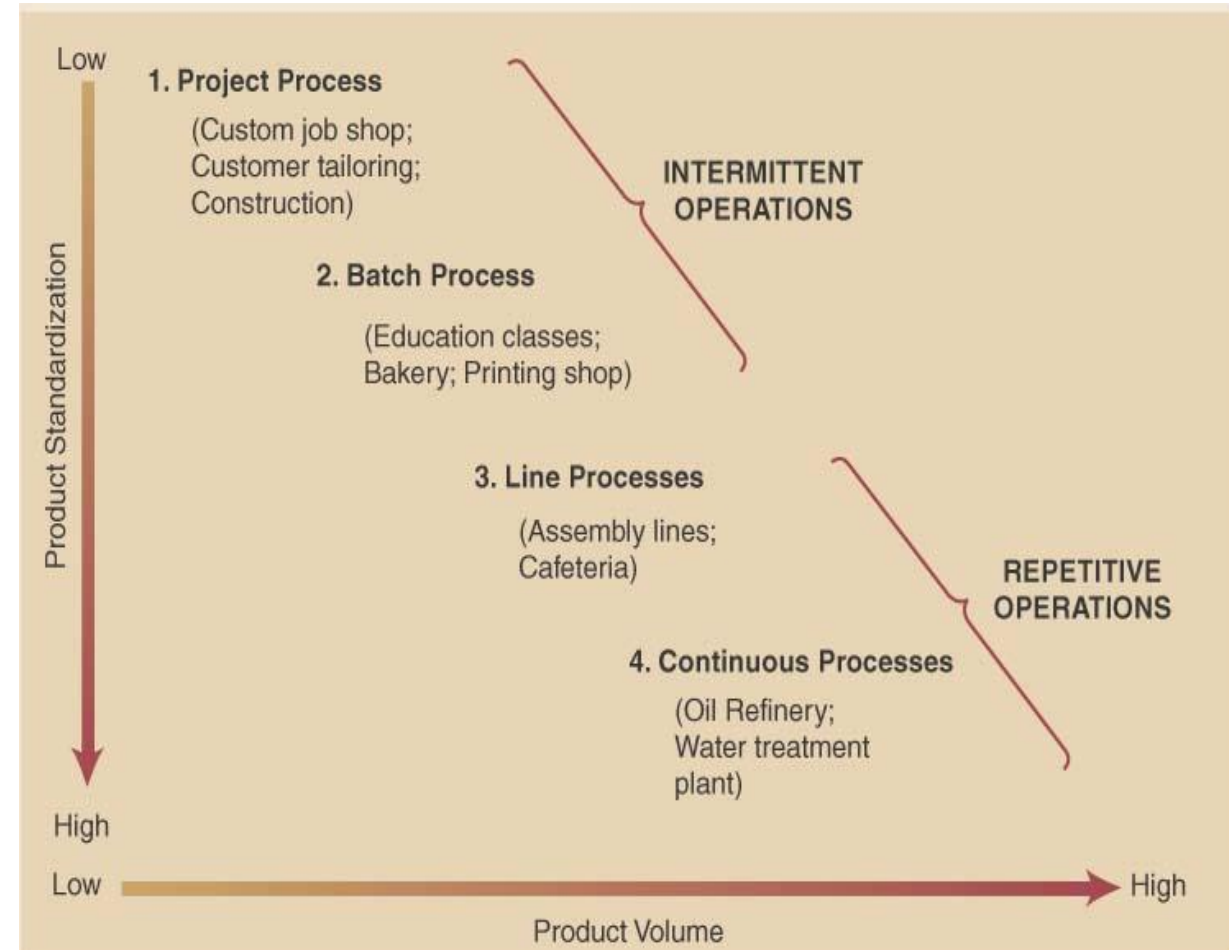
- Process flow analysis
- Process flowchart

Design considerations include

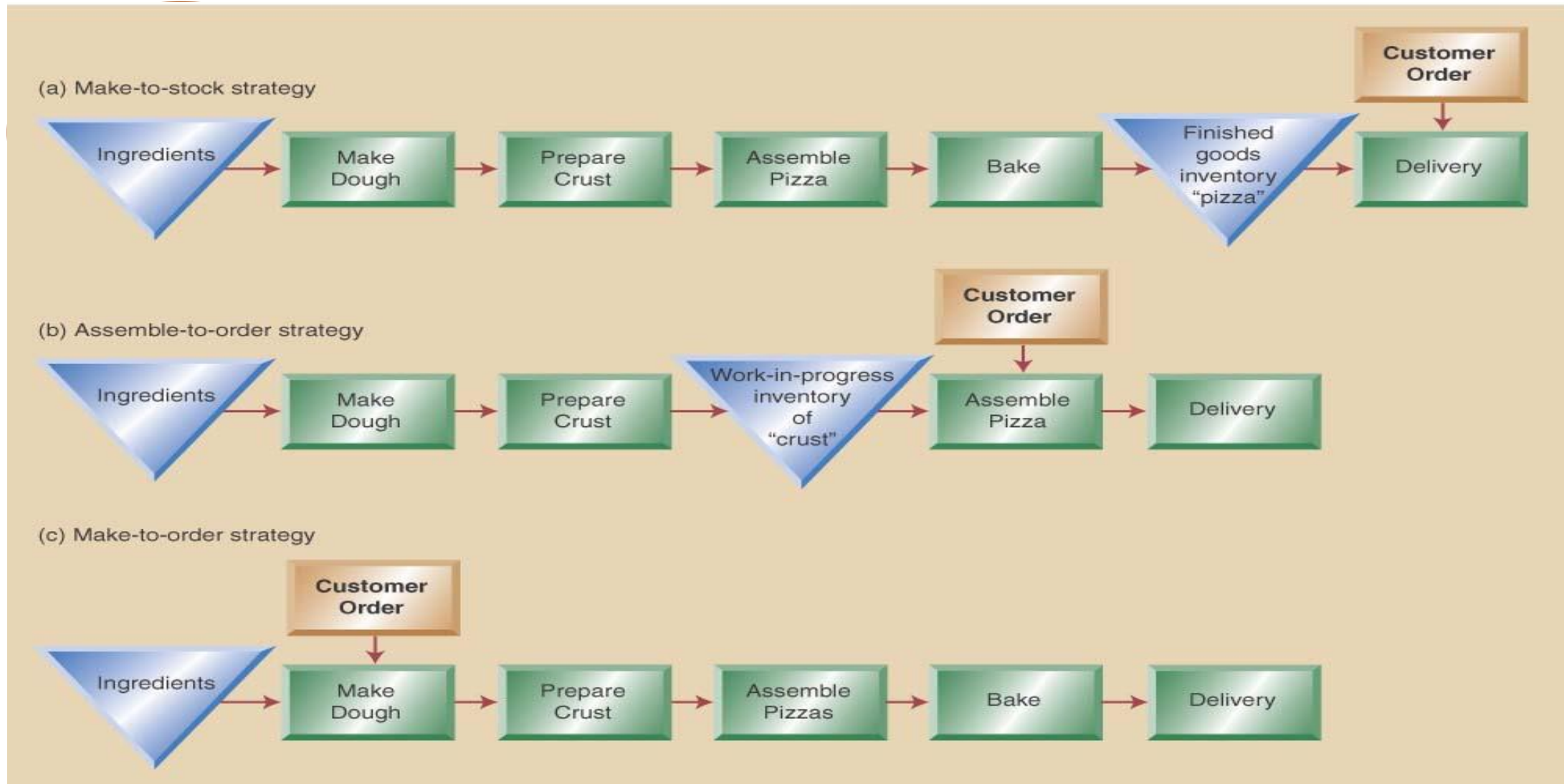
- Make-to-stock strategy
- Assemble-to-order strategy
- Make-to-order strategy

Process Selection

- Process types can be:
 - **Project process** – make a one-at-a-time product exactly to customer specifications
 - **Batch process** – small quantities of product in groups or batches based on customer orders or specifications
 - **Line process** – large quantities of a standard product
 - **Continuous process** – very high volumes of a fully standard product

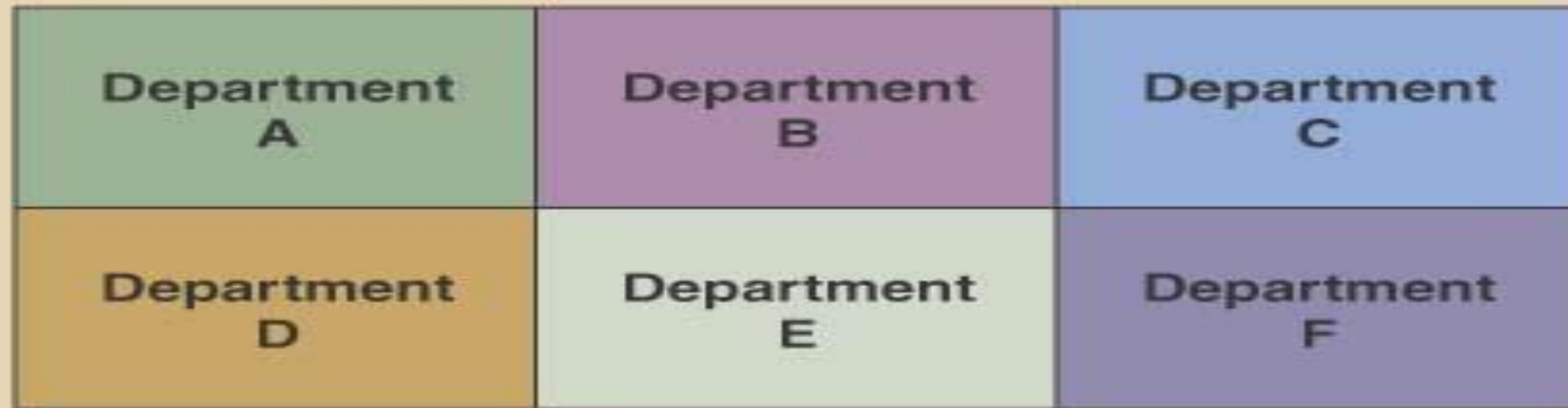


Facility Layout and Process Choice

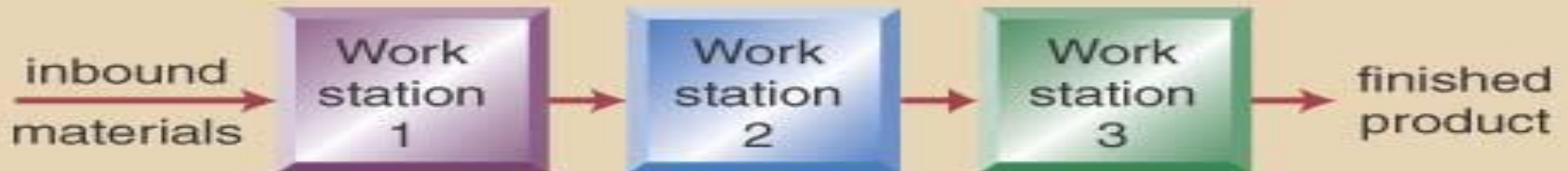


Intermittent VS. Repetitive Layouts

(a) Intermittent Operations
(resources grouped by function)



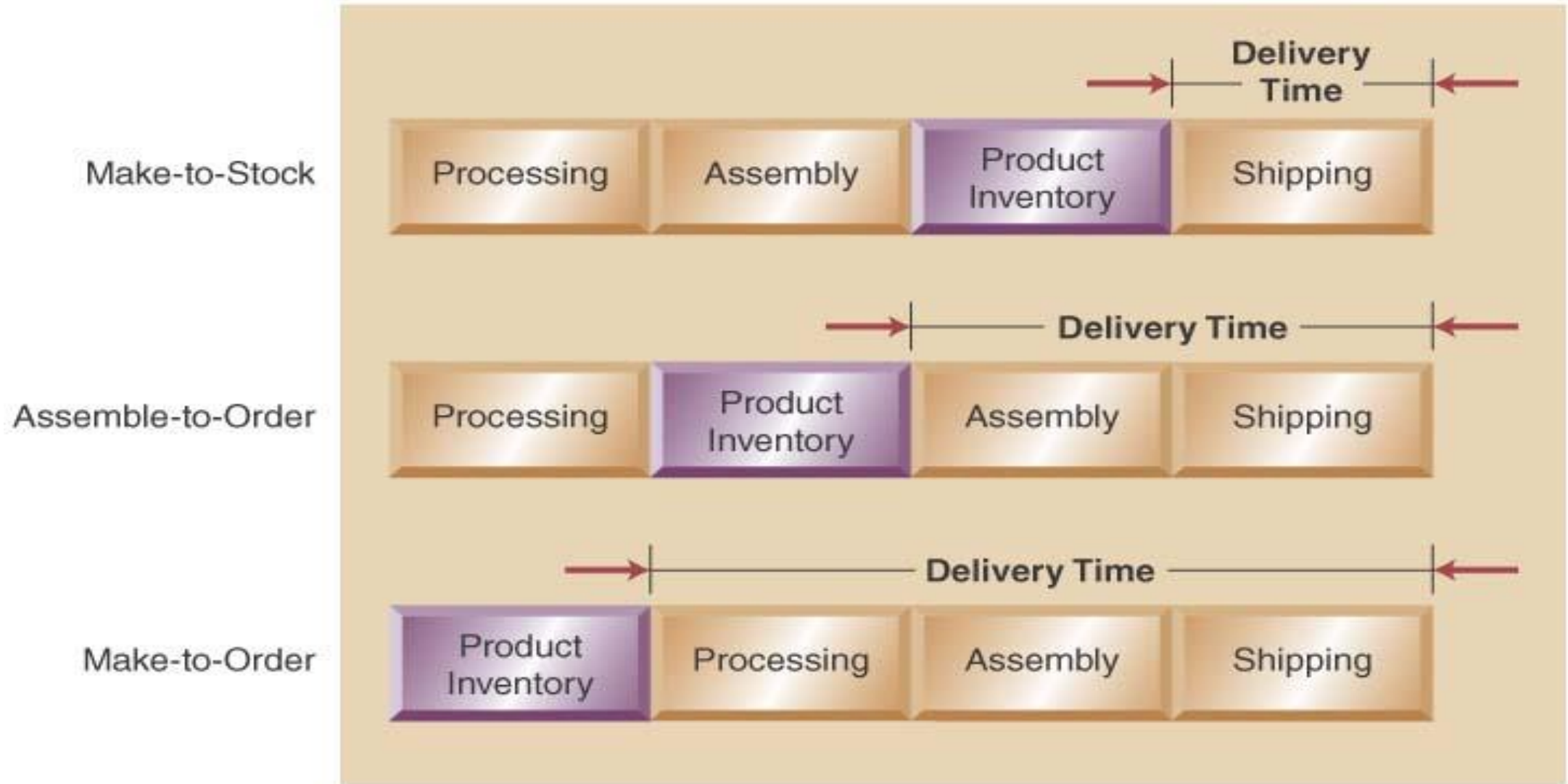
(b) Repetitive Operations
(resources arranged in sequence)



Linking Design & Process Selection

Decision	Intermittent Operations	Repetitive Operations
Product design	Early stage of product life cycle	Later stage of product life cycle
Competitive priorities	Delivery, flexibility, and quality	Cost and quality
Facility layout	Resources grouped by function	Resources arranged in a line
Product strategy	Make-to-order/assemble-to-order	Make-to-stock
Vertical integration	Low	High

Product and Service Strategy Options



Process Analysis Terms

- **Process:** Is any part of an organization that takes inputs and transforms them into outputs.
- **Cycle Time:** Is the average successive time between completions of successive units.
- **Utilization:** Is the ratio of the time that a resource is actually activated relative to the time that it is available for use.

Process Analysis Terms

Throughput: the output of a production process per unit time (in aircraft/month, patients/hour, \$/year). Sometimes also called flow or 'I'.

Stock: the inventory between the start and end of the process (in aircraft, patients, dollars). Sometimes also called number in system or work in process (WIP) or 'L'.

Lead time: time from entry into the system until exit from the system (in months, hours, years). Sometimes also called time in system or flow time or cycle time or 'W'.

Raw process time: time necessary to complete actual work. Or, time for one unit of the product to traverse an otherwise empty system

Process Analysis

A Fundamental Relationship



John D.C. Little at MIT gave the first mathematical proof of the 'law' in 1961.

Little's Law:

$$(\text{average stock}) = (\text{average throughput}) * (\text{average lead time})$$

Warning: Little's Law will apply to any process as long as:

- consistent units are used.
- long-term averages are used (during the observation period we take a large 'sample' and most of what has come in has also gone out).
- consistent flows are measured.

Process Analysis: Little's Law Example

$$\textit{(Average stock)} = \textit{(Average throughput)} * \textit{(Average lead time)}$$

At a/c case,

avg. throughput = 5 aircraft/month,

avg. lead time = 2 months

avg. stock = 10 aircraft

Process Performance Metrics

- Operation time = $\frac{\text{Setup time}}{\text{Run time}}$
- Throughput time = Average time for a unit to move through the system
- Velocity = $\frac{\text{Throughput time}}{\text{Value-added time}}$
- Cycle time = Average time between completion of units
- Throughput rate = $\frac{1}{\text{Cycle time}}$
- Efficiency = $\frac{\text{Actual output}}{\text{Standard Output}}$
- Productivity = $\frac{\text{Output}}{\text{Input}}$
- Utilization = $\frac{\text{Time Activated}}{\text{Time Available}}$

Cycle Time Example

- Suppose you had to produce 600 units in 80 hours to meet the demand requirements of a product. What is the cycle time (in minutes) to meet this demand requirement?
- Answer: There are 4,800 minutes (60 minutes/hour x 80 hours) in 80 hours. So the average time between completions would have to be: Cycle time = $4,800/600$ units = 8 minutes.

Process Throughput Time Reduction

- Perform activities in parallel.
- Change the sequence of activities.
- Reduce interruptions.

Product/Production relationships

Product parameters that are influential in determining how the products are manufactured;

- Prod. Quantity
- Prod. Variety-----hard product variety and soft product variety
- Complexity of **assembles products**
- Complexity of **individual parts**

Contd...

- Q= production quantity
- P= product variety
- QP= product variety and product relationships
- Q= the number of units of a given part or product that and produced annually by a plant
- Q_j = annual quantity of style j
- Q_f = total quantity of all parts or products made by the factory
- P= total number of different part or product styles
- Where $j=1,2,3,\dots,P$

$$Q_f = \sum_{j=1}^P Q_j$$

Contd..

- Number of component n_p represents the product complexity
- The number of processing steps required to produce it n_o

Type of Plant	Np-no	Description
Parts producer	$n_p=1, n_o>1$	Produce individual component and requires multiple processing
Assembly plant	$n_p>1; n_o=1$	A pure assembly plant produces no parts
Vertically integrated plant	$n_p>1, n_o>1$	The pure plant of this type makes all its parts and assembles them into final product

Designing factory process

n_{pf} = *total* number of parts made in the factory (pcs/year)

Q_j = *annual* quantity of product style j

n_{pj} = *number* of parts in product j (pcs/product)

$$n_{pf} = \sum_{j=1}^P Q_j \cdot n_{pj}$$

n_{of} = total number of operations cycles performed in factory (ops/year)

n_{ojk} = number of processing ops for each part k, summed over the number of parts in product j, n_{pj}

$$n_{of} = \sum_{j=1}^P Q_j \cdot \sum_{k=1}^{n_{pj}} n_{ojk}$$

Contd..

- If we assume the number of product design P are produced in equal quantities Q , all products have the same number of the components n_p , and all components require an equal number of processing steps n_o
- Then, total number of product units $Q_f = P.Q$
- Total number of the parts produced by the factory $n_{pf} = P.Q.n_p$
- Total number of manufacturing operations cycles $n_{of} = P.Q.n_p.n_o$

Plant capabilities

- The plant capabilities is based on
- Technological processing capability
- Production capacity

Example

- A company has designed a **new product line**. It will build a new plant to manufacture this product line. The new line consists of 100 different product types. Annual production of the company is 10,000 units each product. Every product has an average of 1000 parts. The average number of operations required for each part is 10. All parts will be made in the plant. Each operations takes an average of 1 minutes.

Compute

- How many products will the company produce?
- How many parts will the plant process?
- How many operations will the plant perform?
- How many workers will be needed for the plant, if it operates one shift for 250 days/yr?

Answer

The number of products $P=100$

Number of parts: $P.Q.n_p$

$$100 * 10000 * 1000 = 10^9$$

The number of operations $P.Q.n_p.n_o$

$$100 * 10000 * 1000 * 10 = 10^{10}$$

Workforce required

Number of operations $= 10^{10}$

$T=1$ min/cycle $D=250$ days/year

$S=1$ shift/day $H=8$ hrs/shift

$$\text{workers} = \frac{n_{of} \cdot T_c}{D \cdot S \cdot H \cdot 60} = 83333 \text{ person}$$

Production Process planning

- Production capacity is defined as the maximum rate of output that a production facility able to produce under set of assumed operating conditions.

$$\text{Plant capacity} = n.S.H.R_p$$

n = no of work center

S = number of shift per week

H = number of hours per shift

R_p = hourly production rate (pc/hours)

if each work unit is routed through n_o and

each operation requires a new setup or processing on different m/c then

$$PC = \frac{n.S.H.R_p}{n_o}$$

Example

A Pizza baking shop having six baking oven, all devoted to the production of the same type of the pizza. The shop operates 10shifts/week. The number of hours per shift averages 8.0. Average production rate of each oven is 17 pc/hour. Determine the weekly production capacity.

$$PC = 6 * 10 * 8 * 17 = 8160 \text{ pizza/week}$$

Utilization

- Utilization refers to the amount of output of a production facility relative to its capacity
- $U = Q/PC$
- If all ovens are able to produce only 6000 units per week and was idle remaining time then
- $U = 6000/8160 = 73.50 \%$

Process availability

- Availability is a common measure of reliability for equipment.
- Mean time between failure (MTBF)- is the average time during equipment is running
- Mean time to repair (MTTR) is the average time required for servicing a equipment
- $\%A = (MTBF - MTTR) / MTBF$
- With the previous data, if a oven is availability is 90% and utilisation of oven 80% then final quantity produced
- $PC.U.A = 8160 * .8 * .9 = 5875$

Work in process computation

- $WIP = (A.U.PC.Lead\ time) / S.H.$

S= no of shifts per week

H= no of hours in a shift

Problem

A batch production plant processes all parts through 4 m/c. 25 batches are produced every week. Average operating time is 9 minute. Average set up time is 6 hours. Average size of batch is 40 parts. Average non-operating time per batch is 8hours/machine. There are 16 machines in the plant. The plant performs an average of 80 hours per week. The rate of scrap is negligible. Availability of m/cs is 90%. Determine the amount of WIP and other PPM components.

Solution

Given data

- $N= 16$ $Q_f= 25$ batches= $25*40 =1000$ pieces $no= 4$ operations
- $Q=40$ pcs
- $T_s= 6$ hours $T_c=9$ min $T_{no}= 8$ hours
- $S= 10$ shifts/week
- $H= 8$ hours/ shift $A=90\%$

Solution

$$T_b = T_s + Q \cdot T_c = 6 + 40 \cdot (9/60) = 12 \text{ hours}$$

$$T_p = T_b / Q = 12 / 40 = 0.3 \text{ hours} = 18 \text{ min}$$

$$R_p = 60 / T_p = 60 / 18 = 3.33 \text{ pieces/ hours}$$

$$PC = (n \cdot S \cdot H \cdot R_p) / no = (16 \cdot 10 \cdot 8 \cdot 3.33) / 4 = 1066.67 \text{ pc/week}$$

$$U = Q_f / PC$$

$$= 1000 / (1066.67) = 93.75\%$$

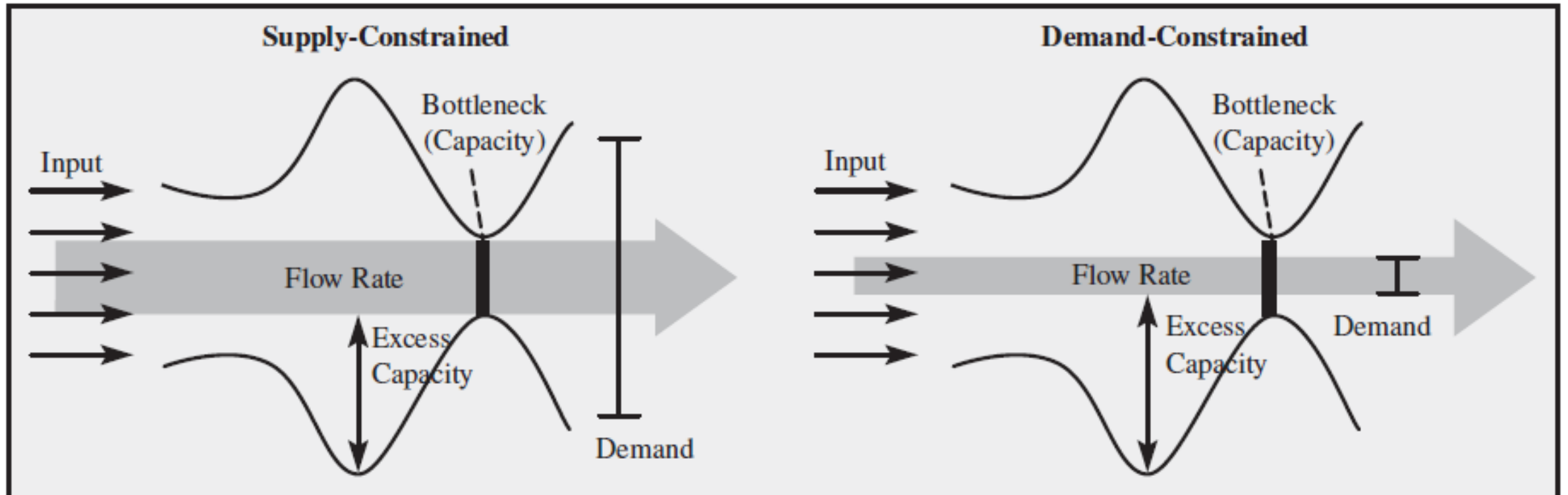
$$\text{Manufacturing lead time} = no \cdot (\text{Total time}) = 4 \cdot (6 + 40 \cdot 0.15 + 8) = 80 \text{ hours}$$

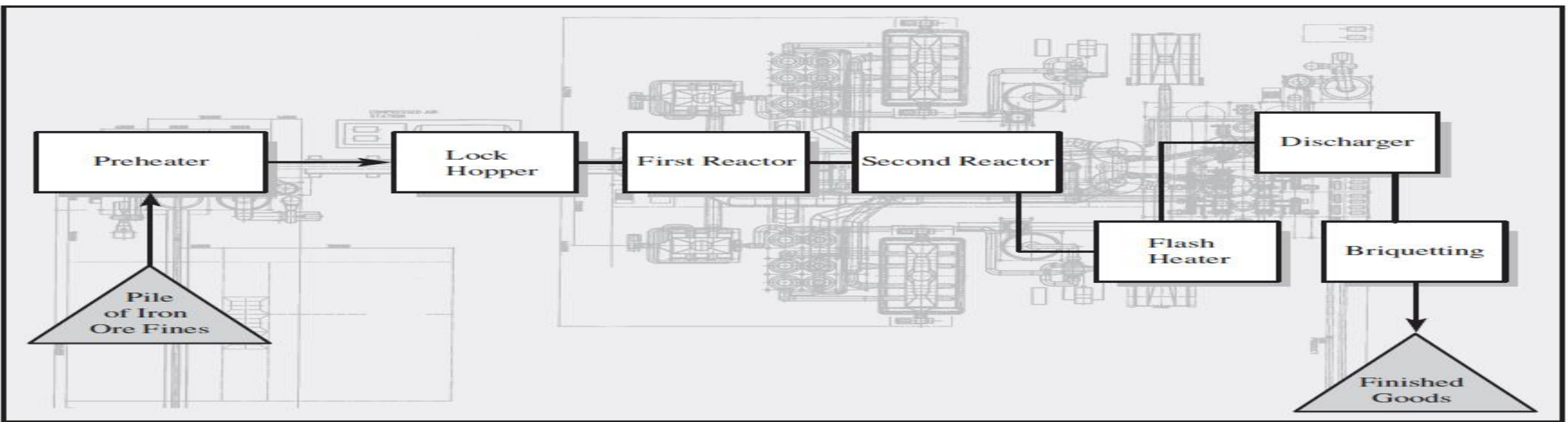
$$WIP = (A \cdot U \cdot PC \cdot MLT) / S \cdot H = 900 \text{ pieces}$$

Nature of production process

If demand exceeds supply, the process is *supply-constrained*. Depending on what limits product supply, the process is either input-constrained or capacity-constrained.

If demand is lower than supply (i.e., there is sufficient input available and the process has enough capacity), the process would produce at the rate of demand, independent of the process capacity. We refer to this case as *demand-constrained*.





Process Step	Calculations	Capacity
Preheater		120 tons per hour
Lock hoppers		110 tons per hour
First reactor	Little's Law: Flow rate = 28 tons/0.25 hour	112 tons per hour
Second reactor	Little's Law: Flow rate = 400 tons/4 hours	100 tons per hour
Flash heater		135 tons per hour
Discharger		118 tons per hour
Briquetting machine	Consists of three machines: 3 × 55 tons per hour	165 tons per hour
Total process	Based on bottleneck, which is the second reactor	100 tons per hour

Process capacity = Minimum {120, 110, 112, 100, 135, 118, 165} = 100

Process utilisation and capacity utilisation

Process Step	Calculations	Utilization
Preheater	657,000 tons/year/[120 tons/hour × 8,760 hours/year]	62.5%
Lock hoppers	657,000 tons/year/[110 tons/hour × 8,760 hours/year]	68.2%
First reactor	657,000 tons/year/[112 tons/hour × 8,760 hours/year]	66.9%
Second reactor	657,000 tons/year/[100 tons/hour × 8,760 hours/year]	75.0%
Flash heater	657,000 tons/year/[135 tons/hour × 8,760 hours/year]	55.6%
Discharger	657,000 tons/year/[118 tons/hour × 8,760 hours/year]	63.6%
Briquetting	657,000 tons/year/[165 tons/hour × 8,760 hours/year]	45.5%
Total process	657,000 tons/year/[100 tons/hour × 8,760 hours/year]	75%

Process Step	Calculations	Utilization
Preheater	100/120	83.3%
Lock hoppers	100/110	90.9%
First reactor	100/112	89.3%
Second reactor	100/100	100.0%
Flash heater	100/135	74.1%
Discharger	100/118	84.7%
Briquetting machine	100/165	60.6%
Total process	100/100	100%

Utilization

100%

90%

80%

70%

60%

50%

40%

30%

20%

10%

0%

Mismatch between Demand and Supply at the Process Level

Imbalance Relative to Bottleneck

Preheater

Lock
Hoppers

1st reactor

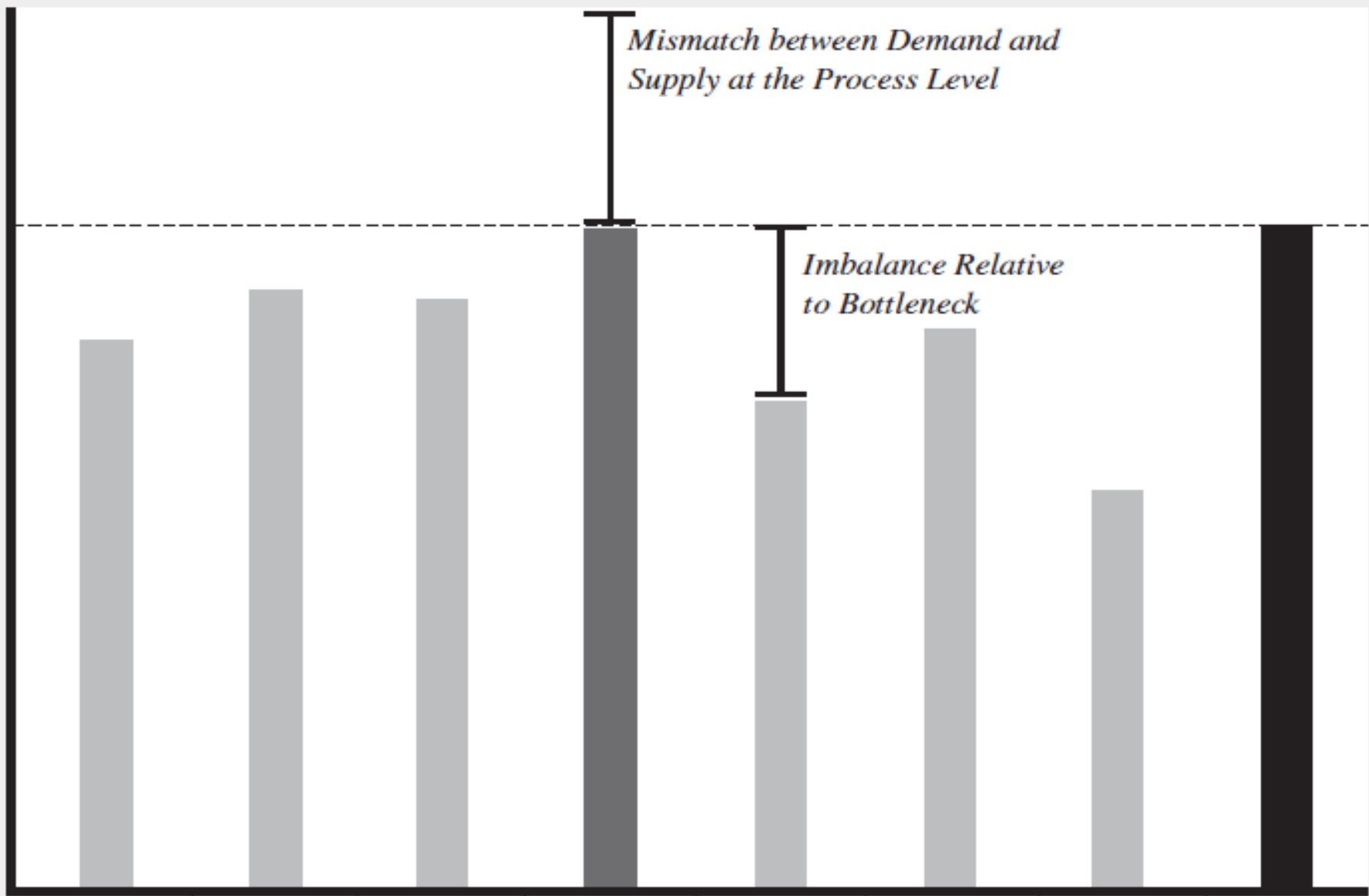
2nd
Reactor
(Bottleneck)

Flash
Heater

Discharger

Briquetting
Machine

Total
Process



Implied utilisation

$$\text{Implied utilization} = \frac{\text{Demand}}{\text{Capacity}}$$

Process Step	Calculations	Implied Utilization	Utilization
Preheater	125/120	104.2%	83.3%
Lock hoppers	125/110	113.6%	90.9%
First reactor	125/112	111.6%	89.3%
Second reactor	125/100	125%	100.0%
Flash heater	125/135	92.6%	74.1%
Discharger	125/118	105.9%	84.7%
Briquetting machine	125/165	75.8%	60.6%
Total process	125/100	125%	100%