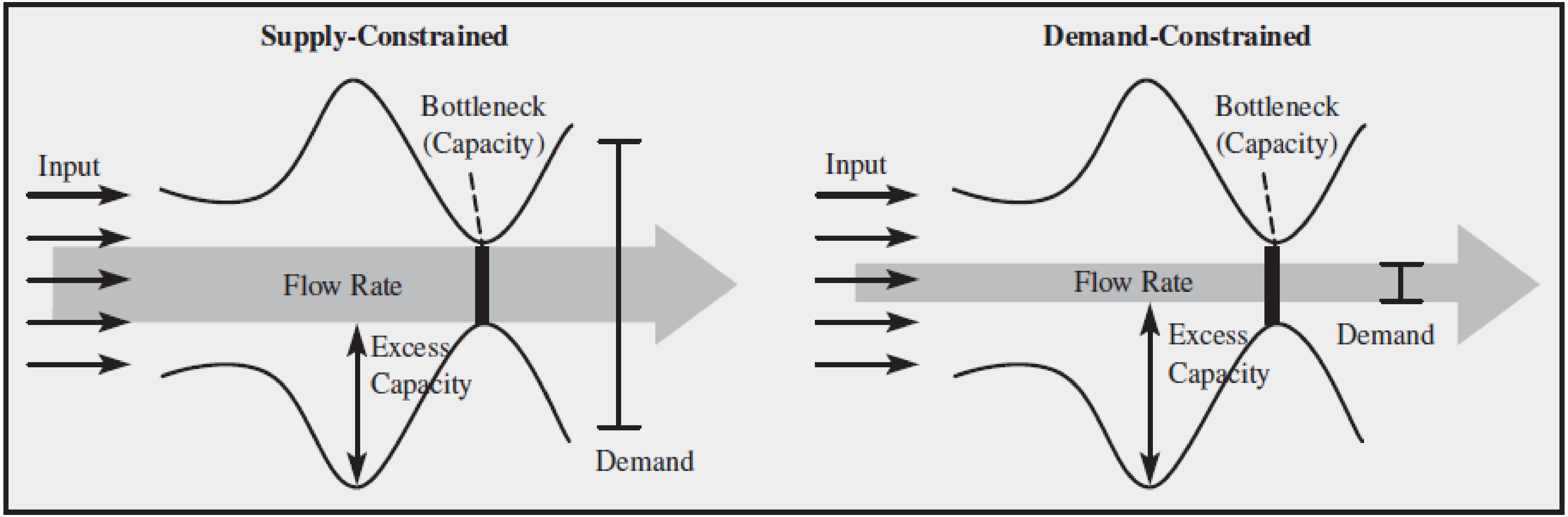
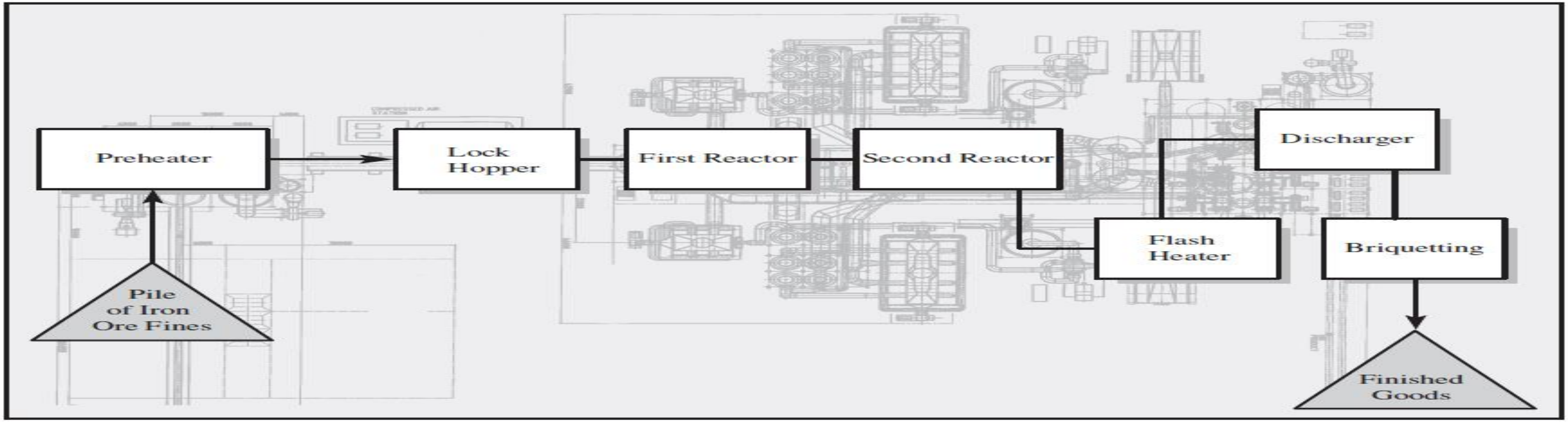
Nature of production process

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.*





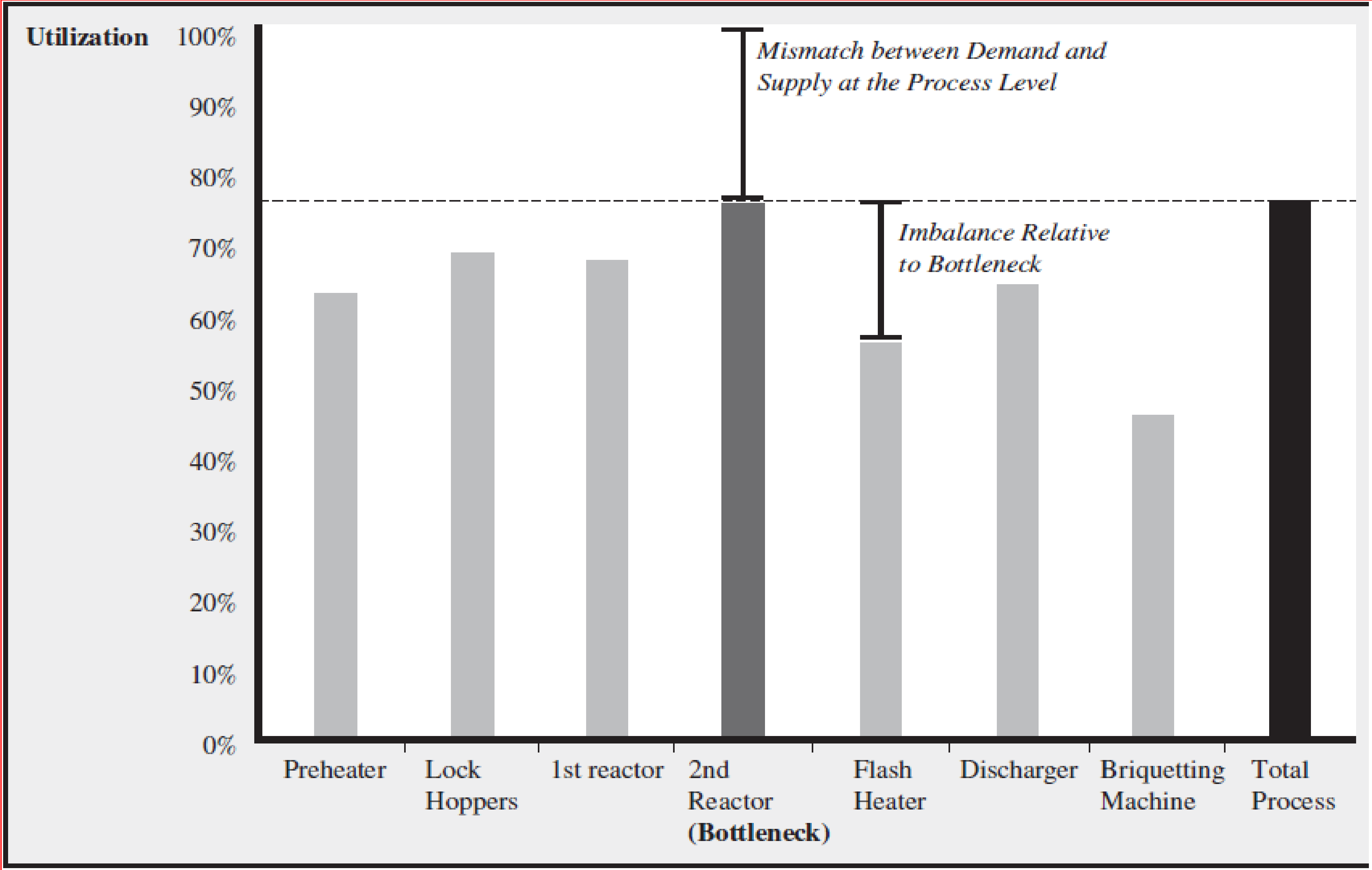
Process Step	Calculations	Capacity
Preheater		120 tons per hour
Lock hoppers		110 tons per hour
First reactor	Little's Law: Flow rate = 28 tons/0.25 hour	112 tons per hour
Second reactor	Little's Law: Flow rate = 400 tons/4 hours	100 tons per hour
Flash heater		135 tons per hour
Discharger		118 tons 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%**

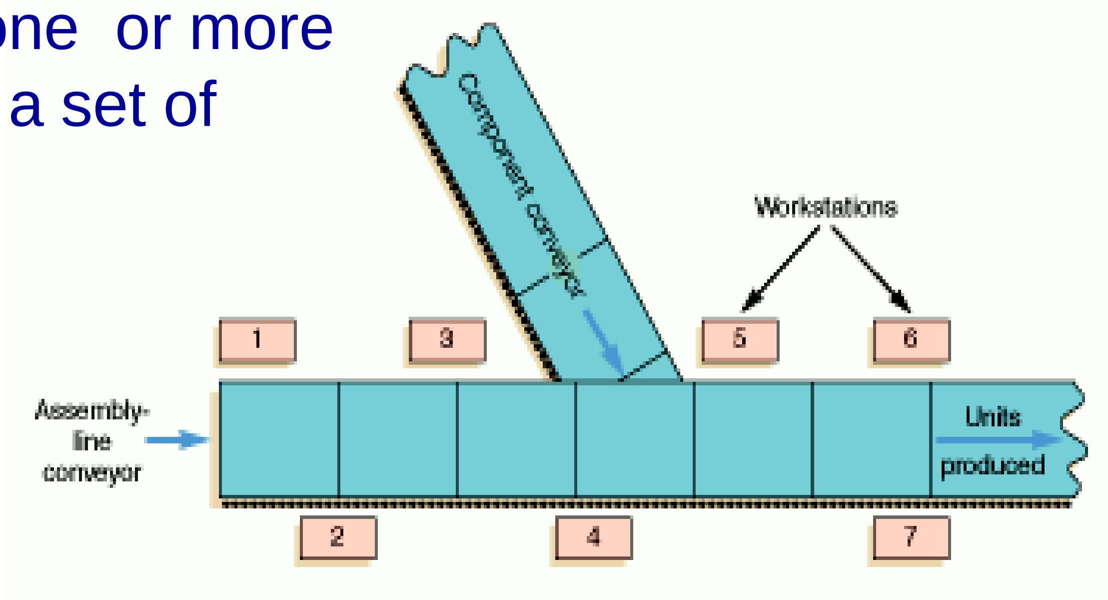
Assembly Line: Ford Model T

Product Layout: Primary Question

- How should we assign tasks to workstations?

bits of work performed at a workstation

locations where one or more workers perform a set of tasks



Goal is to balance work across the workstations.

Advantages of Product Layout

- Little work-in-process inventory
- Short throughput and manufacturing lead times (shorter cash cycle)
- Lower unit cost

Assembly Line Balancing Problem

You've just been assigned the job a setting up an electric fan assembly line with the following tasks.

Task	Time (Mins)	Description	Predecessors
A	2	Assemble frame	None
B	1	Mount switch	A
C	3.25	Assemble motor housing	None
D	1.2	Mount motor housing in frame	A, C
E	0.5	Attach blade	D
F	1	Assemble and attach safety grill	E
G	1	Attach cord	B
H	1.4	Test	F, G

ALB steps

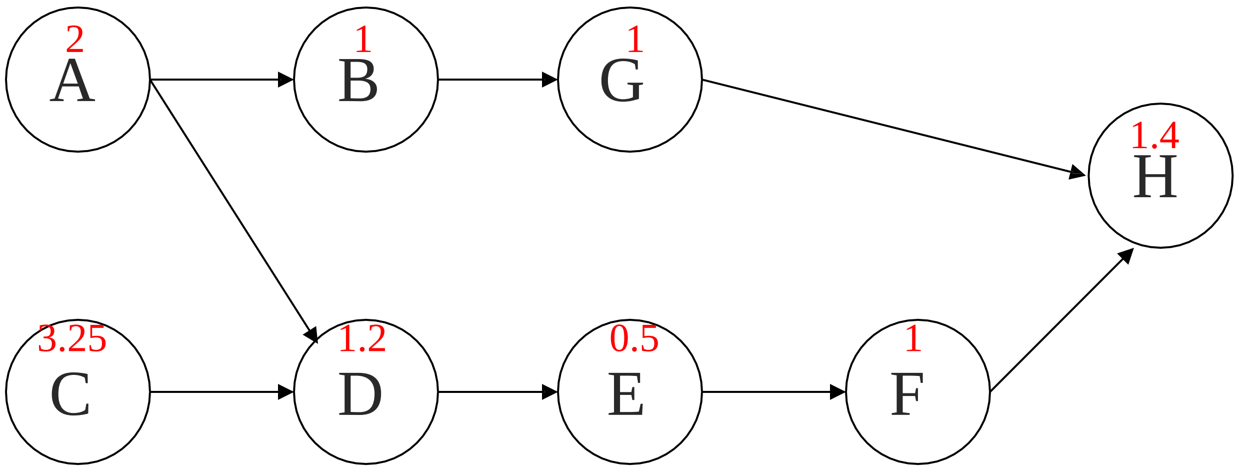
- Draw Precedence diagram
- Calculate cycle time
- Determine number of workstation
- Make line balancing
- Determine the line efficiency

Precedence Diagram

Task	Time (Mins)	Description	Predecessors
A	2	Assemble frame	None
B	1	Mount switch	A
C	3.25	Assemble motor housing	None
D	1.2	Mount motor housing in frame	A, C
E	0.5	Attach blade	D
F	1	Assemble and attach safety grill	E
G	1	Attach cord	B
H	1.4	Test	F, G

Question: What is the time between successive units coming off the line?

"Cycle Time"



CT= Production time per day/number of products

CT= 8hr shift=480 minute/100 units

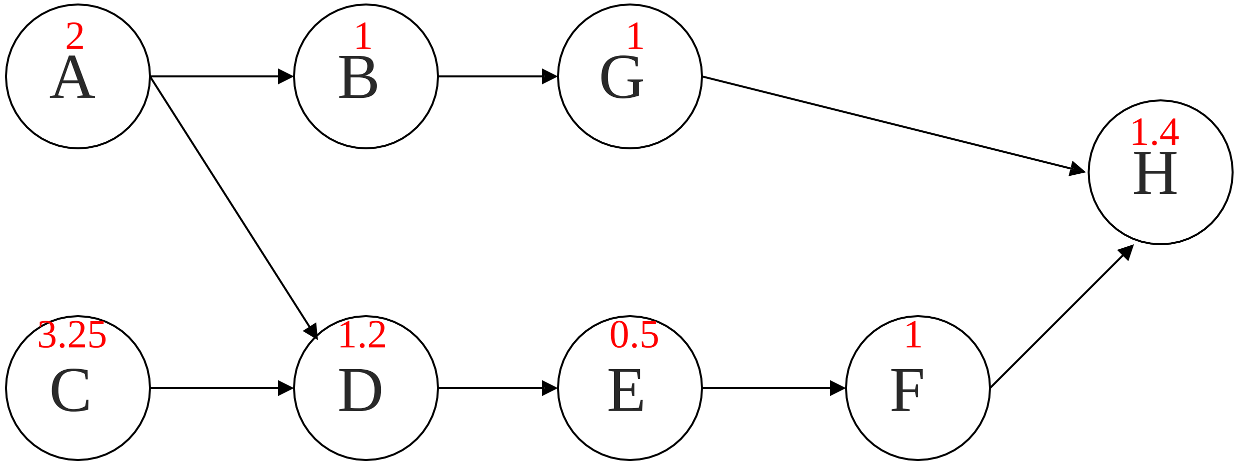
CT=4.8 min/unit

CT=3.25 minutes

Production Rate

Task	Time (Mins)	Description	Predecessors
A	2	Assemble frame	None
B	1	Mount switch	A
C	3.25	Assemble motor housing	None
D	1.2	Mount motor housing in frame	A, C
E	0.5	Attach blade	D
F	1	Assemble and attach safety grill	E
G	1	Attach cord	B
H	1.4	Test	F, G

Question: How many units will be produced per hour?



$$\textbf{Production Rate} = \frac{1}{\text{cycle time}} = \frac{1 \text{ unit}}{3.25 \text{ min}} \times \frac{60 \text{ min}}{1 \text{ hr}} = 18.46 \text{ units/hr}$$

Min number workstations

Task	Time (Mins)
A	2
B	1
C	3.25
D	1.2
E	0.5
F	1
G	1
H	1.4

T = 11.35 min

What is the theoretical minimum number of workstations that we can have on the assembly line to achieve the 4 minute cycle time?

$$N_{min} = \left(\frac{\text{Sum of task times (T)}}{\text{Cycle time (C)}} \right) = \left(\frac{11.35}{4} \right) = \lceil 2.84 \rceil = 3$$

Now let's try to improve the efficiency of our line by dividing the tasks among workstations

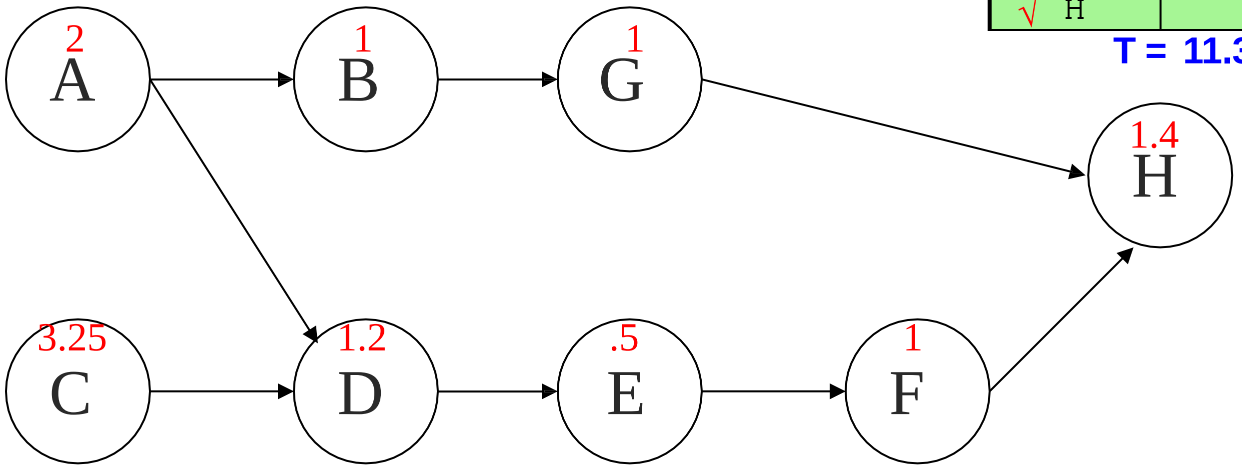
Methods to groups tasks into workstations

1. Longest task time (LTT)
   - Assign feasible task with greatest task time
2. Largest number of following tasks (NFT)
   - Assign feasible task with largest # of tasks following it
3. Shortest task time (STT)
   - Assign feasible task with the shortest task time

Longest Task Time (LTT)

Task	Time (Mins)	Predecessors
√ A	2	None
√ B	1	A
√ C	3.25	None
√ D	1.2	A, C
√ E	0.5	D
√ F	1	E
√ G	1	B
√ H	1.4	F, G

T = 11.35 min



cycle $time_{max}$ = 4

Time @ Station:

	Workstation 1	Workstation 2	Workstation 3	Workstation 4
Time @ Station	3.25	CT = 3.7	3	1.4
Tasks	C (3.25) ~~A (2)~~	A (2) D (1.2) ~~B (1)~~ E (.5) ~~F (1)~~	B (1) F (1) G (1) ~~H (1.4)~~	H (1.4)

3.25+2 = 5.25 > 4

2+1.2+1=4.2 > 4

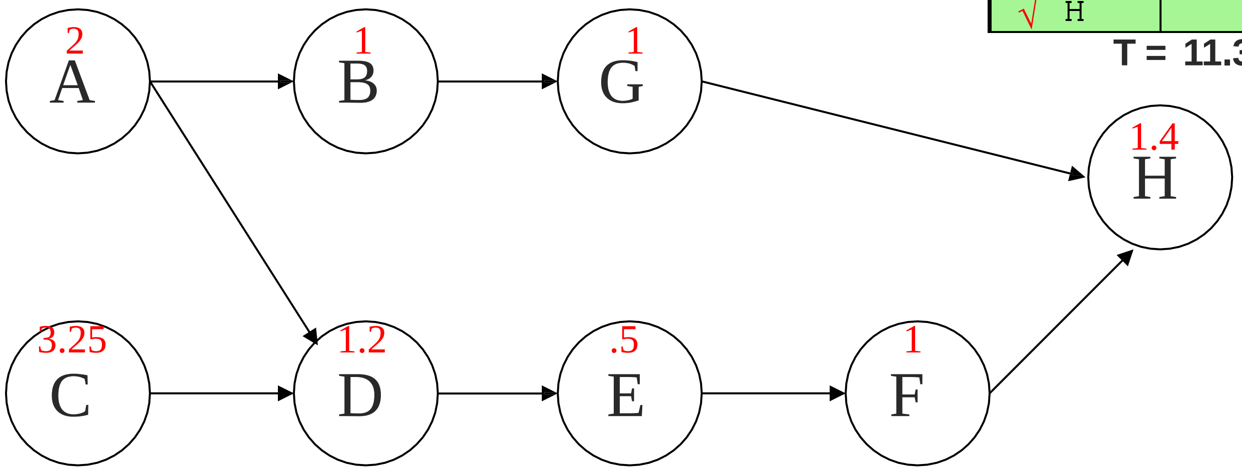
2+1.2+.5+1=4.7 > 4

1+1+1+1.4=4.4 > 4

Longest Task Time

Task	Time (Mins)	Predecessors
√ A	2	None
√ B	1	A
√ C	3.25	None
√ D	1.2	A, C
√ E	0.5	D
√ F	1	E
√ G	1	B
√ H	1.4	F, G

T = 11.35 min



cycle $time_{max}$ = 4

Time @ Station:

	Workstation 1	Workstation 2	Workstation 3	Workstation 4
Time @ Station	3.25	CT = 3.7	3	1.4
Tasks	C (3.25) ~~A (2)~~	A (2) D (1.2) ~~B (1)~~ E (.5) ~~F (1)~~	B (1) F (1) G (1) ~~H (1.4)~~	H (1.4)

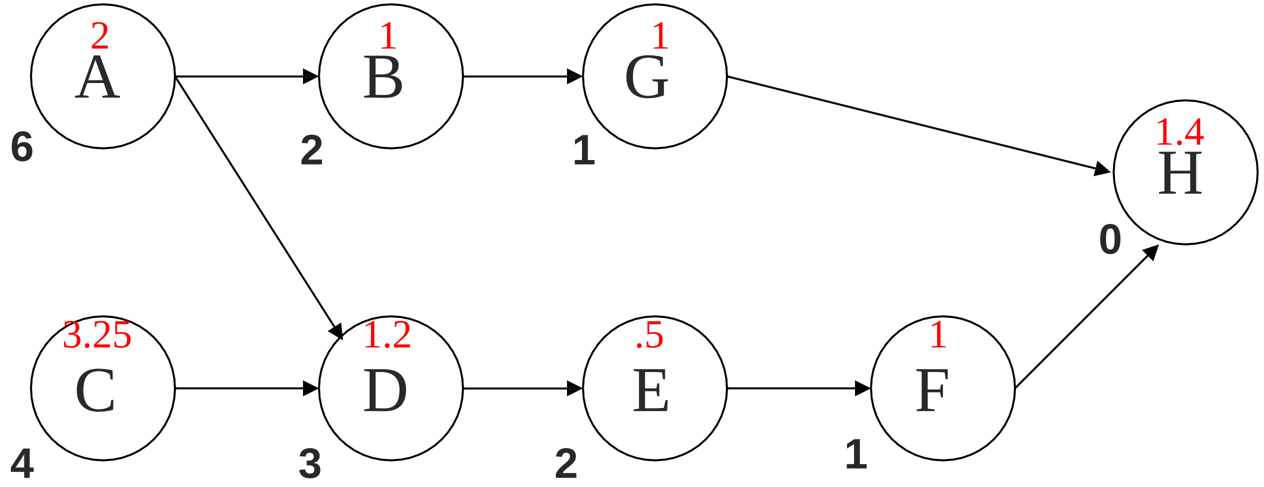
$$\text{Line efficiency} = \frac{\text{Sum of task times}}{\text{(\#stations)(max station time)}}$$

= 11.35/(4 x 3.7) = 0.767= 76.7%

Largest # of Following Task (NFT)

Task	Time (Mins)	Predecessors
A	2	None
B	1	A
C	3.25	None
D	1.2	A, C
E	0.5	D
F	1	E
G	1	B
H	1.4	F, G

T = 11.35 min

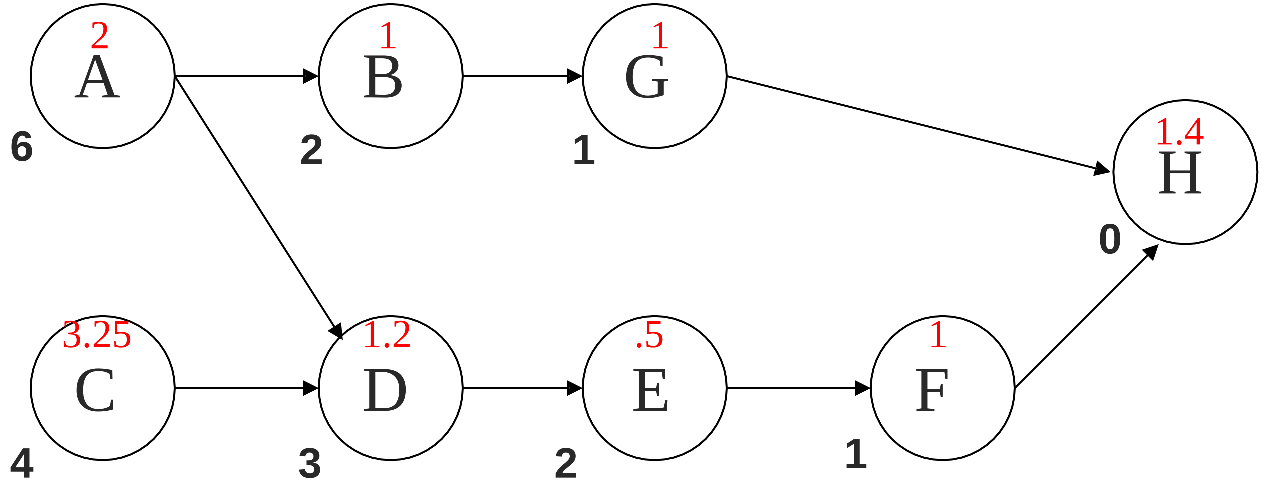


cycle $time_{max}$ = 4

Time @ Station:

Workstation 1	Workstation 2	Workstation 3	Workstation 4
4 = CT	3.25	2.7	1.4
A (2)	C (3.25)	D (1.2)	H (1.4)
~~C (3.25)~~	~~D (1.2)~~	E (.5)	
B (1)		F (1)	
G (1)		~~H (1.4)~~	

2+3.25=5.25 > 4 3.25+1.2 = 4.45 > 4 1.2+.5+1+1.4 = 4.1 > 4



Time @ Station:	4 = CT	3.25	2.7	1.4
	Workstation 1	**Workstation 2**	**Workstation 3**	**Workstation 4**
	A (2)	C (3.25)	D (1.2)	H (1.4)
	~~C (3.25)~~	~~D (1.2)~~	E (.5)	
	B (1)		F (1)	
	G (1)		~~H (1.4)~~	

$$\text{efficiency} = \frac{\text{Sum of task times}}{\text{(\#stations)(max station time)}}$$

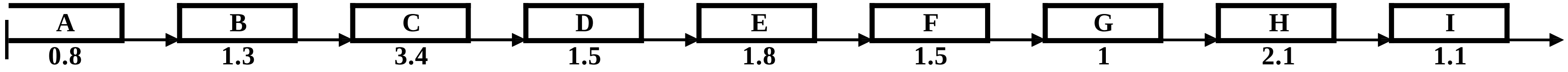
$$= 11.35/(4 \times 4) \quad = 0.709 = 70.9\%$$

Assembly Line Balancing

Suppose that the following nine tasks are required to make one item; but that the tasks have precedence relationships.

Task	Preceded by	Time (minutes)
A	-	0.8
B	A	1.3
C	A	3.4
D	-	1.5
E	B	1.8
F	C,D	1.5
G	E	1.0
H	E,F	2.1
I	G,H	1.1
	Total	14.5

Suppose that each of these tasks is performed in a separate Work Station like in the Assembly Line shown below:



Does this line meet all the precedence requirements?

Yes

The cycle time for the above line will be:

One unit every 3.4 minutes

The corresponding production rate will be:

60 / 3.4 = 17.65 units per hour

The efficiency (E) of an assembly line is given by the following formula:

14.5

$$E = \frac{\sum \text{Task Time}}{\left(\begin{array}{c}\text{Actual No.}\\ \text{of Stations}\end{array}\right)\left(\begin{array}{c}\text{Max. WS}\\ \text{Time}\end{array}\right)}$$

5 **3.4**

Task	Preceded by	Time (minutes)
A	-	0.8
B	A	1.3
C	A	3.4
D	-	1.5
E	B	1.8
F	C,D	1.5
G	E	1.0
H	E,F	2.1
I	G,H	1.1
	Total	14.5

For the above production line, the Efficiency will be E = 14.5 / (5 * 3.4) = 0.8529.

Considering the above example; is it possible to improve the efficiency of the line for the same cycle time of 3.4 minutes? How?

Yes **Group the tasks better, somehow.**

Inventory Management

- Inventory management is an important function in controlling assets in the supply chain.
- Individuals working in the supply chain should have at least a basic understanding of the roles, costs, and benefits of inventories.
- Inventory is often obtained from suppliers in the form of raw materials and other goods and materials through the procurement department.
- Inventory also includes work in process and finished products from manufacturing operations.

Inventory Basics

Inventory Includes:

- Raw Materials
- Work in Progress (WIP)
- Finished goods
- Merchandise
- Spare parts
- Other operating supplies

Inventories may be found in:

- Factories
- Warehouses
- Retail Stores
- Other type of storage facilities

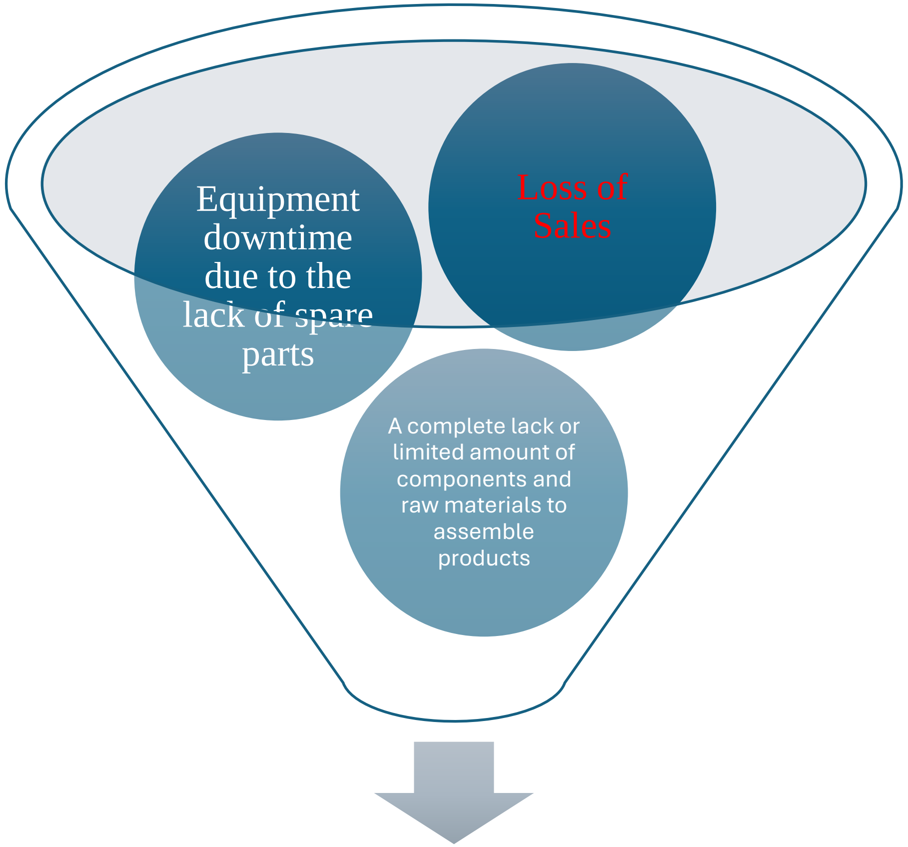
Inventory Basics

- Ideally, an organization would have sufficient inventory to satisfy customer demands for products without losing any revenue due to insufficient stock.
- An organization does not want to have too much inventory on hand, because it costs too much money to both acquire and hold inventory.

Inventory Basics

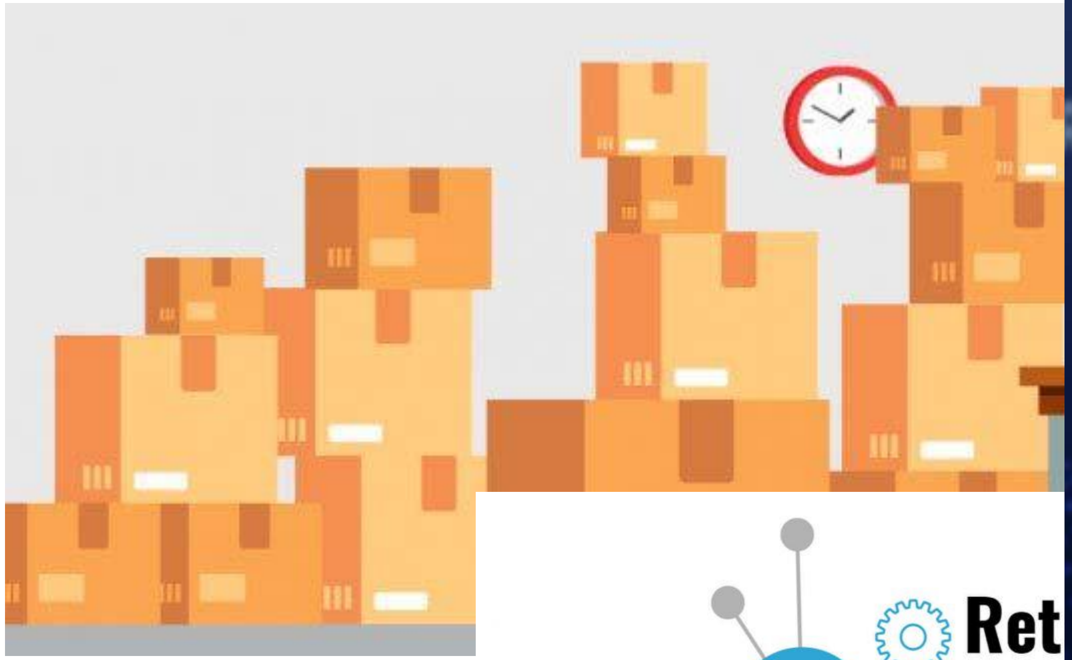
- Inventory management involves striking a balance between three classes of costs:
  - **Acquisition costs** are incurred during purchase order (PO) preparation and processing and during receiving and inspecting purchase items
  - **Carrying costs** are incurred in maintaining a stock of goods in storage
  - **Stockout costs** (also called shortage costs) are incurred when an item is out of stock

Inventory basics



Insufficient Inventory

Why inventory management



Different type of inventory

Inventory types

Inventory form	Inventory function	Driver of demand
Finished goods (FG) for sale (new and refurbished)	Cycle stock; safety stock; in-transit inventory; pre-build inventory to support market launches	Customer and consumer demand
Service parts (spare parts)	Service level based on criticality	Mean time between failure (MTBF)
Work in progress (WIP)	Sub-assemblies awaiting further production. Postponement; assemble to order (ATO)	FG inventory; production capacity; customer orders
Raw materials (RM)	Dependent demand items. Component parts; packaging materials	Purchased items required for production
Maintenance, repair and overhaul (MRO)	Service level based on criticality	Mean time between failure (MTBF)
Consumables	Support production. Two bin replacement system	As required based on production
General supplies	Office and technical items. Two bin replacement	As required by the enterprise

Critical analysis (VBL)

https://www.youtube.com/watch?v=tn0OCaf3O1Y

- Why is excess inventory a negative factor for companies?
- Why cut prices to move excess inventory?
- What can retailers do to prevent excess inventory?

Chapter 14/Inventory management/ p-585

- IM at Nike

Nike’s IM system uses long-term forecasts that provide retailers with significant discounts.

A mismatch between demand and production.

“on-demand "order reduces supply chain variability.

Henry Ford's famous proclamation

Customers can have any color they want, as long as it is black.

Practical challenges

- Customer do not easily forgive shortage of delivery delays
- Inventory management critical to a firm's strategic viability
- Success stores in retailing (Wal-Mart), auto (Toyota), computer (Dell) are founded on operational capabilities that among other things keep inventories lean
- Amazon.com

  - operation without huge inventory

  - innovation in inventory management enabled by technology

Need of inventory planning

- The average manufacturing company spends over one-half of its sales revenue on inventory. Because of the large investment and expenditure required for acquiring and controlling inventories and their effect on profits, successful companies devote a great deal of attention to inventory management.

How much inventory is enough?

Marketing department wants large inventory, it does not like stockouts.

Finance department likes low inventory and high turnover to minimize funds tied up in inventories; opportunity cost of capital.

Production department likes to keep production costs low. It likes uniform production and long uninterrupted runs of a small number of products.

Inventory system

Types of inventory systems

- Order point planning (OPP)
- Fixed-Quantity system
- Fixed-Interval system -
- Minimum-Maximum System, (s,S)-system
- Material requirement planning (MRP)
- Just-in-time system

- Information technology allows us to easily keep and update information
- Simple inventory system can include:
  - forecasting module
  - determination of order points and order quantities
  - monitoring of inventory levels

Costs

- holding costs including opportunity costs
- ordering or setup costs
- shortage costs or service levels

Capacity Constraints

- demand distribution
- lead times

Inventory Costs type/p.589-590

- Item purchase Cost
- Ordering Cost
- Shortage Costs
- Risk costs
- Storage costs

Method for Order Quantities

Lot-for-lot	Order exactly what is needed
Fixed-order quantity	Specifies the number of units to order whenever an order is placed
Min-max system	Places a replenishment order when the on-hand inventory falls below the predetermined minimum level.

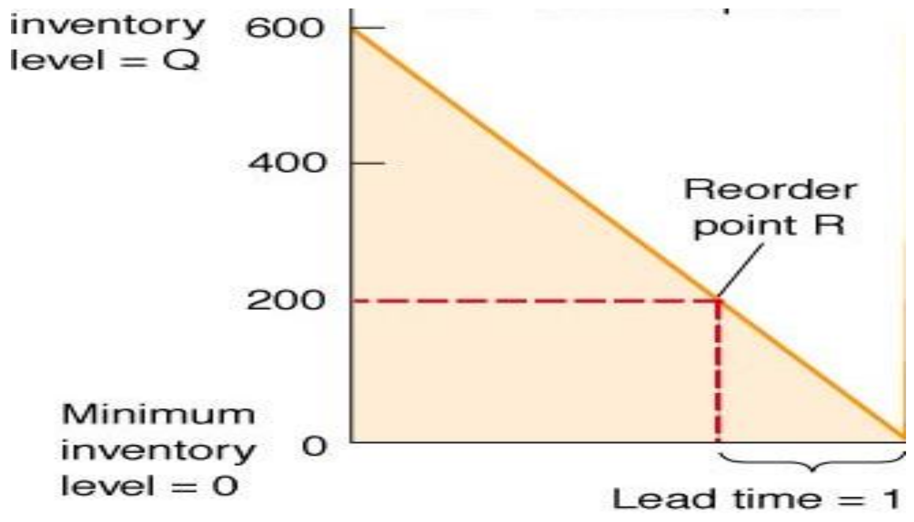
Mathematical Models for Determining Order Quantity/ inventory control system-p 590-591

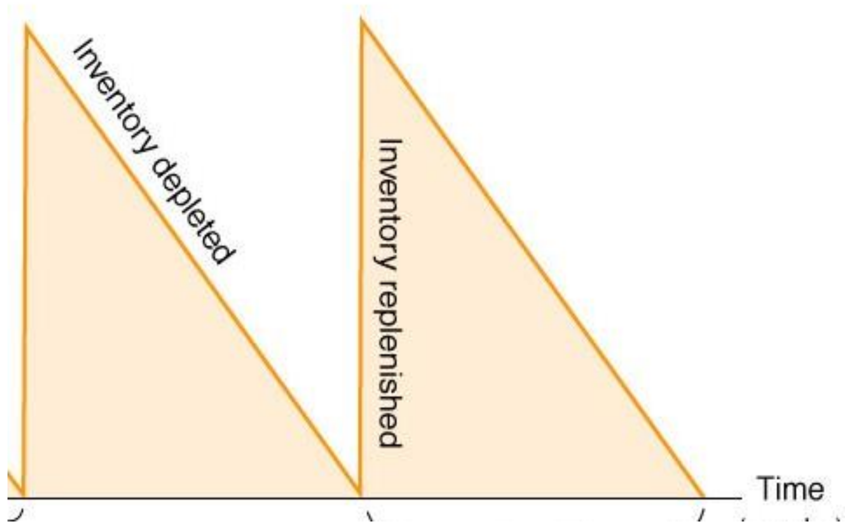
- Economic Order Quantity (EOQ or Q System)
  - An optimizing method used for determining order quantity and reorder points
  - Part of continuous review system which tracks on-hand inventory each time a withdrawal is made
  - Periodic review system is also called as fixed time system
- Economic Production Quantity (EPQ)
  - A model that allows for incremental product delivery
- Quantity Discount Model
  - Modifies the EOQ process to consider cases where quantity discounts are available

Economic Order Quantity p.594

Assumptions:

- Demand is known & constant - no safety stock is required
- Lead time is known & constant
- No quantity discounts are available
- Ordering (or setup) costs are constant
- All demand is satisfied (no shortages)
- The order quantity arrives in a single shipment

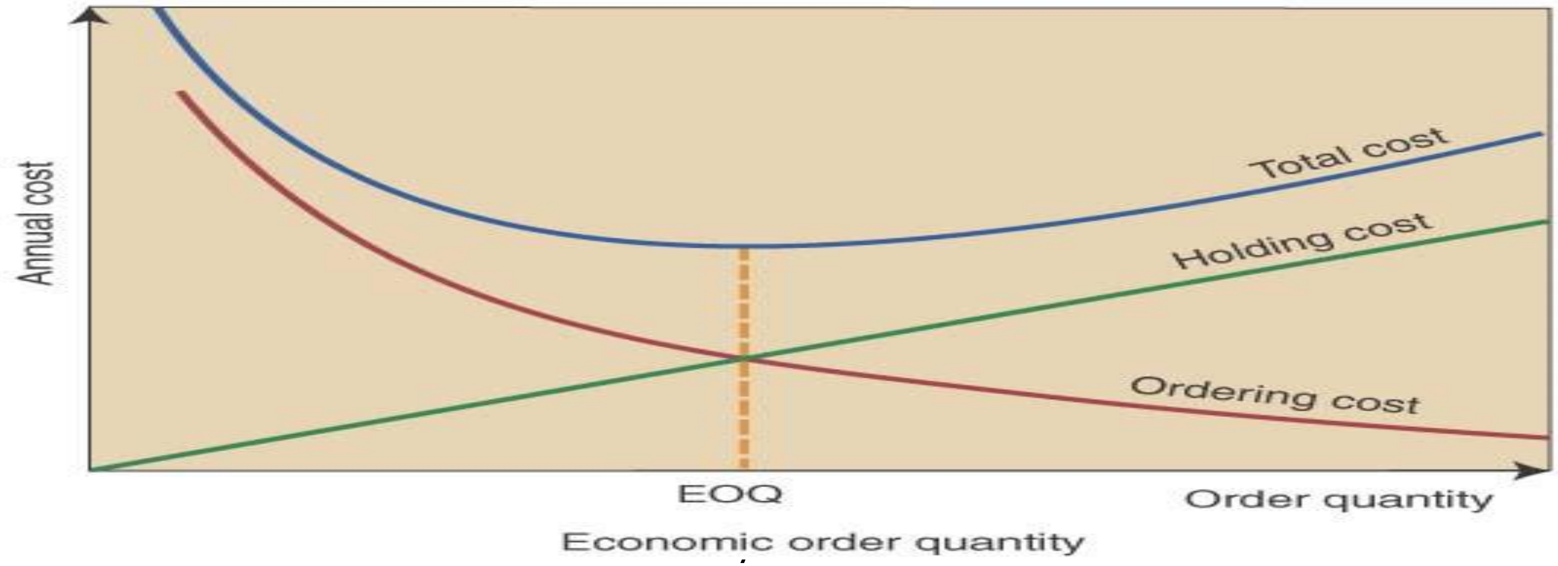




Total AIC with EOQ Model

- **Total annual cost= annual ordering cost + annual holding costs**

$$TC_Q = \left(\frac{D}{Q}\right)S + \left(\frac{Q}{2}\right)H; \quad \text{and} \quad Q = \sqrt{\frac{2DS}{H}}$$



Continuous (Q) Review System Example: A computer company has annual demand of 10,000. They want to determine EOQ for circuit boards which have an annual holding cost (H) of $6 per unit, and an ordering cost (S) of $75. They want to calculate TC and the reorder point (R) if the purchasing lead time is 5 days.

- **EOQ (Q)**

$$Q = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2 * 10{,}000 * \$75}{\$6}} = 500 \text{ units}$$

- **Reorder Point (R)**

$$R = \text{Daily Demand x Lead Time} = \frac{10{,}000}{250 \text{ days}} * 5 \text{ days} = 200 \text{ units}$$

- **Total Inventory Cost (TC)**

$$TC = \left(\frac{10{,}000}{500}\right)\$75 + \left(\frac{500}{2}\right)\$6 = \$1500 + \$1500 = \$3000$$

Reorder point computation 604

- EOQ models answer the question of how much to order, but not the question of when to order.
- The reorder point occurs when the quantity on hand drops to a predetermined amount.
- That amount generally includes expected demand during lead time and perhaps an extra cushion of stock, which serves to reduce the probability of experiencing a stockout during lead time.
- There are four determinants of the reorder point quantity:

1. The rate of demand (usually based on a forecast)
2. The lead time
3. The extent of demand and/or lead time variability
4. The degree of stockout risk acceptable to management

- If demand and lead time are both constant, the reorder point is simply

$$ROP = d \times LT$$

d=daily demand

Class exercise/Ex.14.2

The epaint store stocks paint in its warehouse ans sells it online on its website. The store stocks several brands of paint; however, its biggest seller is Sherman-Wilson iron coat paint. The company wants yo determine the optimal order size and total inventory cost for ironcoat paint given an estimated annual demand of 10000 gallons of paint, an annual carrying cost of $ 0.75 per gallon, and an ordering cost of $150 per order. It would also like to know the number of orders that will be made annually and the time between orders. Assume company operates 300 days annually.

Answer

D=10000

S=$150

H=$0.75

EOQ =2000 gallons

Tcmin= ordering cost+holding cost= 750+750=1500USD

No .of orders per year= D/EOQ= 10000/2000=5 orders per year

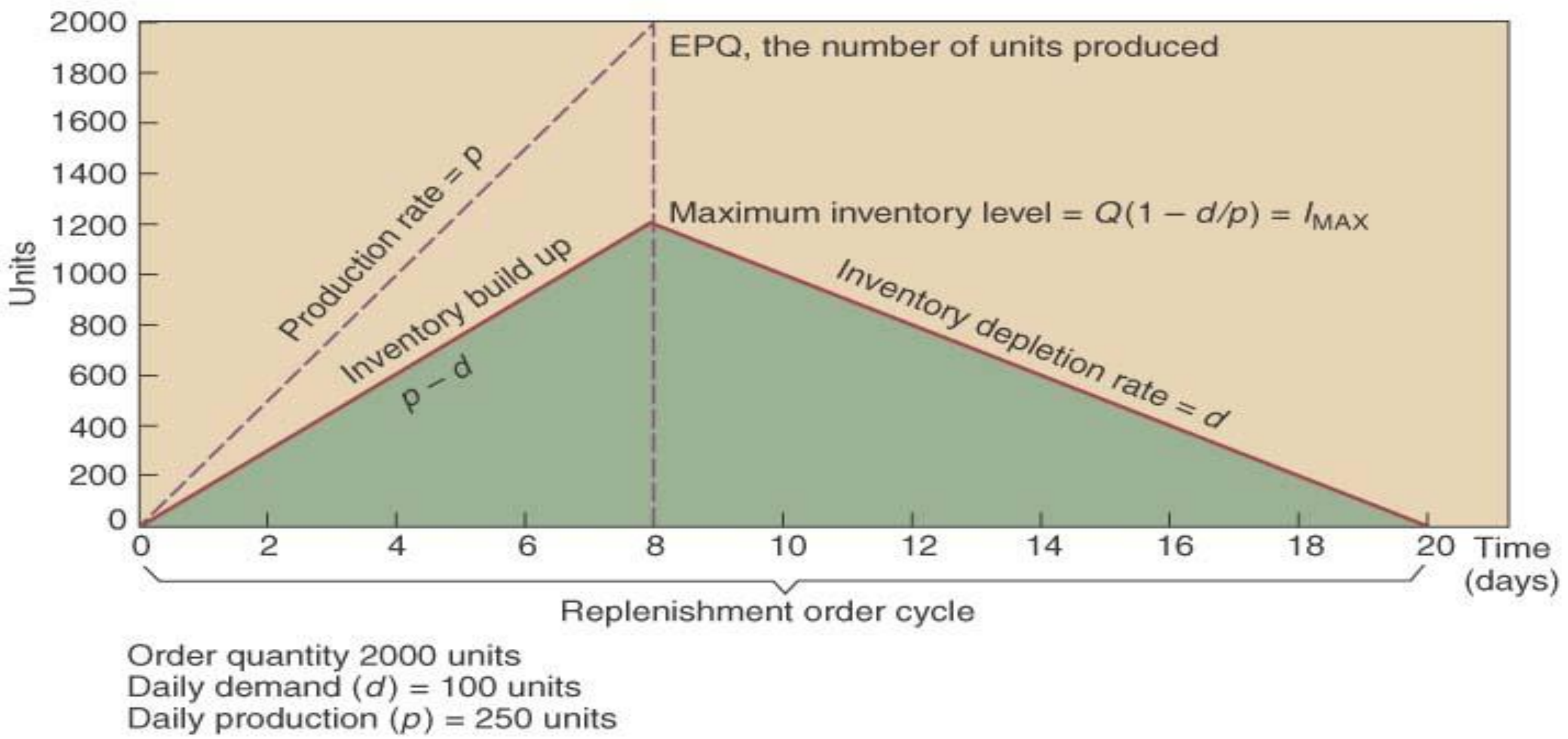
Order cycle time= working time/no .of orders =300/5= 75 days

Extension 14.5

If store open 31 days per year and demand 10000 gallons and lead time to receive orders is 10 days then reorder point = dL=(10000/311)*10 = 321.54 gallons

Economic Production Quantity (EPQ)

- Same assumptions as the EOQ except: inventory arrives in increments & is drawn down as it arrives



Model formulation

- **Total cost:**

$$TC_{EPQ} = \left(\frac{D}{Q}S\right) + \left(\frac{I_{MAX}}{2}H\right)$$

- **Maximum inventory:**
  - d=avg. daily demand rate
  - p=daily production rate

$$I_{MAX} = Q\left(1 - \frac{d}{p}\right)$$

- **Calculating EPQ**

$$EPQ = \sqrt{\frac{2DS}{H\left(1 - \frac{d}{p}\right)}}$$

EPQ Problem: HP Ltd. Produces its premium plant food in 50# bags. Demand is 100,000 lbs. per week and they operate 50 wks. each year and HP can produce 250,000 lbs. per week. The setup cost is $200 and the annual holding cost rate is $.55 per bag. Calculate the EPQ. Determine the maximum inventory level. Calculate the total cost of using the EPQ policy.

$$\mathbf{EPQ} = \sqrt{\frac{\mathbf{2DS}}{\mathbf{H}\left(\mathbf{1} - \frac{\mathbf{d}}{\mathbf{p}}\right)}}$$

$$\mathbf{I}_{\mathbf{MAX}} = \mathbf{Q}\left(\mathbf{1} - \frac{\mathbf{d}}{\mathbf{p}}\right)$$

$$\mathbf{TC}_{\mathbf{EPQ}} = \left(\frac{\mathbf{D}}{\mathbf{Q}}\mathbf{S}\right) + \left(\frac{\mathbf{I}_{\mathbf{MAX}}}{\mathbf{2}}\mathbf{H}\right)$$

$$EPQ = \sqrt{\frac{2(50)(100{,}000)(200)}{.55\left(1 - \frac{100{,}000}{250000}\right)}} = 77{,}850\,Bags$$

$$I_{MAX} = 77{,}850\left(1 - \frac{100{,}000}{250{,}000}\right) = 46{,}710\,bags$$

$$TC = \left(\frac{5{,}000{,}000}{77{,}850}\right)(200) + \left(\frac{46{,}710}{2}\right)(.55) = \$25{,}690$$

Class exercise 14.3

The Production Quantity Model

Assume that the ePaint Store has its own manufacturing facility in which it produces Iron-coat paint. The ordering cost, C_o, is the cost of setting up the production process to make paint. $C_o = \$150$. Recall that $C_c = \$0.75$ per gallon and $D = 10{,}000$ gallons per year. The manufacturing facility operates the same days the store is open (i.e., 311 days) and produces 150 gallons of paint per day. Determine the optimal order size, total inventory cost, the length of time to receive an order, the number of orders per year, and the maximum inventory level.

$$C_o = \$150$$
$$C_c = \$0.75 \text{ per gallons}$$
$$D = 10{,}000 \text{ gallons}$$
$$d = \frac{10{,}000}{311} = 32.2 \text{ gallons per day}$$
$$p = 150 \text{ gallons per day}$$

The optimal order size is determined as follows:

$$Q_{opt} = \sqrt{\frac{2C_oD}{C_c\left(1 - \frac{d}{p}\right)}}$$

$$= \sqrt{\frac{2(150)(10{,}000)}{0.75\left(1 - \frac{32.2}{150}\right)}}$$
$$= 2256.8 \text{ gallons}$$

Although an order of 2256.8 gallons should be rounded to 2257, we will use the 2256.8 to compute total cost. This value is substituted into the following formula to determine total minimum annual inventory cost:

$$TC_{min} = \frac{C_oD}{Q} + \frac{C_cQ}{2}\left(1 - \frac{d}{p}\right)$$
$$= \frac{(150)(10{,}000)}{2256.8} + \frac{(0.75)(2256.8)}{2}\left(1 - \frac{32.2}{150}\right)$$
$$= \$1329$$

The length of time to receive an order for this type of manufacturing operation is commonly called the length of the *production run*.

$$\text{Production run} = \frac{Q}{p}$$
$$= \frac{2256.8}{150}$$
$$= 15.05 \text{ days per order}$$

The number of orders per year is actually the number of production runs that will be made:

$$\text{Number of production runs (from orders)} = \frac{D}{Q}$$
$$= \frac{10{,}000}{2256.8}$$
$$= 4.43 \text{ runs per year}$$

Finally, the maximum inventory level is

$$\text{Maximum inventory level} = Q\left(1 - \frac{d}{p}\right)$$
$$= 2256.8\left(1 - \frac{32.2}{150}\right)$$
$$= 1772 \text{ gallons}$$

Thus, ePaint will need to set aside storage space sufficient to accommodate these 1772 gallons of paint.