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 ‘l’.

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

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……..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 assemblies 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

$\text{n}_{pj} = number$ of parts in product j (pcs/product)

$$\text{n}_{pf} = \sum_{j=1}^{P} Q_j.\text{n}_{pj}$$

n_{of} = total number of operations cycles performed in factory (ops/year0

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

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

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 $n_{of} = P.Q.n_p.n_o$

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=250days/year

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

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

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.

$$\text{Plantcapacity} = n.S.H.R_p$$

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 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 %

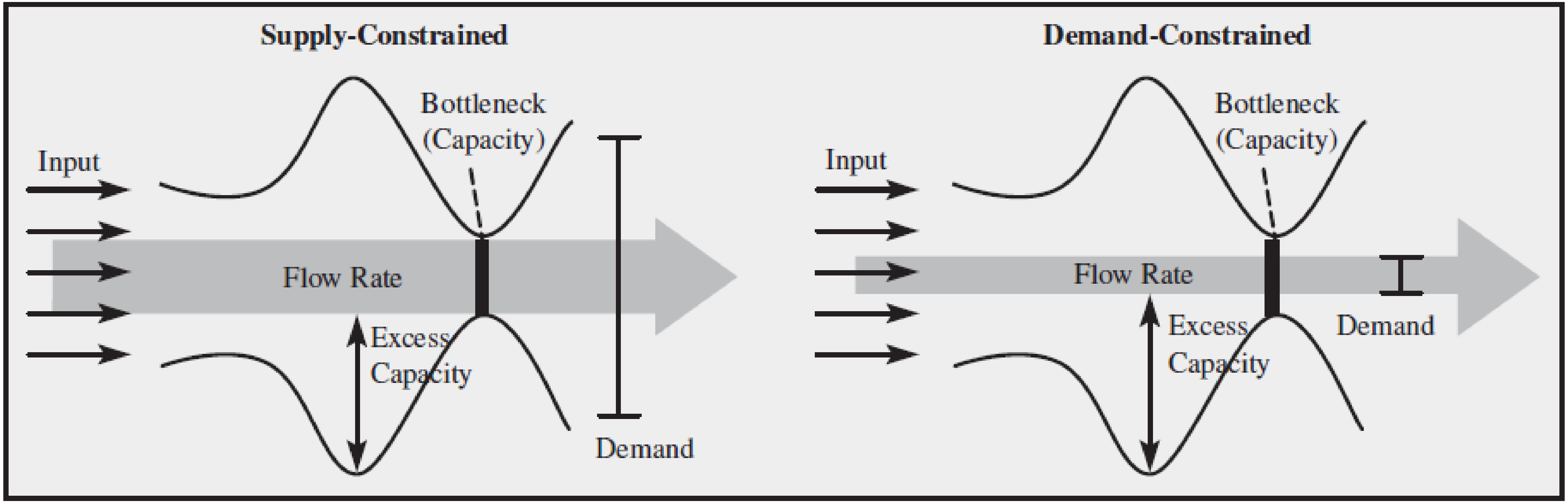
Process availability

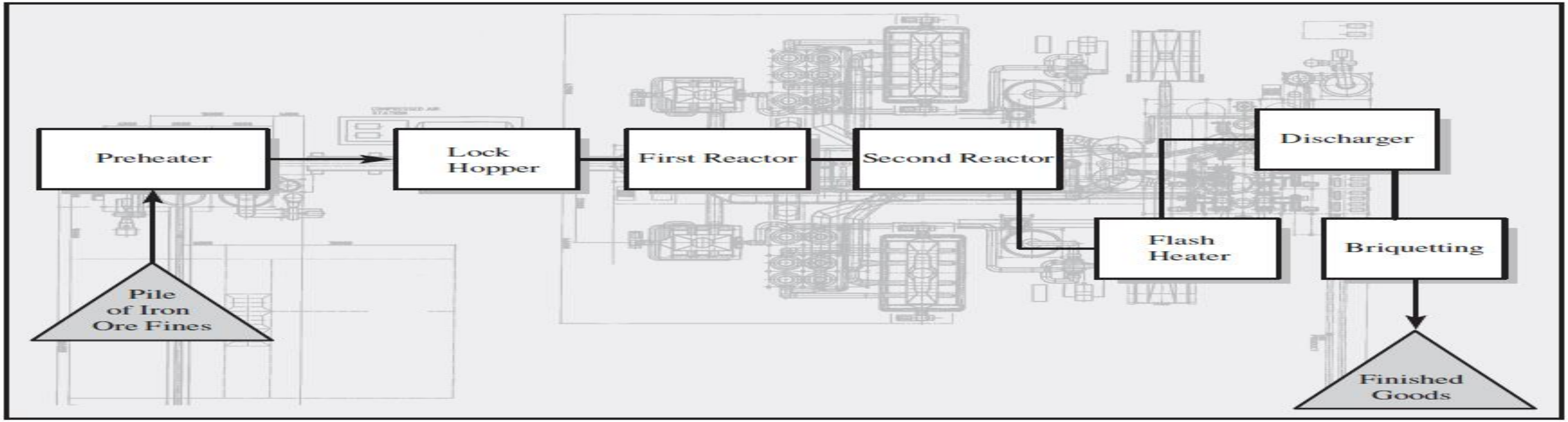
- Availability is a common measure of reliability for equipment.
- Mean time between failure (MTBF)- is the average time during equipment is running
- Mean time to repair (MTTR) is the average time required for servicing a equipment
- %A= (MTBF-MTTR)/MTBF
- With the previous data, if a oven is availability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

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.*





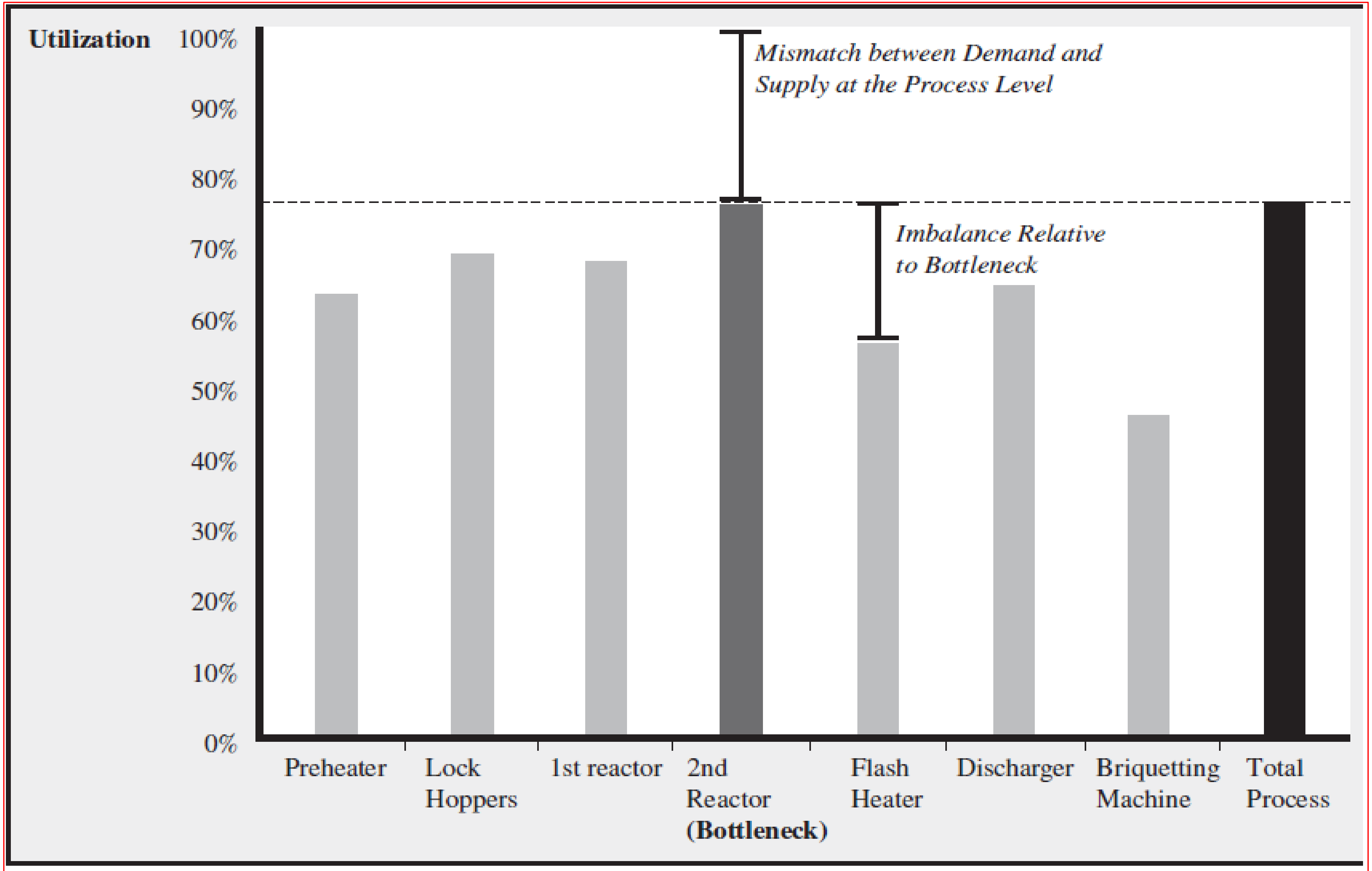
Process Step	Calculations	Capacity
Preheater		120 tons per hour
Lock hoppers		110 tons per hour
First reactor	Little's Law: Flow rate = 28 tons/0.25 hour	112 tons per hour
Second reactor	Little's Law: Flow rate = 400 tons/4 hours	100 tons per hour
Flash heater		135 tons per hour
Discharger		118 tons per hour
Briquetting machine	Consists of three machines: 3 x 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%**

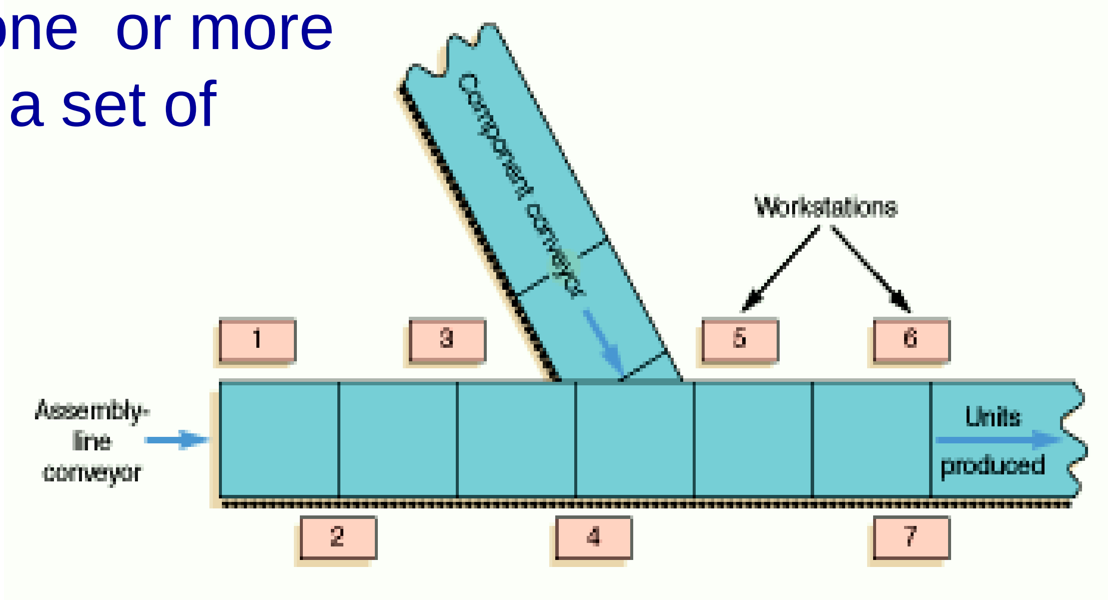

Utilization
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Mismatch between Demand and Supply at the Process Level
Imbalance Relative to Bottleneck
Preheater
Lock Hoppers
1st reactor
2nd Reactor (Bottleneck)
Flash Heater
Discharger
Briquetting Machine
Total Process

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.

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

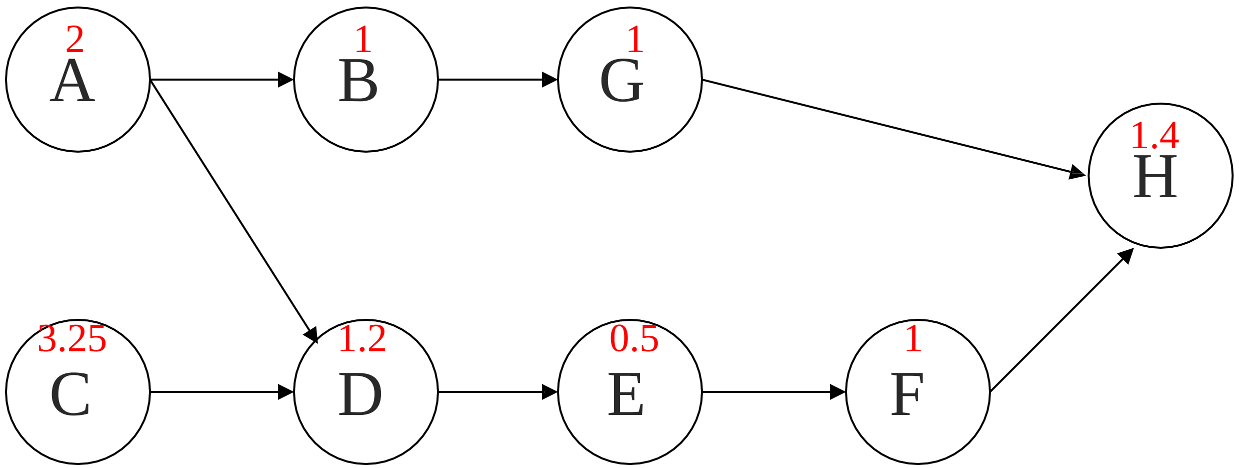
- Draw Precedence diagram
- Calculate cycle time
- Determine number of workstation

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"



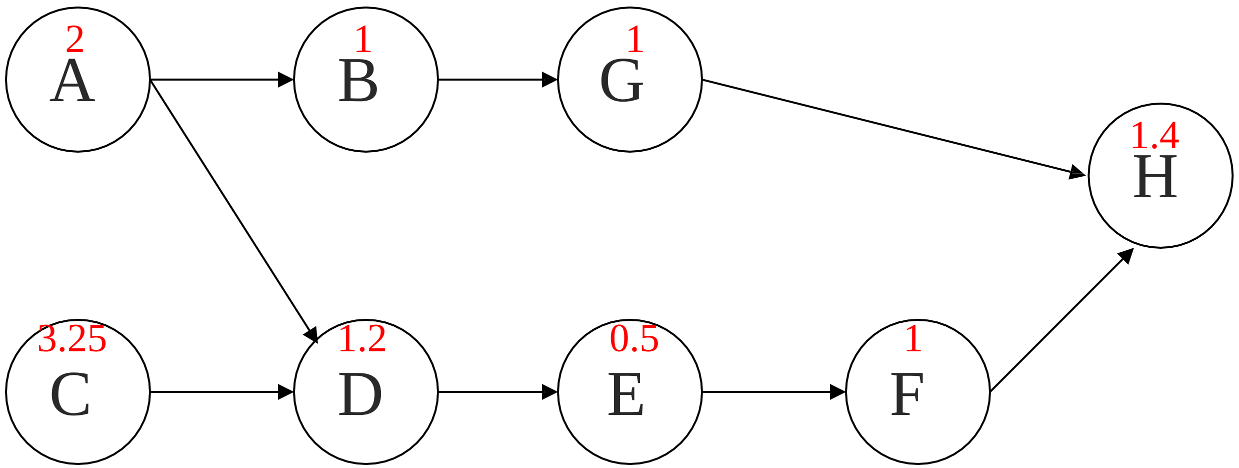
CT= Production time per day/number of products
CT= 8hr shift=480 minute/100 units
CT=4.8 min/unit

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?



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

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

Trips Logistics problem

- The manager must decide whether to lease warehouse space for the coming three years and the quantity to lease.
- The manager anticipates uncertainty in demand and spot prices for warehouse space over the coming three years.
- The long-term lease is cheaper but the space could go unused if demand is lower than anticipated.
- The long-term lease may also end up being more expensive if future spot market prices come down. The manager is considering three options:

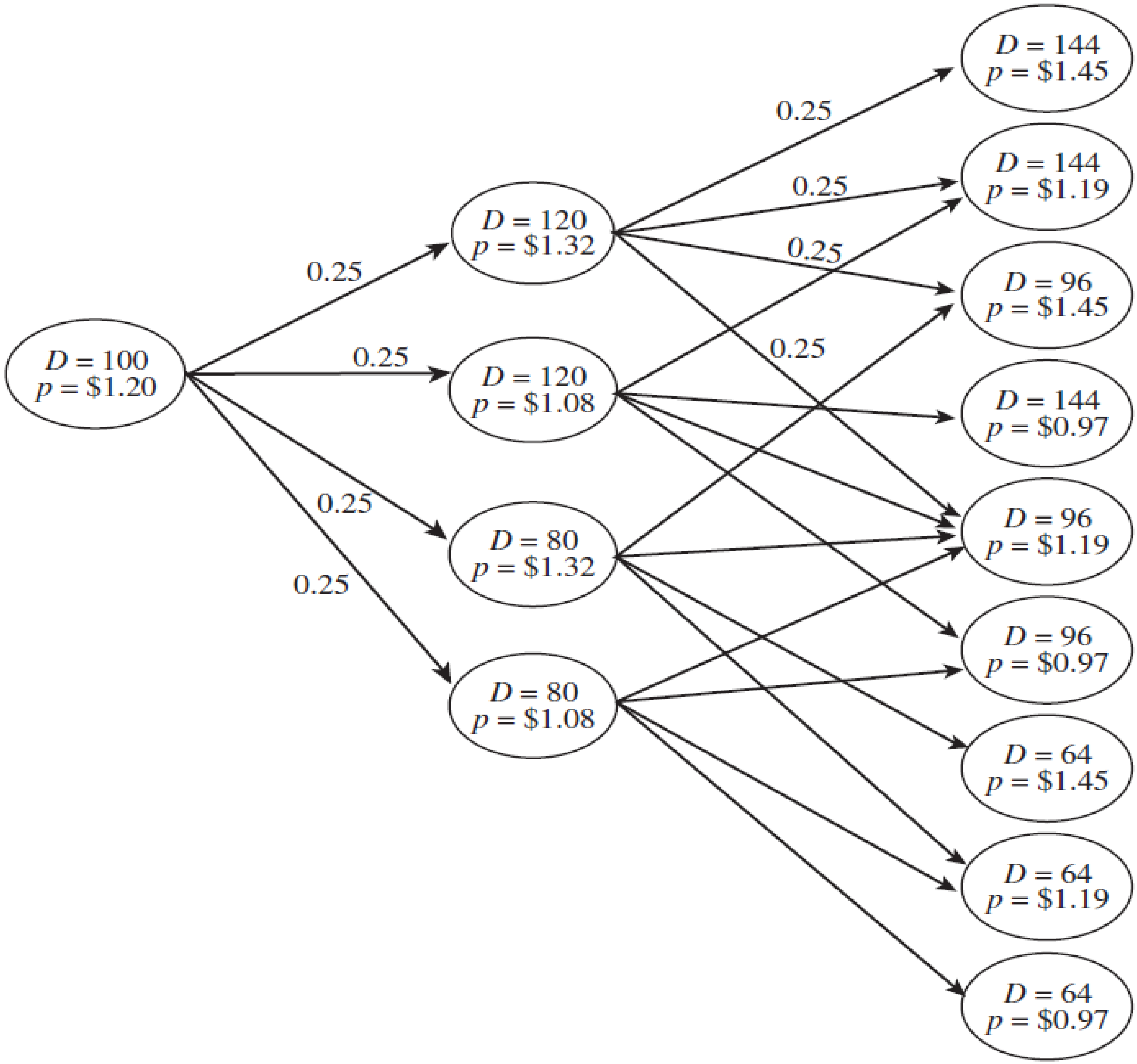
1. Get all warehousing space from the spot market as needed.
2. Sign a three-year lease for a fixed amount of warehouse space and get additional requirements from the spot market.
3. Sign a flexible lease with a minimum charge that allows variable usage of warehouse space up to a limit, with additional requirements from the spot market

- We now discuss how the manager can evaluate each decision, taking uncertainty into account.
- One thousand square feet of warehouse space is required for every 1,000 units of demand, and the current demand at Trips Logistics is for 100,000 units per year.
- The manager forecasts that from one year to the next, demand may go up by 20 percent, with a probability of 0.5, or go down by 20 percent, with a probability of 0.5.
- The probabilities of the two outcomes are independent and unchanged from one year to the next.
- The general manager can sign a three-year lease at a price of $1 per square foot per year. Warehouse space is currently available on the spot market for $1.20 per square foot per year.

Data given

1000 sq. ft. of warehouse space needed for 1000 units of demand

- Current demand = 100,000 units per year
- Binomial uncertainty: Demand can go up by 20% with $p = 0.5$ or down by 20% with $1 - p = 0.5$
- Lease price = \$1.00 per sq. ft. per year
- Spot market price = \$1.20 per sq. ft. per year
- Spot prices can go up by 10% with $p = 0.5$ or down by 10% with $1 - p = 0.5$
- Revenue = \$1.22 per unit of demand
- $k = 0.1$



D = 100
p = $1.20
0.25
0.25
0.25
0.25
D = 120
p = $1.32
D = 120
p = $1.08
D = 80
p = $1.32
D = 80
p = $1.08
0.25
0.25
0.25
0.25
D = 144
p = $1.45
D = 144
p = $1.19
D = 96
p = $1.45
D = 144
p = $0.97
D = 96
p = $1.19
D = 96
p = $0.97
D = 64
p = $1.45
D = 64
p = $1.19
D = 64
p = $0.97

Evaluating the Spot Market Option

- Analyze the option of not signing a lease and using the spot market
- Start with last period and calculate the profit at each node

For D = 144, p = \$1.45, in Period 2:

$$C(D = 144, p = 1.45, 2) = 144{,}000 \times 1.45$$
$$= \$208{,}800$$
$$P(D = 144, p = 1.45, 2) = 144{,}000 \times 1.22$$
$$- C(D = 144, p = 1.45, 2)$$
$$= 175{,}680 - 208{,}800$$

Net = −\$33,120

Evaluating the Spot Market Option

Period 2 Calculations for Spot Market Option

	Revenue	Cost $C(D =, p =, 2)$	Profit $P(D =, p =, 2)$
D = 144, p = 1.45	144,000 × 1.22	144,000 × 1.45	–$33,120
D = 144, p = 1.19	144,000 × 1.22	144,000 × 1.19	$4,320
D = 144, p = 0.97	144,000 × 1.22	144,000 × 0.97	$36,000
D = 96, p = 1.45	96,000 × 1.22	96,000 × 1.45	–$22,080
D = 96, p = 1.19	96,000 × 1.22	96,000 × 1.19	$2,880
D = 96, p = 0.97	96,000 × 1.22	96,000 × 0.97	$24,000
D = 64, p = 1.45	64,000 × 1.22	64,000 × 1.45	–$14,720
D = 64, p = 1.19	64,000 × 1.22	64,000 × 1.19	$1,920
D = 64, p = 0.97	64,000 × 1.22	64,000 × 0.97	$16,000

Evaluating the Spot Market Option

- Expected profit at each node in Period 1 is the profit during Period 1 plus the present value of the expected profit in Period 2
- Expected profit E P(D =, p =, 1) at a node is the expected profit over all four nodes in Period 2 that may result from this node
- Present value E P(D =, p =, 1) is the present value of this expected profit and P(D =, p =, 1), and the total expected profit, is the sum of the profit in Period 1 and the present value of the expected profit in Period 2.

Evaluating the Spot Market Option

- From node $D = 120$, $p = \$1.32$ in Period 1, there are four possible states in Period 2
- Evaluate the expected profit in Period 2 over all four states possible from node $D = 120$, $p = \$1.32$ in Period 1 to be

$$
\begin{aligned}
E\,P(D = 120, p = 1.32, 1) = 0.25 \times [&P(D = 144, p = 1.45, 2) \\
&+ P(D = 144, p = 1.19, 2) \\
&+ P(D = 96, p = 1.45, 2) \\
&+ P(D = 96, p = 1.19, 2)
\end{aligned}
$$

$$
\begin{aligned}
&= 0.25 \times [-33{,}120 + 4{,}320 \\
&\quad - 22{,}080 + 2{,}880] \\
&= -\$12{,}000
\end{aligned}
$$

Evaluating the Spot Market Option

The present value of this expected value in Period 1 is

$$PVEP(D = 120, p = 1.32, 1) = \frac{EP(D = 120, p = 1.32, 1)}{(1 + k)}$$

$$= \frac{-\$12{,}000}{(1.1)}$$

$$= -\$10{,}909$$

Evaluating the Spot Market Option

The total expected profit *P(D* = 120, *p* = 1.32,1) at node *D* = 120, *p* = 1.32 in Period 1 is the sum of the profit in Period 1 at this node, plus the present value of future expected profits possible from this node

$$P(D=120, p=1.32,1) = (120{,}000 \times 1.22) - (120{,}000 \times 1.32)$$
$$+PVEP(D=120, p=1.32,1)$$
$$= -\$12{,}000 - \$10{,}909 = -\$22{,}909$$

Evaluating the Spot Market Option

Period 1 Calculations for Spot Market Option

Node	$EP(D =, p =, 1)$	$P(D =, p =, 1)$ $= D \times 1.22 - D \text{ x } p +$ start fraction E P at left parenthesis D =, p =, 1 right parenthesis over left parenthesis 1 + k right parenthesis end fraction $\dfrac{EP(D =, p =, 1)}{(1 + k)}$
$D = 120,\ p = 1.32$	−$12,000	−$22,909
$D = 120,\ p = 1.08$	$16,000	$32,073
$D = 80,\ p = 1.32$	−$8,000	−$15,273
$D = 80,\ p = 1.08$	$11,000	$21,382

Evaluating the Spot Market Option

For Period 0, the total profit $P(D = 100, p = 120{,}0)$ is the sum of the profit in Period 0 and the present value of the expected profit over the four nodes in Period 1

$$EP(D = 100, p = 1.20,0) = 0.25 \times [P(D = 120, p = 1.32,1) + P(D = 120, p = 1.08,1) + P(D = 96, p = 1.32,1) + P(D = 96, p = 1.08,1)]$$

$$= 0.25 \times [-22{,}909 + 32{,}073 - 15{,}273) + 21{,}382]$$

$$= \$3{,}818$$

Evaluating the Spot Market Option

$$PVEP(D = 100, p = 1.20,1) = \frac{EP(D = 100, p = 1.20,0)}{(1+k)}$$

$$= \frac{\$3,818}{(1.1)} = \$3,471$$

$$P(D = 100, p = 1.20,0) = (100,000 \times 1.22) - (100,000 \times 1.20) + PVEP(D = 100, p = 1.20,0)$$

$$= \$2,000 + \$3,471 = \$5,471$$

Therefore, the expected N P V of not signing the lease and obtaining all warehouse space from the spot market is given by N P V (Spot Market) = $5,471

Evaluating the Fixed Lease Option

Period 2 Profit Calculations at Trips Logistics for Fixed Lease Option

Node	**Leased Space**	**Warehouse Space at Spot Price (*S*)**	**Profit *P*(*D* =, *p* =, 2) = *D* × 1.22 – (100,000 × 1 + *S* x *p*)**
D = 144, *p* = 1.45	100,000 sq. ft. (aval. For 100k)	44,000 sq. ft.	$11,880
D = 144, *p* = 1.19	100,000 sq. ft.	44,000 sq. ft.	$23,320
D = 144, *p* = 0.97	100,000 sq. ft.	44,000 sq. ft.	$33,000
D = 96, *p* = 1.45	100,000 sq. ft.	0 sq. ft.	$17,120
D = 96, *p* = 1.19	100,000 sq. ft.	0 sq. ft.	$17,120
D = 96, *p* = 0.97	100,000 sq. ft.	0 sq. ft.	$17,120
D = 64, *p* = 1.45	100,000 sq. ft.	0 sq. ft.	–$21,920
D = 64, *p* = 1.19	100,000 sq. ft.	0 sq. ft.	–$21,920
D = 64, *p* = 0.97	100,000 sq. ft.	0 sq. ft.	–$21,920

Evaluating the Fixed Lease Option

Period 1 Profit Calculations at Trips Logistics for Fixed Lease Option

Node	***EP*(*D* =, *p* =, 1)**	**Warehouse Space at Spot Price (*S*)**	***P*(*D* =, *p* =, 1) = *D* x 1.22–(100,000 x 1 + *S* x *p*) + *EP*(*D* =, *p* = ,1)(1 + *k*)**
D = 120, *p* = 1.32	0.25 × [*P*(*D* = 144, *p* = 1.45,2) + *P*(*D* = 144, *p* = 1.19,2) + *P*(*D* = 96, *p* = 1.45,2) + *P*(*D* = 96, *p* = 1.19,2)] = 0.25 × (11,880 + 23,320 + 17,120 + 17,120) = $17,360	20,000	$35,782
D = 120, *p* = 1.08	0.25 × (23,320 + 33,000 + 17,120 + 17,120) = $22,640	20,000	$45,382
D = 80, *p* = 1.32	0.25 × (17,120 + 17,120–21,920 – 21,920) = –$2,400	0	–$4,582
D = 80, *p* = 1.08	0.25 × (17,120 + 17,120 – 21,920 –21,920) = –$2,400	0	–$4,582

Evaluating the Fixed Lease Option

Using the same approach for the lease option, NPV (Lease) = $38,364

$$EP(D = 100, p = 1.20,0) = 0.25 \times [P(D = 120, p = 1.32,1) + P(D = 120, p = 1.08,1) + P(D = 80, p = 1.32,1) + P(D = 80, p = 1.08,1)]$$

$$= 0.25 \times [35{,}782 + 45{,}382 - 4{,}582 - 4{,}582]$$

$$= \$18{,}000$$

Evaluating the Fixed Lease Option

$$PVEP(D = 100, p = 1.20, 1) = \frac{EP\left(D = 100, p = 1.20, 1\right)}{\left(1 + k\right)}$$

$$= \frac{\$18{,}000}{\left(1.1\right)} = \$16{,}364$$

$$P(D = 100,\ p = 1.20, 0) = (100{,}000 \times 1.22) - (100{,}000 \times 1)$$
$$+\ PVEP(D = 100,\ p = 1.20, 0)$$

$$= \$22{,}000 + \$16{,}364 = \$38{,}364$$

Evaluating the Fixed Lease Option

- Recall that when uncertainty was ignored, the N P V for the lease option was $60,182
- However, the manager would probably still prefer to sign the three-year lease for 100,000 sq. ft. because this option has the higher expected profit

Evaluating the Flexible Lease Option

Period 2 Profit Calculations at Trips Logistics with Flexible Lease Contract

Node	Warehouse Space at \$1 (W)	Warehouse Space at Spot Price (S)	Profit $P(D =, p =, 2) = D \times 1.22 - (W \times 1 + S \times p)$
$D = 144, p = 1.45$	100,000 sq. ft.	44,000 sq. ft.	\$11,880
$D = 144, p = 1.19$	100,000 sq. ft.	44,000 sq. ft.	\$23,320
$D = 144, p = 0.97$	100,000 sq. ft.	44,000 sq. ft.	\$33,000
$D = 96, p = 1.45$	96,000 sq. ft.	0 sq. ft.	\$21,120
$D = 96, p = 1.19$	96,000 sq. ft.	0 sq. ft.	\$21,120
$D = 96, p = 0.97$	96,000 sq. ft.	0 sq. ft.	\$21,120
$D = 64, p = 1.45$	64,000 sq. ft.	0 sq. ft.	\$14,080
$D = 64, p = 1.19$	64,000 sq. ft.	0 sq. ft.	\$14,080
$D = 64, p = 0.97$	64,000 sq. ft.	0 sq. ft.	\$14,080

Evaluating the Flexible Lease Option

Period 1 Profit Calculations at Trips Logistics with Flexible Lease Contract

Node	***EP*(*D* =, *p* =, 1)**	**Warehouse Space at $1 (*W*)**	**Warehouse Space at Spot Price (*S*)**	***P*(*D* =, *p* =, 1) = *D* × 1.22 – (*W* x 1 + *S* x *p*) + *EP*(*D* =, *p* = ,1)(1 + *k*)**
D = 120, *p* = 1.32	0.25 × (11,880 + 23,320 + 21,120 + 21,120) = $19,360	100,000	20,000	$37,600
D = 120, *p* = 1.08	0.25 × (23,320 + 33,000 + 21,120 + 21,120) = $24,640	100,000	20,000	$47,200
D = 80, *p* = 1.32	0.25 × (21,120 + 21,120 + 14,080 + 14,080) = $17,600	80,000	0	$33,600
D = 80, *p* = 1.08	0.25 × (21,920 + 21,920 + 14,080 + 14,080) = $17,600	80,000	0	$33,600

Decision Tree – Trips Logistics

Option	**Value**
All warehouse space from the spot market	$5,471
Lease 100,000 sq. ft. for three years	$38,364
Flexible lease to use between 60,000 and 100,000 sq. ft.	$46,545