

# Practice

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# Practice

## TUTORIAL 1: DEMAND FORECASTING

- 1) An electrical contractor's records during the last five weeks indicate the following number of job requests:

Week:	1	2	3	4	5
Requests:	20	22	18	21	22

Predict the number of requests for week 6 using each of these methods:

- a) Naïve
- b) Four-week moving average
- c) Exponential smoothing with  $\alpha = 0.3$ .

a) 22

b)  $\frac{22+18+21+22}{4} = 20.75$

c)  $F_t = F_{t-1} + \alpha(A_{t-1} - F_{t-1})$

$$F_1 = 20$$

$$F_2 = 20 + 0.3(20 - 20) = 20$$

$$F_3 = 20 + 0.3(22 - 20) = 20.6$$

$$F_4 = 20.6 + 0.3(18 - 20.6) = 19.82$$

$$F_5 = 19.82 + 0.3(21 - 19.82) = 20.17$$

$$F_6 = 20.17 + 0.3(22 - 20.17) = 20.72$$

# Practice

2. A manager has just received an evaluation from an analyst on two potential forecasting methods. The analyst is indifferent between the two methods, saying that they should be equally accurate and in control. The demand and the forecasts using the two methods for nine periods follow:

Period:	1	2	3	4	5	6	7	8	9
Demand:	37	39	37	39	45	49	47	49	51
Method 1:	36	38	40	42	46	46	46	48	52
Method 2:	36	37	38	38	41	52	47	48	52

- i. Calculate the MSE, MAD, and MAPE for each method. Does one method seem superior? Explain.
- ii. Do all three measures of method errors provide the same conclusion (i.e. are they consistent) in this scenario? Do you expect consistent results in every case? Explain.
- iii. In practice, either MAD, MSE, or MAPE would be employed to compute a measure of forecast errors. What factors might lead a manager to favour one?
- iv. Calculate 2s control limits and construct a 2s control chart for each method and interpret them. Do you agree with the analyst?

i.  $MSE = \frac{\sum(A_i - F_i)^2}{n}, MAD = \frac{\sum|e|}{n}, MAPE = \frac{\sum\left|\frac{|A_i - F_i|}{A_i}\right| \times 100}{n}$

Method	MSE	MAD	MAPE
1	3.7	1.7	4.0
2	3.8	16	3.6

Both methods have similar *MSE*, *MAD*, *MAPE*, so neither is superior.

- ii. In this case, all calculations are similar, but may not be the same in other cases.
- iii. *MSE* is more sensitive to large forecast errors, *MAD* is easy to calculate, *MAPE* is easy to understand.
- iv.  $s_1 = \sqrt{MSE_1} = \sqrt{3.7} = 1.92, s_2 = \sqrt{MSE_2} = \sqrt{3.78} = 1.95$

Method 1: 2s control limits:  $0 \pm 2s_1 = 0 \pm 2(1.92) \Rightarrow 0 \pm 3.8$

Method 2: 2s control limits:  $0 \pm 2s_2 = 0 \pm 2(1.95) \Rightarrow 0 \pm 3.9$

Similar 2s control limits, however some errors outside limits.

# Practice

- 3) Develop a linear trend equation for the following data on demand for white bread loaves at a bakery (using Excel is recommended).
- Use the linear trend equation to forecast demand on days 16.

Day	Loafs
1	200
2	214
3	211
4	228
5	235
6	232
7	248
8	250
9	253
10	267
11	281
12	275
13	280
14	288
15	310

- The variations around the linear trend line seem to have above and below the line runs. Therefore, use trend-adjusted exponential smoothing with  $\alpha$  and  $\beta$  to model the bread demand. Use the first four days to estimate the initial smoothed series (use the average of the first four days) and smoothed trend (use the increase from day 1 to day 4 divided by 3). Start forecasting day 5. What is the forecast for day 16?

$$\alpha = 0.3, \beta = 0.2$$

- Equation of the trend:  $y = 7x + 195.47$

$$D_{16} = 7(16) + 195.47 \Rightarrow D_{16} = 307.47$$

- $S_t = TAF_t + \alpha(A_t - TAF_t)$

$$T_t = T_{t-1} + \beta(S_t - S_{t-1} - T_{t-1})$$

$$TAF_{t+1} = S_t + T_t$$

$$T_4 = \frac{228 - 200}{3} = 9.33, S_4 = \frac{200 + 214 + 211 + 228}{4} = 213.25$$

Use above equations each time to get  $TAF_{16} = S_{15} + T_{15} = 303.53 + 7.64 = 311.17$ .

## Practice

- 4) A gift shop in a tourist centre is open only on weekends (Friday, Saturday, and Sunday). The owner-manager hopes to improve scheduling of part-time employees by determining seasonal relatives for each of these days. Data on recent activity at the store (sales transactions per day) are shown in the following table:

	Week					
	1	2	3	4	5	6
Friday	149	154	152	150	159	163
Saturday	250	255	260	268	273	276
Sunday	166	162	171	173	176	183

- a) Develop seasonal relatives for each day using the centered moving average method.
  - b) Deseasonalize the data, fit an appropriate model to the deseasonalized data, project three days ahead, and reseasonalize the projections to forecast the sales transactions for each day, Friday to Sunday, of next week.

a) Seasonal relatives are shown as the values in the *adjusted* row:

P3-11					
a	Week	Day	Sales	CMA <sub>3</sub>	Sales/CMA <sub>3</sub>
1	Fri	149		188.3	1.327
	Sat	250		190.0	0.874
	Sun	166		191.7	0.803
2	Fri	154		190.3	1.340
	Sat	255		189.7	0.854
	Sun	162		191.3	0.794
3	Fri	152		194.3	1.338
	Sat	260		193.7	0.883
	Sun	171		196.3	0.764
4	Fri	150		197.0	1.360
	Sat	268		200.0	0.865
	Sun	173		201.7	0.788
5	Fri	159		202.7	1.347
	Sat	273		204.0	0.863
	Sun	176		205.0	0.795
6	Fri	163		207.3	1.331
	Sat	274			
	Sun	183			
		Fri	Sat	Sun	
		Week 1	1.327	0.874	
		Week 2	0.803	1.340	0.854
		Week 3	0.794	1.338	0.883
		Week 4	0.764	1.360	0.865
		Week 5	0.788	1.347	0.863
		Week 6	0.795	1.331	
		avg	0.799	1.341	0.868
		adjusted	0.799	1.342	0.868

CMA<sub>3</sub> → no. of seasons  
Fri & Sat, Sun

$250/188.3 = 1.327$

$276/207.3 = 1.331$

Next Step: calculate avg. of Sales/CMA<sub>3</sub> for each season

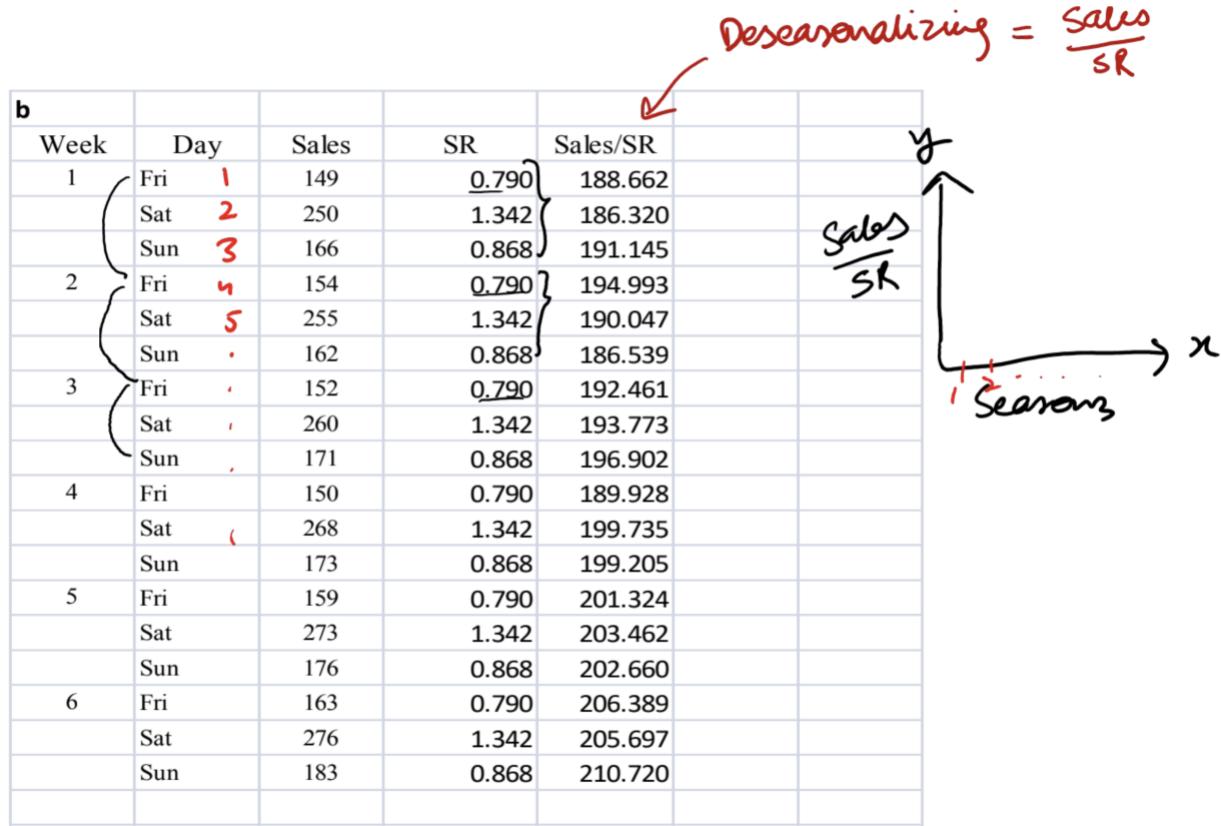
Adjusted SR = Avg<sub>S</sub> ×  $\frac{\text{No. of seasons}}{\text{Avg}}$

$= 0.789 \times \frac{3}{2.997}$

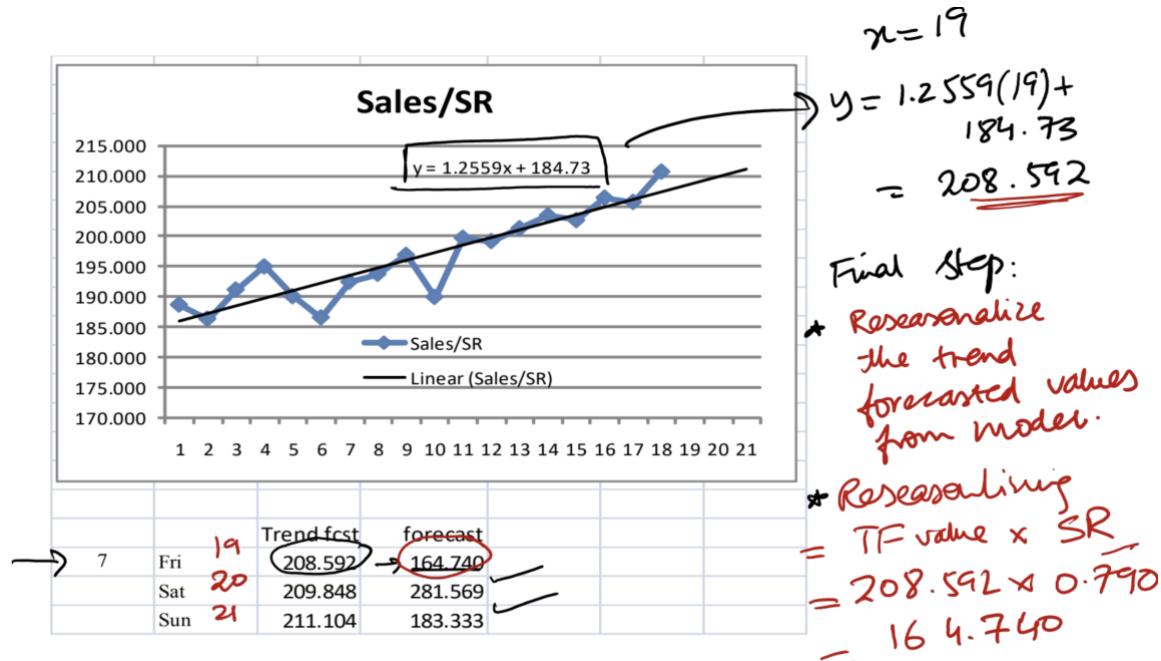
$= 0.790$

# Practice

- b) Deseasonalized data is shown as the values in the *Sales/SR* column:



The model, projection, and reseasonalized data is shown below:



# Practice

## TUTORIAL 2: CAPACITY PLANNING AND FACILITY LAYOUT

1. Determine the utilization and the efficiency for each of these situations:
  - a. A loan processing operation that processes an average of 7 loans per day. The operation has a design capacity of 10 loans per day and an effective capacity of 8 loans per day.
  - b. A furnace repair team that services an average of four furnaces a day if the design capacity is six furnaces a day and the effective capacity is five furnaces a day.
  - c. Would you say that systems that have higher efficiency ratios than other systems will always have higher utilization ratios than those other systems? Explain.

- a. *actual output = 7, design capacity = 10, effective capacity = 8*

$$\text{utilization} = \frac{\text{actual output}}{\text{design capacity}} = \frac{7}{10} = 70\%$$

$$\text{efficiency} = \frac{\text{actual output}}{\text{effective capacity}} = \frac{7}{8} = 87.5\%$$

- b. *actual output = 4, design capacity = 6, effective capacity = 5*

$$\text{utilization} = \frac{\text{actual output}}{\text{design capacity}} = \frac{4}{6} = 66\%$$

$$\text{efficiency} = \frac{\text{actual output}}{\text{effective capacity}} = \frac{4}{5} = 80\%$$

- c. No because utilization depends on design capacity while efficiency depends on effective capacity.

# Practice

2. Corner Tavern is a small-town bar that sells only bottled beer. The average price of a bottle of beer at the tavern is \$3.00 and the average cost of bottle of beer to the tavern is \$1.00. The tavern is open every night. One bartender and two to three waitresses are on duty each night. The fixed costs (salaries, rent, tax, utilities, etc.) total \$260,000 per year.

- a. The owner wishes to know how many bottles of beer the tavern must sell during the year to start making profit.
- b. What is the revenue at the break-even quantity found in part a.
- c. The owner thinks \$50,000 is a reasonable annual profit. How many bottles of beer should the tavern sell to make \$50,000 profit?
- d. An available option is to open the tavern earlier on the weekends. The attraction would be discount of \$0.50 off the regular price. The extra salaries of waitresses and bartender for the whole year are estimated to be \$30,000. How many extra bottles of beer must the tavern sell in order to break-even in this option?

a.  $\text{average price } (R) = \$3.00, \text{average cost } (v) = \$1.00, \text{fixed cost } (FC) = \$260,000$

$$Q_{BEP} = \frac{FC}{R - v} = \frac{260,000}{3 - 1} = 130,000 \text{ bottles}$$

b.  $TR_{BEP} = Q_{BEP} \cdot R = 130,000 \cdot 3 = \$390,000$

c.  $Q = \frac{P+FC}{R-v} = \frac{50,000+260,000}{3-1} = 155,000 \text{ bottles}$

d.  $Q'_{BEP} = \frac{FC'}{R'-v} = \frac{30,000}{2.5-1} = 20,000 \text{ bottles}$

# Practice

3. A producer of pottery is considering the addition of a new plant to absorb the backlog of demand that now exists. The primary location being considered will have fixed costs of \$9,200 per month and variable costs of 70 cents per unit produced. Each item is sold to retailers at a price that averages 90 cents.

- What volume per month is required in order to break even?
- What profit would be realized on a monthly volume of 61,000 units? 87,000 units?
- What volume is needed to obtain a profit of \$16,000 per month?
- What volume is needed to provide a revenue of \$23,000 per month?
- Plot the total cost and total revenue lines.

a.  $FC = \$9,200, v = 70 \text{ cents} \rightarrow \$0.7, R = 90 \text{ cents} \rightarrow \$0.9$

$$Q_{BEP} = \frac{FC}{R - v} = \frac{9,200}{0.9 - 0.7} = 46,000 \text{ units}$$

b.  $P = Q(R - v) - FC$

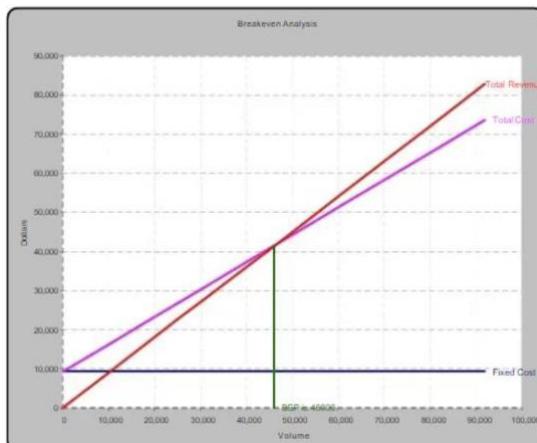
$$P_1 = 61,000(0.9 - 0.7) - 9,200 = \$3,000$$

$$P_2 = 87,000(0.9 - 0.7) - 9,200 = \$8,200$$

c.  $Q = \frac{P+FC}{R-v} = \frac{16,000+9,200}{0.9-0.7} = 126,000 \text{ units}$

d.  $Q = \frac{P+FC}{R-v} = \frac{23,000+9,200}{0.9-0.7} = 161,000 \text{ units}$

e. Plot of *total cost* ( $TC$ ) =  $0.7Q + 10,000$  and *total revenue* ( $TR$ ) =  $0.9Q$  lines:



# Practice

## TUTORIAL 3: PROCESS DESIGN AND FACILITY LAYOUT

- 1) An assembly line with 17 tasks is to be balanced. The longest task is 2.4 minutes, and the total time for all tasks is 18 minutes. The line will operate for 450 minutes per day.
  - a. What are the minimum and maximum cycle times?
  - b. What range of output is theoretically possible for the line?
  - c. What is the minimum number of workstations needed if the maximum output rate is to be sought?
  - d. What cycle time will provide an output rate of 125 units per day?
  - e. What output potential will result if the cycle time is (1) 9 minutes? (2) 15 minutes?

$$OT = 450 \text{ minutes}$$

a. *Minimum cycle time = length of longest task = 2.4 minutes*

*Maximum cycle time =  $\sum$  task times = 18 minutes*

b. At 2.4 min:  $\frac{450}{2.4} = 187.5 \text{ units}$

*At 18 min:  $\frac{450}{18} = 25 \text{ units}$*

c.  $N = \frac{D \times \sum t}{OT} = \frac{187.5 \times 18}{450} = 7.5 \rightarrow 8$

d. *Output =  $\frac{OT}{CT}$ , Solving for CT:  $CT = \frac{450}{125} = 3.6 \text{ minutes/cycle}$*

e. Potential output:

(1)  $CT = 9 \text{ min} \rightarrow \frac{OT}{CT} = \frac{450}{9} = 50 \text{ units}$

(2)  $CT = 15 \text{ min} \rightarrow \frac{450}{15} = 30 \text{ units}$

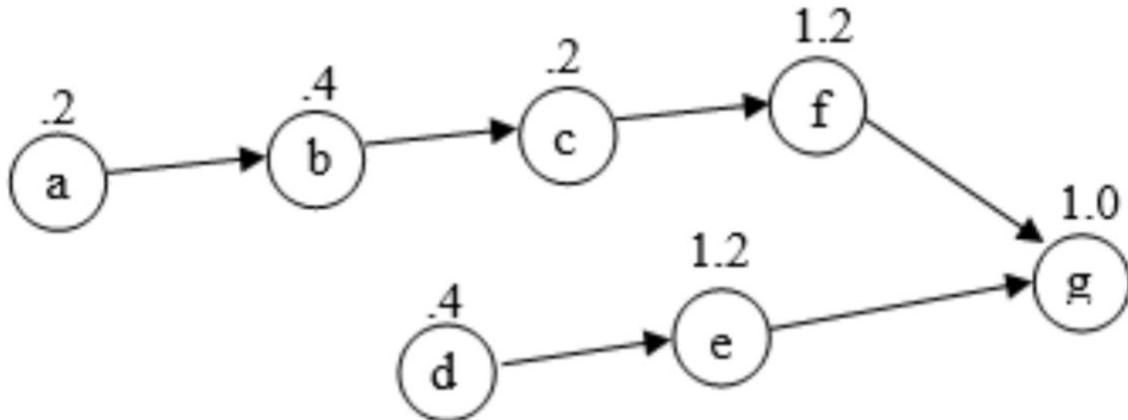
# Practice

- 2) As part of a major plant renovation project, the industrial engineering department has been asked to balance a revised assembly operation to achieve an output of 240 units per eight-hour day. Task times and precedence relationships are as follows:

- Draw the precedence diagram.
- Determine the minimum cycle time, the maximum cycle time, and the calculated cycle time.
- Determine the minimum number of stations needed.
- Assign tasks to workstations on the basis of greatest number of following tasks. Use longest processing time as a tiebreaker. If ties still exist, assume indifference in choice.
- Compute the percentage of idle time for the assignment in part d.

Task	Duration (minutes)	Immediate Predecessor
a	0.2	—
b	0.4	a
c	0.2	b
d	0.4	—
e	1.2	d
f	1.2	c
g	1.0	e, f

- a. Precedence diagram:



- b. *Minimum cycle time = maximum task time = 1.2 minutes*

$$\text{Maximum cycle time} = 0.2 + 0.4 + 0.2 + 0.4 + 1.2 + 1.2 + 1.0 = 4.6 \text{ minutes}$$

$$CT = \frac{OT}{\text{output}} = \frac{480 \text{ min/day}}{240 \text{ units/day}} = 2 \text{ minutes}$$

- c.  $N = \frac{\sum t}{CT} = \frac{4.6}{2.0} = 2.3 \rightarrow 3 \text{ stations}$

- d. Assign tasks to workstations:

# Practice

**Task              Number of following tasks**

A	4
B	3
C	2
D	2
E	1
F	1
G	0

**Assembly Line Balancing Table (CT = 2 minutes)**

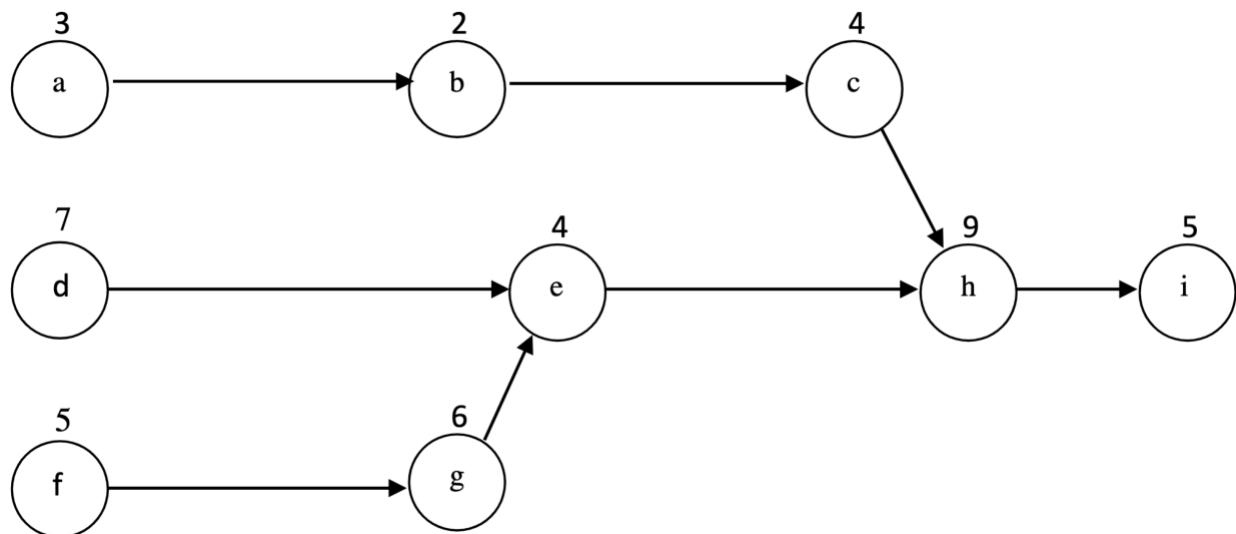
Work Station	Assigned Task	Task Time	Time Remaining	Feasible tasks Remaining
I	A	0.2	1.8	B,D
	B	0.4	1.4	C, D
	D	0.4	1.0	C
	C	0.2	0.8	E
II	E	1.2	0.8	F
III	F	1.2	0.8	G
IV	G	1.0	1.0	-

e.  $\text{Idle percent} = \frac{0.8+0.8+0.8+1.0}{(4)(2)} = \frac{3.4}{8.0} = 42.5\%$

# Practice

- 3) A manager wants to assign tasks to workstations in order to achieve an hourly output rate of four units. The department uses a working time of 56 minutes per hour.

- a. Assign the tasks shown in the following precedence network (times are on the nodes and are in minutes) to workstations using the following heuristic rules: (i) "Assign the task with the largest positional weight." (ii) Tiebreaker: "Assign the task with the longest time." If a tie still exists, choose randomly.
- b. What is the efficiency?
- c. Calculate the percentage idle time for the line.



a. *Desired output = 4 units/hour*

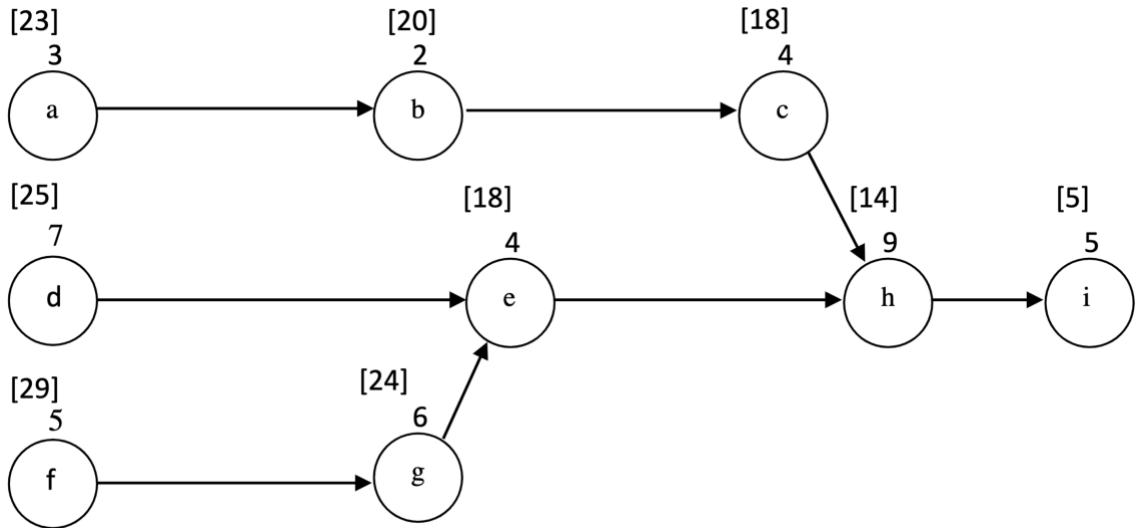
*Operating time = 56 minutes/hour*

$$CT = \frac{\text{Operating time}}{\text{Desired output}} = \frac{56 \text{ minutes/hour}}{4 \text{ units/hour}} = 14 \text{ minutes/unit}$$

$$N_{min} = \frac{\sum t}{CT} = \frac{3+2+4+7+4+5+6+9+5}{14} = 3.21 \rightarrow 4 \text{ workstations}$$

Positional weights:

# Practice



Station	Time Remaining	Feasible Remaining	Assigned Task	Task Time	Idle
1	14	a, d, f	f	(5)	
	9	a, d, g	d	(7)	
	2	a, g	--		2
2	14	a, g	g	(6)	
	8	a, e	a	(3)	
	5	b, e	b	(2)	
	3	c, e	--		3
3	14	c, e	c*, e	(4)	
	10	e	e	(4)	
	6	h	--		6
4	14	h	h	h (9)	
	5	i	i	i (5)	0
					11

b. Efficiency =  $1 - \frac{\text{Total idle time}}{CT \times \# \text{ of stations}} = 1 - \frac{11}{14 \times 4} = 80.4\%$

c. Percentage idle time =  $\frac{\sum(\text{idle time})}{N \times CT} \times 100 = \frac{11}{4 \times 14} \times 100 = 19.64\%$

4. Fixed-Position Layout: Product or project remains stationary, and workers, materials, and equipment are moved as needed.

5. Cycle Time: The maximum time allowed at each workstation to complete its set of tasks on a unit.

# Practice

## TUTORIAL 4: QUALITY MANAGEMENT AND STATISTICAL CONTROL

- 1) An air-conditioning repair department manager has compiled on the primary reason for 41 service calls during the previous week, as shown. Using the data, make a check sheet for the problem types for each customer type, and then construct a Pareto chart for each type of customer.

Job Number	Problem/Customer Type	Job Number	Problem/Customer Type	Job Number	Problem/Customer Type
1	F/R	15	F/C	29	O/C
2	O/R	16	O/C	30	N/R
3	N/C	17	W/C	31	N/R
4	N/R	18	N/R	32	W/R
5	W/C	19	O/C	33	O/R
6	N/R	20	F/R	34	O/C
7	F/R	21	F/R	35	N/R
8	N/C	22	O/R	36	W/R
9	W/R	23	F/R	37	O/C
10	N/R	24	N/C	38	O/R
11	N/R	25	F/R	39	F/R
12	F/C	26	O/R	40	N/R
13	N/R	27	W/C	41	O/C
14	W/C	28	O/C		

Key:

**Problem Type**

N: Noisy

F: Equipment Failure

W: Runs warm

O: Odour

**Customer Type**

C: Commercial customer

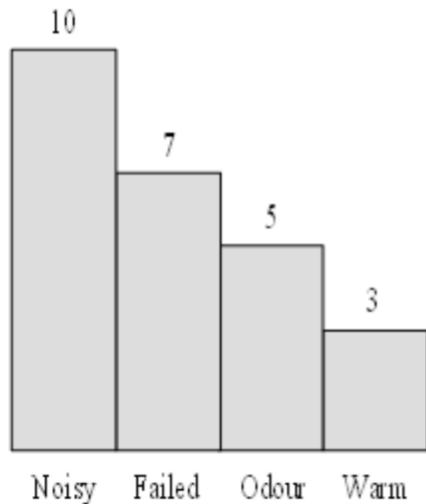
R: Residential customer

# Practice

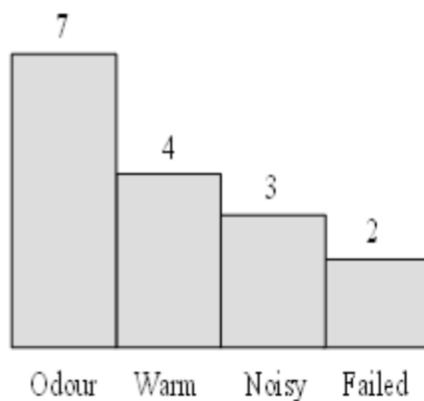
*Check sheet*

Equipment Problem					
Customer Type	Noisy	Failed	Odour	Warm	Totals
Residential	10	7	5	3	25
Commercial	3	2	7	4	16
<i>Totals</i>	<i>13</i>	<i>9</i>	<i>12</i>	<i>7</i>	<i>41</i>

Residential Customers



Commercial Customers

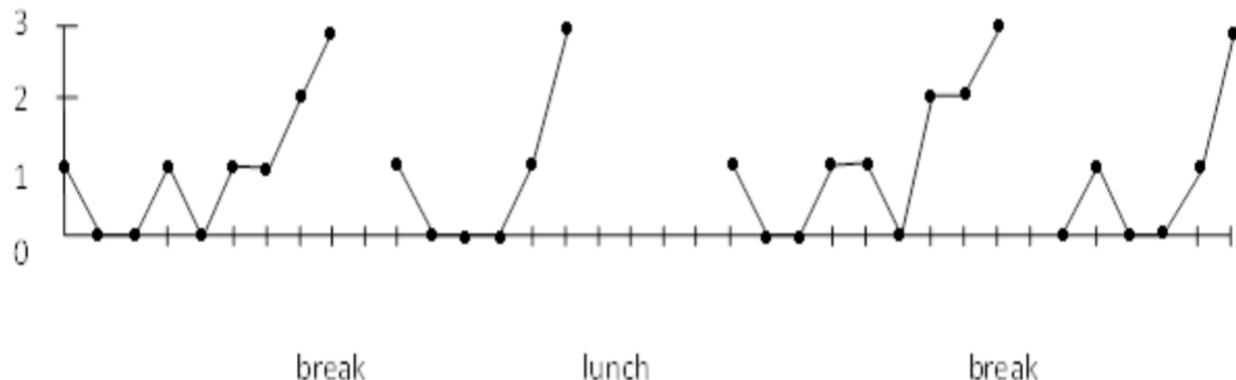


# Practice

- 2) Prepare a run chart for the number of defective computer monitors produced in a plant show below. Workers are given a 15-minute break at 10:15 a.m. and 3:15 p.m., and a lunch break at noon. What can you conclude?
- 

## MSCI 432 Winter 2020 – Production and Service Operations Management

Interval start time	Number of Defects	Interval start time	Number of Defects	Interval start time	Number of Defects
8:00	1	10:45	0	2:15	0
8:15	0	11:00	0	2:30	2
8:30	0	11:15	0	2:45	2
8:45	1	11:30	1	3:00	3
9:00	0	11:45	3	3:30	0
9:15	1	1:00	1	3:45	1
9:30	1	1:15	0	4:00	0
9:45	2	1:30	0	4:15	0
10:00	3	1:45	1	4:30	1
10:30	1	2:00	1	4:45	3



Increasing pattern of errors just before the break times, lunch, and the end of the shift.

# Practice

- 3) Prepare a scatter diagram for each of the following pairs of variables and then express in words the apparent relationship between the two variables. Put the first variable on the horizontal axis and the second variable on the vertical axis.

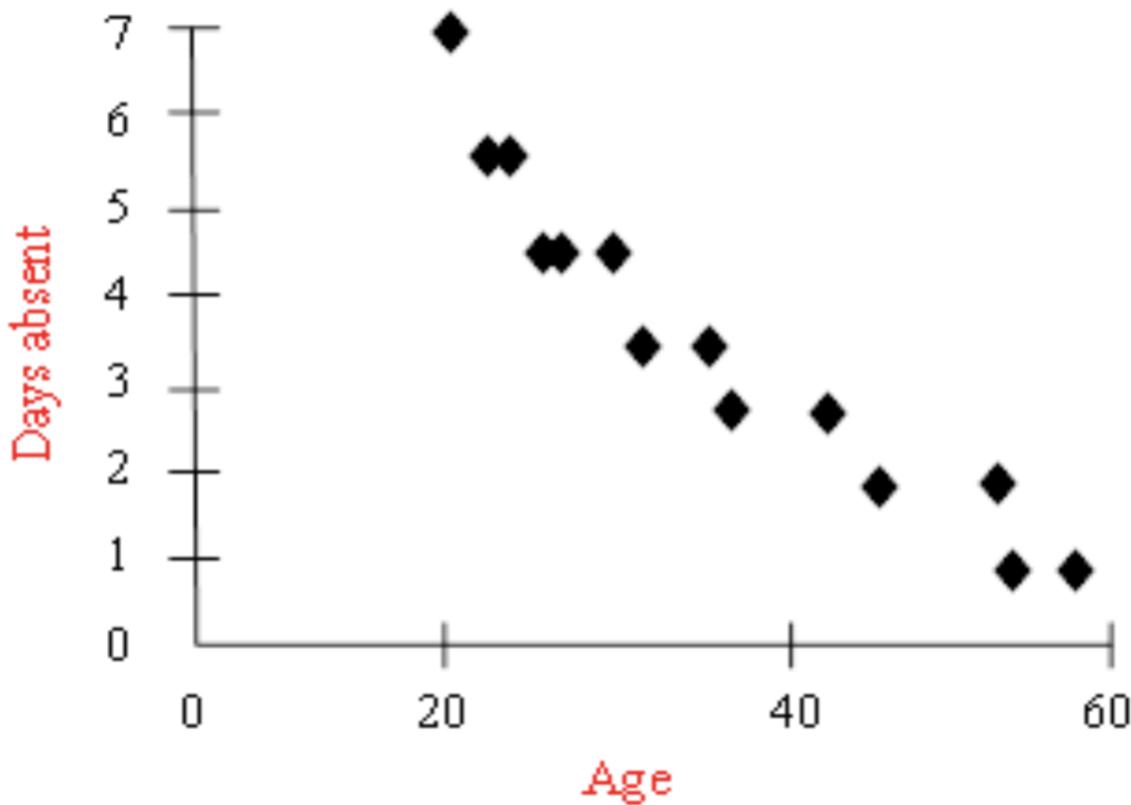
a.

Age	24	30	22	25	33	27	36	58	37	47	54	28	42	55
Days Absent	6	5	7	6	4	5	4	1	3	2	2	5	3	1

b.

Temperature	18	17	22	19	28	14	24	30	25	18	26
Error Rate	1	2	0	0	3	3	1	5	2	1	3

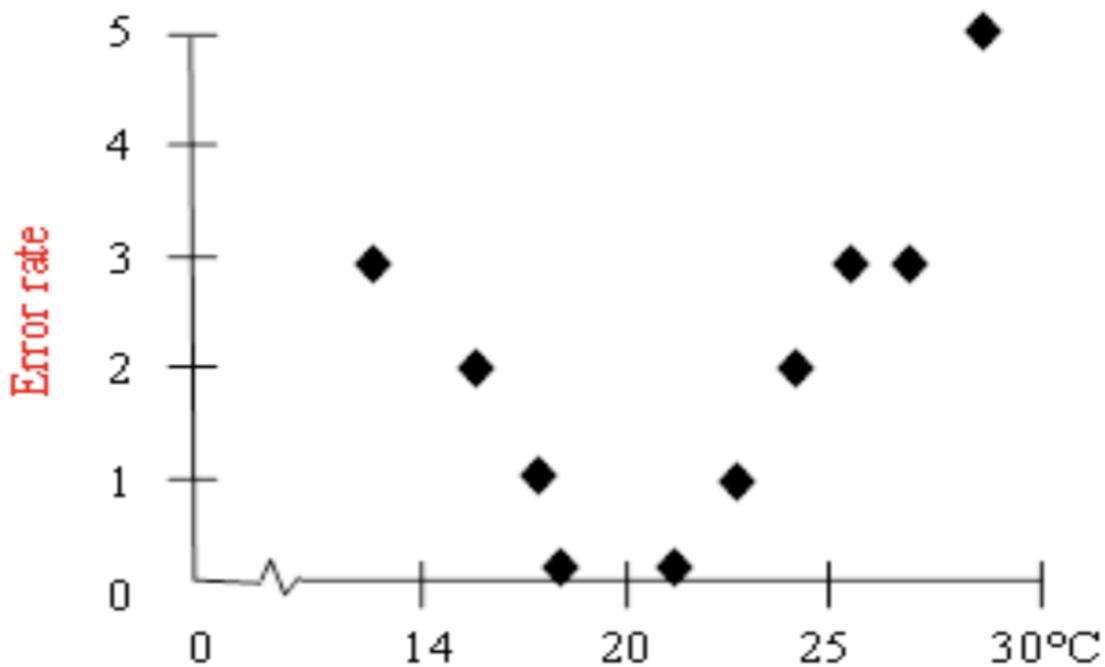
a. Scatter diagram for a:



Age and days absent are inversely related. Older employees missed fewer days.

# Practice

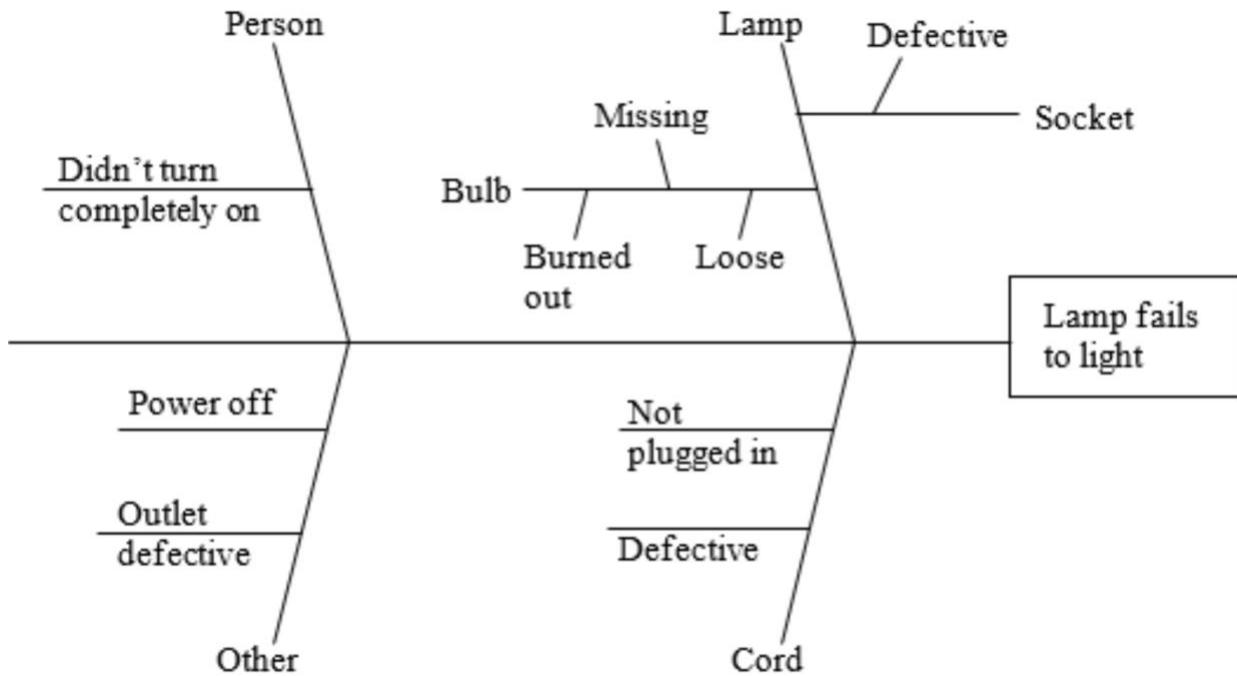
b. Scatter diagram for  $b$ :



Error rate is non-linearly related to temperature. It increases in colder or hotter temperatures. The lowest error rate occurs around  $20^{\circ}\text{C}$ .

# Practice

- 4) Suppose that a table lamp fails to light when turned on. Prepare a simple cause-and-effect diagram to analyze possible causes.



# Practice

- 5) An automatic filling machine is used to fill 2-litre bottles of cola. The machine's output is known to be approximately Normal with a mean of 2.0 litres and a standard deviation of 0.01 litres. Output is monitored using means of samples of five observations.
- Determine the upper and lower control limits that will include roughly 95.5 percent of sample means.
  - If the means for 6 samples are 2.005, 2.001, 1.998, 2.002, 1.995, and 1.999, is the process in control?

$$\mu = 2.0 \text{ litres}, \sigma = 0.01 \text{ litres}, n = 5$$

a. Control limits:  $\mu \pm z \frac{\sigma}{\sqrt{n}}$

$$95.44\% \rightarrow z = 2$$

$$UCL = 2.0 + 2 \frac{0.01}{\sqrt{5}} = 2.009 \text{ litres}$$

$$LCL = 2.0 - 2 \frac{0.01}{\sqrt{5}} = 1.991 \text{ litres}$$

- b. Yes, because they all fall within the control limits and the pattern of data seems random.

# Practice

- 6) Computer upgrades have a nominal time of 80 minutes. Samples of five observations each have been taken, and the results are as listed. Using factors from Table 10.3 , determine upper and lower control limits for mean and range charts, and decide if the process is in control.

SAMPLE						Grand	
1	2	3	4	5	6		
79.2	80.5	79.6	78.9	80.5	79.7		
78.8	78.7	79.4	79.4	79.6	80.6		
80.0	81.0	80.4	79.7	80.4	80.5		
78.4	80.4	80.3	79.4	80.8	80.0		
81.0	80.1	80.8	80.6	78.8	81.1		
<b>Mean</b>	79.5	80.14	80.10	79.60	80.02	80.38	79.95
<b>Range</b>	2.6	2.3	1.4	1.7	2.0	1.4	1.90

For  $n = 5$ , from Table 10 – 3:  $A_2 = 0.58$ ,  $D_3 = 0$ ,  $D_4 = 2.11$  (page 37 of lecture notes)

Mean control limits:

$$\bar{\bar{X}} \pm A_2 \bar{R} = 79.95 \pm 0.58(1.90) = 79.95 \pm 1.1$$

$$UCL = 81.05, LCL = 78.85$$

Range control limits:

$$UCL = D_4 \bar{R} = 2.11(1.90) = 4.009$$

$$LCL = D_3 \bar{R} = 0(1.90) = 0$$

Process is in control because all sample means and ranges fall within respective control limits.

7. Type I error concludes a process has changed when it actually has not, and Type II error concludes a process is in control when it is actually not.

# Practice

## TUTORIAL 5: SUPPLY CHAIN MANAGEMENT

- 1) Given the following data, determine the total annual cost of making and buying from each vendor A and vendor B. Estimated demand is 15,000 units a year. Which alternative is best?

	Make	Vendor A	Vendor B
Variable cost per unit	\$8	\$11	\$10
Annual fixed cost	\$20,000	\$0	\$5,000 (annual charge)

$$\text{Total Annual Cost} = \text{Fixed Cost} + \text{Variable Cost Per Unit} \times \text{Annual Quantity}$$

$$\text{Make: } \$20,000 + \$8 \times 15,000 = \$140,000$$

$$\text{Vendor A: } \$0 + \$11 \times 15,000 = \$165,000$$

$$\text{Vendor B: } \$5,000 + \$10 \times 15,000 = \$155,000$$

Thus, making the products yourself would be the best alternative.

- 2) Given the following data, determine the total annual cost of making with each of process A and B and of buying. Estimated demand is 10,000 units a year. Which alternate is best?

	Make		
	Process A	Process B	Buy
Variable cost per unit	\$50	\$52	\$51
Annual fixed cost	\$40,000	\$36,000	
Transportation cost per unit			\$2

$$\text{Process A: } \$40,000 + \$50 \times 10,000 = \$540,000$$

$$\text{Process B: } \$36,000 + \$52 \times 10,000 = \$556,000$$

$$\text{Buy: } \$51 \times 10,000 + \$2 \times 10,000 = \$530,000$$

Thus, buying would have the lowest total annual cost.

- 3) For the previous problem, suppose that the operations manager has said that it would be possible to achieve a 10 percent reduction in the fixed cost of Process B and a 10 percent reduction in B's variable cost per unit. Would that be enough to change your answer if the estimated annual cost to achieve those savings was \$8,000? Explain.

$$\text{New Process B: } \$36,000 \times 0.9 + \$8,000 + \$52 \times 0.9 \times 10,000 = \$508,400$$

Yes, the amount is less than buying, therefore make using Process B.

# Practice

4)

- a. Determine which delivery alternative would be most economical for 80 boxes of parts. Each box costs \$200 and annual holding cost is 30 percent of cost. Assume 365 days per year. Freight costs are:

Alternative	Freight Cost (for all 80 boxes)
Overnight	\$300
Two-day	\$260
Six-day	\$180

- b. For what range of unit cost for a box would each delivery alternative be least costly?

$$H = 0.30 \times 80 \text{ boxes} \times \$200 = \$4,800$$

a. Overnight:  $\$300 + \$4,800 \times \frac{1}{365} = \$313.15$

Two Day:  $\$260 + \$4,800 \times \frac{2}{365} = \$286.30$

Six Day:  $\$180 + \$4,800 \times \frac{6}{365} = \$258.90$

Six-day alternative is cheapest.

- b. Let  $X = \text{cost per box}$ . Then  $H = 24X$ , and the total costs will be:

$$\text{Overnight: } \$300 + \frac{24}{365}X$$

$$\text{Two Day: } \$260 + \frac{48}{365}X$$

$$\text{Six Day: } \$180 + \frac{144}{365}X$$

Overnight cheapest:

$$300 + \frac{24}{365}X < 260 + \frac{48}{365}X \Rightarrow X > \$608.33$$

$$300 + \frac{24}{365}X < 180 + \frac{144}{365}X \Rightarrow X > \$365.00$$

Two-day cheapest:

$$260 + \frac{48}{365}X < 300 + \frac{24}{365}X \Rightarrow X < \$608.33$$

# Practice

$$260 + \frac{48}{365}X < 180 + \frac{144}{365}X \Rightarrow X > \$304.17$$

Six-day cheapest:

$$180 + \frac{144}{365}X < 300 + \frac{24}{365}X \Rightarrow X < \$365.00$$

$$180 + \frac{144}{365}X < 260 + \frac{48}{365}X \Rightarrow X < \$304.17$$

Overnight is cheapest if  $unit\ cost > \$608.33$

Two-day cheapest if  $\$304.17 < unit\ cost < \$608.33$

Six-day cheapest if  $unit\ cost < \$304.17$

# Practice

- 5) Pratt & Whitney, a major aircraft engine manufacturer, wants to re-evaluate the transportation mode it uses to send unfinished parts to its joint-venture facility in Chengdu, China. Annual demand is 2,900 units. At present the company uses air freight. It takes approximately six days from Los Angeles to Chengdu (including pickup and delivery and customs delays). There are 20 parts in a lot, each weighing 30 kilograms. The air freight cost per part is \$90. The pickup and delivery charges at origin and destination add up to \$15 per part.

The alternative is to use an ocean liner to ship the parts to Shanghai and from there to either use a truck or a train (a 2,000 km distance). The ocean freight for this lot size will cost \$30 per part and will take 15 days. The truck from Shanghai to Chengdu will cost \$20 per part and will take six days (including pickup and delivery and customs delays). Transportation by rail will cost \$15 per part and will take 14 days (including pickup and delivery and customs delays). In addition, for rail there is a \$10 per part charge for pickup and delivery.

The company's inventory holding cost rate is 12 percent per year, and the value of each part is \$1,000. Assume 365 days per year.

Due to variability of lead times, at the destination, safety stocks of 60, 210, and 290 units will be kept if air, ship and truck, and ship and train are used, respectively. Determine the cheapest (total freight, delivery, and in-transit and safety holding cost) mode of transportation for these parts.

Hint: The value of a part in Chengdu for calculating the safety-stock holding cost should include the freight cost.

Mode	Duration (days)	Cost (\$) Per Part
Air	6	$90 + 15 = 105$
Ocean, Truck	$15 + 6 = 21$	$30 + 20 = 50$
Ocean, Train	$15 + 14 = 29$	$30 + 15 + 10 = 55$

Mode	Annual Freight & Delivery Costs
Air	$\$105 \times 2,900 = \$304,500$
Ocean, Truck	$\$50 \times 2,900 = \$145,000$
Ocean, Train	$\$55 \times 2,900 = \$159,500$

# Practice

<b>Mode</b>	<b>Annual In-Transit Holding Costs</b>
Air	$\$1,000 \times 0.12 \times \frac{6}{365} \times 2,900 = \$5,720.55$
Ocean, Truck	$\$1,000 \times 0.12 \times \frac{21}{365} \times 2,900 = \$20,021.92$
Ocean, Train	$\$1,000 \times 0.12 \times \frac{29}{365} \times 2,900 = \$27,649.32$

<b>Mode</b>	<b>Annual Safety Stock Holding Costs</b>
Air	$60 \times (\$1,000 + \$105) \times 0.12 = \$7,956$
Ocean, Truck	$210 \times (\$1,000 + \$50) \times 0.12 = \$26,460$
Ocean, Train	$290 \times (\$1,000 + \$55) \times 0.12 = \$36,714$

<b>Mode</b>	<b>Annual Total Cost</b>
Air	$\$304,500 + \$5,720.55 + \$7,956 = \$318,176.55$
Ocean, Truck	$\$145,000 + \$20,021.92 + \$26,460 = \$191,481.92$
Ocean, Train	$\$159,500 + \$27,649.32 + \$36,714 = \$223,863.32$

The cheapest mode of transportation for these parts is by ocean and truck.

# Practice

## TUTORIAL 6: INVENTORY MANAGEMENT I

1)

A large bakery buys flour in 25-pound bags. The bakery uses an average of 1,215 bags a year. Preparing an order and receiving a shipment of flour involves a cost of \$10 per order. Annual carrying costs are \$75 per bag.

- a. Determine the economic order quantity.
- b. What is the average number of bags on hand?
- c. How many orders per year will there be?
- d. Compute the total cost of ordering and carrying flour.
- e. If holding costs were to increase by \$9 per year, how much would that affect the minimum total annual cost?

$$D = 1,215 \text{ bags a year}, S = \$10 \text{ per order}, H = \$75 \text{ per bag}$$

a.  $Q_0 = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(1,215)(10)}{75}} = \sqrt{324} = 18 \text{ bags}$

The EOQ of the bakery is 18 bags.

b.  $\text{Average inventory level} = \frac{Q_0}{2} = \frac{18}{2} = 9 \text{ bags}$

The average number of bags on hand is 9.

c.  $\text{Orders per year} = \frac{\text{Annual demand}}{\text{Economic order quantity}} = \frac{1,215}{18} = 67.5 \text{ bags}$

The number of orders per year is 67.5 bags.

d.  $\text{Total cost} = \text{Carrying cost} + \text{Ordering cost}$

$$\text{Total cost} = \frac{Q_0}{2}H + \frac{D}{Q_0}S = \frac{18}{2} \times 75 + \frac{1,215}{18} \times 10 = \$1,350$$

Total cost of ordering and holding flour is \$1,350.

e.  $\text{New carrying cost} = \$75 + \$9 = \$84$

$$Q_0 = \sqrt{\frac{2(1,215)(10)}{84}} = \sqrt{289.28} = 17.27 \text{ bags (round to 17 bags)}$$

$$\text{New total cost} = \frac{17}{2} \times 84 + \frac{1,215}{17} \times 10 = \$1,428.70$$

$\text{Affect in total cost} = \text{New total cost} - \text{Old total cost}$

$$\text{Affect in total cost} = \$1,428.70 - \$1,350 = \$78.70$$

The affect in total cost is \$78.70.

# Practice

2)

A produce distributor uses 800 packing crates a month, which it purchases at a cost of \$10 each. The manager has assigned an annual carrying cost of 35 percent of the purchase price per crate. Ordering costs are \$28. Currently the manager orders once a month. How much could the firm save annually in ordering and carrying costs by using the EOQ?

$$\text{Crates/month} = 800, \text{Purchase cost/crate} = \$10, H = 35\% \text{ of purchase cost}, S = \$28$$

Step 1: Calculate the annual demand:

$$D = \text{Monthly demand} \times 12 = 800 \times 12 = 9,600 \text{ crates}$$

Step 2: Calculate carrying cost:

$$H = 0.35 \times \$10 = \$3.5$$

Step 3: Calculate the EOQ:

$$Q_0 = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(9,600)(28)}{3.5}} = \sqrt{153,600} = 391.92 \approx 392 \text{ crates}$$

Step 4: Calculate the total cost when EOQ is ordered:

$$\text{Total cost} = \text{Carrying cost} + \text{Order cost} = \frac{Q}{2}H + \frac{D}{Q}S$$

$$\text{Total cost}_{EOQ} = \frac{392}{2} \times 3.5 + \frac{9,600}{392} \times 28 = 686 + 685.7 = \$1,372$$

Step 5: Calculate the total cost when 800 units are ordered per month:

$$\text{Total cost}_{800} = \frac{800}{2} \times 3.5 + \frac{9,600}{800} \times 28 = 1,400 + 336 = \$1,736$$

Step 6: Calculate the savings when EOQ is used:

$$\text{Amount saved} = \text{Total cost}_{800} - \text{Total cost}_{EOQ} = \$1,736 - \$1,372 = \$364$$

The amount that will be saved using EOQ is \$364.

# Practice

3)

The Friendly Sausage Factory (FSF) can produce hot dogs at a rate of 5,000 per day. FSF supplies hot dogs to local restaurants at a steady rate of 250 per day. The cost to prepare the equipment for producing hot dogs is \$66. Annual holding costs are 45 cents per hot dog. The factory operates 300 days a year. Find:

- a. The optimal run size.
- b. The number of runs per year.
- c. The length (in days) of a run.

$$p = 5,000/\text{day}, d = 250/\text{day}, S = \$66, H = \$0.45/\text{hot dog, days/year} = 300$$

a.  $D = \text{usage rate} \times \# \text{ of working days} = 250 \times 300 = 75,000 \text{ hot dogs/year}$

$$Q_p = \sqrt{\frac{2DS}{H}} \sqrt{\frac{p}{p-d}} = \sqrt{\frac{2(75,000)(66)}{0.45}} \sqrt{\frac{5,000}{5,000-250}} = 4812.37 \approx 4,812$$

The optimal run size is 4,812.

b.  $\text{Number of runs per year} = \frac{D}{Q_p} = \frac{75,000}{4,812} = 15.59 \text{ runs per year}$

The number of runs per year is 15.59.

c.  $\text{Number of days of a run} = \frac{Q_p}{p} = \frac{4,812}{5,000} = 0.96 \text{ days}$

The number of days to produce optimal run capacity is 0.96 days.

# Practice

4)

A chemical firm produces sodium bisulfate in 100-pound bags. Demand for this product is 20 tons per day. The capacity for producing the product is 50 tons per day. Setup costs \$100, and storage and handling costs are \$5 per ton a year. The firm operates 200 days a year. (*Note: 1 ton = 2,000 pounds.*)

- a. How many bags per run are optimal?
- b. What would the average inventory be for this lot size?
- c. Determine the approximate length of a production run, in days.
- d. About how many runs per year would there be?
- e. How much could the company save annually if the setup cost could be reduced to \$25 per run?

$$d = 20 \text{ tons/day}, p = 50 \text{ tons/day}, S = \$100, H = \$5/\text{ton/year}, \text{operation days} = 200$$

a.  $D = d \times \text{operation days} = 20 \text{ tons/day} \times 200 \text{ days} = 4,000 \text{ tons}$

Hence,  $D = 4,000$  tons.

- b. Step 1: Calculate the optimum quantity using the EPQ formula:

$$Q = \sqrt{\frac{2DS}{H}} \sqrt{\frac{p}{p-d}} = \sqrt{\frac{2(4,000)(100)}{5}} \sqrt{\frac{50}{50-20}} = 516.4 \text{ tons}$$

Step 2: Calculate the maximum inventory:

$$I_{MAX} = \frac{Q}{p}(p - d) = \frac{516.4}{50}(50 - 20) = 309.84 \text{ tons}$$

Step 3: Calculate the average inventory:

$$\text{Average inventory} = \frac{I_{MAX}}{2} = \frac{309.84}{2} = 154.92$$

The average inventory for this lot size is 154.92.

c. Length of production time =  $\frac{Q}{p} = \frac{516.4}{50} = 10.33 \text{ days}$

The approximate length of a production run is 10.33 days.

d. Production runs per year =  $\frac{D}{Q} = \frac{4,000}{516.4} = 7.75 \text{ runs} \approx 8 \text{ runs}$

The number of runs per year are about 8 runs.

- e. Step 1: Calculate the total cost of production at the current setup cost:

$$\text{Total cost} = \frac{I_{MAX}}{2} \times H + \frac{D}{Q} \times S = \frac{309.84}{2} \times \$5 + \frac{4,000}{516.4} \times \$100 = \$1,549$$

Step 2: Now, at the new setup cost, calculate the new optimal production quantity:

# Practice

$$Q = \sqrt{\frac{2DS}{H}} \sqrt{\frac{p}{p-d}} = \sqrt{\frac{2(4,000)(25)}{5}} \sqrt{\frac{50}{50-20}} = 258.2 \text{ tons}$$

Step 3: Calculate the new maximum inventory:

$$I_{MAX} = \frac{Q}{p}(p - d) = \frac{258.2}{50}(50 - 20) = 154.92 \text{ tons}$$

Step 4: Calculate the new total cost:

$$\text{Total cost} = \frac{I_{MAX}}{2} \times H + \frac{D}{Q} \times S = \frac{154.92}{2} \times \$5 + \frac{4,000}{258.2} \times \$25 = \$774.5$$

Step 5: Calculate the difference between the total costs:

$$\text{Difference} = \$1,549 - \$774.5 = \$774.5$$

The company can save \$774.5 by reducing the setup cost to \$25.

5) Explain briefly how a higher carrying cost can result in a decrease in inventory.

As holding inventory becomes more expensive, the company will order in smaller quantities (note  $H$  in the formula for EOQ). This will result in more frequent orders.

6) Explain how a decrease in setup time can lead to a decrease in the average amount of inventory a firm holds, and why that would be beneficial.

As machine setup time decreases, setup cost decreases, resulting in lower run size (note  $S$  in the EPQ), which results in lower average amount of WIP inventory. Overall inventory costs would decrease. Also, lower WIP results in less confusion and better quality.

7. When does the total cost curve reach its minimum value?

When *Ordering costs* = *Carrying costs*.

# Practice

## TUTORIAL 7: INVENTORY MANAGEMENT II

1. A manufacturer of exercise equipment purchases pulleys from a supplier who lists these prices: less than 1,000, \$5 each; 1,000 to 3,999, \$4.95 each; 4,000 to 5,999, \$4.90 each; and 6,000 or more, \$4.85 each. Ordering cost is \$50 per order, annual holding cost is 20% of purchase cost, and annual usage is 4,900 pulleys. Determine the order quantity that will minimize total cost.

$$D = 4,900 \text{ pulleys/year}, H = 0.20R, S = \$50$$

Range	R
0 – 999	\$5.00
1,000 – 3,999	\$4.95
4,000 – 5,999	\$4.90
6,000 +	\$4.85

$$EOQ_{R=\$4.85} = \sqrt{\frac{2DS}{iR}} = \sqrt{\frac{2(4,900)(50)}{0.20(4.85)}} = 710.7 \text{ or } 711 \text{ pulleys. } 711 < 6,000, \text{ EOQ is not feasible.}$$

$$EOQ_{R=\$4.90} = \sqrt{\frac{2(4,900)(50)}{0.20(4.90)}} = 707.1 \text{ or } 707 \text{ pulleys. } 707 < 4,000, \text{ EOQ is not feasible.}$$

$$EOQ_{R=\$4.95} = \sqrt{\frac{2(4,900)(50)}{0.20(4.95)}} = 703.53 \text{ or } 704 \text{ pulleys. } 704 < 1,000, \text{ EOQ is not feasible.}$$

$$EOQ_{R=\$5.00} = \sqrt{\frac{2(4,900)(50)}{0.20(5.00)}} = 700 \text{ pulleys. } 0 \leq 700 < 999, \text{ EOQ is feasible. Next, need to}$$

compare total cost of  $Q = 700$  units with those of  $Q = 1,000, Q = 4,000, Q = 6,000$ .

$$TC_{700} = \frac{Q}{2}H + \frac{D}{Q}S + RD = \frac{700}{2}(0.20)(5.00) + \frac{4,900}{700}(50) + 5.00(4,900) = \$25,200$$

$$TC_{1,000} = \frac{1,000}{2}(0.20)(4.95) + \frac{4,900}{1,000}(50) + 4.95(4,900) = \$24,995$$

$$TC_{4,000} = \frac{4,000}{2}(0.20)(4.90) + \frac{4,900}{4,000}(50) + 4.90(4,900) = \$26,031.25$$

$$TC_{6,000} = \frac{6,000}{2}(0.20)(4.85) + \frac{4,900}{6,000}(50) + 4.85(4,900) = \$26,715.83$$

Therefore, the order quantity that will minimize total cost is 1,000.

# Practice

2. Demand for an item is projected to be 100 units per month. The monthly holding cost is \$2 per unit, and it costs \$55 to process an order.

a. Determine the EOQ.

b. If the demand can wait at the cost of \$5 per unit per month, what should the order quantity and the amount short per order cycle be?

$$D = 100 \text{ units/month}, H = \$2/\text{unit/month}, S = \$55$$

a.  $EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(100)(55)}{2}} = 74.16 \text{ round to 74 units}$

b.  $B = \$5/\text{unit/month}$

$$Q = \sqrt{\frac{2DS}{H} \times \frac{H+B}{B}} = \sqrt{\frac{2(100)(55)}{2} \times \frac{2+5}{5}} = 87.75 \text{ round to 88 units}$$

$$Q_b = Q \times \frac{H}{H+B} = 88 \times \frac{2}{2+5} = 25.1 \text{ round to 25}$$

# Practice

3. A supermarket is open 360 days per year. Daily use of cash register tape averages 10 rolls, normally distributed, with a standard deviation of two rolls per day. The cost of ordering tapes is \$10 per order, and holding cost is 40 cents per roll a year. Lead time is three days.

- a. What is the EOQ?
- b. What ROP will provide a lead time service level of 96 percent?
- c. What ROP will provide an annual service level (i.e., fill rate) of 96 percent if order quantity = EOQ is used?

360 days,  $\bar{d} = 10 \text{ rolls/day}$ ,  $\sigma_d = 2 \text{ rolls/day}$ ,  $S = \$10$ ,  $H = \$0.40/\text{roll/year}$ ,  $LT = 3$

a.  $D = \bar{d} \times \text{number of days} = 10 \text{ rolls/day} \times 360 \text{ days/year} = 3,600 \text{ rolls/year}$

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(3,600)(10)}{0.40}} = 424.3 \text{ round to 424 rolls}$$

b. Lead time  $SL$  of 96%  $\rightarrow z = 1.75$  from Table 12-3

$$ROP = \bar{d} \cdot LT + z\sqrt{LT} \cdot \sigma_d = 10(3) + 1.75\sqrt{3}(2) = 36.06 \text{ round to 36}$$

c.  $SL_{\text{annual}} = 96\% = 0.96$

$$\sigma_{dLT} = \sigma_d \sqrt{LT} = 2\sqrt{3} = 3.46$$

$$E(z) = \frac{Q(1-SL_{\text{annual}})}{\sigma_{dLT}} = \frac{424(1-0.96)}{3.46} = 4.90$$

$\Rightarrow$  Table 12-3 to get  $z$ , but  $E(z) = 4.90$  is not in the table.

However, note that for values of  $E(z) > 2.4$ ,  $z = -E(z)$ .

Therefore, for  $E(z) = 4.90$ ,  $z = -4.90$ .

$$ROP = \bar{d} \cdot LT + z\sigma_{dLT} = 10(3) - 4.90(3.46) = 13.05 \text{ round to 13}$$

# Practice

**4.** Demand for vanilla ice cream at a small ice cream shop can be approximated by a Normal Distribution with a mean of 21 litres per week and a standard deviation of 3.5 litres per week. The ice cream is purchased from an ice cream producer. The store manager desires a lead time service level of 90 percent. Lead time from the producer is two days. The store is open seven days a week.

- If the EOQ/ROP model is used for ordering the ice cream from the producer, what ROP would be consistent with the desired lead time service level?
- If a fixed interval model is used instead, what order quantity should be used if the order interval is 7 days and 8 litres are in hand and none are on order at the time of order?

$$\bar{d} = 21 \text{ litres/wk}, \sigma_d = 3.5 \text{ litres/wk}, SL = 90\%, LT_{days} = 2 \text{ days}, \text{open 7 days/wk}$$

- $SL = 0.9 \rightarrow z = 1.28$  from Table 12-3

$$LT_{weeks} = \frac{LT_{days}}{\text{number of days/week}} = \frac{2 \text{ days}}{7 \text{ days/week}} = \frac{2}{7} \text{ weeks}$$

$$ROP = \bar{d} \cdot LT + z\sqrt{LT} \cdot \sigma_d = 21 \left(\frac{2}{7}\right) + 1.28 \sqrt{\frac{2}{7}}(3.5) = 8.39 \text{ litres}$$

- $OI_{days} = 7 \text{ days, on hand (inventory position)} = 8 \text{ litres}, I_{max}: \text{order up to level}$

$$OI_{weeks} = \frac{OI_{days}}{\text{number of days}} = \frac{7 \text{ days}}{7 \text{ days/week}} = \frac{7}{7} \text{ weeks}$$

$$I_{max} = \bar{d}(OI + LT) + z \cdot \sigma_d \sqrt{OI + LT} = 21 \left(\frac{7}{7} + \frac{2}{7}\right) + 1.28(3.5) \sqrt{\frac{7}{7} + \frac{2}{7}} = 32.08 \text{ round}$$

to 32 litres

$$Q(\text{order quantity}) = I_{max} - \text{on hand} = 32 - 8 = 24 \text{ litres}$$

# Practice

## TUTORIAL 8: AGGREGATE OPERATIONS PLANNING

**Procedure for Trial-and-Error worksheet approach in aggregate planning:**

- Determine production output by permanent workers (during regular time) for each period.
- Determine total units short and periods short.
- Determine the cheapest way (using trade-off analysis) to meet the units short, e.g.,
  - Hire temporary and/or part-time workers.
  - Use permanent workers during overtime.
  - Carry inventory from previous periods.
  - Meet demand from following periods (backorder).

# Practice

- 1) Calculate the total cost for each of the following aggregate plans using these unit costs:  
 Regular output = \$40, Overtime = \$50, Subcontract = \$60, Inventory per month = \$10.

a)

Month	Jan	Feb	Mar	Apr	May	Jun
<b>Forecast</b>	300	320	320	340	320	320
<b>Output</b>						
Regular	300	300	300	300	300	300
Overtime	20	20	20	20	20	20
Subcontract	0	0	0	0	0	0
<b>Output - Forecast</b>						
<b>Inventory</b>						
Beginning						
Ending						
Average						

b)

Month	Jul	Aug	Sep	Oct	Nov	Dec
<b>Forecast</b>	320	340	360	380	400	400
<b>Output</b>						
Regular	300	300	300	300	300	300
Overtime	20	20	20	20	30	30
Subcontract	20	30	40	40	60	70
<b>Output - Forecast</b>						
<b>Inventory</b>						
Beginning						
Ending						
Average						

- c) (Refer to part b) After complaints from some workers about working overtime every month during the first half of the year, the manager is now considering adding some temporary workers for the second half of the year, which would increase regular output to a steady 350 units a month, not using any overtime, and using subcontracting to make up the shortage. Determine the total cost.

# Practice

- a) Total cost from January to June:

Month			Jan	Feb	Mar	Apr	May	Jun	Total
Forecast			300	320	320	340	320	320	1,920
Output			320	320	320	320	320	320	1,920
Regular			300	300	300	300	300	300	1,800
Part Time									0
Overtime			20	20	20	20	20	20	120
Subcontract			0	0	0	0	0	0	0
Output - Forecast			20	0	0	-20	0	0	
Inventory									
Beginning			0	20	20	20	0	0	
Ending			20	20	20	0	0	0	
Average			10	20	20	10	0	0	60
Backorder									0
Costs:									
Regular	@	40	\$12,000	\$12,000	\$12,000	\$12,000	\$12,000	\$12,000	72,000
Part Time	@		\$0	\$0	\$0	\$0	\$0	\$0	0
Overtime	@	50	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000	6,000
Subcontract	@	60	\$0	\$0	\$0	\$0	\$0	\$0	0
Hire/Layoff									0
Inventory	@	10	\$100	\$200	\$200	\$100	\$0	\$0	600
Back orders	@		\$0	\$0	\$0	\$0	\$0	\$0	0
Total			\$13,100	\$13,200	\$13,200	\$13,100	\$13,000	\$13,000	\$ 78,600

- b) Total cost from July to December:

Month			Jan	Feb	Mar	Apr	May	Jun	Total
Forecast			320	340	360	380	400	400	2,200
Output			340	350	360	360	390	400	2,200
Regular			300	300	300	300	300	300	1,800
Part Time									0
Overtime			20	20	20	20	30	30	140
Subcontract			20	30	40	40	60	70	260
Output - Forecast			20	10	0	-20	-10	0	
Inventory									
Beginning			0	20	30	30	10	0	
Ending			20	30	30	10	0	0	
Average			10	25	30	20	5	0	90
Backorder									0
Costs:									
Regular	@	40	\$12,000	\$12,000	\$12,000	\$12,000	\$12,000	\$12,000	72,000
Part Time	@		\$0	\$0	\$0	\$0	\$0	\$0	0
Overtime	@	50	\$1,000	\$1,000	\$1,000	\$1,000	\$1,500	\$1,500	7,000
Subcontract	@	60	\$1,200	\$1,800	\$2,400	\$2,400	\$3,600	\$4,200	15,600
Hire/Layoff									0
Inventory	@	10	\$100	\$250	\$300	\$200	\$50	\$0	900
Back orders	@		\$0	\$0	\$0	\$0	\$0	\$0	0
Total			\$14,300	\$15,050	\$15,700	\$15,600	\$17,150	\$17,700	\$ 95,500

# Practice

- c) Increase regular output for overtime and subcontract:

Month			Jan	Feb	Mar	Apr	May	Jun	Total
Forecast			320	340	360	380	400	400	2,200
Production (Output)			350	350	350	350	350	350	2,100
Regular			350	350	350	350	350	350	2,100
Part Time									0
Overtime			0	0	0	0	0	0	0
Subcontract			0	0	0	0	0	0	0
Output - Forecast			30	10	-10	-30	-50	-50	-100
Inventory									
Beginning			0	30	40	30	0	-50	
Ending			30	40	30	0	-50	-100	
Average			15	35	35	15	-25	-75	0
Backorder							50	50	100
Costs:									
Regular	@	40	\$14,000	\$14,000	\$14,000	\$14,000	\$14,000	\$14,000	\$84,000
Part Time	@		\$0	\$0	\$0	\$0	\$0	\$0	0
Overtime	@	50	\$0	\$0	\$0	\$0	\$0	\$0	0
Subcontract	@	60	\$0	\$0	\$0	\$0	\$0	\$0	0
Hire/Layoff									0
Inventory	@	10	\$150	\$350	\$350	\$150	<span style="color:red;">-\$250</span>	<span style="color:red;">-\$750</span>	0
Back orders	@		\$0	\$0	\$0	\$0	\$0	\$0	0
Total			\$14,150	\$14,350	\$14,350	\$14,150	\$13,750	\$13,250	\$ 84,000

Add subcontract to eliminate backorder:

Month			Jan	Feb	Mar	Apr	May	Jun	Total
Forecast			320	340	360	380	400	400	2,200
Production (Output)			350	350	350	350	400	400	2,200
Regular			350	350	350	350	350	350	2,100
Part Time									0
Overtime			0	0	0	0	0	0	0
Subcontract			0	0	0	0	50	50	100
Output - Forecast			30	10	-10	-30	0	0	0
Inventory									
Beginning			0	30	40	30	0	0	
Ending			30	40	30	0	0	0	
Average			15	35	35	15	0	0	100
Backorder							0	0	0
Costs:									
Regular	@	40	\$14,000	\$14,000	\$14,000	\$14,000	\$14,000	\$14,000	\$84,000
Part Time	@		\$0	\$0	\$0	\$0	\$0	\$0	0
Overtime	@	50	\$0	\$0	\$0	\$0	\$0	\$0	0
Subcontract	@	60	\$0	\$0	\$0	\$0	\$3,000	\$3,000	6,000
Hire/Layoff									0
Inventory	@	10	\$150	\$350	\$350	\$150	\$0	\$0	1,000
Back orders	@		\$0	\$0	\$0	\$0	\$0	\$0	0
Total			\$14,150	\$14,350	\$14,350	\$14,150	\$17,000	\$17,000	\$ 91,000

# Practice

- 2) A manager would like to know the total cost of a plan that meets the forecasts below using a steady regular production rate of 200 units a month, a maximum of 20 units per month of overtime, and subcontracting as needed to make up any shortages. The unit costs are:  
 Regular output = \$35, Overtime = \$70, Subcontract = \$80

Month	1	2	3	4	5	6
Forecast	230	200	240	240	250	240

Month			Jan	Feb	Mar	Apr	May	Jun	Total
Forecast			230	200	240	240	250	240	1,400
Production (Output)			230	200	240	240	250	240	1,400
Regular			200	200	200	200	200	200	1,200
Part Time									0
Overtime			20	0	20	20	20	20	100
Subcontract			10	0	20	20	30	20	100
Output - Forecast			0	0	0	0	0	0	0
Inventory									
Beginning			0	0	0	0	0	0	
Ending			0	0	0	0	0	0	
Average			0	0	0	0	0	0	0
Backorder							0	0	0
Costs:									
Regular	@	35	\$7,000	\$7,000	\$7,000	\$7,000	\$7,000	\$7,000	42,000
Part Time	@		\$0	\$0	\$0	\$0	\$0	\$0	0
Overtime	@	70	\$1,400	\$0	\$1,400	\$1,400	\$1,400	\$1,400	7,000
Subcontract	@	80	\$800	\$0	\$1,600	\$1,600	\$2,400	\$1,600	8,000
Hire/Layoff									0
Inventory	@	0	\$0	\$0	\$0	\$0	\$0	\$0	0
Back orders	@		\$0	\$0	\$0	\$0	\$0	\$0	0
Total			\$9,200	\$7,000	\$10,000	\$10,000	\$10,800	\$10,000	\$ 57,000

# Practice

- 3) A manufacturer of heavy truck engines must develop a production plan, given the following demand forecasts for engine. The company currently has 13 workers and makes 130 engines per month. Regular labour cost is \$500 per engine. The beginning inventory is zero. Overtime labour costs \$750 per engine. Hiring cost is \$3000 per worker. Inventory holding cost is \$50 per engine per month, and backorder cost is \$250 per engine per month. Develop the minimum cost plan for this company. Hint: Start with level output / workforce plan, and use the trade-off analysis to show that changing this plan will only increase the total cost.

Month	1	2	3	4	5	6	7	8	Total
Forecast	120	135	140	120	125	125	140	135	1,040

Meeting demand not using the backorder:

Month			1	2	3	4	5	6	7	8	Total
Forecast			120	135	140	120	125	125	140	135	1,040
Production (Output)			130	130	130	130	130	130	130	130	1,040
	Regular		130	130	130	130	130	130	130	130	1,040
	Part Time										0
	Overtime										0
	Subcontract										0
Output - Forecast			10	-5	-10	10	5	5	-10	-5	0
Inventory											0
	Beginning		0	10	5	0	10	15	20	10	70
	Ending		10	5	0	10	15	20	10	5	75
	Average		5	8	3	5	13	18	15	8	73
Backorder					5						5
Costs:											0
	Regular	@ 500	\$65,000	\$65,000	\$65,000	\$65,000	\$65,000	\$65,000	\$65,000	\$65,000	520,000
	Part Time	@	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	0
	Overtime	@ 750	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	0
	Subcontract	@									0
	Hire/Layoff	@ 0									0
	Inventory	@ 50	\$250	\$375	\$125	\$250	\$625	\$875	\$750	\$375	3,625
	Back orders	@ 250	\$0	\$0	\$1,250	\$0	\$0	\$0	\$0	\$0	1,250
Total			\$65,250	\$65,375	\$65,125	\$65,250	\$65,625	\$65,875	\$65,750	\$65,375	523,625

Meeting demand using the backorder:

Month			1	2	3	4	5	6	7	8	Total
Forecast			120	135	140	120	125	125	140	135	1,040
Production (Output)			130	130	130	130	130	130	130	130	1,040
	Regular		130	130	130	130	130	130	130	130	1,040
	Part Time										0
	Overtime										0
	Subcontract										0
Output - Forecast			10	-5	-10	10	5	5	-10	-5	0
Inventory											0
	Beginning		0	10	5	0	5	10	15	5	50
	Ending		10	5	0	5	10	15	5	0	50
	Average		5	8	3	3	8	13	10	3	50
Backorder					5						5
Costs:											0
	Regular	@ 500	\$65,000	\$65,000	\$65,000	\$65,000	\$65,000	\$65,000	\$65,000	\$65,000	520,000
	Part Time	@	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	0
	Overtime	@ 750	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	0
	Subcontract	@									0
	Hire/Layoff	@ 300									0
	Inventory	@ 50	\$250	\$375	\$125	\$125	\$375	\$625	\$500	\$125	2,500
	Back orders	@ 250	\$0	\$0	\$1,250	\$0	\$0	\$0	\$0	\$0	1,250
Total			\$65,250	\$65,375	\$66,375	\$65,125	\$65,375	\$65,625	\$65,500	\$65,125	523,750

# Practice

Trade-Off Analysis	
OT	3750
Regular	5500
Meet demand but with backorders	1250 <span style="background-color: #e0e0e0;">&lt;-- Low Cost Solution</span>

# Practice

- 4) Banner Good Samaritan Medical Center is a 662-bed hospital. Like other hospitals, the number of its patients increases in the winter. The full-time equivalent (FTE) nurse requirements for Q1 to Q4 of next year are forecasted to be Q1: 1,300 FTE; Q2: 1,000 FTE; Q3: 800 FTE; and Q4: 1,000 FTE. Banner Good Samaritan employs 1,000 FTE permanent throughout the year. During peak season, it can employ up to 500 additional FTE temporary nurses from local temp agencies. Also, it can use up to 500 FTE of overtime (hours worked beyond an eight-hour shift in a day). Each FTE permanent nurse receives an average of \$8,000 a quarter. Each FTE of overtime work receives \$12,000 a quarter. Each FTE temp receives \$8,000 a quarter, but needs an average of \$1,000 for training (charged to the first quarter of employment).
- a) Set up this problem as a planning problem and determine the minimum cost plan. Briefly, state the trade-off analysis you used. Calculate the total cost. Note: if demand is less than the number of permanent nurses in a quarter, the nurses will still be paid but the idle time will be used as paid holidays and/or for further training.

Total cost using temporary FTEs:

Month			Q1	Q2	Q3	Q4	Total
Forecast			1300	1000	800	1000	4,100
Employees							4,300
	FTE		1000	1000	1000	1000	4,000
	Temp FTE <=500		300				300
	OT <=500		0				0
	New Temp FTEs		300				
Manpower Shortage							0
Costs per employee							0
	FTE	@ 8,000	\$8,000,000	\$8,000,000	\$8,000,000	\$8,000,000	32,000,000
	Temp FTE (Salary)	@ 8,000	\$2,400,000	\$0	\$0	\$0	2,400,000
	OT <=500	@ 12,000	\$0	\$0	\$0	\$0	0
	Temp/FTE (Training)	@ 1,000	\$300,000	\$0	\$0	\$0	300,000
Total			\$10,700,000	\$8,000,000	\$8,000,000	\$8,000,000	34,700,000

Total cost using overtime:

Month			Q1	Q2	Q3	Q4	Total
Forecast			1300	1000	800	1000	4,100
Employees							4,300
	FTE		1000	1000	1000	1000	4,000
	Temp FTE <=500		0				0
	OT <=500		300				300
	New Temp FTEs		0				
Manpower Shortage							0
Costs per employee							0
	FTE	@ 8,000	\$8,000,000	\$8,000,000	\$8,000,000	\$8,000,000	32,000,000
	Temp FTE (Salary)	@ 8,000	\$0	\$0	\$0	\$0	0
	OT <=500	@ 12,000	\$3,600,000	\$0	\$0	\$0	3,600,000
	Temp/FTE (Training)	@ 1,000	\$0	\$0	\$0	\$0	0
Total			\$11,600,000	\$8,000,000	\$8,000,000	\$8,000,000	35,600,000

Trade-Off Analysis		
Hiring Temp FTEs	34.7	<-- Low Cost
Overtime	35.6	