UNIVERSIDADE CATÓLICA PORTUGUESA
FACULDADE DE CIÊNCIAS ECONÓMICAS E EMPRESARIAIS

Operations Management

Work Book

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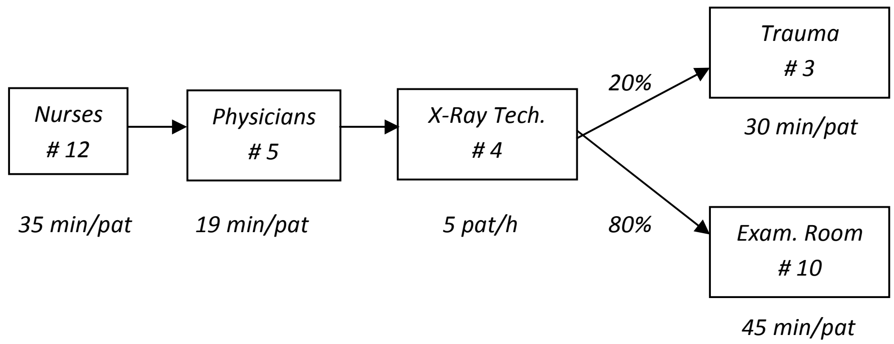
Operations Management

Work Book

MODULE 1 - PROCESS AND CAPACITY ANALYSIS

EXERCISE 1.1



a) What is the capacity of each resource in patient arrivals per hour?

Nurses = 20,6 patient/hour

Physicians = 15,8 patients/hour

X-ray Technicians = 20,0 patients/ hour

Examination Rooms = 16,7 patients/hour

Trauma Bays = 30,0 patients/hour

b) What is the system capacity in patient arrivals per hour? Which resource(s) is (are) the bottleneck?

The capacity of the ED is 15,8 patients/hour, and the physicians are the bottleneck.

c) How can the ED increase its capacity to be able to serve 16 patients per hour?

Physicians = 5,06 (6 Physicians) + 1 Physician

If the hospital were to add an additional physician to bring the total to 6, the maximum capacity of that resource would increase to 18.9 patients/hour. This would bring all resource capacities above the desired level of 16 patients/hour.

d) What resources (and how many of each) would the ED need to add to be able to serve 21 patients per hour if the trauma rate drops from 20% to 10%?

Nurses = 12,25 (~ 13) + 1 Nurse

Physicians = 6,65 (~ 7) + 2 Physicians

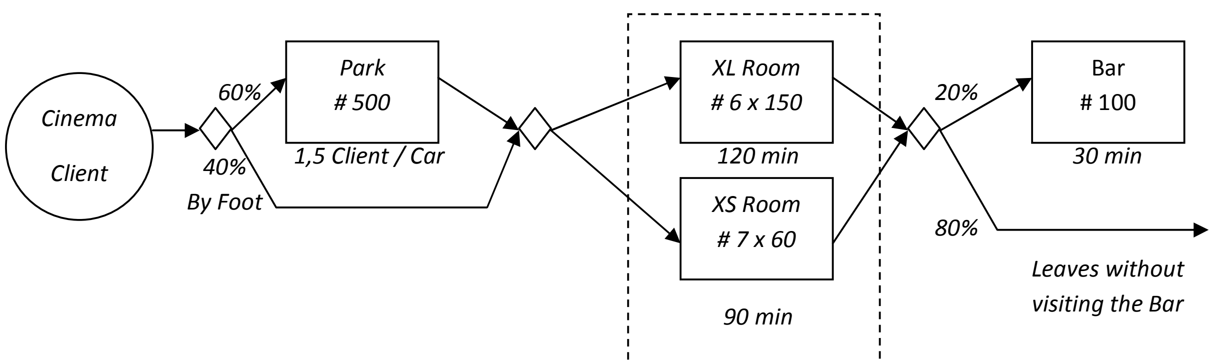
X-ray Technicians = 4,2 (~ 5) + 1 X-ray Technicians

Examination Rooms = 14,2 (~ 15) + 5 Examination Rooms

Trauma Bays = 1,05 (~ 2) No Need

Resource	*Current #*	*Current Capacity (patients/hr)*	*Additional # of Units Needed*	*Capacity After Increase (patients/hr)*
Nurses	*12*	*20.6*	*1*	*22.3*
Physicians	*5*	*15.8*	*2*	*22.1*
X-ray Technicians	*4*	*20.0*	*1*	*25.0*
Examination rooms	*10*	*16.7*	*5*	*22.2*
Trauma bays	*3*	*30.0*	*0*	*60.0*

EXERCISE 1.2



a) What is the capacity of each of the four areas (large and small theatres, parking, bar) in total customer arrivals per hour?

Theatre = 450 + 280 = 730 clients/h ($C_{XL\ Room}$ *= 450 clients/h and* $C_{XS\ Room}$ *= 280 clients/h)*

Park = 655 clients/h

Bar = 1.000 client/h

b) What is the system capacity in total customer arrivals per hour? Which area(s) is the bottleneck?

The different theatres are complementary offers and are equally well utilized, such that their aggregate capacity is 450 + 280 = 730 customers/hour.

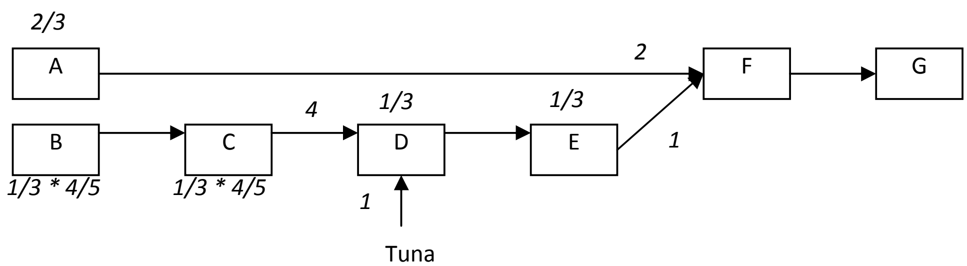
Thus parking is the bottleneck and determines the system's capacity, which is 655 customers/hour.

c) Under the given circumstances, would you add more theatres to your complex? Explain your answer. What would be your reaction to a steadily increasing *retro*-tendency to watch classical and foreign movies (in smaller theatres)?

Under the given circumstances it does not seem to make sense to add capacity in form of new theatres, as the parking lot determines the system's capacity.

However, we currently assume that the two kinds of theatres are equally well utilized. As soon as this balance is shifted in favor of the smaller theatres, it might become profitable to consider adding capacity to the smaller theatres – as soon as they turn out to be the limiting area.

EXERCISE 1.3



a) What is the system capacity in meals per hour? Where do bottleneck(s) occur?

C_{System} = 225 lbs/h or meals/hour

Bottleneck = Step B

b) How much slack (unused capacity) is available in pounds per hour at each step? (Calculate these slacks measured in pounds of final product per hour!)

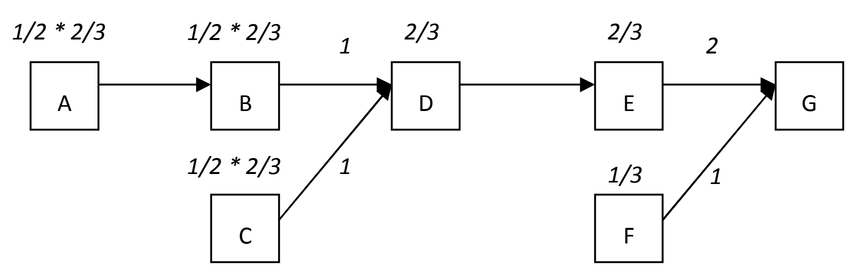
Step	C_{Design} [lbs/h]	$C_{Effective}$ [lb/h]	SLACK $C_{Effective} - C_{System}$
A	*200*	*300*	*75*
B	***60***	***225***	***0***
C	*80*	*300*	*75*
D	*180*	*540*	*315*
E	*240*	*720*	*495*
F	*450*	*450*	*225*
G	*270*	*270*	*45*

c) How much system capacity (in meals per hour) can be gained by increasing the current capacity at the bottleneck by 40%? What is the new bottleneck?

Bottleneck (Step B) = 60 + 40% = 84 lbs/ h

New Bottleneck = Step G (270 lbs/h) [Step B = 72 lbs/h; increase of 20% was enough]

EXERCISE 1.4



a) What is the system capacity in gallons per hour? Which department(s) is (are) the bottleneck?

C_{System} = 120 g/h

Bottleneck = Step C

b) How much slack (unused capacity) is available in the other departments (in gallons per hour)?

Step	*C* *Design* [g/h]	*C* *Effective* [g/h]	*SLACK* $C_{Effective} - C_{System}$
A	85	255	135
B	60	180	60
C	**40**	**120**	**0**
D	130	195	75
E	90	135	15
F	50	150	30
G	150	150	30

c) If we increased the capacity of C by 10 gallons/hour what would be the new bottleneck?

C_{System} = 135 g/h

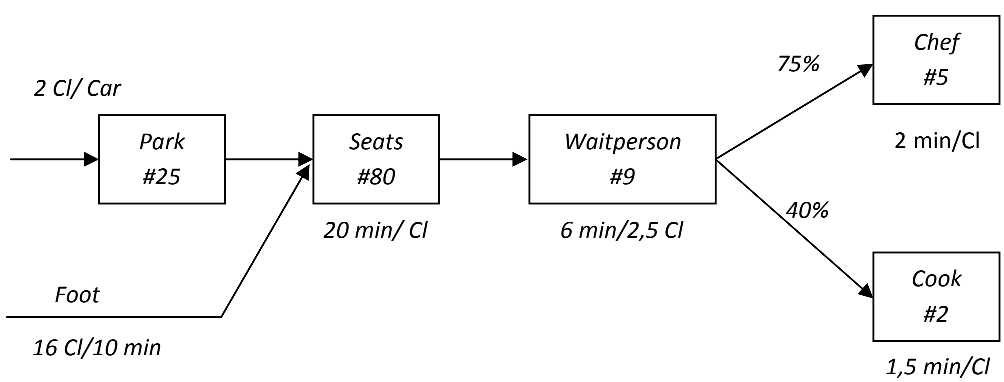
New Bottleneck = Step E

d) Relative to part (a), how much system capacity (in gallons per hour) can be gained by adding 10 gallons of capacity to C and 10 gallons of capacity to E?

C_{System} = 150 g/h

Gain = 30 g/h

EXERCISE 1.5



a) What is the capacity of each resource (in numbers of customer arrivals per hour)?

Arrivals = 150 by car + 96 by foot = 246 customers/hr

Seats = 240 customers/hr

Waitpersons = 225 customers/hr

Chefs = 200 customers/hr

Cooks = 200 customers/hr

b) What is the system capacity per hour (in customer arrivals per hour)? Which resource is (are) the bottlenecks?

C_{System} = 200 customers/hr

Bottleneck = Chefs and Cooks

c) How can David Jones increase the capacity of the Jones' Diner to 250 customer arrivals per hour? Indicate how much of each resource needs to be added and what the new capacity level for each resource is.

Arrivals = Presumably an unlimited number of people can walk in. So we will look at the parking constraint.

Park = 25,67 (~ 26) + 1 space

Chefs = 6.25 (~ 7) + 2 chefs

Cooks = 2.5 (~ 3) + 1 cook

Seating = 83,33 (~ 84) + 4 seats

Waitpersons = 10 + 1 waitperson

New Capacity Level for each resource:

Arrivals = 156 by car + 96 by foot = 252 customers/hr

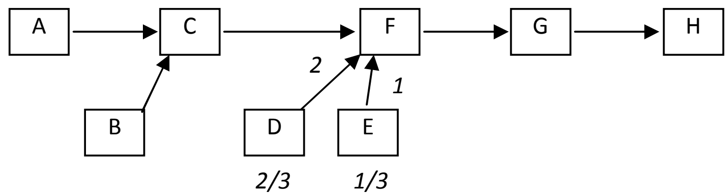
Seats = 252 customers/hr

Waitpersons = 250 customers/hr

Chefs = 280 customers/hr

Cook = 300 customers/hr

EXERCISE 1.6



a) What is the system capacity in terms of pizzas per hour? Which department(s) is (are) the bottlenecks? Display your answers to one decimal place.

b) How much slack (i.e. unused capacity) is available in the other departments (in terms of pizzas per hour)? Display your answers to one decimal place.

Station	***C_{Design}***	***$C_{Effective}$* [Piz/h]**	***SLACK* $C_{Effective} - C_{System}$**
A	*200 Piz/h*	*200,0*	*33,3*
B	*25 g/h*	*416,7*	*250,0*
C	*175 Piz/h*	*175,0*	*8,3*
D	***40 lb/h***	***166,7***	***0***
E	*30 lb/h*	*250,0*	*83,3*
F	*210 Piz/h*	*210,0*	*43,3*
G	*520 sq feet/h*	*192,6*	*25,9*
H	*250 Piz/h*	*250,0*	*83,3*

C_{System} = 166,7 Piz/h

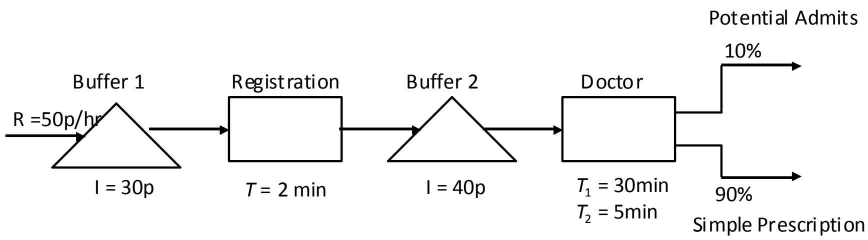
Bottleneck = Station D

c) How much additional system capacity (in pizzas per hour) can be gained by adding sufficient capacity to overcome the current bottleneck(s)? Display your answer to one decimal place. Which department(s) is (are) then the new bottleneck?

By reworking the problem and adding infinite capacity to station D, the new bottleneck becomes station C and the new system capacity will be 175 pizzas/hour. This is a gain of 8,3 pizzas/hour.

EXERCISE 1.7

a) Draw a process flow diagram for the ER.



b) On average, how long does a patient stay in the ER?

There are two flow units:

Those that are potential admits: flow rate = 5 patients/hr

Those that get a simple prescription: flow rate = 45 patients/hr

To find the average flow times, we use Little's law at each activity:

Buffer 1: R = 50 patients/hr; I = 30 patients; T = 0.6 hours = 36 minutes

Registration: T = 2 min; R = 50 patients/hr; I = 1.67 patients

Buffer 2: R = 50 patients/hr; I = 40 patients; T = 0.8 hours = 48 minutes

Doctor time: depends on the flow unit:

potential admits: T = 30 minutes

simple prescription: T = 5 minutes

For a potential admit, average flow time (buffer 1 + registration + buffer 2 + doctor) = 36 + 2 + 48 + 30 = 116 minutes

For a person ending up with a prescription, average flow time (buffer 1 + registration + buffer 2 + doctor) = 36 + 2 + 48 + 5 = 91 minutes

*T = 10% * 116 + 90%*91 = 93.5 minutes.*

c) On average, how many patients are being examined by doctors?

Potential admits: R = 5 patients/hr; T = 30 min = 0.5 hr; I = 2.5 patients

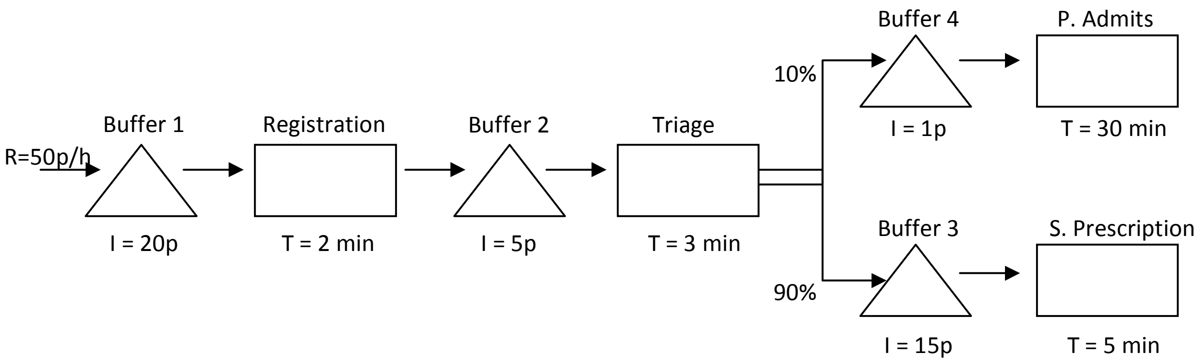
Simple prescription: R = 45 patients/hr; T = 5 min = (5/60) hr; I = 3.75 patients

I = 2.5 + 3.75 = 6.25 patients.

c) On average, how many patients are in the ER?

Total inventory in ER = inventory in buffer 1 + inventory in registration + inventory in buffer 2 + inventory with doctors = 30 + 1.67 + 40 + 6.25 = 77.92 patients.

EXERCISE 1.8



a) Under the proposed plan, <u>how long</u>, on average, will a patient stay in the ER?

T_{B1} = *0,4 h = 24 min*

T_{B2} = *0,1 h = 6 min*

T_{B3} = *15/45 = 0,33 h = 20 min*

T_{B4} = *1/5 = 0,20 h = 12 min*

Average Flow Time to Simple Prescription = 24 + 2 + 6 + 3 + 20 + 5 = 60 min

Average Flow Time to Potential Admits = 24 + 2 + 6 + 3 + 12 + 30 = 77 min

b) On average, <u>how many</u> patients will be in the ER?

I_{Reg} = 1,67 patients

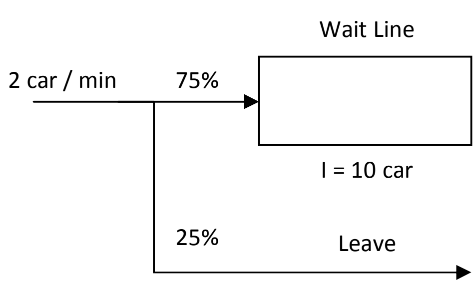
I_{Nur} = 2,5 patients

I_{Adm} = 2,5 patients

I_{Presc} = 3,75 patients

I_{Total} = 20 + 1,67 + 5 + 2,5 + (1+2,5) + (15 + 3,75) = 51,42 patients

EXERCISE 1.9



T = 6,67 min.

EXERCISE 1.10

I = $ 3.000

Turns = 6 / year

Average Flow Time = T = 1 / Turns = 1 / 6 = 0,1667 (2 month)

Throughput = R = I / T = 3.000 / 2 = $ 1.500 / month.

MODULE 2 - STATISTICAL PROCESS CONTROL

EXERCISE 2.1

a) Calculate the 3σ control limits for X-bar and R charts based on the first 12 samples reflecting the process before any problems were denounced.

$A_2 = 1.023$; $D_3 = 0$; $D_4 = 2.574$

X-double-bar = 0.255

R-bar = 0.027

X-bar-chart

*UCL_X = X-double-bar + A_2 * R-bar = 0.255 + 1.023 (0.027) = 0.283*

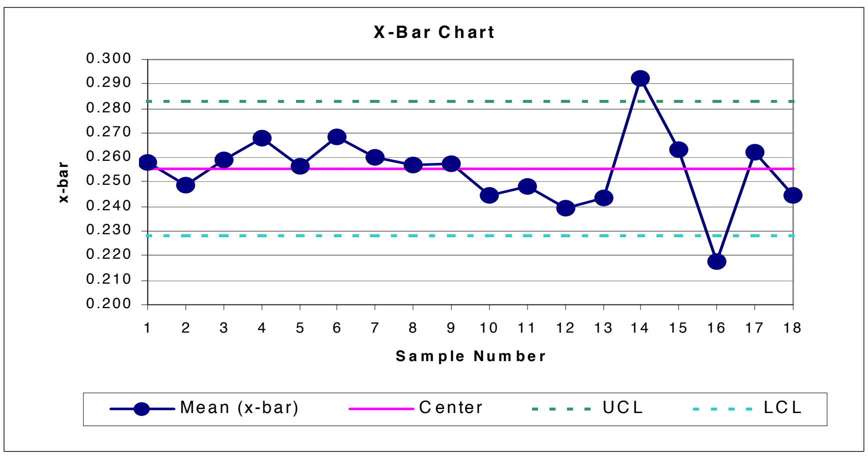
*LCL_X = X-double-bar - A_2 * R-bar = 0.255 – 1.023 (0.027) = 0.228*

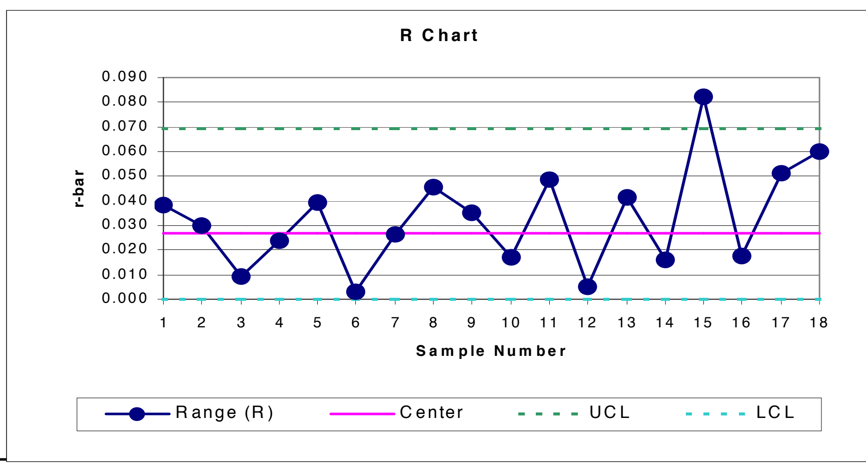
R-chart

*$UCL_R = D_4$ * R-bar = 2.574 * 0.027 = 0.069*

*$LCL_R = D_3$ * R-bar = 0 * 0.027 = 0.000*

b) Plot X-bar and R charts labelling the data points, upper and lower control limits, and centre lines on both charts. Plot the means/ranges of all 18 samples, but use the control limits and centre lines calculated for the first 12 samples.





c) Do you feel that the screw production process is in control? Is there something suspicious?

The graphs confirm that the customers complaints are justified – it really seems as if the variation in the screw diameters has increased significantly. The R-chart suggests significant differences even within single samples! Clearly some corrective measures have to be taken to bring this process back under control!

EXERCISE 2.2

a) Calculate the 3σ control limits for the supplier's manufacturing process based on the first 15 weeks (i.e. weeks 1-15, when the quality of the alloy did not seem to be an issue).

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Flaws per 200	8	9	11	8	10	11	12	10	9	12	14	13	16	13	18
Proportion (P)	0.040	0.045	0.055	0.040	0.050	0.055	0.060	0.050	0.045	0.060	0.070	0.065	0.080	0.065	0.090

n = 200

p-bar = 0.058

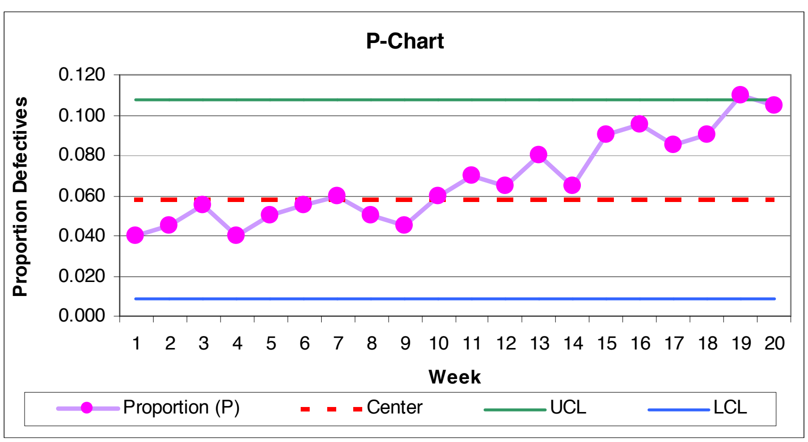
σ = 0.01653

$UCL_{p\text{-}bar}$ = *p-bar + 3 σ =0 .058 + 3(0.01653) = 0.10758*

$LCL_{p\text{-}bar}$ = *p-bar – 3 σ =0 .058 - 3(0.01653) =0.0084*

b) Create the SPC chart including the weekly data, control limits, and the centre line. Plot the defective fractions of all 20 weeks, but use the control limits and the centre line of the first 15 weeks!! Interpret the chart – what does it suggest?

Week	16	17	18	19	20
Flaws per 200	19	17	18	22	21
Proportion (P)	0.095	0.085	0.090	0.110	0.105



Clearly there is an upward tendency in the fraction of defective packages of alloy. Even though the problem was not noticed before week 15, it seems as if this process started already in week 9. The magnitude of the fluctuations is not as alarming as is the steady upward tendency. Even though only the very last weeks reveal defective fractions outside the control limits, the graph gives the impression that the fractions will keep on increasing in future. It seems as if more and more sulphur was used in blending the alloy. Whatever the reasons for this increase might be, it leads to severe quality problems of Screwed's final products and cannot be accepted. Definitely this problem should be looked into more carefully

EXERCISE 2.3

a) Construct both a X-bar and R-chart using the data provided above. Be sure to label all the limits and points.

n=4

$A_2 = 0.729$; $D_3 = 0$; $D_4 = 2.282$

X-double bar = 3.60 (historical data)

R-bar = 0.18 (historical data)

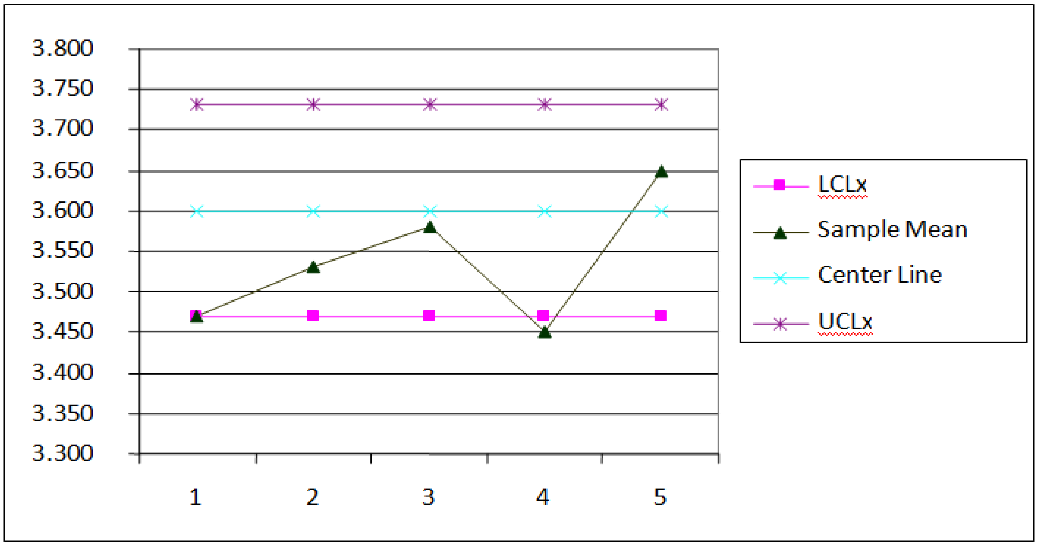
LCLx-bar = X-double bar – A_2 ** R-bar = 3.469*

UCLx-bar = X-double bar + A_2 ** R-bar = 3.731*

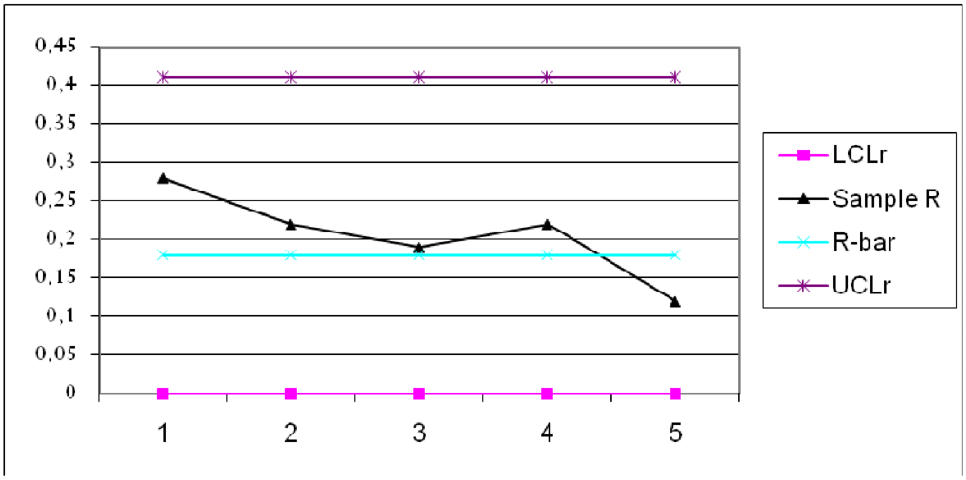
LCLr = D_3 ** R-bar = 0*

UCLr = D_4 ** R-bar = 0.41076*

X-bar



R-chart



b) Is the process in control? Explain your answer.

The process is not in control because the sample mean for sample 4 (in the X-bar graph) falls outside the control limits

EXERCISE 2.4

a) Calculate the 3σ control limits for Chapel Ville Telebooking's wrong customer orders number.

Sample	***Incorrect Orders***	***Propotion***
1	*10*	*0.050*
2	*12*	*0.060*
3	*15*	*0.075*
4	*2*	*0.010*
5	*19*	*0.095*
6	*8*	*0.040*
7	*24*	*0.120*
8	*7*	*0.035*
9	*10*	*0.050*
10	*7*	*0.035*
11	*15*	*0.075*
12	*3*	*0.015*
	Average	*0.055*

n = 200

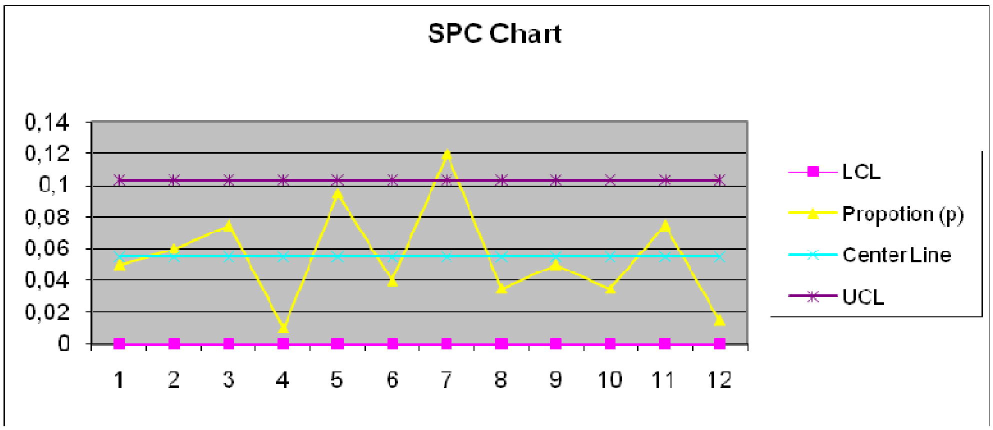
p-bar = 0.055

σ *= 0.01612*

$UCL_{p\text{-}bar}$ *= p-bar + 3* σ *=0.1034*

$LCL_{p\text{-}bar}$ *= p-bar – 3* σ *=0.00664*

b) Create the SPC chart for the process. Be sure to label the control limits, centre line and data points. Is the process in control? Explain your answer.



The data in part a (proportion of sample) shows that the sample in week 7 exceeds the upper control limit. Therefore, the process is seen to be out of control. The reasons for the poor performance that week should be analyzed

EXERCISE 2.5

a) What are the control limits (upper and lower) for the X-bar chart?

n=5

A_2 *= 0.577*

X-double bar = 249.3

R-bar = 15.6

LCLx-bar = X-double bar – A_2 ** R-bar = 240.3*

UCLx-bar = X-double bar + A_2 ** R-bar = 258.3*

b) Acme's customers are willing to accept axles between 240 and 260 mm. What is the process capability index (Cpk) of this line? (Hint: as discussed in class, you can use d2 from the list of quality parameters to estimate the standard deviation of the process.)

UTL= 260 ; LTL= 240 ; d_2 *= 2.326*

σ *= R-bar /* d_2 *= 6.71*

C_{pk} = Min {(UTL – X-double bar)/3 σ ; (X-double bar – LTL)/3 σ } = Min {0.532 ; 0.462} (different values, the process is not centered)

C_{pk} = 0.462 (< 1 the process cannot produce with quality)

c) What percentage of Acme's production meets their customers' specifications?

z_{UTL} = (X-double bar – UTL) / σ = - 1.595 → tab. 2 → 5.59% (are too big)

z_{LTL} = (LTL - X-double bar) / σ = - 1.386 → tab. 2 → 8.23% (are too small)

% that meet specifications = 100% – (5.59% + 8.23%) = 86.18%

d) Assuming that the diameter of the axles is measured at the end of the process (i.e., after the axles have been rolled, cut and finished), what is the capacity of Acme's production line measured in axles/week that they can ship to their customers?

Note: Each axle requires one cut, since one end was cut for the previous axle, and two end finishes

$$Rolling = \frac{16{,}000\ Feet}{1\ Week} \times \frac{1\ Axle}{8\ Feet} = 2{,}000\ Axles/Week$$

$$Cutting = \frac{1\ Axle}{1\ Cut} \times \frac{1\ Cut}{1\ min} \times \frac{60\ min}{1\ hr} \times \frac{40\ hr}{1\ Week} = 2{,}400\ Axles/Week$$

$$Finishing = \frac{1\ Axle}{2\ Ends} \times \frac{1\ End}{12\ min} \times \frac{60\ min}{1\ hr} \times \frac{40\ hr}{1\ Week} \times 19\ people = 1{,}900\ Axles/Week$$

*But only 86.18% of the 1,900 axles meet the specification, thus Capacity = 0 .8618 * 1,900 = 1,637 axles/week*

e) If the measurement equipment was moved so that axle diameters could be measured immediately after the rolling step, what would be the capacity of the production line (again measured in axles/week that Acme can ship to their customers)?

With axles measured after the rolling step, we get only good axles flowing into the bottleneck (the finishing step)

*Good axles from Rolling: 0 .8618 * 2,000 = 1,723 axles/week*

All the other steps in the process, including finishing, can support this production level, so the new capacity is 1,723 axles/week

MODULE 3 - FORECASTING

EXERCISE 3.1

a) Test a 3-period simple moving average by calculating the month-in-advance "forecast" of embarkations for months 4-13. Your table should include columns for month, actual embarkations, forecast, error, absolute error and squared error. Display your answers to one decimal place.

Month	Embarkations [D]	Forecast [F]	Error [E]	Absolute error [|E|]	Squared error [E^2]
1	19				
2	13				
3	14				
4	15	15,3	-0,3	0,3	0,1
5	11	14,0	-3,0	3,0	9,0
6	16	13,3	2,7	2,7	7,1
7	18	14,0	4,0	4,0	16,0
8	17	15,0	2,0	2,0	4,0
9	9	17,0	-8,0	8,0	64,0
10	9	14,7	-5,7	5,7	32,1
11	13	11,7	1,3	1,3	1,8
12	15	10,3	4,7	4,7	21,8
13		12,3			
			SUM	31,3	155,8
			MEAN	3,92	19,47

b) One way to decide the appropriate number of periods to use in the forecasting model is by experimentation. Therefore, you decide to use a 4-period simple moving average to calculate the month-in-advance "forecast" of embarkations for months 5-13. Your table should include columns for month, actual embarkations, forecast, error, absolute error and squared error. Display your answers to one decimal place.

Month	Embarkations [D]	Forecast [F]	Error [E]	Absolute error [|E|]	Squared error [E^2]
1	19				
2	13				
3	14				
4	15				
5	11	15,3	-4,3	4,3	18,1
6	16	13,3	2,8	2,8	7,6
7	18	14,0	4,0	4,0	16,0
8	17	15,0	2,0	2,0	4,0
9	9	15,5	-6,5	6,5	42,3
10	9	15,0	-6,0	6,0	36,0
11	13	13,3	-0,3	0,3	0,1
12	15	12,0	3,0	3,0	9,0
13		11,5			

SUM	28,8	132,9
MEAN	3,59	16,62

c) You suspect that recent data contains more useful information than older data. Thus you decided to test another forecasting approach, this time employing a 3-month weighted moving average with weights 0.5, 0.3 and 0.2 (most recent to least recent) to "forecast" months 4-13. Display your answers to one decimal place.

Month	Embarkations [D]	Forecast [F]	Error [E]	Absolute error [|E|]	Squared error [E^2]
1	19				
2	13				
3	14				
4	15	14,7	0,3	0,3	0,1
5	11	14,3	-3,3	3,3	10,9
6	16	12,8	3,2	3,2	10,2
7	18	14,3	3,7	3,7	13,7
8	17	16,0	1,0	1,0	1,0
9	9	17,1	-8,1	8,1	65,6
10	9	13,2	-4,2	4,2	17,6
11	13	10,6	2,4	2,4	5,8
12	15	11,0	4,0	4,0	16,0
13		13,2			
			SUM	29,9	140,8
			MEAN	3,74	17,60

d) Using the error terms for periods 5-12, compute the Mean Absolute Deviation (MAD) and Mean Squared Error (MSE) for the forecasting methods in a), b) and c) above and display your answers to two decimal places. Based on the error calculations, what method would you recommend for predicting the number of Fast Track's embarkations? Why?

	MAD	MSE
a)	3,92	19,47
b)	3,59	16,62
c)	3,74	17,60

EXERCISE 3.2

a) Evaluate two forecasting approaches for weeks 2-21 using single order exponential smoothing. For the first approach, use α = 0.2. For the second, use α = 0.7. Assume the forecast for week 1 is equal to the actual demand in week one. Your spreadsheets should include columns referring to week, actual sales, forecast, error, absolute error and absolute % error. Display your answers to one decimal place.

α = 0.2

Week	Actual sales [D]	Forecast [F]	Error [E]	Absolute error [|E|]	Absolute % error [%Ea]
1	230	230,0			
2	221	230,0	-9,0	9,0	4,1%
3	190	228,2	-38,2	38,2	20,1%
4	340	220,6	119,4	119,4	35,1%
5	341	244,4	96,6	96,6	28,3%
6	350	263,8	86,2	86,2	24,6%
7	360	281,0	79,0	79,0	21,9%
8	150	296,8	-146,8	146,8	97,9%
9	245	267,4	-22,4	22,4	9,2%
10	170	263,0	-93,0	93,0	54,7%
11	212	244,4	-32,4	32,4	15,3%
12	230	237,9	-7,9	7,9	3,4%
13	230	236,3	-6,3	6,3	2,7%
14	211	235,1	-24,1	24,1	11,4%
15	222	230,2	-8,2	8,2	3,7%
16	350	228,6	121,4	121,4	34,7%
17	310	252,9	57,1	57,1	18,4%
18	119	264,3	-145,3	145,3	122,1%
19	250	235,2	14,8	14,8	5,9%
20	240	238,2	1,8	1,8	0,8%
21		238,6			
			SUM	1109,9	514,3%
			MEAN	58,4	27,1%

α = 0.7

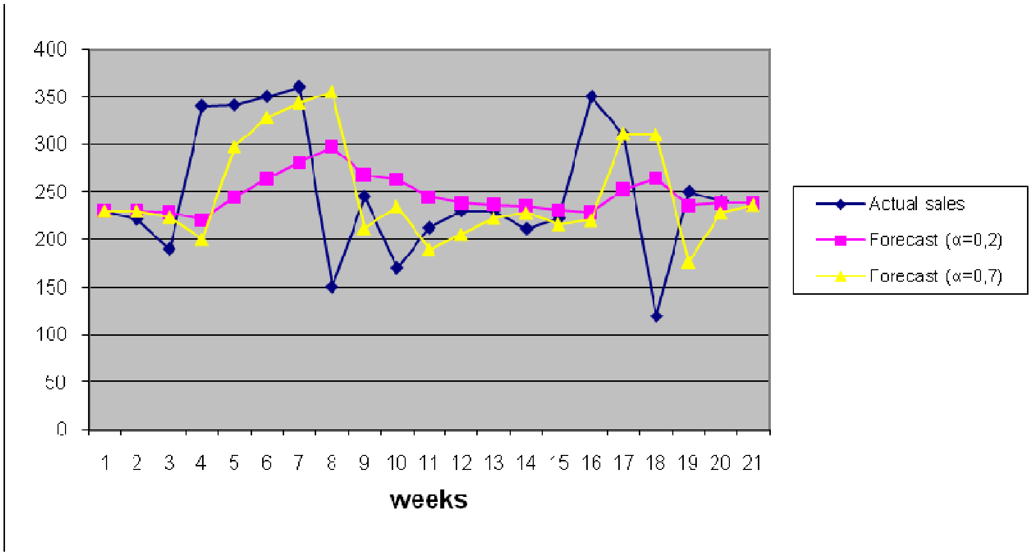
Week	Actual sales [D]	Forecast [F]	Error [E]	Absolute error [|E|]	Absolute % error [%Ea]
1	230	230,0			
2	221	230,0	-9,0	9,0	4,1%
3	190	223,7	-33,7	33,7	17,7%
4	340	200,1	139,9	139,9	41,1%
5	341	298,0	43,0	43,0	12,6%
6	350	328,1	21,9	21,9	6,3%
7	360	343,4	16,6	16,6	4,6%
8	150	355,0	-205,0	205,0	136,7%
9	245	211,5	33,5	33,5	13,7%
10	170	235,0	-65,0	65,0	38,2%
11	212	189,5	22,5	22,5	10,6%
12	230	205,2	24,8	24,8	10,8%
13	230	222,6	7,4	7,4	3,2%

14	211	227,8	-16,8	16,8	7,9%
15	222	216,0	6,0	6,0	2,7%
16	350	220,2	129,8	129,8	37,1%
17	310	311,1	-1,1	1,1	0,3%
18	119	310,3	-191,3	191,3	160,8%
19	250	176,4	73,6	73,6	29,4%
20	240	227,9	12,1	12,1	5,0%
21		236,4			
			SUM	1052,8	542,9%
			MEAN	55,4	28,6%

	MAD	**MAD (%)**
α=0,2	58,4	27,1%
α=0,7	55,4	28,6%

b) Explain the effect of the different smoothing constants (α's).

Week	Actual sales	Forecast (α=0,2)	Forecast (α=0,7)
1	230	230,0	230,0
2	221	230,0	230,0
3	190	228,2	223,7
4	340	220,6	200,1
5	341	244,4	298,0
6	350	263,8	328,1
7	360	281,0	343,4
8	150	296,8	355,0
9	245	267,4	211,5
10	170	263,0	235,0
11	212	244,4	189,5
12	230	237,9	205,2
13	230	236,3	222,6
14	211	235,1	227,8
15	222	230,2	216,0
16	350	228,6	220,2
17	310	252,9	311,1
18	119	264,3	310,3
19	250	235,2	176,4
20	240	238,2	227,9
21		238,6	236,4



c) What would you forecast for weeks 22 and 23?

Since we are assuming there is no trend or seasonality, and there is no information about the sales in periods 21 and 22 the forecast for weeks 22 and 23 should be the same as for week 21

EXERCISE 3.3

a) Determine the least squares regression line relating demand to time period. Use all 16 time-periods of data beginning with the 1st quarter of 2000 and concluding with the 4th quarter of 2003. Present the values for slope and intercept. Display your answer to 2 decimal places.

Year	Quarter	Period(X)	Demand(Y)
1	1	1	49
	2	2	234
	3	3	401
	4	4	100
2	1	5	67
	2	6	321
	3	7	590
	4	8	170
3	1	9	75
	2	10	243
	3	11	830
	4	12	285
4	1	13	98
	2	14	425
	3	15	1160

4	16	215

a - Intercept	107,58
b - Slope	26,04

Y=107,58+26,04X

b) Forecast demand for the next 4 quarters using seasonal indexes. Display the seasonally adjusted forecast to 2 decimal places.

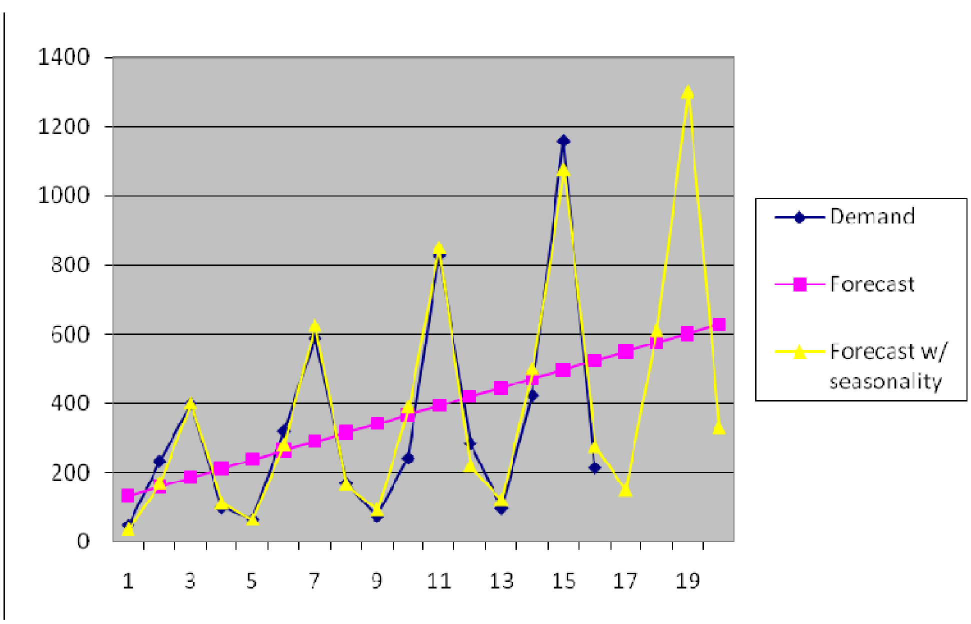
{ Ft = a + bX --- Ft = 107,58 + 26,04 t }
Dt = Ft x St --- St = Dt / Ft
{ St* - Seasonal Index (St Mean of the 4 years by period) }
Forecast w/ Seasonality = Forecast x Seasonal Index Trim.

Year	Quarter	Period [t]	Demand [Dt]	Forecast (Ft)	Seasonal index (St)	Forecast w/ seasonality (Fts)
1	1	1	49	133,62	0,37	36,33
	2	2	234	159,66	1,47	169,35
	3	3	401	185,70	2,16	400,63
	4	4	100	211,75	0,47	111,11
2	1	5	67	237,79	0,28	64,65
	2	6	321	263,83	1,22	279,84
	3	7	590	289,87	2,04	625,36
	4	8	170	315,92	0,54	165,77
3	1	9	75	341,96	0,22	92,97
	2	10	243	368,00	0,66	390,33
	3	11	830	394,04	2,11	850,09
	4	12	285	420,09	0,68	220,43
4	1	13	98	446,13	0,22	121,29
	2	14	425	472,17	0,90	500,82
	3	15	1160	498,21	2,33	1074,82
	4	16	215	524,26	0,41	275,09
5	1	17		550,30		149,61
	2	18		576,34		611,32
	3	19		602,39		1299,56
	4	20		628,43		329,75

Seasonal index	**St***
1º Trim de cada ano	0,27
2º Trim de cada ano	1,06
3º Trim de cada ano	2,16
4º Trim de cada ano	0,52

c) Produce a graph showing the actual demand, the forecasts and the regression line versus time.

Period	Demand	Forecast	Forecast w/ seasonality
1	49	133,62	36,33
2	234	159,66	169,35
3	401	185,70	400,63
4	100	211,75	111,11
5	67	237,79	64,65
6	321	263,83	279,84
7	590	289,87	625,36
8	170	315,92	165,77
9	75	341,96	92,97
10	243	368,00	390,33
11	830	394,04	850,09
12	285	420,09	220,43
13	98	446,13	121,29
14	425	472,17	500,82
15	1160	498,21	1074,82
16	215	524,26	275,09
17		550,30	149,61
18		576,34	611,32
19		602,39	1299,56
20		628,43	329,75



EXERCISE 3.4

α = 0,4; β = 0,3 ; $A_1 = D_1$; T_1 = 3,0

$S_t = \alpha A_t + (1-\alpha)(S_{t-1} + T_{t-1})$
$T_t = \beta (S_t - S_{t-1}) + (1-\beta) T_{t-1}$
$F_{t+1} = S_t + T_t$ (smothing+trend)

Month	Sales	Smoothed value	Smoothed trend	Adjusted Forecast
	At	St	Tt	Ft
1	12	12,0	3,0	-
2	17	15,8	3,2	15,0
3	17	18,2	3,0	19,0
4	19	20,3	2,7	21,2
5	16	20,2	1,9	23,1
6	44	30,9	4,5	22,1
7	35	35,2	4,5	35,4
8	34	37,4	3,8	39,7
9	56	47,1	5,6	41,2
10	64	57,2	6,9	52,7
11	-	-	-	64,1

EXERCISE 3.5

Given that demand is influenced by seasonality, the best method would be one that takes seasonal indexes into consideration

EXERCISE 3.6

We know that the average level demand will decrease. The best solution would be to recommend an initial reduction of the number of periods considered in the moving average forecast as recent periods will be much more representative of the changed level of demand. We want forecast that is responsive to the changed level of average demand. In the long term, one the new average level of demand has stabilized again they can increase of the number of periods considered in the forecast

MODULE 4 - AGGREGATED PRODUCTION PLANNING

EXERCISE 4.1

a) Prepare a level production plan for Piedmont. What is the total cost of that plan?

Month	Demand	Production	Big Inv.	Final Inv.	Workforce	Hire	Lay Off
January	800	1475	650	1325	123	33	0
February	900	1475	1325	1900	123	0	0
March	1300	1475	1900	2075	123	0	0
April	1600	1475	2075	1950	123	0	0
May	1400	1475	1950	2025	123	0	0
June	1800	1475	2025	1700	123	0	0
July	2000	1475	1700	1175	123	0	0
August	2100	1475	1175	550	123	0	0
September	1700	1475	550	325	123	0	0
October	1800	1475	325	0	123	0	0
November	1400	1475	0	75	123	0	0
December	1200	1475	75	350	123	0	0
January			350		90	0	33
TOTAL	**18000**	**17700**		**13.450**	**1.476**	**33**	**33**
COST				**47.075**	**3.247.200**	**26.400**	**4.950**
						$	**3.325.625**

b) Prepare a chase production plan for Piedmont. What is the total cost of that plan?

Month	Demand	Production	Initial. Inv.	Final Inv.	Workforce	Hire	Laid Off
January	800	150	650	0	13	0	77
February	900	900	0	0	75	62	0
March	1300	1300	0	0	109	34	0
April	1600	1600	0	0	134	25	0
May	1400	1400	0	0	117	0	17
June	1800	1800	0	0	150	33	0
July	2000	2000	0	0	167	17	0
August	2100	2100	0	0	175	8	0
September	1700	1700	0	0	142	0	33
October	1800	1800	0	0	150	8	0
November	1400	1400	0	0	117	0	33
December	1200	1200	0	0	100	0	17
January			0		90	0	10
TOTAL	**18000**	**17350**		**0**	**1.449**	**187**	**187**
COST				**0**	**3.187.800**	**149.600**	**28.050**
							3.365.450

c) Total cost is an example of a relevant criterion for evaluating the merit of a production plan. Suggest two additional criteria and compare the plans from (a) and (b) based on these criteria.

A strategy that keeps the workforce constant, but varies its utilization to match the demand forecast. Or a strategy that relies on anticipation inventories, backorders, and stockouts to keep both the output rate and the workforce constant.

EXERCISE 4.2

a) Determine Citicorpse's workforce requirements for the period of February through October using a chase strategy.

b) Compute the total costs of the workforce plan.

Month	Expected Customer Support Calls	Required Data Entry Hours	Students Required for Phone Support	Students Required for Data Entry	Total Students Required	Hires	Lay-offs
February	11.500	400	14,375	3,077	18	8	0
March	12.000	500	15	3,846	19	1	0
April	14.000	450	17,5	3,462	21	2	0
May	11.800	620	14,75	4,769	20	0	1
June	13.500	530	16,875	4,077	21	1	0
July	15.200	420	19	3,231	23	2	0
August	14.900	580	18,625	4,462	24	1	0
September	12.100	490	15,125	3,769	19	0	5
October	13.700	550	17,125	4,231	22	3	0
TOTAL					187	18	6
COSTS					177650	4500	480
						Total COST	**182.630,00**

c) How would your plan change if Citicorpse moved to a level staffing strategy (i.e. they employed only full-time employees)? Assume that no overtime is permitted, 100% of the data entry is performed, and that all customer support calls are answered. Compare this to the plan from part (a).

Month	Expected Customer Support Calls	Required Data Entry Hours	Students Required for Phone Support	Students Required for Data Entry	Total Students Required	Hires	Lay-offs
February	11.500	400	14,375	3,077	24	14	0
March	12.000	500	15	3,846	24	0	0
April	14.000	450	17,5	3,462	24	0	0
May	11.800	620	14,75	4,769	24	0	0
June	13.500	530	16,875	4,077	24	0	0
July	15.200	420	19	3,231	24	0	0
August	14.900	580	18,625	4,462	24	0	0
September	12.100	490	15,125	3,769	24	0	0
October	13.700	550	17,125	4,231	24	0	0
TOTAL					216	14	0
COSTS					205200	3500	0
						Total COST	**208.700,00**

EXERCISE 4.3

a) After reviewing demand for the next year, Randy realizes that it would be inefficient to have a level production plan for the entire year. Why?

A level production plan for the year would be making 1000 per month, but in this case you would go below zero by April. Assuming you cannot go below zero, you would need to make at least 1100 per month to get over that 1st big hump in demand for April & May.
But, by making 1100 a month, you'll end the year with 1200 units in inventory – a lot of inventory!

Note that the solution to a and b can be observed graphically from the graph. A level production plan corresponds to a line. Because of the kink in April, a standard level plan would dip below the kink in April. Any level plan that does not allow negative inventory in April will cause the line to shoot above the cumm demand line. Part b could be answered by drawing two lines: one from Jan to April and the other from April to December.

b) Randy decides that he could live with one adjustment to the workforce in the year. What should be the resulting plan? Please show monthly worker levels and inventory levels. Assume that part-time workers are allowed.

Level assumes that there may be an adjustment at the start of the year. Randy is permitting one additional adjustment as well. Here's a good plan, with the adjustment at the beginning of May

Period	Demand Forecast	Number of workers	Production	Ending Inventory
January	700	11	1100	450
February	800	11	1100	750
March	1400	11	1100	450
April	1550	11	1100	0
May	600	9.5	950	350
June	800	9.5	950	500
July	750	9.5	950	700
August	900	9.5	950	750
September	950	9.5	950	750
October	1100	9.5	950	600
November	1250	9.5	950	300
December	1200	9.5	950	50

EXERCISE 4.4

Level Strategy

Quarterly Production = Total Production / 4 = 400,000 / 4 = 100,000

Employees Needed = Quarterly Production / Production per employee = 100

Production	Demand	Inventory	Workforce	Hire	Fire
100,000	80,000	20,000	100	0	0
100,000	50,000	70,000	100	0	0
100,000	120,000	50,000	100	0	0
100,000	150,000	0	100	0	0

Total Cost = $0.50 * Total Inventory = $0.50 * 140,000 = $70,000

Chase Strategy

Production	Demand	Inventory	Workforce	Hire	Fire
80,000	80,000	0	80	0	20
50,000	50,000	0	50	0	30
120,000	120,000	0	120	70	0
150,000	150,000	0	150	30	0

Total Cost = $300 * Hires + $1,500 * Fires = $300 * 100 + $1,500 * 50 = $105,000

Therefore, the Level Strategy is more economically efficient.

MODULE 5 - MRP & LEARNING CURVE

EXERCISE 5.1

LEVEL 1

ITEM	A										
LS =	LFL		LT =	2 weeks							
PERIOD			1	2	3	4	5	6	7	8	9	10
Gross Requirements			-	-	-	160	-	220				
Scheduled Receipts			0	0	0	0	0	0				
Planned Order Receipts			-	-	-	150	-	220				
Available Balance	30		30	30	30	20	20	20				
Planned Order Releases			-	150	-	220	-	-				
Safety Stock 20												

LEVEL 1

ITEM	B											
LS =	180		LT =	1 week								
PERIOD			1	2	3	4	5	6	7	8	9	10
Gross Requirements			-	-	-	160	120	315				
Scheduled Receipts			0	0	0	0	0	0				
Planned Order Receipts			-	-	-	180	180	235				
Available Balance	0		0	0	0	20	80	0				
Planned Order Releases			-	-	180	180	235	-				
Safety Stock 0												

LEVEL 1

ITEM	C											
LS =	40		LT =	1 week								
PERIOD			1	2	3	4	5	6	7	8	9	10
Gross Requirements			-	-	-	-	360	285				
Scheduled Receipts			40	0	0	0	0	0				
Planned Order Receipts			-	-	-	-	320	320				
Available Balance	20		60	60	60	60	20	55				
Planned Order Releases			-	-	-	320	320	-				
Safety Stock 20												

LEVEL 2

ITEM	D										
LS =	120	LT =	1 week								
PERIOD		1	2	3	4	5	6	7	8	9	10
Gross Requirements		-	300	-	1.400	960	-				
Scheduled Receipts		0	0	0	0	0	0				
Planned Order Receipts		-	360	-	1.320	960					
Available Balance	50	50	110	110	30	30	30				
Planned Order Releases		360	-	1.320	960	-	-				
Safety Stock 0											

LEVEL 2

ITEM	E										
LS =	LFT	LT =	1 week								
PERIOD		1	2	3	4	5	6	7	8	9	10
Gross Requirements		-	150	-	220	-	-				
Scheduled Receipts		0	0	0	0	0	0				
Planned Order Receipts		-	130	-	220	-	-				
Available Balance	20	20	0	0	0	0	0				
Planned Order Releases		130	-	220	-	-	-				
Safety Stock 0											

LEVEL 2

ITEM	F										
LS =	60	LT =	2 weeks								
PERIOD		1	2	3	4	5	6	7	8	9	10
Gross Requirements		-	-	-	640	640	-				
Scheduled Receipts		60	0	0	0	0	0				
Planned Order Receipts		-	-	-	540	660	-				
Available Balance	50	110	110	110	10	30					
Planned Order Releases		-	540	660	-	-	-				
Safety Stock 0											

EXERCISE 5.2

a) **You've estimated that the learning curve effect is roughly 90%. Your crew works 7 days a week with no holidays (they go on vacation after the series is completed). How many days will it take to finish all 16 boats (show your answer to one decimal place)?**

Time required to finish the 16 boats is 240,8 days.

b) **If the first boat took 20 days to complete, and your crew had an 80% learning curve (instead of 90%), how long would it take to finish the complete series? What boat would you be working on at the end of April (i.e., after 120 days)?**

Time to finish the 16 boats is 178,4 days

At 120 days we are producing boat 10

EXERCISE 5.3

a) **GCC has estimated that the learning curve is roughly 90%. GCC architects work 7 days a week including holidays. How many days will it take to complete all 8 golf courses (show your answer to one decimal place).**

Time it takes to complete all 8 golf courses is 197,2 days

b) **If the Lisbon course took 30 days to complete, and GCC's architects had an 80% learning curve (instead of 90%), how long would it take to finish all 8 golf courses? Which golf course would the architects be working on after 130 days?**

Time it takes to complete all 8 golf courses is 160,4 days

After 130 days the architects will be working on golf course 7

EXERCISE 5.4

100th Report:

Real Result = 1,36 days

Theoretical Result

$b = ln(0,85)/(\ln 2) = -0,234$ | $T_1 100 = 4 \times 100^{(-0,234)} = 1,36$ days

200th Report:

Real Result = 1,16 days

Theoretical Result

$b = ln(0,85)/(\ln 2) = -0,234$ | $T_1 200 = 4 \times 200^{(-0,234)} = 1,16$ days

There is no problem with the employee, she is performing as expected.

MODULE 6 - WAITING LINES

EXERCISE 6.1

a) Utilization of the lube team.

$$\rho = \frac{\lambda}{\mu} = \frac{3}{4} \cong 75\%$$

b) The average numbers of cars in line.

$$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{3^2}{4(4-3)} = 2,25 \text{ cars in line}$$

c) The average time a car waits before it is lubed.

$$W_q - \frac{L_q}{\lambda} - 2,\frac{25}{3} - 0,75 \text{ h } (45 \text{ min})$$

d) The total time it takes to go through the system (that is, waiting in line plus lube time)

$$W_S = \frac{L_S}{\lambda} = \frac{\frac{\lambda}{\mu - \lambda}}{\lambda} = 1 \text{ h (wait + lub.)}$$

EXERCISE 6.2

- 1 Worker - Total cost = $41,50 / h
- 2 Worker - Total cost = $26,75 / h
- 3 Worker - Total cost = $27,00 / h

The optimal maintenance crew size for servicing the machines is 2.

EXERCISE 6.3

- Option 1 - New employee saves $281,25/week
- Option 2 - Extra Counter saves $ 300/week

Conclusion

Adding an employee results in savings and improved customer service

Adding a new counter result in slightly greater savings and improved customer service, but only after the initial investment has been recovered

A new counter results in more idle time for employees

A new counter would take up potentially valuable floor space

EXERCISE 6.4

a) What is the average utilization of the concession clerks?

The problem is consistent with the multiple-server model

$$\rho = \frac{\lambda}{S.\mu} = 1,\frac{35}{3 \times 0,5} = 0,9\ (90\%)$$

b) What is the average time spent in the concession area?

S = 3 ; $\rho = 0,9$ --- Tab. ---- L_q = 7,35 average number of customers in the queue

$$L_S = L_q + \frac{\lambda}{\mu} = 7,35 + 1,\frac{35}{0},5 = 10,05$$

$$W_S = \frac{L_S}{\lambda} = 10,\frac{05}{1},35 = 7,44 \text{ min.}$$

EXERCISE 6.5

a) What is the average time a customer waits before he sits?

Model MM1

$$W_S = \frac{1}{\mu \quad \lambda} = \frac{1}{2 - 1,67} = 3,03 \text{ min.}$$

b) What would be the effect on the "sitting" time of having a second ticket taker doing nothing but the validations and card punching, thereby cutting the average service time to 20 seconds?

Model MM1

$$\mu = \frac{1}{20 \text{ sec.}} = 3 \frac{\text{customers}}{\text{min.}}$$

$$W_S = \frac{1}{\mu \quad \lambda} = \frac{1}{3 - 1,67} = 0,75 \text{ min.}$$

c) Would "sitting" time be less than in b) if a second window was opened with each server doing all the tasks?

Model MMS

$S = 2\ \mid\ \lambda = 1.67\ \mid\ \mu = 2$

$$\rho = \frac{\lambda}{S.\mu} = 1,\frac{67}{2 \times 2} = 0,42$$

$\rho = 0{,}42$ | $\mathbf{S = 2}$ --- Tab. --- $\mathbf{L_q = 0,18}$

$$L_S = L_q + \frac{\lambda}{\mu} = 0,18 + 1,\frac{67}{2} = 1,015$$

$$W_S = \frac{L_S}{\lambda} = 1,\frac{015}{1},67 = 0,6 \text{ min.}$$

EXERCISE 6.6

a) If you wish that each customer don't wait longer than 3 minutes, how many employees should you have at each moment (consider the usual distributions)? On average, how many customers are waiting to be served?

$(W_q \leq 3) \quad L_q = \lambda.W_q \qquad L_q < 2 \times 3 \qquad L_q < 6$

$\rho = \frac{\lambda}{S.\mu}$ --- $S.\mu > \lambda \gg S \times 0.25 > 2 \gg S > 8$

$S = 9$ --- $\rho = \frac{2}{0.25 \times 9} = 0.89$ --- Tab. --- $L_q = 5,4 < 6$

$L_q = 5,4 < 6 \gg \text{Nr. employees} = 9$

b) Now imagine that the VIP customers are only willing to wait one-minute (before they start penalizing the service quality). Given the importance of these customers the company is considering the following options.
What is the best option? Justify with calculus and qualitatively your option.

$W_q \leq 1$ | $L_q = \lambda.W_q$ | $L_q \leq 1 \times 2$ --- $L_q \leq 2$

- **Increase the number of employees in order to serve all customers in less than one minute, independently of its type**

  $S.\mu > \lambda \gg S \times 0.25 > 2 \gg S > 8$

  $S = 10$ --- $\rho = \frac{2}{0.25 \times 10} = 0,8$ --- Tab. --- $L_q = 1,64 < 2$

  In order to $W_q \leq 1 \gg 10 \text{ employees} \qquad COSTS = 10 \times \frac{15€}{h} = \frac{150€}{h}$

- **Create a new phone number with exclusive employees and resources to VIP customers, around 20% of demand.**

  $\text{VIP Arrivals: } 20\% \gg \lambda_{VIP} = 20\% \times 2 = 0,4 \frac{\text{calls}}{\text{min.}}$

  $\text{NORMAL Arrivals: } 80\% \gg \lambda_{NOR} = 80\% \times 2 = 1,6 \frac{\text{calls}}{\text{min.}}$

  <u>VIP SERVICE</u>

  $W_q \leq 1 \gg L_q \leq 1 \times 0,4$ --- $L_q \leq 0,4$

  $S.\mu > \lambda \gg S \geq 2$

$$S = 3 - - - \quad \rho = 0, \frac{4}{0,25 \times 3} = 0,533 \quad - - - Tab. - - \quad L_q = 0,3 \quad \leq 0,4$$

Tree employees for VIP Service (exclusive)

<u>NORMAL SERVICE</u>

$$W_q \leq 3 \quad \gg \quad L_q \leq 3 \times 1,6 - - - \quad L_q \leq 4,8$$

$$S.\mu > \lambda \quad \gg \quad S \geq 7$$

$$S = 8 - - - \quad \rho = 1, \frac{6}{0,25 \times 8} = 0,8 \quad - - - Tab. - - - L_q = 1,83 \quad \leq 4,8$$

Eight employees for NORMAL Service

TOTAL EMPLOYEES = 3 + 8 = 11 | COSTS = 11 x 15€/h = 165 €/h

First option is better because is less expensive.

c) **Market research suggests that the exclusive service to VIP customers can arise additionally revenues, with the training of these employees as sellers. How much revenues would this additionally service have to raise on average on each call in order to pay all the implementation of this VIP service (against the base solution of 3 minutes waiting time per customer from a)?**

$$\text{Extra Cost } (+2 \text{ employees}) = 2 \times 15 = \frac{30€}{h}$$

$$\lambda = 2 \frac{calls}{min} = 120 \frac{calls}{h}$$

$$80\% \text{ NORMAL} = 96 \frac{calls}{h}$$

Revenues needed to cover the costs:

$$\frac{30 €}{24 \text{ calls}} = 1,25 \frac{€}{call} \quad : \text{each VIP call needs to generate } 1,25 €$$

MODULE 7 - INVENTORY CONTROL

EXERCISE 7.1

a) Determine the Economic Order Quantity and the resulting annual inventory cost for this item.

$$Q^* = \sqrt{\frac{2.D.C_O}{C_H}} = \sqrt{\frac{2 \times 9000 \times 50}{1}} = 949 \text{ items}$$

$$TC = \frac{D}{Q^*}.C_O + \frac{Q^*}{2}.C_H + D.C_I = \frac{9000}{949} \times 50 + \frac{949}{2} \times 1 + 9000 \times 5,00 = \$45948,68$$

b) Given that the company runs 7 days per week and the demand for this material is constant, what is the reorder point?

$$d = \frac{D}{\text{nr. Working days}} = \frac{180}{7} = 25,7$$

$$R = d \times L_T = 25,7 \times 5 = 129$$

c) Suppose all orders must be placed in a multiple of 35 pounds (per container), what is the new order quantity?

$Q^* = 949 \text{ items}$ » $\frac{949}{35} = 27,11$

$Q^{\dagger} * \text{ New} = 35 \times 27 = 945$ (Lower Cost)

EXERCISE 7.2

ORDER QUANTITY	PRICE PER POUND	C_H	C_O	Q^*	Q^{**}	TC
1 – 999	$5,00	$1	$50	949	949	$45.949
1000 – 1499	$4,80	$0,96	$50	968	1000	$44.130
1500 and up	$4,60	$0,92	$50	989	1500	$42.390

EXERCISE 7.3

a) What is the optimal batch size for production of lotion?

$$Q^* = \sqrt{\frac{2 \times 520 \times 50}{31}.25} = 40.79 = 41 \text{ cases}$$

b) **Whole Foods would like Burt's Bees to supply them with lip balm at the rate of 19 cases/week (and is willing to pay them a little extra for the guaranteed supply). What is the smallest batch size of lotion that Burt's Bees could implement and still be able to meet the demand for lotion while also providing Whole Foods with their entire supply of lip balm?**

In order to supply 19 cases/week of lip balm to Whole Foods, Burt's Bees will have to dedicate an average of 19 hours/week to the production of lip balm. In addition, they must average 20 hours/week (10 cases/week * 2 hours/case) on the production of lotion. This only leaves 1 hour/week that they can devote, on average, to setting up the equipment. Given that it takes 5 hours to set up the machine, Burt's Bees can only afford to set up the machine 1 time every 5 weeks. This implies that the minimum batch size for lotion is 50 cases/batch (5 weeks/batch * 10 cases/week)

EXERCISE 7.4

a) **Determine the economic production quantity for this chemical**

$$Q^* = \sqrt{\frac{2.D.C_S}{C_H.\left(1-\frac{D}{P}\right)}} = \sqrt{\frac{2 \times 10500 \times 200}{0.21 \times \left(1-10,\frac{500}{66500}\right)}} = 4873,4 \text{ barrels}$$

b) **Calculate the total annual cost for this item**

$$TC = \frac{Q^*}{2}.\left(1-\frac{D}{P}\right).C_H + \frac{D}{Q^*}.C_S$$

$$TC = 4873,\frac{4}{2} \times \left(1-\frac{10500}{66500}\right) \times 0,21 + \frac{10500}{4873},4 \times 200 = \$861,82$$

c) **Calculate the cycle length**

$$\text{Cycle Length} = \frac{Q^*}{d} = 4873,\frac{4}{30} = 163 \text{ days}$$

d) **Calculate the production time per lot**

$$\text{Production Time} = \frac{Q^*}{p} = 4873,\frac{4}{190} \cong 26 \text{ days}$$

EXERCISE 7.5

a) **Determine the economic production lot size**

$$Q^* = \sqrt{\frac{2.D.C_S}{C_H.\left(1-\frac{D}{P}\right)}} = \sqrt{\frac{2 \times 5200 \times 351}{8 \times \left(1-\frac{5200}{20800}\right)}} = 780 \text{ units}$$

b) **What is the average time between orders**

$$\text{Cycle Length} = \frac{Q^*}{d} = \frac{780}{100} = 7,8 \text{ weeks}$$

c) **What is the total of the annual holding costs and setup costs**

$$TC = \frac{Q^*}{2}.\left(1 - \frac{D}{P}\right).C_H + \frac{D}{Q^*}.C_S + D.C_I$$

$$TC = \frac{780}{2} \times \left(1 - \frac{5200}{20800}\right) \times 8 + \frac{5200}{780} \times 351 + 5200 \times 40 = \$212680$$

EXERCISE 7.6

Manufacturing

$$Q^* = \sqrt{\frac{2.D.C_S}{C_H.\left(1 - \frac{D}{P}\right)}} = \sqrt{\frac{2 \times 500 \times 8000}{800 \times \left(1 - \frac{500}{2000}\right)}} = 115,47 \text{ engines}$$

$$TC - \frac{Q^*}{2}.\left(1 - \frac{D}{P}\right).C_H + \frac{D}{Q^*}.C_S + D.C_I$$

$$TC = 115,\frac{47}{2} \times \left(1 - \frac{500}{2000}\right) \times 800 + \frac{500}{115},47 \times 8000 + 500 \times 10100 = 5.119.282,03$$

Buying

$$Q^* = \sqrt{\frac{2.D.C_S}{C_H}} = \sqrt{\frac{2 \times 500 \times 8000}{800}} = 100$$

$$TC = \frac{D}{Q^*}.C_S + \frac{Q^*}{2}.C_H + D.C_I = \frac{500}{100} \times 8000 + \frac{100}{2} \times 800 + 500 \times 10000 = 5.080.000$$

The best strategy is buying the engines

EXERCISE 7.7

$$\sigma_{L+T} - \sqrt{(T + L_T).\sigma_d^2} - \sqrt{(14 + 2) \times 5^2} - 20$$

Service Level = 0.98 ; Z = 2.05

$$q = \bar{d}.(T + L_T) + Z.\sigma_{L+T} - I$$

$$581 = 60 \times (2 + 14) + 2.05 \times 20 - I \rightarrow I = 420$$

EXERCISE 7.8

a) **Currently how long, on average, does a disk spend in the store? What is the annual ordering and holding cost under such a policy?**

Time a disk spend in the store:

$$R = \bar{d}.L_T + Z.\sigma_{dLT} = \bar{d}.L_T + SS$$

$$SS = R - \bar{d}.L_T = 4200 - (1000 \times 4) = 200 \text{ disks}$$

$$\text{Average Inventory} = \bar{I} = \frac{Q^*}{2} + SS = \frac{20000}{2} + 200 = 10200 \text{ disks}$$

$$t_{stock} = \frac{\bar{I}}{\bar{d}} = \frac{10200}{1000} = 10,2 \text{ weeks}$$

<u>Annual ordering cost:</u>

$$\frac{D}{Q^*}.C_0 = \frac{1,000 \times 50}{20},000 \times 100 = \$250$$

<u>Annual holding cost:</u>

$$\bar{I} \times C_H = \left(\frac{Q^*}{2} + SS\right).C_H = \left(\frac{20000}{2} + 200\right) \times (0,25 \times 1) = 2550 \frac{\$}{\text{year}}$$

b) **Assuming that the retailer wants the probability of stocking out in a cycle to be no more than 5%, recommend an optimal inventory policy (i.e. order quantity and SS). Under your policy, how long, on average, would a box of DVDs spend in the store?**

$$Q^* = \sqrt{\frac{2.D.C_0}{C_H}} = \sqrt{\frac{2 \times (1000 \times 50) \times 100}{0}},25 = 6325$$

Service Level = 95% (100-5%) ; Z = 1.65

$$\sigma_{dLT} = \sqrt{L_T}.\sigma_d = \sqrt{4} \times 150 = 300$$

$$SS = Z.\sigma_{dLT} = 1.65 \times 300 = 495$$

$$\bar{I} = \frac{Q^*}{2} + SS = \frac{6325}{2} + 495 = 3657,3$$

$$t_{stock} = \frac{\bar{I}}{\bar{d}} = 3657,\frac{3}{1000} = 3,66 \text{ weeks}$$

c) **Claiming that it will lower lead time to 1 week, the supplier is trying to push an EDI system on the retailer. In terms of costs and flow times, what benefits can the retailer expect to realize by adopting the EDI system?**

$$\sigma_{dLT} = \sqrt{L_T}.\sigma_d = \sqrt{1} \times 150 = 150$$

$$SS = Z.\sigma_{dLT} = 1.65 \text{ x } 150 = 247,5$$

$$\bar{I} = \frac{Q^*}{2} + SS = \frac{6325}{2} + 247,5 = 3409,75$$

$$t_{stock} = \frac{\bar{I}}{\bar{d}} = 3409,\frac{75}{1000} = 3,41 \text{ weeks}$$

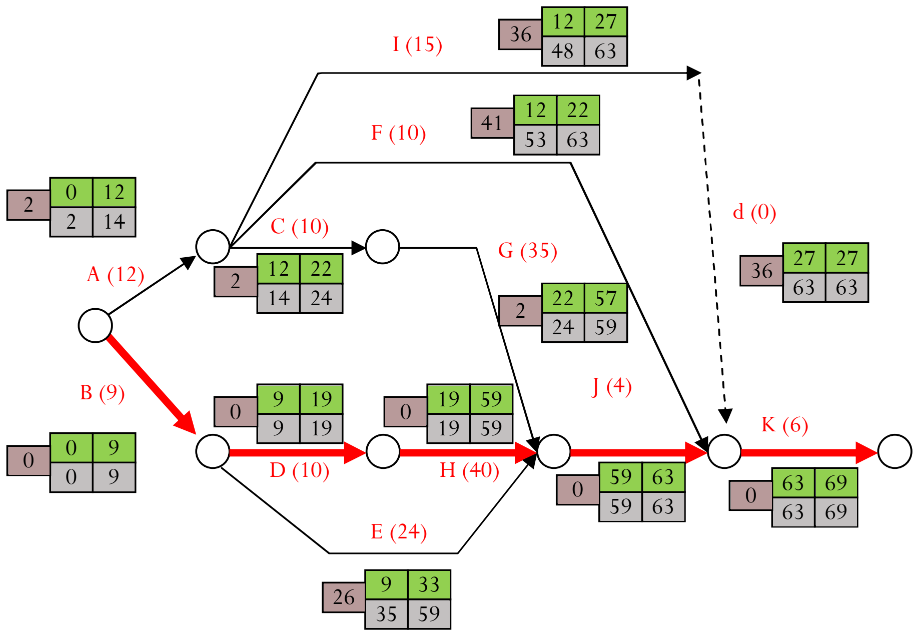
Holding Cost = 3409,75 x 0,25 = 852,43 $/year

We are willing to pay 914,325 – 852,43 = 61,9 $

MODULE 8 - PROJECT MANAGEMENT

EXERCISE 8.1

a) Create an activity-on-arc (AOA) network diagram for this project.



b) Calculate the early start (ES), early finish (EF), late start (LS), and late finish (LF) for each activity. Add these values to your path diagram.

Forward: ES and EF ; Backwards: LS and LF; (are given in the network)

c) Determine the critical path for the project. What is its length (in weeks)?

The critical path (slack = 0) is shown in red and is 69 weeks long (B – D – H – J – K)

d) Calculate the slack for each activity not on the critical path.

Slack = LS - ES or Slack = LF – EF; (are given in the network)

EXERCISE 8.2

a) What is the crash cost per week for all activities in the network?

ACTIVITY	MAXIMUM TIME REDUCTION	CRASH COST ($)	COST TO CRASH PER WEEK
A	1	1000	1000
B	2	14000	7000
C	5	3000	600
D	2	4000	2000
E	10	80000	8000
F	4	6000	1500
G	10	30000	3000
H	5	60000	12000
I	5	12500	2500
J	3	3000	1000
K	1	4000	4000

b) Which activities did you crash to achieve the 63 weeks?

Select activities from the critical path

Start from the cheap activities

J (3 Weeks); D (2 Weeks); K (1 week)

Verify other critical paths

New critical path: A – C – G – J – K

c) What is the cost of completing the project in 63 weeks?

J = 3 Weeks * $1000

D = 2 Weeks * $2000

K = 1 week * $4000

Total cost = $11000

d) What will it cost to decrease the schedule to 62 weeks from 63 weeks?

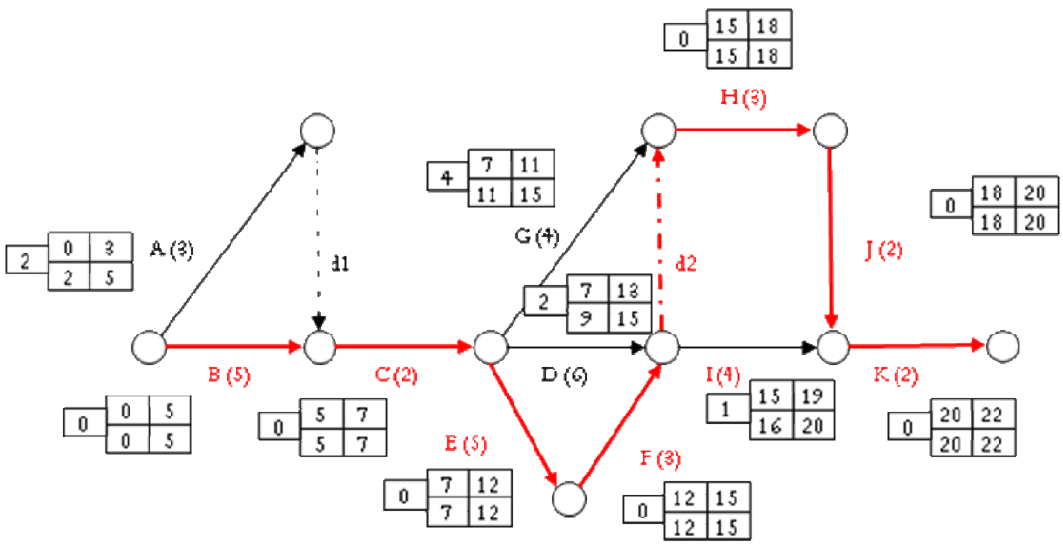
Coming from B – D – H – J – K <u>Crash B</u> ($7000)

Coming from A – C – G – J – K   Crash C ($600)

Total cost = $7600

EXERCISE 8.3

a) Prepare an activity-on-arc network diagram for the project.



b) Calculate the ES, LS, EF and LF for each activity. Add these to your diagram from (a).

c) What is the critical path for this project? What is its length in weeks?

The critical path (slack = 0) is shown in red and is 22 weeks long (B – C – E – F – d2 – H – J – K)

d) What is the slack for each activity not on the critical path?

The slack are given in the network

EXERCISE 8.4

a) Show how to crash the project down to the required project length of 18 weeks. Use the heuristic procedure provided in the text.

Step 1 – list all path lengths in the network prior to crashing:

PATH	LENGTH (WEEKS)
B – C – G – H – J – K	18
B – C – D – I – K	19
B – C – D – d2 – H – J – K	20
B – C – E – F – d2 – H – J – K	**22**
B – C – E – F – I – K	21
A – d1 – C – G – H – J – K	16
A – d1 – C – D – I – K	17
A – d1 – C – D – d2 – H – J – K	18
A – d1 – C – E – F – d2 – H – J – K	20
A – d1 – C – E – F – I – K	19

Step 2 – Crash the activity on the critical path with the minimum crash cost/week. This is activity E, which can be crashed at a cost of $475/week. We crash activity **E** by 2 weeks because this is the amount until another path, B – C – D – d2 – H – J – K , becomes critical. This costs $950 ($475*2 weeks).
The new list of path lengths is as follows:

PATH	LENGTH (WEEKS)
B – C – G – H – J – K	18
B – C – D – I – K	19
B – C – D – d2 – H – J – K	**20**
B – C – E – F – d2 – H – J – K	**20**
B – C – E – F – I – K	19
A – d1 – C – G – H – J – K	16
A – d1 – C – D – I – K	17
A – d1 – C – D – d2 – H – J – K	18
A – d1 – C – E – F – d2 – H – J – K	18
A – d1 – C – E – F – I – K	17

Step 3 – The critical paths are now B – C – D – d2 – H – J – K and B – C – E – F – d2 – H – J – K. Activity **C** is now the activity on the critical path with the lowest crash cost/week. Crash C to its maximum extent since all path lengths contain this activity. This costs $750 ($500*1,5 weeks), and yields the following path lengths:

PATH	LENGTH (WEEKS)
B – C – G – H – J – K	16,5
B – C – D – I – K	17,5
B – C – D – d2 – H – J – K	**18,5**
B – C – E – F – d2 – H – J – K	**18,5**
B – C – E – F – I – K	17,5
A – d1 – C – G – H – J – K	14,5
A – d1 – C – D – I – K	15,5
A – d1 – C – D – d2 – H – J – K	16,5
A – d1 – C – E – F – d2 – H – J – K	16,5
A – d1 – C – E – F – I – K	15,5

Step 4 – The critical paths remain as B – C – D – d2 – H – J – K and B – C – E – F – d2 – H – J – K. Activity **B** now has the lowest total crashing cost on the critical path at $750/week. Since we only need to reduce the project by 0,5 weeks now, crash activity B by this amount at a cost of $375 ($750*0,5 weeks). The project completion target of 18 weeks is now achieved. The final crashed path lengths are as follows:

PATH	LENGTH (WEEKS)
B – C – G – H – J – K	16
B – C – D – I – K	17
B – C – D – d2 – H – J – K	**18**
B – C – E – F – d2 – H – J – K	**18**
B – C – E – F – I – K	17
A – d1 – C – G – H – J – K	14,5
A – d1 – C – D – I – K	15,5
A – d1 – C – D – d2 – H – J – K	16,5
A – d1 – C – E – F – d2 – H – J – K	16,5
A – d1 – C – E – F – I – K	15,5

b) What is the total cost of crashing?

The total cost of crashing the project down to 18 weeks is $2075 ($950 +$ 750 + $375)

c) What is the critical path for the crashed project?

The final critical paths are B – C – D – d2 – H – J – K and B – C – E – F – d2 – H – J – K

MODULE 9 - SHOP FLOOR CONTROL

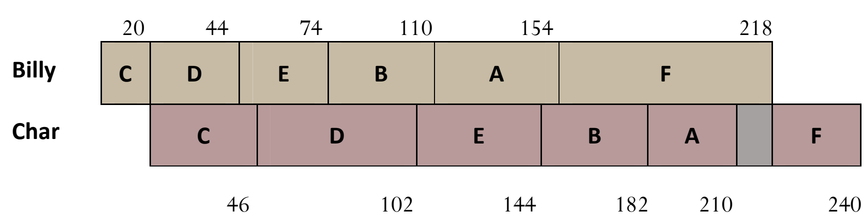
EXERCISE 9.1

a) Use Johnson's rule to schedule Billy and Charlie (i.e. sequence the 6 bikes!).

Bike	Billy	Charlie
1st C	20	26
3rd D	24	56
5th E	30	42
6th B	36	38
4th A	44	28
2nd F	64	22

b) Using the results from part a), determine the completion time for each bike (in minutes starting at zero for simplicity). Construct a Gantt chart for the recommended schedule.

	Billy		Charlie		
Bike	Start	End	Start	End	Flow Time
C	0	20	20	46	46
D	20	44	46	102	102
E	44	74	102	144	144
B	74	110	144	182	182
A	110	154	182	210	210
F	154	218	218	240	240



c) **Assuming that the repair of all bikes could be started at time zero, calculate the average flow time for the sequence determined in part a)**

$$\text{Average Flow Time} = \frac{46 + 102 + 144 + 182 + 210 + 240}{6} = 154$$

EXERCISE 9.2

a) **Develop job sequences using the following rules: SPT (break ties using EDD), EDD and FCFS (break ties using SPT). For each rule, calculate the following: average flow-time, average lateness and maximum lateness.**

Shortest Processing Time

War	Release Date (week)	Processing Time (week)	Due Date (week)	Start	End	Flow Time	Lateness
Korean Conflict	2	1	5	2	3	1	0
Vietnam War	4	2	7	4	6	2	0
Desert Storm	2	3	8	6	9	7	1
Persian Gulf War	3	3	12	9	12	9	0
Israel-Arab Conflicts	6	4	10	12	16	10	6
					Average	5.8	1.4
					Max.		6

Earliest Due Date

War	Release Date (week)	Processing Time (week)	Due Date (week)	Start	End	Flow Time	Lateness
Korean Conflict	2	1	5	2	3	1	0
Vietnam War	4	2	7	4	6	2	0
Desert Storm	2	3	8	6	9	7	1
Israel-Arab Conflicts	6	4	10	9	13	7	3
Persian Gulf War	3	3	12	13	16	13	4
					Average	6	1.6
					Max.		4

First Come, First Served

War	Release Date (week)	Processing Time (week)	Due Date (week)	Start	End	Flow Time	Lateness
Korean Conflict	2	1	5	2	3	1	0
Desert Storm	2	3	8	3	6	4	0
Persian Gulf War	3	3	12	6	9	6	0
Vietnam War	4	2	7	9	11	7	4
Israel-Arab Conflicts	6	4	10	11	15	9	5
					Average	5.4	1.8
					Max.		5

b) Does any sequence determined in (a) result in 0 lateness? If so, which rule(s)? Which rule would you recommend? Justify your answer.

No scheduling rule provides a job sequence with no lateness.
Depends upon the environment in which the manager is making the decision.
If the lateness is the main concern – SPT is best
If flow time is the main concern – FCFS is best

EXERCISE 9.3

t = 0	0.25		0.75		1.25		1.75		2.25		2.75		3.25		3.75	
	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00
Lathe	A	A	B	B	B	B	D	D	D							
Drill	B	C	C	A	A	A										
Grinder							A	A	A	A	A	A	B	B	B	

EXERCISE 9.4

a) Use Johnson's Rule to create a shop schedule for Fiber World (i.e. sequence these six jobs).

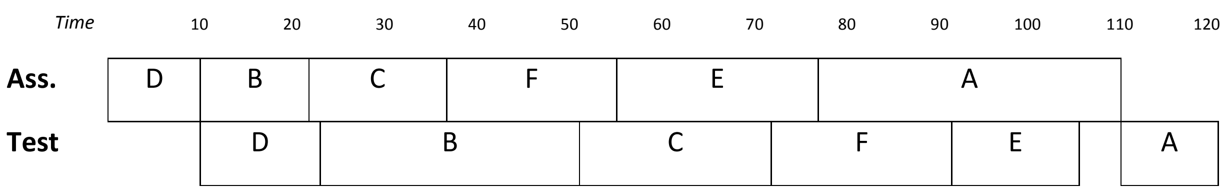
Job	Assembly	Test
D	10	13
B	12	28

C	15	21
F	18	19
E	22	14
A	32	11

b) Using the result from part (a), determine the completion time for each of the six jobs (from time = 0 hours). Construct a Gantt chart of the recommended schedule.

			ASSEMBLY		TESTING	
Job	**Ass. Time**	**Testing Time**	**Start**	**Finish**	**Start**	**Finish**
D	10	13	0	10	10	23
B	12	28	10	22	23	51
C	15	21	22	37	51	72
F	18	19	37	55	72	91
E	22	14	55	77	91	105
A	32	11	77	109	109	120

Gantt Chart:



c) Assuming that all the jobs were released to the floor at time = 0, calculate the average flow-time for the sequence of jobs you determined in part (a).

$$\text{Average Flow Time} = \frac{23 + 51 + 72 + 91 + 105 + 120}{6} = 77$$

MODULE 10 - ASSEMBLY/PRODUCTION LINE BALANCING

EXERCISE 10.1

a) How many sails must be produced per hour (production rate)?

$$r = \frac{\text{Required Output}}{\text{Amount of Time Worked}} = 1,\frac{600}{5 \times 8} = 40\,\frac{\text{sails}}{\text{h}}$$

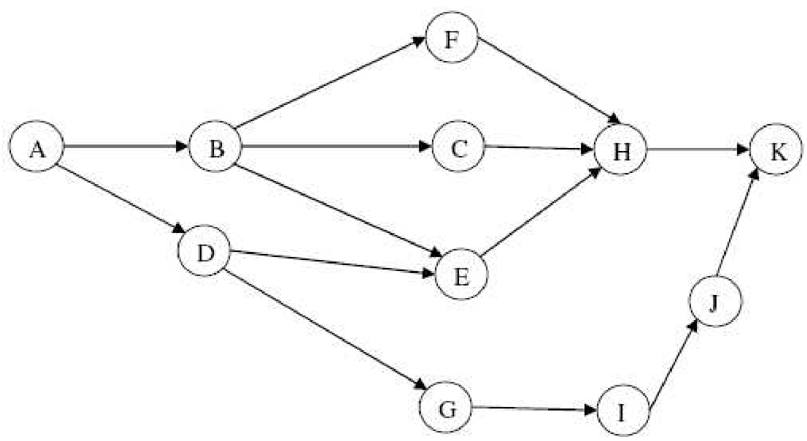
b) What is the desired cycle time (in seconds)?

$$c = \frac{\text{Production Time}}{\text{Production Rate}} = \frac{50}{40} = 1.25\,\frac{\text{min}}{\text{sale}}\left(75\,\frac{\text{sec}}{\text{sale}}\right)$$

c) What is the theoretical number of workstations?

$$N = \frac{\text{Total Tasks Time}}{\text{Cycle Time}} = \frac{368}{75} = 4.91 \;\approx 5 \text{ stations}$$

d) Draw the precedence diagram.



e) Balance the production line.

Station	Candidates	Choice	Cumulative Time (Seconds)	Remaining Time (Seconds)	Idle Time (Seconds)
1	A	A	23	52	
	B,D	B	67	8	8
2	C,D,F	D	43	32	
	C,E	E	61	14	14
3	C,F,G	G	61	14	14
4	C,F,I	F	39	36	

	C,I	I	63	12	12
5	C,J	J	37	38	
	C	C	52	23	23
6	H	H	52	23	
	K	K	64	11	11

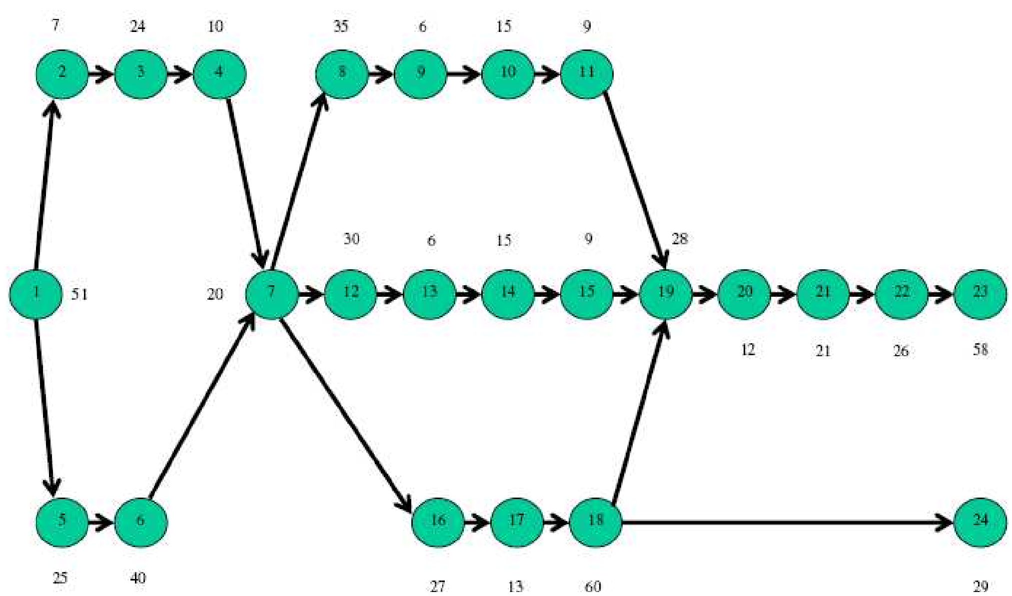
f) Calculate the efficiency (or balance delay) for this line.

$$\text{Balance Delay} = \frac{\text{Idle Time}}{\text{Time Available in Line}} = \frac{82}{6 \times 75} = 18.2\%$$

$$\text{Efficiency} = 1 - 0.182 = 81.77\%$$

EXERCISE 10.2

a) Construct a precedence diagram for the Big Broadcaster spreader.



b) Given the requirement of 2400 spreaders/week, calculate the process cycle time.

$$\text{Production Rate} = 2,\frac{400}{40} = 60\,\frac{sp}{week}$$

$$\text{Cycle Time} = \frac{1}{\text{Production Time}} = \frac{1}{60} = \frac{60}{60} = 1\,\text{min}$$

c) **Calculate the theoretical minimum number of workstations necessary to produce Big Broadcasters at this plant. (Assume 1 person per workstation.)**

$$TM = \frac{\sum Station\ Time}{Cycle\ Time} = \frac{576}{60} = 9.6 \approx 10\ stations$$

d) **Balance the production line using all of the information above and your answers from (a) – (c).**

Tasks Available	Task Selected	Assigned to Station	Time Remaining at Station (seconds)	Station Idle Time (seconds)
1	1	STA1	9	
2	2	STA1	2	2
3, 5	5	STA2	35	
3	3	STA2	11	
4	4	STA2	1	1
6	6	STA3	20	
7	7	STA3	0	0
8, 12, 16	8	STA4	25	
9	9	STA4	19	
10	10	STA4	4	4
11, 12, 16	12	STA5	30	
11, 13, 16	16	STA5	3	3
11, 13, 17	17	STA6	47	
11, 13	11	STA6	38	
13	13	STA6	32	
14	14	STA6	17	
15	15	STA6	8	8
18	18	STA7	0	0
19, 24	24	STA8	31	
19	19	STA8	3	3
20	20	STA9	48	
21	21	STA9	27	
22	22	STA9	1	1
23	23	STA10	2	2

e) **Calculate the efficiency for this line.**

$$Efficiency = 1 - \frac{IdleTime}{\#Stations \times CycleTime} = 1 - \frac{24}{10 \times 60} = 96\%$$