COURSE TITLE: **ADDITIVE MANUFACTURING AND PRODUCTION SYSTEMS**

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EXERCISE 3

PART_A FLEXIBLE MANUFACTURING SYSTEMS

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GROUP NUMBER: 10

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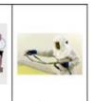
PART_A FLEXIBLE MANUFACTURING SYSTEMS

Demand pcs/month	Machine	 SLM 280	 Stratasys J750	 Stratasys F170	 DWS XPRO S	 Wire Electro Discharge Machine	 Manual removal job shop	 Chemical bath	 Ultrasonic Washer	 UV oven	 Sand Blasting machine	 Powder coating system	 Spray Coating job shop
	Machine cost	450 k€	375 k€	28 k€	95 k€	55 k€	5 k€	8 k€	12 k€	8 k€	9 k€	15 k€	4.5 k€
40	 A	21h				2.5h					15’		
29	 B				27h			1.5h		1.5h			1h
49	 C		23h				2h						
34	 D			15h			1h					0.5h	
31	 E				23h				1h	1h			
23	 F	16h				1.5h	2.5h						
33	 G		21h					4h			30’	1h	

For simplicity we convert the machine names into number in the same sequence as they appear in the table.

Steps involved,

- Dividing the products into manufacturing cells by applying KING’S algorithm.
- Add duplicate machines if necessary.
- Apply HOLLIER method to find the sequence of machines in the manufacturing cell.
- Apply Bottleneck methods to find Production Rate of Manufacturing cell, percentage Utilization of machines and Production rate of each product in the manufacturing cell.
- Apply Extended Bottleneck method to find critical number of products, mean lead time and waiting time in each manufacturing cell based on two different cases where N<N* and N>=N*.

Step 1. Apply KING’S algorithm. P and M signifies products and machines.

P/M	1	2	3	4	5	6	7	8	9	10	11	12
A	1				1					1		
B				1			1		1			1
C		1				1						
D			1			1					1	
E				1				1	1			
F	1				1	1						
G		1					1			1	1	

Taking transpose of this table and apply the row and column sorting.

M/P	A	B	C	D	E	F	G
1	1					1	
2			1				1
3				1			
4		1			1		
5	1					1	
6			1	1		1	
7		1					1
8					1		
9		1			1		
10	1						1
11				1			1
12		1					

M/P	A	B	C	D	E	F	G	Row Sorting
1	1					1		66
2			1				1	17
3				1				8
4		1			1			36
5	1					1		66
6			1	1		1		26
7		1					1	33
8					1			4
9		1			1			36
10	1						1	65
11				1			1	9
12		1						32
	2^6	2^5	2^4	2^3	2^2	2^1	2^0	
	64	32	16	8	4	2	1	

M/P	A	B	C	D	E	F	G	Row Sorting
1	1					1		66

5	1					1		66
10	1						1	65
4		1			1			36
9		1			1			36
7		1					1	33
12		1						32
6			1	1		1		26
2			1				1	17
11				1			1	9
3				1				8
8					1			4

M/P			A	B	C	D	E	F	G
1	2^11	2048	1					1	
5	2^10	1024	1					1	
10	2^9	512	1						1
4	2^8	256		1			1		
9	2^7	128		1			1		
7	2^6	64		1					1
12	2^5	32		1					
6	2^4	16			1	1		1	
2	2^3	8			1				1
11	2^2	4				1			1
3	2^1	2				1			
8	2^0	1					1		
COLOM SORTING			3584	480	24	22	385	3088	588

M/P	A	F	G	B	E	C	D
1	1	1					
5	1	1					
10	1		1				
4				1	1		
9				1	1		
7			1	1			
12				1			
6		1				1	1
2			1			1	
11			1				1
3							1
8					1		

M/P	A	F	G	B	E	C	D

1	1	1					
5	1	1					
10*	1						
6*		1					
10			1				
2*			1				
11*			1				
4				1	1		
9				1	1		
7			1	1			
12				1			
8					1		
6						1	1
2						1	
11							1
3							1

product	A	B	C	D	E	F	G
demand	40	29	49	34	31	23	33

Step 2 Apply HOLLIER method in each Manufacturing cell.

MANUFACTURIN CELL_1

M/P	A	F
1	1	1
5	1	1
10*	1	
6*		1

P(A)	0.634921	PART
P(F)	0.365079	MIX

product	A	F	SUM
demand	40	23	63

PART_A	OPERATIONS	L/U	1	5	10	L/U
PART_F	OPERATIONS	L/U	1	5	6	L/U

FROM TO

A	1	5	10	6
1		40		
5			40	
10				
6				

FROM TO

F	1	5	10	6
1		23		
5				23
10				
6				

FROM TO

SUM	1	5	10	6	FROM	FROM/TO
1		63			63	infinity
5			40	23	63	1
10					0	0
6					0	0
TO	0	63	40	23	126	

CELL_1	Option a	1	5	10	6
	Option b	1	5	6	10

MANUFACTURING CELL_2

M/P	G	B	E
10	1		
2*	1		
11*	1		
4		1	1
9		1	1
7	1	1	
12		1	
8			1

product	demand
G	33
B	29
E	31
SUM	93

P(G)	0.35484	
P(B)	0.31183	PART MIX
P(E)	0.33333	

PART_G	OPERATIONS	L/U	2	7	10	11	L/U
PART_B	OPERATIONS	L/U	4	7	9	12	L/U
PART_E	OPERATIONS	L/U	4	8	9	L/U	

FROM TO

G	10	2	11	4	9	7	12	8
10			33					
2						33		
11								
4								
9								
7	33							
12								
8								

FROM TO

B	10	2	11	4	9	7	12	8
10								
2								
11								
4						29		
9							29	
7					29			
12								
8								

FROM TO

E	10	2	11	4	9	7	12	8
10								
2								
11								
4								31
9								
7								
12								
8					31			

FROM TO

SUM	10	2	11	4	9	7	12	8	FROM	FROM/TO
10			33						33	1
2						33			33	Infinite
11									0	0
4						29		31	60	infinite
9							29		29	0.483
7	33				29				62	1
12									0	0
8					31				31	1
TO	33	0	33	0	60	62	29	31	248	

CELL_2	Option a	2	4	10	7	8	9	11	12
	Option b	4	2	7	8	10	9	12	11

MANUFACTURING CELL_3

M/P	C	D
6	1	1
2	1	
11		1
3		1

product	demand
C	49
D	34
SUM	83

P(C)	0.590361	PART MIX
P(D)	0.409639	

PART_C	OPERATIONS	L/U	2	6	L/U	
PART_D	OPERATIONS	L/U	3	6	11	L/U

FROM TO

C	6	2	11	3
6				
2	49			
11				
3				

FROM TO

D	6	2	11	3
6			34	
2				
11				
3	34			

FROM TO

SUM	6	2	11	3	FROM	FROM/TO
6			34		34	0.409639
2	49				49	Infinite
11					0	0
3	34				34	Infinite
TO	83	0	34	0	117	

Step 3 Applying Bottleneck methods and taking some assumptions.

Certain values such as loading time and unloading time are not given so, it is approximated and assumed to be 4 mins and 2 mins respectively. The material handling time (**Tr**) is given to be 2 mins. The number of servers is 1 and so the frequency of operation becomes 1. **fijk = 1.0**

Workload of a station $$WL_i = \sum_j \sum_k T_{cijk} f_{ijk} p_j$$

Workload of the handling system $$WL_{n+1} = n_t T_r \qquad n_t = \sum_i \sum_j \sum_k f_{ijk} p_j - 1$$

Extended bottleneck method:

N	<	N*	→	case 1
N	>=	N*	→	case 2

$$MLT_1 = \sum_{i=1}^{n} WL_i + WL_{n+1} \qquad N^* = R_p^* \left(\sum_{i=1}^{n} WL_i + WL_{n+1} \right)$$

Case 1 → $T_w = 0$ $\qquad R_p = \dfrac{N}{MLT_1}$ $\qquad R_{pj} = p_j R_p$

Case 2 → $R_{pj}^* = p_j R_p^*$ $\qquad MLT_2 = \dfrac{N}{R_p^*}$ $\qquad T_w = MLT_2 - \left(\sum_{i=1}^{n} WL_i + WL_{n+1} \right)$

Tw = waiting time & MLT= mean lead time

MANUFACTURIN CELL_1

Bottleneck Method

PART	MIX P(j)	OPERATION (k)	DESCRIPTION	STATION (i)	SERVER	TIME tijk (min)
A	0.634921	1	L/U	1	1	4
		2	1	2	1	1260
		3	5	3	1	150
		4	10	4	1	15
		5	L/U	1	1	2
F	0.365079	1	L/U	1	1	4
		2	1	2	1	960
		3	5	3	1	90
		4	6	5	1	150
		5	L/U	1	1	2

`

Workload (min)	WL_(L/U)	6
	WL_1	1150.47619
	WL_5	128.0952381
	WL_10	9.523809524
	WL_6	54.76190476
	WL_(n+1)	8

Bottleneck is maximum of all Workloads

Bottleneck is WL_1 which means machine SLM 280

Production Rate at Bottleneck Station		
Rp	0.000869205	pc/min
Rp	0.052152318	pc/hr

production rate A	**Rp*P(j)_A**	**0.033112583**	**pc/hr**
production rate F	**Rp*P(j)_F**	**0.019039735**	**pc/hr**

					in %
Utilization	U_(L/U)	=	WL_(L/U)*Rp	0.005215232	0.521523
	U_1	=	WL_1*Rp	1	100
	U_5	=	WL_5*Rp	0.11134106	11.13411
	U_10	=	WL_10*Rp	0.008278146	0.827815
	U_6	=	WL_6*Rp	0.047599338	4.759934
	U_(n+1)	=	WL_(n+1)*Rp	0.006953642	0.695364

Extended Bottleneck Method

$$MLT_1 = \sum_{i=1}^{n} WL_i + WL_{n+1}$$

$$N* = R_p{*}\left(\sum_{i=1}^{n} WL_i + WL_{n+1}\right)$$

MLT_1 1356.857143 min

N* 1.179387417

N	MLT_1 (min)	Rp (pc/min)	MLT_2 (min)	Tw (min)
1	1356.857143	0.000736997		0
2		0.000869205	2300.952381	944.0952
3		0.000869205	3451.428571	2094.571

MANUFACTURIN CELL_2

Bottleneck Method

PART	MIX P(j)	OPERATION	DESCRIPTION	STATION	SERVER	TIME tijk (min)
G	0.354839	1	L/U	1	1	4
		2	2	2	1	1260
		3	7	3	1	240
		4	10	4	1	30
		5	11	5	1	60
		6	L/U	1	1	2
B	0.311828	1	L/U	1	1	4
		2	4	2	1	1620
		3	7	3	1	90
		4	9	4	1	90
		5	12	5	1	60
		6	L/U	1	1	2
E	0.333333	1	L/U	1	1	4
		2	4	2	1	1380
		3	8	3	1	60
		4	9	4	1	60
		5	L/U	1	1	2

Workload (min)	WL_(L/U)	6
	WL_2	447.0967742
	WL_4	965.1612903
	WL_7	113.2258065
	WL_10	10.64516129
	WL_11	21.29032258
	WL_9	48.06451613
	WL_12	18.70967742
	WL_8	20
	WL_(n+1)	9.333333333

Bottleneck is maximum of all Workloads

Bottleneck is WL_4 which means machine DWS XPRO S

Production Rate at Bottleneck Station

Rp	0.001036096	pc/min
Rp	0.062165775	pc/hr

production rate G	**Rp*Pj_G**	**0.022058824**	**pc/hr**
production rate B	**Rp*Pj_B**	**0.019385027**	**pc/hr**
production rate E	**Rp*Pj_E**	**0.020721925**	**pc/hr**

					in %
Utilization	U_(L/U)	=	WL_(L/U)*Rp	0.006217	0.621657754
	U_2	=	WL_2*Rp	0.463235	46.32352941
	U_4	=	WL_4*Rp	1	100
	U_7	=	WL_7*Rp	0.117313	11.73128342
	U_10	=	WL_10*Rp	0.011029	1.102941176
	U_11	=	WL_11*Rp	0.022059	2.205882353
	U_9	=	WL_9*Rp	0.049799	4.979946524
	U_12	=	WL_12*Rp	0.019385	1.938502674
	U_8	=	WL_8*Rp	0.020722	2.072192513
	U_(n+1)	=	WL_(n+1)*Rp	0.00967	0.967023173

Extended Bottleneck Method

MLT_1	1659.52688
N*	1.71942959

N	MLT_1 (min)	Rp (pc/min)	MLT_2 (min)	Tw (min)
1	1659.52688	0.000602581		0
2		0.001036096	1930.322581	270.7957
3		0.001036096	2895.483871	1235.957

MANUFACTURIN CELL_3

Bottleneck Method

PART	MIX P(j)	OPERATION	DESCRIPTION	STATION	SERVER	TIME tijk (min)
C	0.590361	1	L/U	1	1	4
		2	2	2	1	1380
		3	6	3	1	120
		4	L/U	1	1	2
D	0.409639	1	L/U	1	1	4
		2	3	4	1	900
		3	6	3	1	60
		4	11	5	1	30
		5	L/U	1	1	2

Workload (min)		
	WL_(L/U)	6
	WL_2	814.6987952
	WL_6	95.42168675
	WL_11	12.28915663
	WL_3	368.6746988
	WL_(n+1)	6.819277108

Bottleneck is maximum of all Workloads

Bottleneck is WL_2 which means machine Manual Removal job shop

Production rate at bottleneck station

Rp	0.001227448	pc/min
Rp	0.07364685	pc/hr

production rate C	**Rp*P(j)_C**	0.043478261	pc/hr
production rate D	**Rp*P(j)_D**	0.030168589	pc/hr

					in %
Utilization	U_(L/U)	=	WL_(L/U)*Rp	0.007365	0.7364685
	U_2	=	WL_2*Rp	1	100
	U_6	=	WL_6*Rp	0.117125	11.71251109
	U_11	=	WL_1*Rp	0.015084	1.508429459
	U_3	=	WL_3*Rp	0.452529	45.25288376
	U_(n+1)	=	WL_(n+1)*Rp	0.00837	0.837030464

Extended Bottleneck Method

MLT_1	1303.903614
N*	1.600473233

N	MLT_1 (min)	Rp (pc/min)	MLT_2 (min)	Tw (min)
1	1303.903614	0.000766928		0
2		0.001227448	1629.39759	325.494
3		0.001227448	2444.096386	1140.193