PRODUCTION PLANNING AND SCHEDULING Part 1

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Planning Hierarchy

Forecasting – MPS – MRP – Balancing – Scheduling

- Forecasting
- Master Production Planning (Scheduling)
- Material Requirements Planning (MRP) ⇒ ERP
- Capacity Balancing
- Production Scheduling

Forecasting – MPS – MRP – Balancing – Scheduling

MRP II (Manufacturing Resource Planning II)

ERP = MRP II + ...

History of ERP

- 1970's MRP Material Requirements Planning
- 1980's MRPII Manufacturing Resource Planning
- 1990's ERP Enterprise Resource Planning (e.g., SAP system)

Forecasting – MPS – MRP – Balancing – Scheduling

MRP II ⇒ ERP

Addition of CRM

Master Production Schedule

specifies

Sequence and Quantity of Products (C)

MPS – MRP – Balancing – Scheduling

EXAMPLE

Jan	Feb	March	Month
200 C1	195 C4	385 C1	
150 C7	150 C7	160 C6	
180 C14	180 C12	670 C7	
	128 C17	230 C9	

ERP systems are used from

- Automotive industry

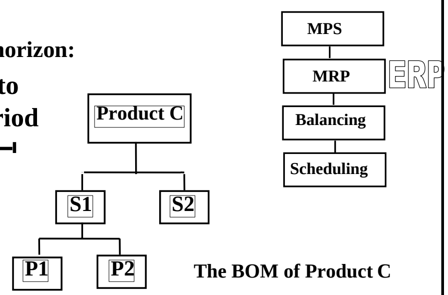
to

- Pharmaceutical industry

MRP ERP

Planning horizon:

1 month to
3 day period



The BOM of Product C

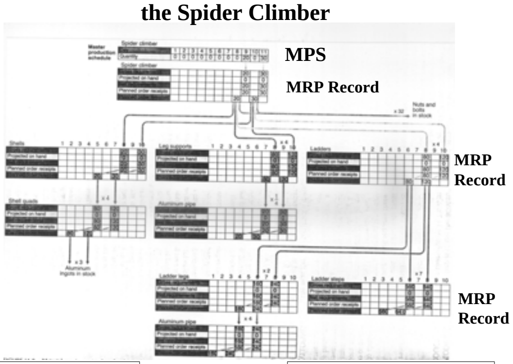
MRP and ERP Systems

Backward (top down) generation of a production plan

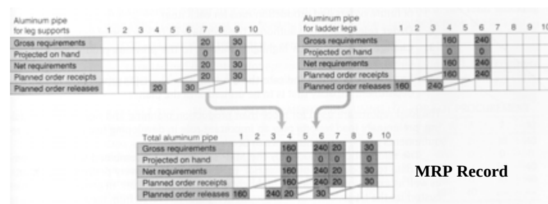
Forward (push) implementation of the production plan

Note: Kanban systems are pull systems

EXAMPLE: Material Requirements Records for the Spider Climber



Merged Material Requirements for Aluminum Pipe



Basic MRP (ERP) Record

From the previous production stage or storage

Period		1	2	3	4	5
Gross requirements			10		40	10
Scheduled receipts		50				
On hand	4	54	44	44	4	-6
Planned order releases	50					

IN ⇧ IN — OUT

Lead time = 1 period
Lot size = 50
Safety stock = 4

Lead time

Note: On hand should be >= Safety stock

The Basic MRP (ERP) Record "Arithmetic"

Period		1	2	3	4	5
Gross requirements			10		40	10
Scheduled receipts		50				
On hand	4	54	44	44	4	-6
Planned order releases						

Lead time = 1 period
Lot size = 50
Safety stock = 4

Question?

Period		1	2	3	4	5
Gross requirements			10		40	10
Scheduled receipts		50				
On hand	4	54	44	44	4	-6
Planned order releases					50?	

Lead time = 1 period
Lot size = 50
Safety stock = 4

What 50?

What will a 50 do to the MRP record?

The Answer

Period		1	2	3	4	5
Gross requirements			10		40	10
Scheduled receipts		50				50
On hand (safety stock)	4	54	44	44	4	~~-6~~ 44
Planned order releases	50				50	

Lead time = 1 period
Lot size = 50
Safety stock = 4

Previously omitted

New order release

Explosion of Requirements for Subassembly S1 and Part P2

S 1

Period		1	2	3	4	5
Gross requirements			10		40	10
Scheduled receipts		50				50
On hand	4	54	44	44	4	~~-6~~ 44
Planned order releases					50	

Lead time = 1 period
Lot size = 50

P 2

		1	2	3	4	5
Gross requirements					50	
Scheduled receipts					100	
On hand	8	8	8	8	~~-42~~ 58	
Planned order releases				100		

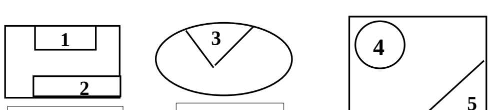
Lead time = 1 period
Lot size = 100

CAPACITY BALANCING

MPS
MRP
Balancing
Scheduling

8 hour period

5 operations to be assigned to 2 machines

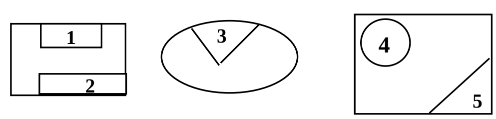


Part 1
2 operations

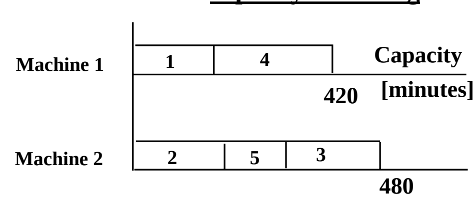
Part 2
1 operation

Part 3
2 operations

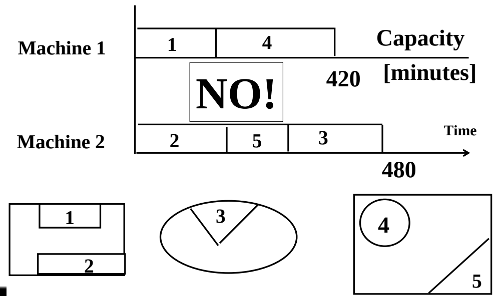
NOTE: Operation is a set of tasks (e.g., removal of machining features) of a part is performed on one machine



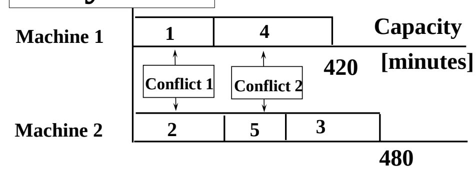
The result of capacity balancing



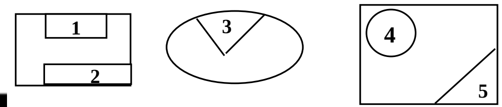
Question:
Is this Gantt chart a feasible schedule?

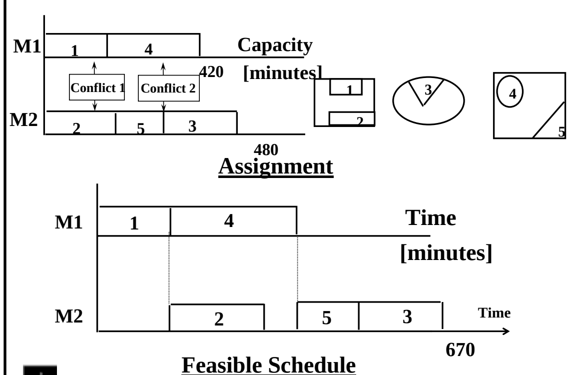


Why Not?



An <u>assignment</u> only due to two conflicts





CAPACITY BALANCING MODELS

MODEL 1: No splitting of batches

<u>Parameters</u>

I	set of batches of operations to be processed
J	set of machines
Tij	time of processing batch i on machine j
Cij	cost of processing batch i on machine j
bj	processing time available on machine j (capacity of machine j)

<u>Decision variable</u>

$$x_{ij} = \begin{cases} 1 & \text{if batch i of operations is processed on machine } j, j \in J \\ 0 & \text{otherwise} \end{cases}$$

Model 1: No splitting of batches

min $\sum_{i \in I} \sum_{j \in J} C_{ij} x_{ij}$ (i: batch, j: machine) — Min total processing cost

$\sum_{j \in J} x_{ij} = 1 \quad i \in I$ — One batch per machine

$\sum_{i \in I} T_{ij} x_{ij} \le b_j \quad j \in J$ — Capacity constraint

$x_{ij} = 0, 1 \quad i \in I, j \in J$ — Integrality constraint

Example

Processing cost $[C_{ij}] =$ (Batch x Machine)

Batch \ Machine	1	2	3
1	4	7	7
2	1.5	1.2	6
3	3	6	5
4	4	5	4
5	2	3	2

Processing time $[T_{ij}] =$

	1	2	3
1	3	8	7
2	1	1	6
3	4	5	4
4	5	6	3
5	1	2	3

Machining capacity $[b_j] = [21, 20, 42]^T$

Min 4x11 + 7x12 + 7x13 + 1.5x21 + ... + 2x53

For batch (row)

i = 1 x11 +x12 +x13 = 1
i = 2 x21 +x22 +x23 = 1
i = 3 x31 +x32 +x33 = 1
i = 4 x41 +x42 +x43 = 1
i = 5 x51 +x52 +x53 = 1

$\sum_{j \in J} x_{ij} = 1$

For machine (column)

j = 1 3x11 +1x21 + 4x31 + 5x41 +1x51<= 21
j = 2 8x12 +1x22 + 5x32 + 6x42 +2x52<= 20
j = 3 7x13 +6x23 +4x33 + 3x43 +3x53<= 42

$\sum_{i \in I} T_{ij} x_{ij} \le b_j$

xij = 0, 1 for i = 1 to 5, j = 1 to 4

Solution

x11 = 1, x22 = 1, x31 = 1, x43 = 1, x53 = 1

Machine 1: batches 1, 3
Machine 2: batch 2
Machine 3: batches 4, 5

Model 2: Limited Tool Magazine Capacity No batch splitting

k_{ij} space occupied in a tool magazine by tools required for operation i at machine j $i \in I, j \in J$
f_j capacity of the tool magazine on machine j, $j \in J$
q_j penalty for using the tool magazine on machine j, $j \in J$
Z_j upper limit on the number of tool magazines to be used on machine j, $j \in J$
z_j number of tool magazines required on machine j, $j \in J$

Model 2

min $\sum_{i \in I}\sum_{j \in J} C_{ij}x_{ij} + q_j z_j$ Min total processing + tool magazine penalty cost

$\sum_{j \in J} x_{ij} = 1$ $i \in I$ One batch per machine

$\sum_{i \in I} T_{ij} x_{ij} \le b_j$ $j \in J$ Machine capacity constraint

$\sum_{i \in I} k_{ij} x_{ij} \le f_j z_j$ for each $j \in J$ Tool magazine capacity constraint

$x_{ij} = 0, 1$ for each $i \in I$, $j \in J$ Integrality constraint

$z_j \le Z_j$ integer for each $j \in J$ Integrality + bounding constraint

Model 3: Batch Splitting is Allowed

tij processing time of each operation from batch i on machine j
cij processing cost of an operation from batch i on machine j
ai required number of operations in batch i (the size of batch i)
yij number of operations of batch i to be processed on machine j

min $\sum_{i \in I}\sum_{j \in J} c_{ij} y_{ij}$ Min total processing cost

$\sum_{j \in J} y_{ij} = a_i$ $i \in I$ Required number of operations

$\sum_{i \in I} t_{ij} y_{ij} \le b_j$ $j \in J$ Machine capacity constraint

$y_{ij} \ge 0$ integer $i \in I$, $j \in J$ Integrality constraint

Example

(1) number of operation types |I| = 10
(2) number of machine types |J| = 3
(3) matrix of machining times

$[t_{ij}]$ = Batch - machine matrix

Batch \ Machine	1	2	3
1	29.1	24.5	∞
2	18.4	∞	20.0
3	31.2	∞	28.0
4	∞	14.5	16.5
5	24.5	22.0	∞
6	16.5	14.5	17.4
7	8.5	6.4	∞
8	35.4	∞	39.1
9	19.4	18.1	∞
10	24.1	26.8	∞

(4) vector of batch sizes

[ai] = [18, 17, 15, 14, 15, 20, 12, 18, 12, 16]

(5) vector of machine capacity

[bj] = [1800, 1000, 1500]

Solution

y12 = 18, y21 = 17, y33 = 15, y42 = 4, y43 = 10, y51 = 9, y52 = 6, y62 = 20, y72 = 12, y81 = 18, y91 = 12, y10,1 = 16

Machine 1: 17 operations (of type 2), 9(5), 18(8), 12(9), 16(10)
Machine 2: 18(1), 4(4), 6(5), 20(6), 12(7)
Machine 3: 15(3), 10(4)

NOTE: Operations 5 are processed on machines 1 and 2

Line Balancing

Assignment of tasks to stations

Task x station matrix

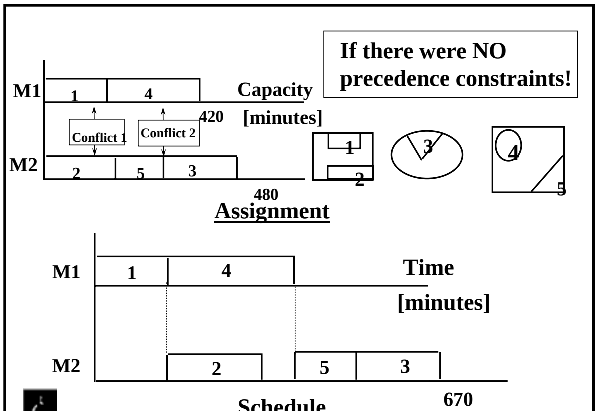
?

What leads to more uniform utilization of machine capacity:

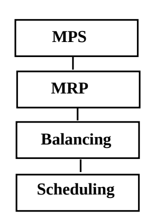
- **Capacity balancing with batch splitting, or**
- **Capacity balancing without batch splitting?**

?

When the capacity loading Gantt chart would be equivalent to the schedule Gantt chart?



Manufacturing Scheduling

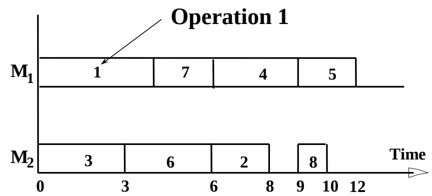


Manufacturing Scheduling

8 hour period

<u>Definition</u>
Scheduling is the assignment of operations, jobs, tasks, etc. to resources in time.

Example: Two machine schedule

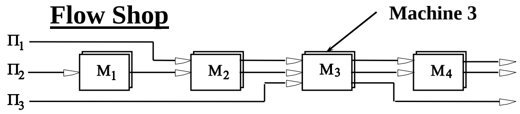


Makespan = 12

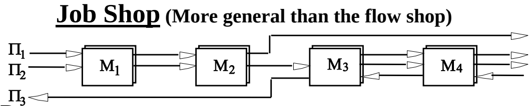
Manufacturing Scheduling

Basic Models

<u>Flow Shop</u>



<u>Job Shop</u> (More general than the flow shop)



Parameters Used in Scheduling Models

tij = processing time of operation oi on machine Mj
ri = readiness of operation oi for processing, i.e., the time operation oi's available for scheduling
di = due date, i.e., the promised delivery time of operation oi
wi = weight (priority), which expresses the relative urgency of operation oi

Ci = completion time of operations oi
Fi = flow time (the difference between completion time and readiness),
Fi = Ci - ri
Li = lateness (the difference between completion time and due date),
Li = Ci - di
Ti = tardiness, Ti = max {Ci - di , 0}