WORKER-MACHINE RELATIONSHIPS

Multiple activity charts: chart on which activities of workers, product and machines are recorded on a common time scale to show their relationships (actually a variety of charts with different names, but all do the same thing):

1) **Worker-machine process chart** (man-machine chart) - seeking most effective relationship between operator(s) and machine(s), i.e. minimum total %idle time.

- a) worker/operator on left
- b) machine on right
- c) common vertical time scale
- d) solid line (dark) = productive time
- e) break in line (white) = idle time
- f) broken/dotted line (shaded) =loading/unloading
- g) summary

2) **Gang process chart** (multi-man chart) - multiple activity chart applied to a group of workers, seeking most effective relationship between several workers, same principles as above

Worker-machine relationships can be of three types:

1) **synchronous** servicing
2) **random** (asynchronous) servicing
3) combination of both - 'real-life'

Synchronous servicing - case with a fixed machine cycle time in which the worker loads/unloads the machine (both worker and machine are utilized simultaneously!) the machine at regular intervals. Ideally, several machines can be serviced (**machine coupling**). In an ideal case:

$$N = \frac{R+m}{R}$$

where: N = number of machines that can be serviced by one operator
R = loading/unloading time per machine = 1
m = machine cycle time (automatic run time) = 2

Operator	Machine #1	Machine #2	Machine #3
Loads #1	Loads #1		
Loads #2		Loads #2	
Loads #3			Loads #3

In real life, the operator will be able to service fewer machines because of w= worker (walk) time:

$$N \leq \frac{R+m}{R+w}$$

Also, N is typically non-integer; then a decision (typically an economic one, lowest unit cost) must be made regarding who (worker vs. machine) will be idle!!

EX: Consider a walk time of 0.1 min (with R = 1.0 and m =2.0). Also the operator earns $10.00/hr and the machine cost $20.00/hr to run. Then N = (R+m)/(R+w)= 3/1.1 = 2.7

Consider 3 machines:

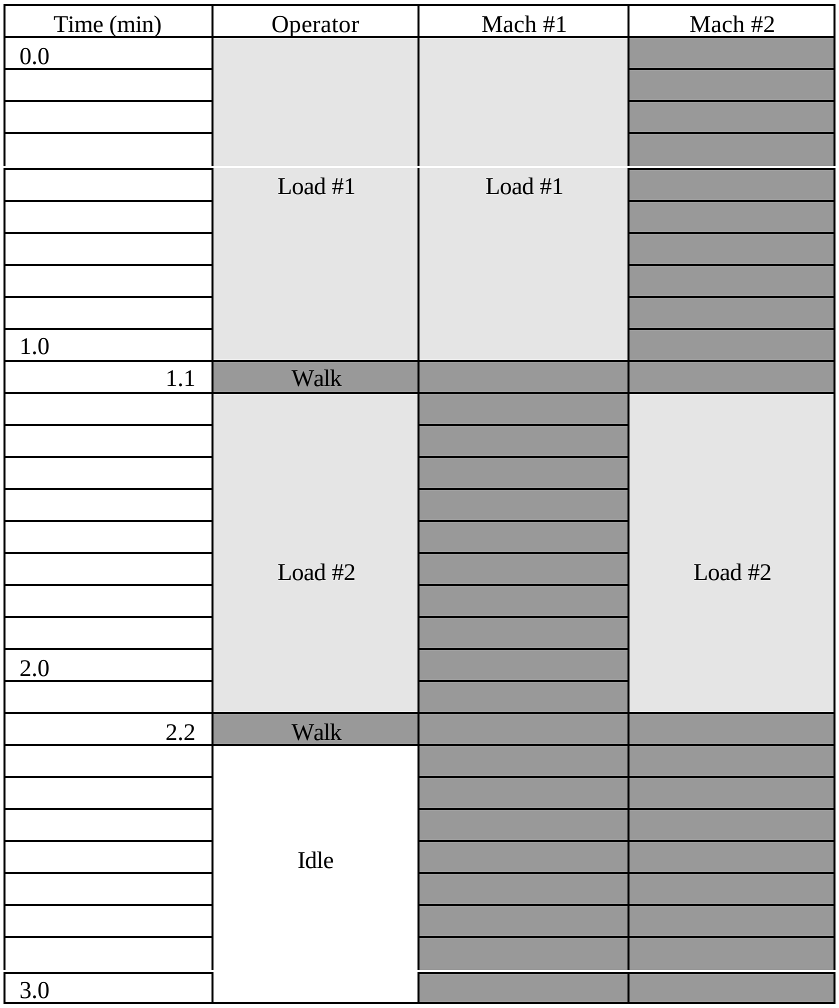
Time (min)	Operator	Mach #1	Mach #2	Mach #3
0.0				
	Load #1	Load #1		
1.0			Idle	
1.1	Walk			
	Load #2		Load #2	
2.0				
2.1				Idle
2.2	Walk			
	Load #3			Load #3
3.0				
		Idle		
3.3	Walk			

Production = (1 unit per machine / 3.3 min) × 3 machines × 60 min/hr = 54.55 units/hr
Cost per hour = $10 for one operator plus 3 machines @ $20 = $70/hr
Unit cost = Cost/Production = $70/54.55 = $1.28/unit
Or more simply find the unit cost from The Expected Cost (TEC) formula:

$$TEC_{N2} = (R+w)(K_1+N_2K_2) = (1 + 0.1)(10 + 3\times20)/60 = \$1.28/\text{unit}$$

where: N_1 = lowest integer of N (round down) = 2
N_2 = largest integer of N (round up) = 3
K_1 = operator rate ($/unit time) = $10/hr
K_2 = machine cost ($/unit time) = $20/hr

EX: Now consider the other possibility - **2 machines**:



Production = (1 unit per machine / 3.0 min) × 2 machines × 60 min/hr = 40 units/hr
Cost per hour = \$10 for one operator plus 2 machines @ \$20 = \$50/hr
Unit cost = Cost/Production = \$50/40 = \$1.25/unit
Or more simply find the unit cost from The Expected Cost (TEC) formula:

$$TEC_{N1} = (R+m)(K_1+N_1K_2)/N_1 = (1 + 2)(10 + 2\times 20)/2/60 = \$1.25/\text{unit}$$

where: N_1 = lowest integer of N (round down) = 2 K_1 = operator rate (\$/unit time) = \$10/hr
N_2 = largest integer of N (round up) = 3 K_2 = machine cost (\$/unit time) = \$20/hr

In conclusion, based on lowest cost, the set up with 2 machines is best.
However, if you can have unlimited sales at a high sales price (consider a ‘hot’ item, e.g. Sony Playstation 2), you would be better off with 3 machines, because you can maximize your profit!!

Another Example:

R = 0.6 min, m = 1.48 min, w = 0, Operator earns \$12/hr; machine costs \$18/hr to run

N = (R + m)/(R + w) = (0.6 + 1.48)/0.6 = 3.5   Therefore can service either 3 or 4 machines

Case #1 - N=4

Time (min)	Operator	Mach #1	Mach #2	Mach #3	Mach #4
.0	Load #1	Load #1			
.6	Load #2		Load #2		
1.2	Load #3			Load #3	
1.8 2.4	Load #4				Load #4
3.0	Load #1	Load #1			
3.6	Load #2		Load #2		
4.2	Load #3			Load #3	

$$TEC_{N2} = (R+w)(K_1+N_2K_2) = 0.6 \times (12 + 4\times18)/60 = \$\ 0.84/\text{unit}$$

Case #2 - N=3

Time (min)	Operator	Mach #1	Mach #2	Mach #3
.0	Load #1	Load #1		
.6 1.2	Load #2		Load #2	
1.8	Load #3			Load #3
2.08				
2.68	Load #1	Load #1		

$$TEC_{N1} = (R+m)(K_1+N_1K_2)/N_1 = (0.6 + 1.48) \times(12 + 3\times18)/3/60 = \$\ 0.76/\text{unit}$$

Therefore, 3 machines produce the lowest cost.

Random Servicing - machine servicing time is not on regular cycle and could be completely random; use probability theory (**binomial expansion**) to estimate %idle time

Probability of *m* (out of *n*) machines down = $\frac{n! * p^m * q^{(n-m)}}{m! * (n-m)!}$

where: p = probability of down time
q = probability of up time = 1-p

EX: n=3, p=0.1, q=0.9 What is the total %idle time?

Machines down (m)	Probability	Machine hours lost with 1 operator	Machine hours lost with 2 operators
0		0	0
1		0	0
2		0.027 x 8 = 0.216	0
3		0.001 x 16 = 0.016	0.001 x 8 = 0.008

Assume the operator is paid $10.00/hr and the CNC-Robotic cell cost $500/hr to run, but produces 120 units per hour.

For one operator:
Production over 8 hours: (24-0.232) x 120 = 2,852.16
Cost for 8 hours: $10 x 8 + $500 x 8 x 3 = $12,080
Unit cost: $12,080/2,852.16 = $4.235

For two operators:
Production over 8 hours: (24-0.008) x 120 = 2,879.04
Cost for 8 hours: $10 x 8 x 2 + $500 x 8 x 3 = $12,160
Unit cost: $12,160/2,879.04 = $4.224

For three operators: (no lost machine time**)**
Production over 8 hours: 24 x 120 = 2,880
Cost for 8 hours: $10 x 8 x 3 + $500 x 8 x 3 = $12,240
Unit cost: $12,240/2,880 = $4.25

Overall cheapest method: have two operators.