

**Questions**

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1. *What does the operation process chart show?*

The operation process chart shows the chronological sequence of all operations and inspections with the operation and inspection times included.

2. *What symbols are used in constructing the operation process chart?*

A small (3/8 inch diameter) circle denotes an operation and a small square an inspection.

3. *How does the operation process chart show materials introduced into the general flow?*

Materials are introduced through horizontal lines feeding into the vertical flow lines.

4. *How does the flow process chart differ from the operation process chart?*

The flow chart contains more detail than the operation process chart. In addition to operations and inspections, it includes transportations, storages, delays, and the times and distance involved.

5. *What is the principal purpose of the flow process chart?*

Its principal purpose is to effect maximum total savings (both direct and indirect costs) of one component of a product or system at a time.

6. *What symbols are used in constructing the flow process chart?*

A small circle is used for an operation, a square for an inspection, a triangle standing on its vertex for a storage, a D for a delay, and an arrow for a transportation.

7. *Why is it necessary to construct process charts from direct observation as opposed to information obtained from the foreman?*

Information from the supervisor frequently is not accurate and may be biased. More reliable information is obtained by personal observation and measurement.

8. *In the construction of the flow process chart, what method can be used to estimate distances moved?*

Distances can be estimated by counting columns that the product moves past and then multiplying the distance between columns by the number of columns minus one.

9. *How can delay times be determined in the construction of the flow process chart? Storage times?*

Delay times can be determined by marking several parts with chalk, recording the exact time they went into storage or were delayed, and then checking periodically to note when the marked parts are

brought back into production.

10. *When would you advocate using the flow diagram?*

Flow diagrams are useful in solving plant layout problems.

11. *How can the flow of several different products be shown on the flow diagram?*

Different products can be shown by using a different color flow line for each product.

12. *What two flowchart symbols are used exclusively in the study of paper work?*

Two concentric circles indicate the creation of a record or a set of papers. A crosshatched circle indicates the addition of information to a record.

13. *What are the limitations of the operation and flow process charts and of the flow diagram?*

Both flow process charts and flow diagrams are useful in stating the problem, i.e. getting, presenting, and analyzing data. Other tools need to be used in developing the ideal method.

14. *Explain how the concept of PERT charting can save a company money.*

A PERT chart primarily serves to improve scheduling at the least cost.

15. *Explain how you would obtain 'optimistic' and 'pessimistic' times to be used in connection with a PERT chart that you are developing.*

If standard data is available (see Chapter 12), the analyst can calculate average activity times with this data; 15% less than average time yields an optimistic estimate; 15% more than the average time yields a pessimistic estimate.

16. *When is it advisable to construct a worker and machine process chart?*

Worker and machine process charts are advisable whenever it appears that an operator or the machine being operated is idle during a portion of the work cycle.

17. *What is machine coupling?*

Machine coupling is the practice of having one employee operate more than one machine.

18. *In what way does an operator benefit through machine coupling?*

The operator benefits with typically higher wages, more responsibility, and increased job knowledge (when assigned to two or more different work assignments).

19. *Explain how you would sell machine coupling to union officials strongly opposed to the technique.*

Point out that higher base rates may result under machine coupling. Also point out that machine coupling has long been accepted in many industries, including the textile and metal trades.

20. How does the gang process chart differ from the worker and machine process chart?

The gang process chart plots the activity of a group of workers servicing one facility or machine, while the worker and machine chart plots the activity of one worker when servicing one or more machines.

21. In a process plant, which of the following process charts has the greatest application: worker and machine, gang, operation, flow? Why?

The flow chart is probably the most useful because it highlights hidden costs such as distances traveled and delays. On the other hand, with like machines located together, the worker and machine process chart is useful for optimizing potential machine coupling.

22. What is the difference between synchronous and random servicing?

Synchronous servicing is where both the worker and the machine being serviced at regular intervals are occupied the whole cycle. It is an ideal case which is seldom achieved. Completely random servicing refers to those cases in which it is not known when a facility will need to be serviced or how long the servicing will take.

## Problems

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1. Based on the following 'emergency' cost table, what would be the minimum time to complete the project described by Figure 2-4, whose normal costs are shown in Table 2-2? What would be the added cost to complete the project within this time period?

Schedule (weeks)	Weeks Gained	Least Expensive Solution	Total Cost
27	0	Normal duration of project	\$22,500
26	1	Reduce activity I by one week for an added cost of \$200	\$22,700
25	2	Reduce activity I by two weeks for an added cost of \$400	\$22,900
24	3	Reduce I by two weeks and J by one week for an added \$1,000	\$23,500
23	4	Reduce I by two, J by one and K by one week for an added \$1,750	\$24,250
22	5	Reduce I by two, J by one, K by one, and M or P by one week for an added cost of \$3,150	\$25,650
21	6	Reduce I by two, J by one, K by one, M by one and P by one week for an added cost of \$4,550	\$27,050
20	7	Reduce I by two, J by one, K by one, M by one, P by one, and F by one week for an added cost of \$6,350 (Note we now have an additional critical path: B-2, E-5, G-3 takes ten weeks as does C-3, F-3, I-4.)	\$28,850

19	8	Reduce I by two, J by one, K by one, M by one, P by one, F by one, and C by one week for an added cost of \$8,750 (Note activity E can be shorted by one week at no extra cost. Thus no extra cost is incurred on path B-2, E-4, G-3.) By allowing activity L to be done in two weeks rather than three weeks, a savings of \$800 can be made. However, activity N under emergency will cost \$300 more for added assurance even though the time of one week has not been changed. This alters final cost.	\$31,250  \$30,750
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2. In the Dorben Company's automatic screw machine department, five machines are assigned to each operator. On a given job, the machining time per piece is 0.164 hours and the machine servicing time is 0.038 hours. With an operator rate of \$12.80 per hour and a machine rate of \$14 per hour, calculate the expected cost per unit of output. Exclude material cost.

$$TEC = (\ell + m) \frac{(K_1 + N_1 K_2)}{N_1} = (.038 + .164) \frac{(\$12.80 + 5 \times \$14.00)}{5} = \$3.35$$

3. At Dorben Company, a worker is assigned to operate several machines. Each of these machines is down at random times during the day. A work sampling study indicated that on the average the machines operate 60 percent of the time unattended. Operator attention time at irregular intervals averages 40 percent. If the machine rate is \$20 per hour and the operator rate is \$12 per hour, what would be the most favorable number of machines (from an economic standpoint) that should be operated by one operator?

#machines	Lost time cases	Hours lost	Productivity	Cost	Unit cost
4	$\frac{4!}{2!2!} 0.4^2 \times 0.6^2 = 0.346$	0.346×8 + 0.154×16 + 0.026×24 = 5.85	(32-5.85)x = 26.15x	8(4×20+12)= \$736	\$736/26.15x = <b>\$28.15/x</b>
	$\frac{4!}{3!1!} 0.4^3 \times 0.6^1 = 0.154$				
	$\frac{4!}{4!0!} 0.4^4 \times 0.6^0 = 0.026$				
3	$\frac{3!}{2!1!} 0.4^2 \times 0.6^1 = 0.288$	0.288×8 + 0.064×16 = 3.33 or 0.14×24 = 3.36	(24-3.33)x = 20.67x	8(3×20+12)= \$576	\$576/20.67x = <b>\$27.9/x</b>
	$\frac{3!}{3!0!} 0.4^3 \times 0.6^0 = 0.064$				
2	$\frac{2!}{2!0!} 0.4^2 \times 0.6^0 = 0.16$	0.16×8 = 1.28	(16-1.28)x = 14.72x	8(2×20+12)= \$416	\$416/14.72x = <b>\$28.26/x</b>
1	None	0	8x	8(20+12)=\$256	\$256/8x= <b>\$32/x</b>

Therefore 3 machines provide lowest cost per unit production (based on x units/hr). Note that 4 machines is a very close second!



4. The analyst in the Dorben Company wishes to assign a number of like facilities to an operator based on minimizing the cost per unit of output. A detailed study of the facilities revealed the following:

Loading machine standard time	=	0.34 minutes
Unloading machine standard time	=	0.26 minutes
Walk time between two machines	=	0.06 minutes
Operator rate	=	\$12.00 per hour
Machine rate (both idle and working)	=	\$18.00 per hour
Power feed time	=	1.48 minutes

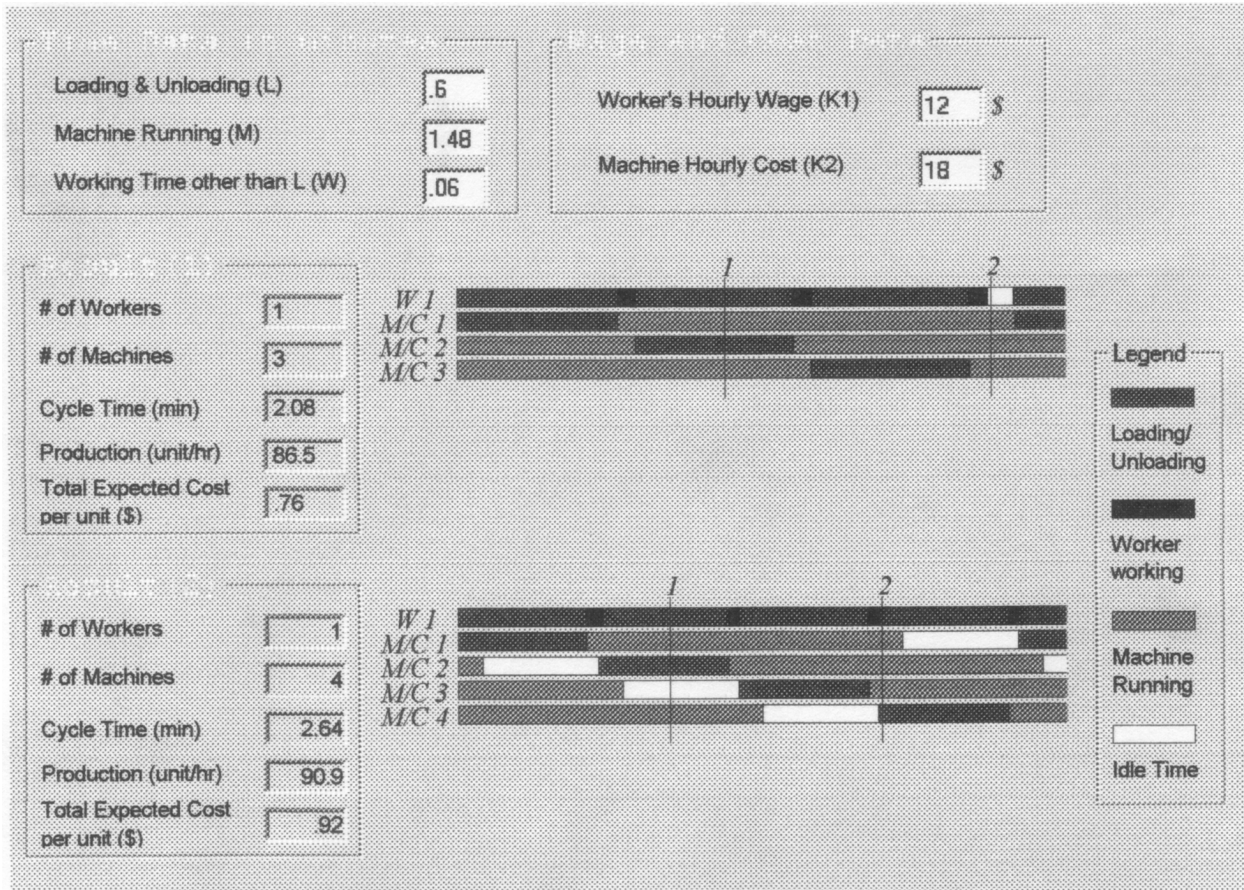
How many of these machines should be assigned to each operator?

$$N_1 \leq \frac{\ell + m}{\ell + w} = \frac{.34 + .26 + 1.48}{.34 + .26 + .06} = 3.15$$

$$TEC_3 = \frac{(\ell + m)}{N_1} (K_1 + N_1 K_2) = \frac{(.6 + 1.48)}{3} \times (\$12 + 3 \times \$18) = \$0.763 \text{ per piece}$$

$$TEC_4 = (\ell + w) (K_1 + N_1 K_2) = \frac{(.6 + 0.06)}{60} \times (\$12 + 4 \times \$18) = \$0.924 \text{ per piece}$$

Therefore three machines are assigned to each operator.



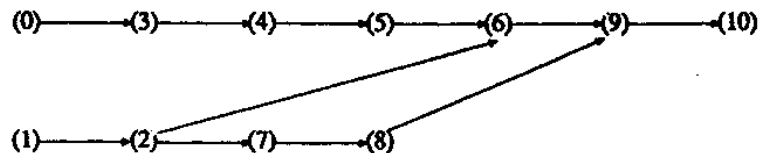
5. A study revealed that a group of three semiautomatic machines assigned to one operator operate 70 percent of the time unattended. Operator service time at irregular intervals averaged 30 percent of the time on these three machines. What would be the estimated machine hours lost per eight-hour day because of lack of an operator?

Machines down	Probability	Machine hours lost
0	$\frac{3!}{0!3!} .3^0 .7^3 = 0.343$	0
1	$\frac{3!}{1!2!} .3^1 .7^2 = 0.441$	0
2	$\frac{3!}{2!1!} .3^2 .7^1 = 0.189$	$(0.189)(8) = 1.512$
3	$\frac{3!}{3!0!} .3^3 .7^0 = 0.027$	$(.027)(2)(8) = 0.432$

A total of  $1.512 + 0.432 = 1.944$  hours are lost per day because of interference.

6. Based upon the following data, develop your recommended allocation of work and the number of work stations.

Work Unit	Estimated Work Unit Time in Minutes
0	0.76
1	1.24
2	0.84
3	2.07
4	1.47
5	2.40
6	0.62
7	2.16
8	4.75
9	0.65
10	1.45



Minimum required production per day is 90 assemblies. A precedence matrix as follows was developed by the analyst:

Estimated Time	Work Unit	Work Unit										
		0	1	2	3	4	5	6	7	8	9	10
0.76	0				1	1	1	1			1	1
1.24	1			1					1	1	1	1
0.84	2							1	1	1	1	1
2.07	3					1	1	1			1	1
1.47	4						1	1			1	1
2.40	5							1			1	1
0.62	6										1	1
2.16	7									1	1	1
4.75	8										1	1
0.65	9											1
1.45	10											

Required production per day is 90 assemblies and should not exceed 105 assemblies per day.  
 Available time = 8 hrs. × 60 min = 480 min per day or 480/90 = 5.33 min per assembly  
 Total work time = 0.76+1.24+0.8 +2.07+1.47+2.40+0.62+2.16+4.75+0.65+1.45 = 18.41 min  
 Required number of operators = 18.41 min / 5.33 min per assembly = 3.45 or 4 operators  
 Thus, each operator should be loaded with approximately 5.33 minutes of work at his/her work station in order to achieve the desired daily output.

Station	Element	Position	Immediate Predecessors	Work Elem. Time	Cum.	Unassigned
1	1	11.09	-	1.24	1.24	4.09
1	2	10.47	1	0.84	2.08	3.25
1	0	9.42	-	0.76	2.84	2.49
1	7	9.01	2	2.16	5.00	0.33
2	3	8.66	0	2.07	2.07	3.26
2	4	6.59	3	1.47	3.54	1.79
3	8	6.55	7	4.75	4.75	0.58
4	5	5.12	4	2.40	2.40	2.93
4	6	2.10	5	0.62	3.02	2.31
4	9	2.10	6	0.65	3.67	1.66
4	10	1.45	9	1.45	5.12	0.21

Thus, this job should be designed for four work stations with elements 1, 2, 0, and 7 assigned to the first station; elements 3 and 4 to the second station; element 3 to the third station; and elements 5, 6, 9, and 10 to the fourth station.

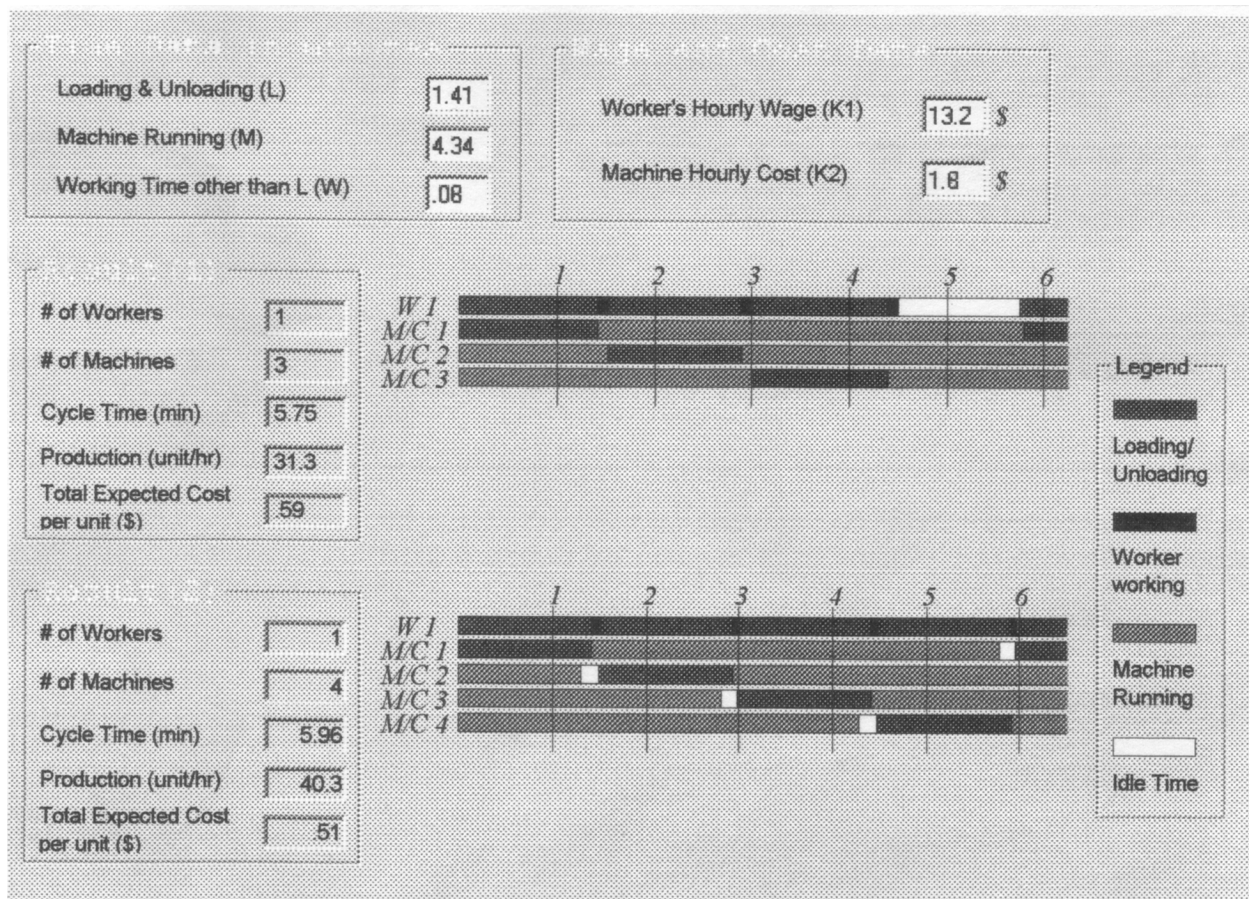
7. How many machines should be assigned to an operator for lowest cost operations when:
- Loading and unloading time one machine, 1.41 minutes.
  - Walking time to next facility, 0.08 minutes.
  - Machine time (power feed), 4.34 minutes.
  - Operator rate, \$13.20 per hour.
  - Machine rate, \$18.00 per hour.

$$N_1 \leq \frac{\ell + m}{\ell + w} = \frac{1.41 + 4.34}{1.41 + 0.8} = 3.859$$

$$TEC_3 = \frac{(\ell + m)}{N_1} (K_1 + N_1 K_2) = \frac{(1.41 + 4.34)}{3} \times (\$13.20 + 3 \times \$18) = \$2.147 \text{ per piece}$$

$$TEC_4 = (\ell + w) (K_1 + N_1 K_2) = \frac{(1.41 + 0.08)}{4} \times (\$13.20 + 4 \times \$18) = \$2.116 \text{ per piece}$$

Therefore, assign four machines to the operator.



8. *What proportion of machine time would be lost in operating four machines when the machine operates 70 percent of the time unattended and the operator attention time at irregular intervals averages 30 percent? Is this the best arrangement on the basis of minimizing the proportion of machine time lost?*

Machines down	Probability	Machine hours lost
0	$\frac{4!}{0!4!} .3^0 .7^4 = 0.2401$	0
1	$\frac{4!}{1!3!} .3^1 .7^3 = 0.4116$	0
2	$\frac{4!}{2!2!} .3^2 .7^2 = 0.2646$	$(0.2646)(8) = 2.1168$
3	$\frac{4!}{3!1!} .3^3 .7^1 = 0.0756$	$(0.0756)(2)(8) = 1.2096$
4	$\frac{4!}{4!0!} .3^4 .7^0 = 0.0081$	$(0.0081)(3)(8) = 0.1944$

A total of  $2.1168 + 1.2096 + 0.1944 = 3.5208$  hours are lost per day because of interference. If two operators were assigned to the four machines, i.e. two machines to each operator, then only

$$\frac{2!}{2!0!} .3^2 .7^0 \times 8 = .09 \times 8 = 0.72 \text{ hours}$$

per pair of machines are lost or only 1.44 hours for all four machines.

9. *In an assembly process involving six distinct operations, it is necessary to produce 250 units per eight-hour day. The measured operation times are as follows:*
- 7.56 minutes.*
  - 4.25 minutes.*
  - 12.11 minutes*
  - 1.58 minutes.*
  - 3.72 minutes.*
  - 8.44 minutes.*

*How many operators would be required at 80 percent efficiency? How many operators will be utilized at each of the six operations?*

One unit of production will be needed every  $480/250 = 1.92$  minutes.

Total work time =  $7.56 + 4.25 + 12.11 + 1.58 + 3.72 + 8.44 = 37.66$  minutes

Required number of operators =  $37.66 \text{ min} / 1.92 \text{ min per assembly} / 0.80 \text{ efficiency} = 24.52$  or 25 operators.







Operation	Std.	Std. Min./ 1.92 min	No. of Operators
1	7.56	3.94	4
2	4.25	2.21	3
3	12.11	6.31	7
4	1.58	0.82	1
5	3.72	1.94	2
6	8.44	4.40	5

Only 22 operators are assigned. However, since we planned for only 80 efficiency, we can use the remaining 3 operators to pick up the slack in the line as relief operators.

10. A study reveals the following steps in the assembly of a truss (small triangle of 3 small pieces within a large triangle of 3 larger pieces):

- forklift delivers 2x4 pieces of pine from outside storage area (20 min)*
- bandsaw operator cuts 6 pieces to appropriate length (10 min)*
- assembler #1 gets 3 short pieces, bolts small triangle (5 min)*
- assembler #2 gets 3 long pieces, bolts large triangle (10 min)*
- assembler #3 gets one of each triangle and fastens into truss (20 min)*
- supervisor inspects complete truss and prepares for delivery (5 min)*

a. Complete a flow process chart of the operation.

Process Description	Chart Symbol	Dist. in Feet	Time (min)
1- Forklift delivers 2x4 pieces of pine from storage	Transportation 	0	20
2- Bandsaw operator cuts 6 pieces to length	Operation 	0	10
3- Assembler #1 gets 3 short pieces, bolts small triangle	Operation 	0	5
4- Assembler #2 gets 3 long pieces, bolts large triangle	Operation 	0	10
5- Assembler #3 gets one of each, fastens into truss	Operation 	0	20
6- Supervisor inspects truss and prepares for delivery	Inspection 	0	5

Location:				
Activity:	<b>Summary</b>			
Date:	Event	Present	Proposed	Savings
Operator:	Operation	4		
Analyst:	Transport	1		
	Delay			
	Inspection	1		
	Storage	0		
Method: Present Proposed	Distance (ft)	0		
Type: Worker Material Machine	Time (min)	70		
	Cost			

b. What is the %idle time and production for an unbalanced, linear assembly line?

Cycle time is based on slowest operation (#1 or #5) = 20 minutes. Production is  $60/20 = 3$  beam/hr.  
 Idle times per operation: #1 = 0, #2 = 10, #3 = 15, #4 = 10, #5 = 0, #6 = 15;  
 Total idle times = 50 min, % idle =  $50/(6 \times 20) \times 100 = 41.7\%$

c. Balance the assembly line using appropriate workstations, given that the company desires to increase production to 6 beam/hour. What the %idle time and production now?

Operation Time	Operation	1	2	3	4	5	6	PW	Pred
20	1	1	1	1	1	1	1	70	-
10	2		1	1	1	1	1	50	1
5	3			1	0	1	1	30	2
10	4				1	1	1	35	2
20	5					1	1	25	3,4
5	6						1	5	5

Required production is 6 beams/hour or one every 10 minutes. Number of workers/workstations is determined from:

$$N = R \times \sum SM = 1 \text{ beam}/10 \text{ min} \times (20+10+5+10+20+5)\text{min} = 7$$

Station	Operation	Number Workers	PW	Immediate Predecessors	Time	Cumulative Time	Unassigned Time
1	1	2	70	-	20	20	0
2	2	1	50	1	10	10	0
3	4	1	35	2	10	10	0
	3		30	2	5		
4	5	3	25	3,4	20	30	0
	5		5	5	5		

Total idle time is 0 for a production rate of 6 beams/hr.

11. The current operation consists of the following elements:

operator removes pressed unit (0.2 min)

operator walks to inspection area, checks for defects (0.1 min)

operator files rough edges (0.2 min)

operator places unit on conveyor for further processing and returns to press (0.1 min)

operator cleans press die element with compressed air (0.3 min)

operator sprays lubricant into die (0.1 min)

operator places sheet metal into press, pushes START (0.2 min)

press cycles automatically for 1.2 min

Given that the operator is paid \$10/hr and that presses cost \$15/hr to run, find and draw the worker-machine chart for the lowest cost operation. What is the production? What is the unit cost?

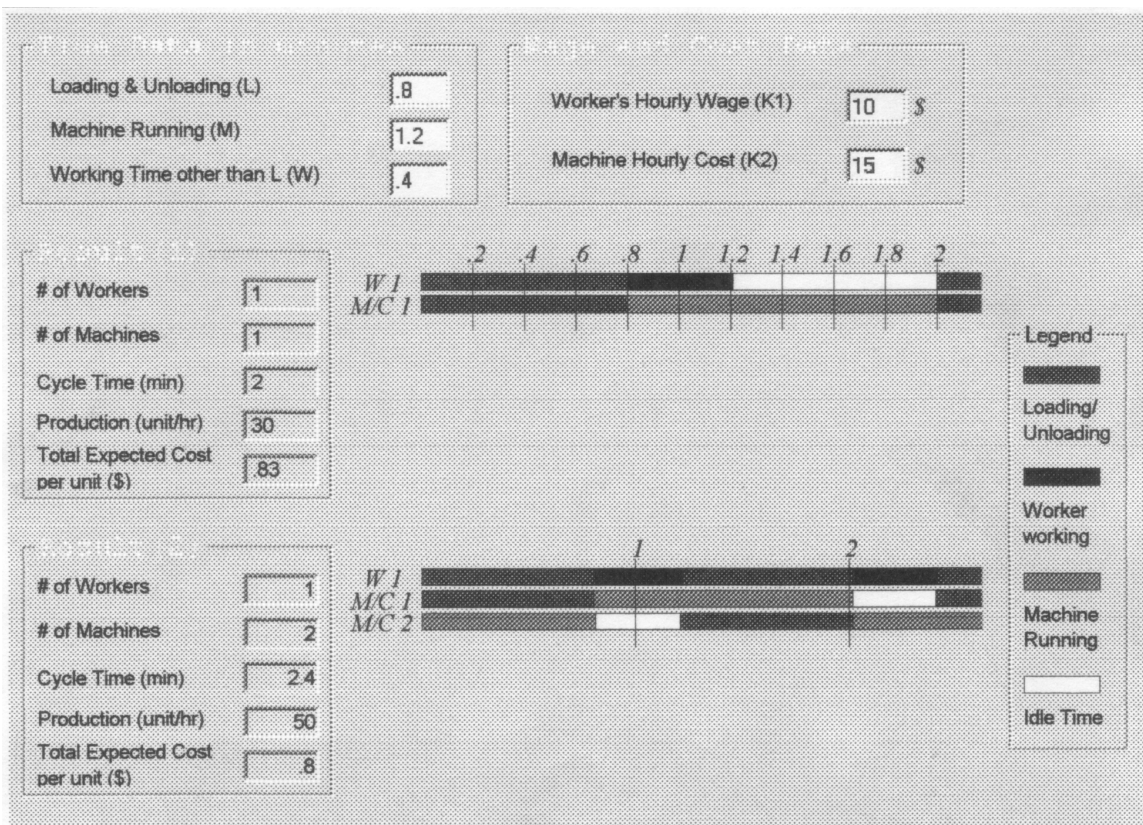
$$\ell = 0.2 + 0.3 + 0.1 + 0.2 = 0.8 \quad w = 0.1 + 0.2 + 0.1 = 0.4$$

$$N \leq \frac{\ell + m}{\ell + w} = \frac{0.8 + 1.2}{0.8 + 0.4} = 1.67$$

$$TEC_1 = \frac{(\ell + m)}{N_1} (K_1 + N_1 K_2) = \frac{(0.8 + 1.2)}{60} (\$10 + \$15) = \$0.833 \text{ per piece}$$

$$TEC_2 = (\ell + w) (K_1 + N_1 K_2) = \frac{(0.8 + 0.4)}{60} (\$10 + 2 \times \$15) = \$0.80 \text{ per piece}$$

The lowest cost is with two machines.

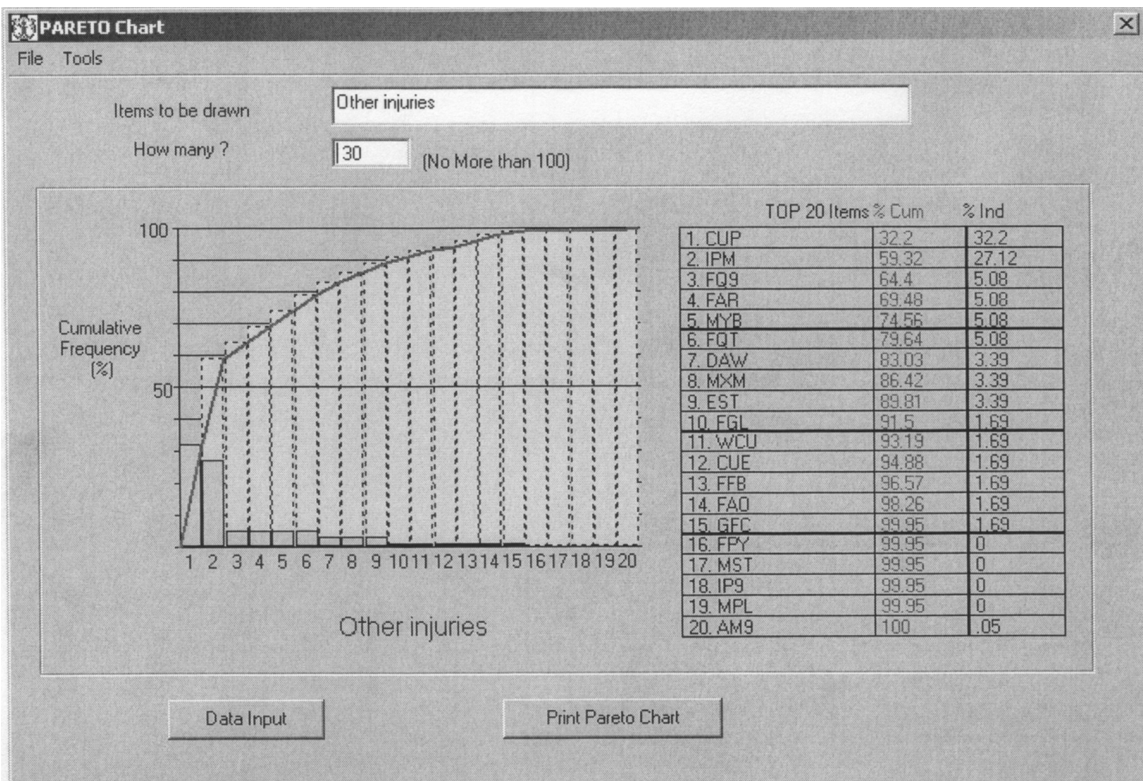




12. Given the following OSHA recordable (i.e. those that must be recorded on the OSHA 200 log and open to inspection) injuries by job code and type of injury from January 1, 1997 to September 1, 1998, what can you conclude about the injuries? Which job code would you study first? I.e. if you had limited resources, where would you put them? (Hint: Draw a Pareto Chart)

Job Code	Type of Injury		
	Strain/sprain	CTD	Other
AM9	1	0	0
BTR	1	2	0
CUE	2	0	1
CUP	4	4	19
DAW	0	0	2
EST	0	0	2
FAO	3	1	1
FAR	3	1	3
FFB	1	0	1
FGL	1	0	1
FPY	1	2	5
FQT	0	0	3
FQ9	2	0	3
GFC	0	0	1
IPM	4	1	6
IPY	1	0	0
IP9	1	0	0
MPL	1	0	0
MST	7	0	6
MXM	1	0	2
MYB	1	1	3
WCU	1	0	1

Neither strains/sprains nor CTD injuries show any critical jobs. Although, 20% of the jobs are not strictly accounting for 80% of injuries, the CUP and IPM jobs are showing large peaks for the “other” category of injuries.



13. Exploratory analysis has identified the following job as a problem area. Complete a flow-process chart (material type) for the following engine stripping, cleaning and degreasing operation.

Engines are stored in the old-engine store room. When needed an engine is picked up by an electric hoist on a monorail, transported to the stripping bay and unloaded onto an engine stand. There the operator strips the engine, putting the engine parts into the degreasing basket. The basket is transported to the degreaser, loaded into the degreaser, degreased and then unloaded from the degreaser. The basket with degreased engine parts is then transported to the cleaning area, where they are simply dumped on the ground for drying. After several minutes of drying, the parts are lifted to the cleaning benches and cleaned. The cleaned parts are collected in special trays to await transport. The parts are loaded onto a trolley and transported to the inspection station. There they are slid from the trays onto the inspection benches.

<b>Location:</b>	Engine repair area	<b>Summary</b>			
<b>Activity:</b>	Stripping, cleaning, degreasing	<b>Event</b>	<b>Present</b>	<b>Proposed</b>	<b>Savings</b>
<b>Date:</b>		Operation	3		
<b>Operator:</b>	John Smith	Transport	4		
<b>Analyst:</b>	af	Delay	2		
		Inspection			
		Storage	1		
<b>Method:</b>	Present      Proposed	Distance (ft)	0		
<b>Type:</b>	Worker      Material      Machine	Time (min)	0		
		Cost			

Process Description	Chart Symbol	Dist in Feet	Time (min)
In storeroom	Storage ▾ ▽	0	0
By hoist to stripping bay	Transportation ▾ →	0	0
Strip engine, parts into basket	Operation ▾ ○	0	0
Part basket to degreaser	Transportation ▾ →	0	0
Degrease parts	Operation ▾ ○	0	0
Degreased parts to cleaning area, dumped	Transportation ▾ →	0	0
Dry on ground, wait to be cleaned	Delay ▾ D	0	0
Parts lifted to bench and cleaned	Operation ▾ ○		
Await transport	Delay ▾ D		
To inspection station	Transportation ▾ →		