INSTRUCTOR'S MANUAL
to accompany

NIEBEL'S METHODS, STANDARDS AND WORK DESIGN

Thirteenth Edition

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SOLUTIONS TO QUESTIONS AND PROBLEMS

Chapter 1 Methods, Standards, and Work Design: Introduction

Questions

1. *What is another name for time study?*

   Another name for time study is work measurement.

2. *What is the principal objective of methods engineering?*

   The principle objective of methods engineering is to improve productivity and decrease the unit cost of output while maintaining the health and safety of the worker.

3. *List the eight steps in applying methods engineering.*

   The eight steps of methods engineering are: 1) select the project, 2) get and present the data, 3) analyze the data, 4) develop the ideal method, 5) present and install the method, 6) develop a job analysis, 7) establish time standards, 8) follow up the method.

4. *Where were time studies originally made and who conducted them?*

   Time studies originated In France in the manufacture of pins by Perronet.

5. *Explain Frederick W. Taylor's principles of scientific management.*

   The principles of scientific management included: time study, standardization of all tools and tasks, use of a planning department, use of slide rules and other time saving implements, instruction cards for workers, bonuses for successful performance, differential rates, mnemonic systems classifying products, routing systems and modern costs systems.

6. *What is meant by motion study, and who are the founders of the motion study technique?*

   Motion study is the study of body motions used in performing an operation, with the thought of improving the operation by eliminating unnecessary motions and simplifying necessary motions, and then establishing the most favorable motion sequence. Frank and Lilian Gilbreth are considered the founders of motion study.

7. *Was the skepticism of management and labor toward rates established by 'efficiency experts' understandable? Why or why not?*

   Yes, many unqualified analysts endeavored to establish standards. The results, in some instance, were quite unsatisfactory giving the profession a poor image.

8. *Which organizations are concerned with advancing the ideas of Taylor and the Gilbreths?*

   The American Management Association, The Society for the Advancement of Management, and The Institute of Industrial Engineers are concerned with promoting the ideas of Taylor and the Gilbreths.

9. *What psychological reaction is characteristic of workers when methods changes are suggested?*

   Resistance to change is very common in workers when methods changes are suggested.

10. *Explain the importance of the humanistic approach in methods and time study work.*

    The humanistic approach must be followed in order to help assure the success of methods and standards work. Regardless of the analyst's technical knowledge and ability, the analyst will not be completely successful in methods and time study work unless the analyst is competent in dealing with the operators as humans rather than as another element in the assembly line.

11. *How are time study and methods engineering related?*

    Time study should not be undertaken until a good method has been developed and installed.

12. *Why is work design an important element of methods study?*

    Work design is an important element of methods study, because if the methods changes are inefficient or even injurious to the operators, any productivity improvements will be negated by increased medical and safety costs.

13. *What important events have contributed to the need for ergonomics?*

    The technological disasters at Three-Mile Island and Bhopal, India as wells as the increase in product liability and personal injury cases have contributed to a need for ergonomics. More recently, the rather dramatic increases in work-related musculoskeletal injuries also emphasizes for balancing the push for productivity with the inclusion of ergonomics.

Questions

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

   The operator 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 maximize total savings (both direct and indirect costs) of a product or system by the elimination of delays, storage, unnecessary transport, or excessive transport distances during its production or service process.

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 for the present method. 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. *What is the purpose of crashing?.*

    The purpose of crashing is to reduce the project completion time, but probably at increased cost..

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. *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.

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

    The flow process 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 in a cell, the worker and machine process chart is useful for optimizing potential machine coupling.

21. *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.

22. *Reducing which of the three times - worker, machine, or loading - would give the greatest effect on increasing productivity? Why?*

    Reducing loading time would have greatest effect on productivity, because it decreases time in both worker and machine columns. That is the whole purpose behind SMED (single minute exchange of die) in the Toyota Production System.

Problems

1. *Based on the following crash 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 Added Cost
27	0	Normal duration of project	$0
25	2	Crash activity I by two weeks for an added cost of $400	$400
24	3	Crash J by one week for an added $600	$1,000
23	4	Crash M (or P) by one week for an added cost of $1,400	$2,400
22	5	Crash P (or M) by one week for an added cost of $1,400	$3,800
21	6	Crash K by one week for an added $1,500	$5,300
20	7	Crash F by one week for an added cost of $1,800 (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.)	$7,100
19	8	Crash C by one week for an added cost of $1,400 (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.)	$8,500

2. *The machining time per piece is 0.164 hours and the machine loading time is 0.038 hours. With an*

operator rate of $12.80 per hour and a machine rate of $14 per hour, calculate the optimum number of machines for lowest cost per unit of output.

$$TEC = (\ell + m)\frac{(K_1 + N_1K_2)}{N_1} = (.038 + .164)\frac{(\$12.80 + 5\times\$14.00)}{5} = \$3.35$$

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*?

#mach	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 = **$28.15/x**
	$\frac{4!}{3!1!}$ $0.4^3 \times 0.6^1 = 0.154$				
	$\frac{4!}{4!0!}$ $0.4^4 \times 0.6^0 = 0.026$				
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 = **$27.9/x**
	$\frac{3!}{3!0!}$ $0.4^3 \times 0.6^0 = 0.064$				
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 = **$28.26/x**
1	None	0	8x	8(20+12)=$256	$256/8x=**$32/x**

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*

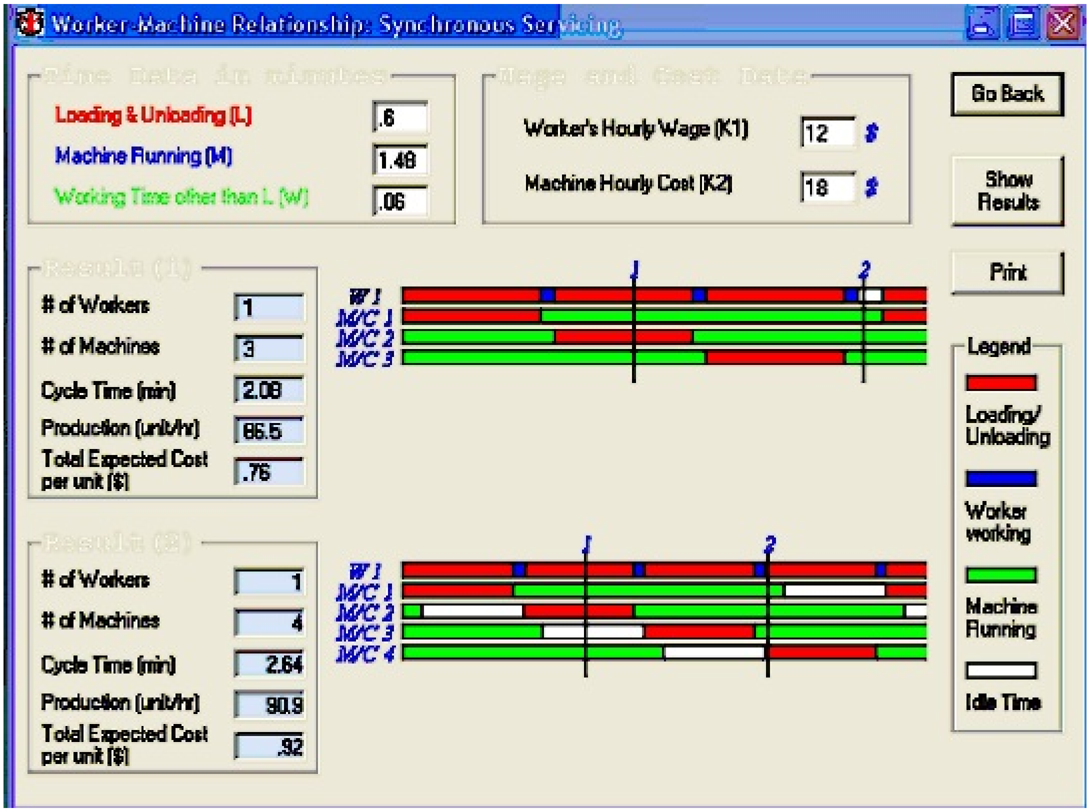
How many of these machines should be assigned to each operator?

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

$$TEC_3 = \frac{(\ell + m)}{60}\frac{(K_1 + N_1K_2)}{N_1} = \frac{(.6 + 1.48)}{60} \times \frac{(\$12 + 3\times\$18)}{3} = \$0.763 \text{ per piece}$$

$$TEC_4 = \frac{(\ell + w)(K_1 + N_1K_2)}{60} = \frac{(.6 + 0.06)}{60} \times (\$12 + 4\times\$18) = \$0.924 \text{ per piece}$$

Therefore three machines are assigned to each operator.



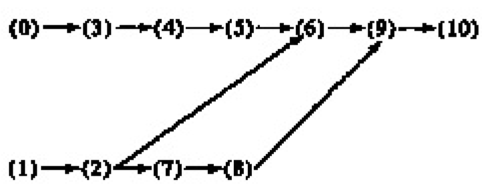
5. *A study revealed that a group of three semiautomatic machines assigned to one operator operate 70 percent of the time unattended. Operator service time at irregular intervals averaged 30 percent of the time on these three machines. What would be the estimated machine hours lost per eight-hour day 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
1.24	1		1	1				1	1	1	1	1
0.84	2			1				1	1	1	1	1
2.07	3				1	1	1	1			1	1
1.47	4					1	1	1			1	1
2.40	5						1	1			1	1
0.62	6							1			1	1
2.16	7								1	1	1	1
4.75	8									1	1	1
0.65	9										1	1
1.45	10											1

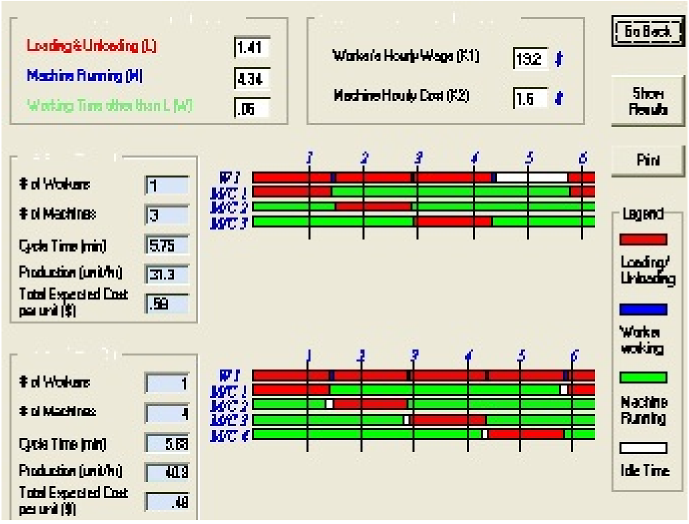
Required production per day is 90 assemblies and should not exceed 105 assemblies per day.
Available time = 8 hrs. × 60 min = 480 min per day or 480/90 = 5.33 min per assembly
Total work time = 0.76+1.24+0.8 +2.07+1.47+2.40+0.62+2.16+4.75+0.65+1.45 = 18.41 min
Required number of operators = 18.41 min / 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	Positional Weight	Immediate Predecessors	Work Elem. Time	Cum.	Unassigned
1	1	11.71	-	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	6.85	7	4.75	4.75	0.58
4	5	5.12	4	2.40	2.40	2.93
4	6	2.72	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:*
   a. Loading and unloading time one machine, 1.41 minutes.
   b. Walking time to next facility, 0.08 minutes.
   c. Machine time (power feed), 4.34 minutes.
   d. Operator rate, \$13.20 per hour.
   e. Machine rate, \$18.00 per hour.



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

$$TEC_3 = \frac{(\ell + m)\ (K_1 + N_1K_2)}{N_1} = \frac{(1.41 + 4.34)}{60} \times \frac{(\$13.20 + 3\times\$18)}{3} = \$2.147 \text{ per piece}$$

$TEC_4 = (\ell + w)(K_1 + N_1K_2) = \dfrac{(1.41 + 0.08)}{60} \times (\$13.20 + 4\times\$18) = \$2.116$ 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:*
a. 7.56 minutes.
b. 4.25 minutes.
c. 12.11 minutes
d. 1.58 minutes.
e. 3.72 minutes.
f. 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?

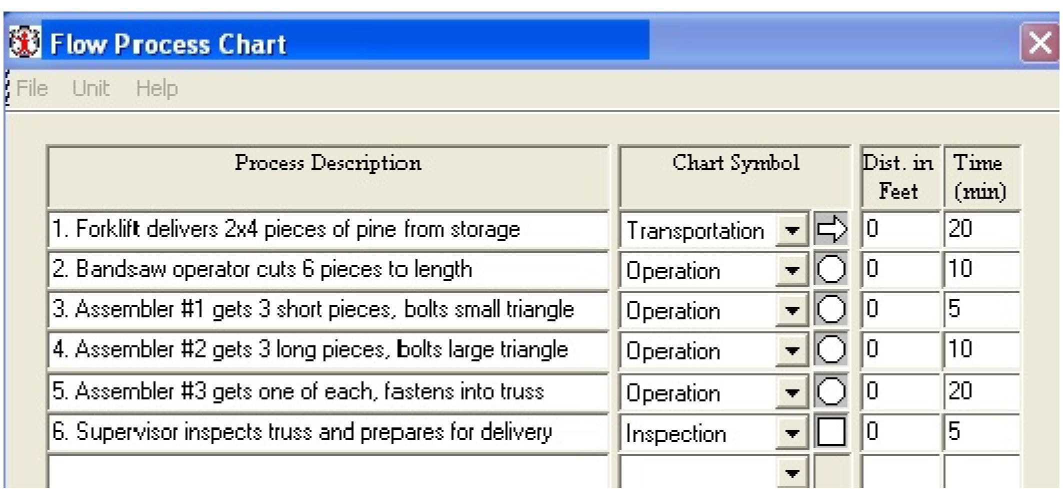
One unit of production will be needed every 480/250 = 1.92 minutes.
Total work time = 7.56 + 4.25 + 12.11 + 1.58 + 3.72 + 8.44 = 37.66 minutes
Required number of operators = 37.66 min / 1.92 min per assembly /0.80 efficiency = 24.52 or 25 operators.

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 0f 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.


Flow Process Chart

File Unit Help

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

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/(6×20) × 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	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:

$N = R \times \sum SM = 1$ beam/10 min×(20+10+5+10+20+5)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?

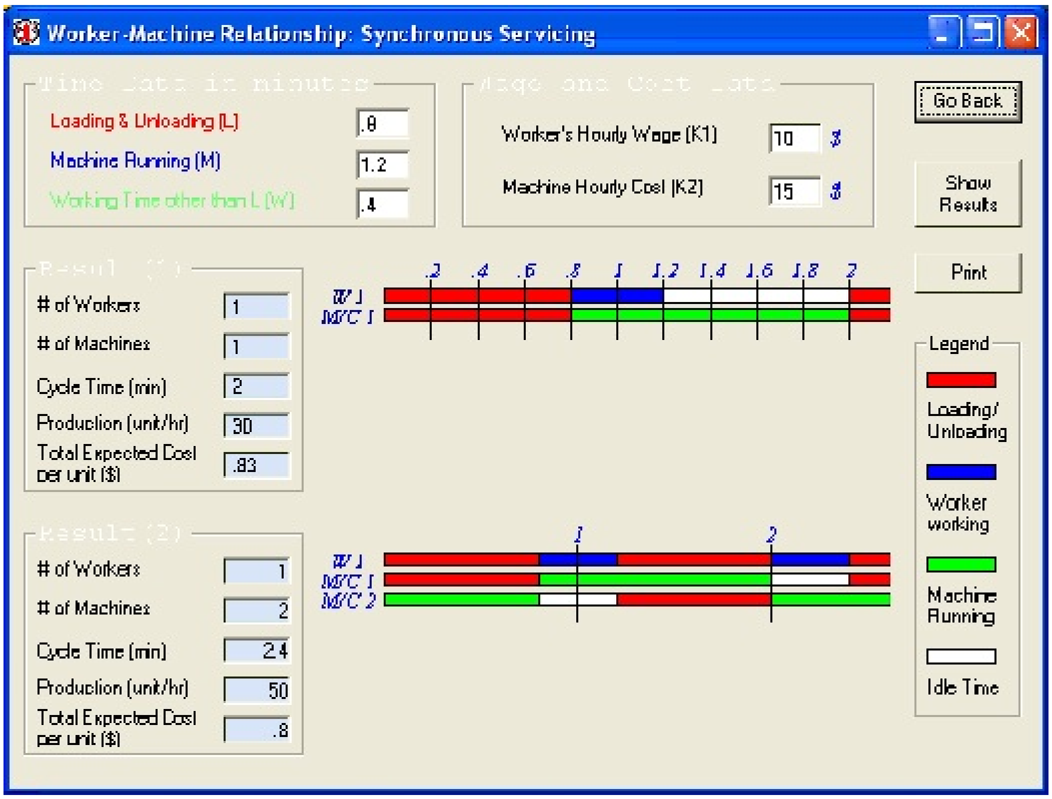
$\ell = 0.2 + 0.3 + 0.1 + 0.2 = 0.8$ $\qquad$ $w = 0.1 + 0.2 + 0.1 = 0.4$

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

$$TEC_1 = \frac{(\ell + m)\ (K_1 + N_1K_2)}{N_1} = \frac{(0.8 + 1.2)}{60} \times (\$10 + \$15) = \$0.833 \text{ per piece}$$

$$TEC_2 = (\ell + w)\ (K_1 + N_1K_2) = \frac{(0.8 + 0.4)}{60} \times (\$10 + 2\times\$15) = \$0.80 \text{ per piece}$$

The lowest cost is with two machines.

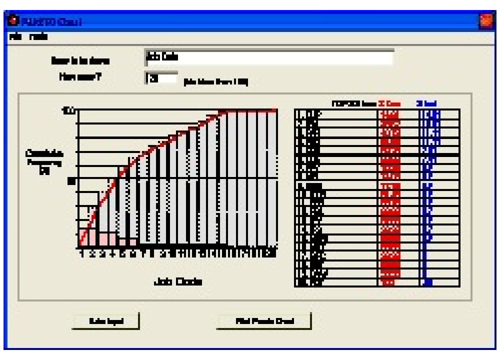


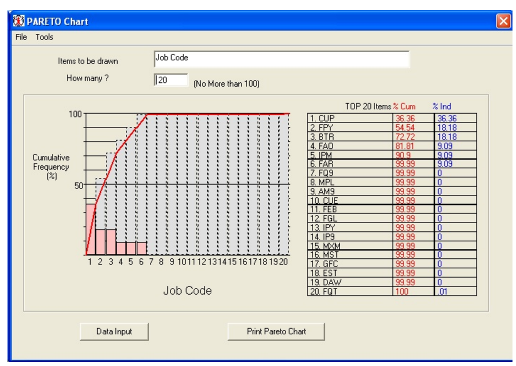
12. *Given the following OSHA recordable (i.e. those that must be recorded on the OSHA 200 log and open to inspection) injuries by job code and type of injury from January 1, 1997 to September 1, 1998, what can you conclude about the injuries? Which job code would you study first? I.e. if you had limited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

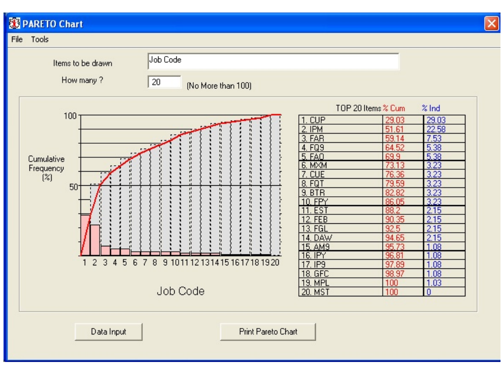
	Type of Injury		
Job Code	Strain/sprain	CTD	Other
AM9	1	0	0
BTR	1	2	0
CUE	2	0	1
CUP	4	4	19
DAW	0	0	2

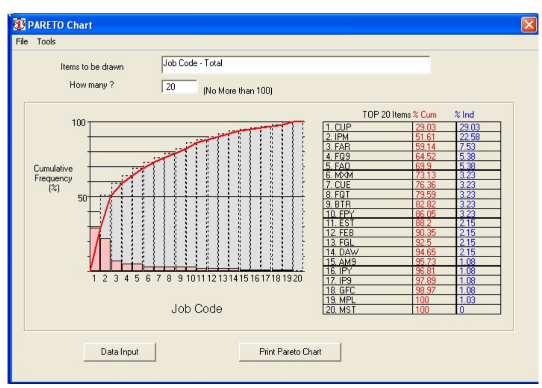
EST	0	0	2
FAO	3	1	1
FAR	3	1	3
FFB	1	0	1
FGL	1	0	1
FPY	1	2	0
FQT	0	0	3
FQ9	2	0	3
GFC	0	0	1
IPM	4	1	16
IPY	1	0	0
IP9	1	0	0
MPL	1	0	0
MST	0	0	0
MXM	1	0	2
MYB	1	1	3
WCU	1	0	1

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.

Flow Process Chart

File Unit Help

Process Description	Chart Symbol		Dist. in Feet	Time (min)
In storeroom	Storage	▽		
by hoist to shipping bay	Transportation	⇨		
Strip engine, parts into basket	Operation	○		
Basket to degreaser	Transportation	⇨		
Degrease parts	Operation	○		
Parts to cleaning area, dumped	Transportation	⇨		
Wait to be cleaned, dry meanwhile	Delay	D		
Parts lifted to bench and cleaned	Operation	○		
Await transport	Delay	D		
To inspection station	Inspection	□		

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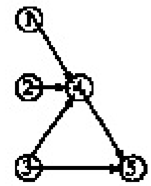
14. *Given the following operations and unit times in minutes (#1 = 1.5, #2 = 3, #3 = 1, #4 = 2, #5 = 4), balance the production line with the goal of producing 30 units/hr.*



Operation Time	Operation	1	2	3	4	5	PW	Pred
1.5	1	1	0	0	1	1	7.5	-
3.0	2		1	0	1	1	9.0	-
1.0	3			1	1	1	7.0	-
2.0	4				1	1	6.0	1,2,3
4.0	5					1	4.0	3,4

Required production is 30 units/hr or 0.5 units/ minute (cycle time = 2 minutes). Number of workers/workstations is determined from:

$$N = R \times \sum SM = 0.5/\text{min} \times (1.5+3+1+2+4)\text{min} = 5.75 \text{ or } 6 \text{ stations}$$

Station	Operation	Number Workers	PW	Immediate Predecessors	Time	Cumulative Time	Unassigned Time
1	2	2	9	-	3	4	0
	3		7	-	1		
2	1	1	7.5	-	1.5	1.5	0.5
3	4	1	6	1,2,3	2	2	0
4	5	2	4	3,4	4	4	0

Total idle time is 0.5 or 4.2%, which is much better than the original 17.9% and a reduction in one operator with the same production rate of 6 beams/hr. (The original unbalanced set up would require 2 workers for each of operations #2 and #5. Idle times are 0.5, 1, 1, 0, 0, respectively for a total idle fraction of 2.5/(7×2) = .179).

15. *The following activities and times (in minutes) were recorded for a mold operator:*

- *removes molded piece from die* 0.6
- *walks 10 ft to a workbench* 0.2
- *boxes widget and places on conveyor* 1.0
- *walks back to molder* 0.2
- *blows out dirt from mold* 0.4
- *sprays oil into mold, pushes "GO"* 0.2
- *mold cycles automatically for* 3.0

The cycle then repeats itself. The operator is paid $10.00/hr and it costs $15.00/hr to run the molder. What is the optimum number machines that can be assigned to the operator to produce the widgets at lowest cost? Draw a worker-machine chart.

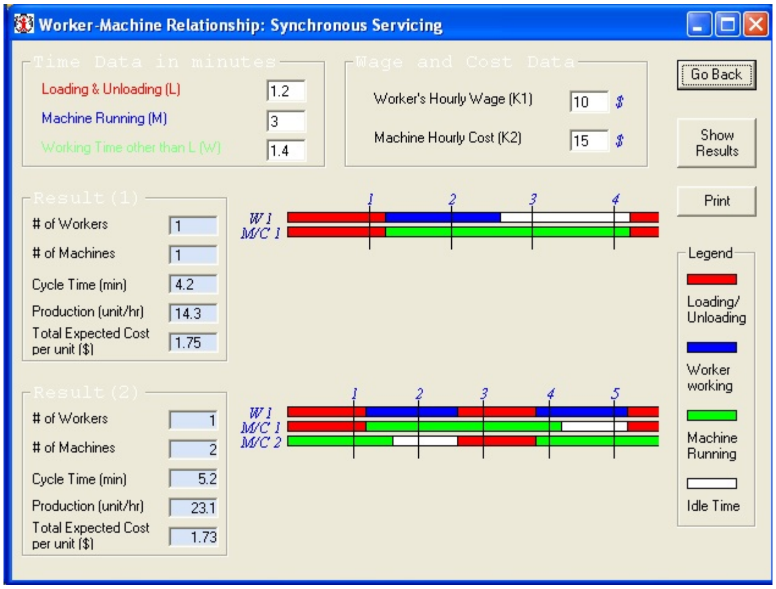
$\ell = 0.6 + 0.4 + 0.2 = 1.2$ $w = 0.2 + 1.0 + 0.2 = 1.4$ $m = 3.0$

$$N \le \frac{\ell + m}{\ell + w} = \frac{1.2 + 3}{1.2 + 1.4} = 1.61$$

$$TEC_1 = \frac{(\ell + m)\ (K_1 + N_1K_2)}{N_1} = \frac{(1.2 + 3)}{60} \times (\$10 + \$15) = \$1.75 \text{ per piece}$$

$$TEC_2 = (\ell + w)\ (K_1 + N_1K_2) = \frac{(1.2 + 1.4)}{60} \times (\$10 + 2\times\$15) = \$1.73 \text{ per piece}$$

The lowest cost is with two machines.



16. *TOYCO produces toy shovels on a 20-ton press. The steps taken by the press operator to produce one shovel are:*

- remove finished shovel and put on conveyor	*0.1 min*
- remove debris from the dies	*0.2 min*
- spray dies with oil	*0.1 min*
- checks raw material (flat sheet) for defects	*0.3 min*
- places flat sheet into press	*0.1 min*
- press cycles automatically for	*1.0 min*

The operator is paid \$10/hr and the press costs \$100/hr to run.
Raw material in shovel costs \$1.00 and it sells for \$4.00.
What is the optimum number of presses for one operator for lowest unit cost? Draw the worker-machine chart for this situation.

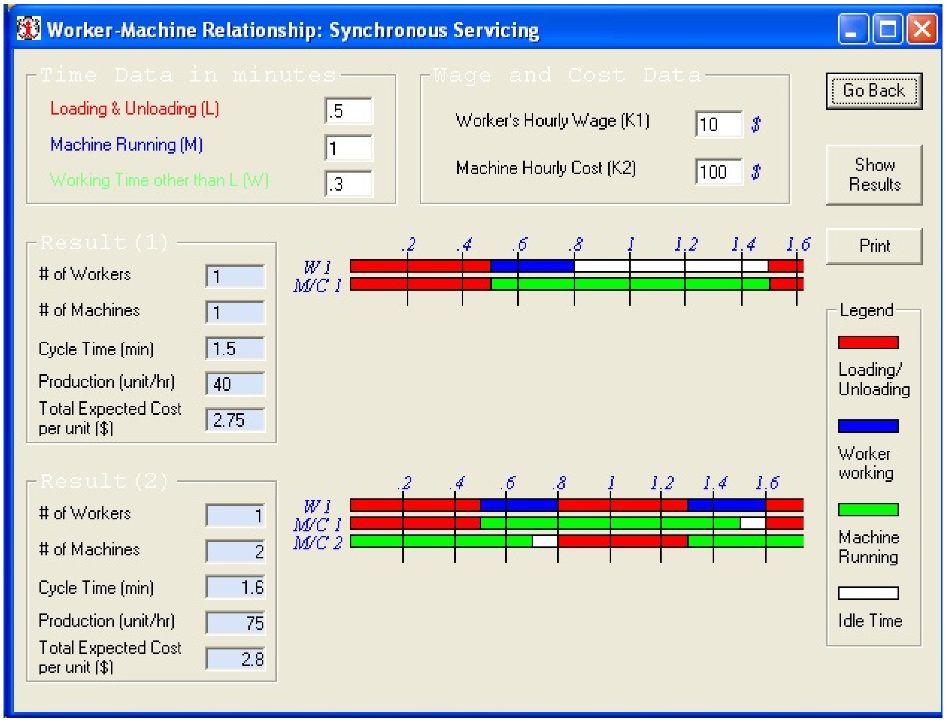
$\ell = 0.1 + 0.2 + 0.1 + 0.1 = 0.5 \quad w = 0.3 \quad m = 1.0$

$$N \le \frac{\ell + m}{\ell + w} = \frac{0.5 + 1.0}{0.5 + 0.3} = 1.875$$

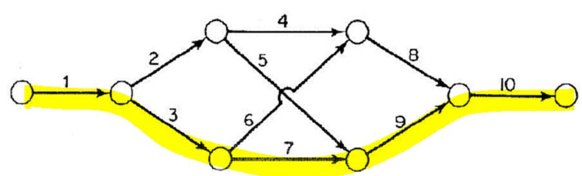
$$TEC_1 = \frac{(\ell + m)\ (K_1 + N_1K_2)}{N_1} = \frac{(0.5 + 1)}{60} \times (\$10 + \$100) = \$2.75 \text{ per piece}$$

$$TEC_2 = (\ell + w)\ (K_1 + N_1K_2) = \frac{(0.5 + 0.3)}{60} \times (\$10 + 2\times\$100) = \$2.80 \text{ per piece}$$

The lowest cost is with one machine.



17. *In the project shown below, activities are represented by arrows, and the number for each activity also indicates its normal duration (in days).*
a) Determine the critical path and the length of this project.
b) Assume that each activity, except 1 and 2, can be crashed up to 2 days at a cost equal to the activity number. E.g. activity 6 normally takes 6 days, but could be crashed to 5 days for a cost of $6, or to 4 days for a total of $12. Determine the least-cost 26-day schedule. Show the activities that are crashed and the total crash costs.



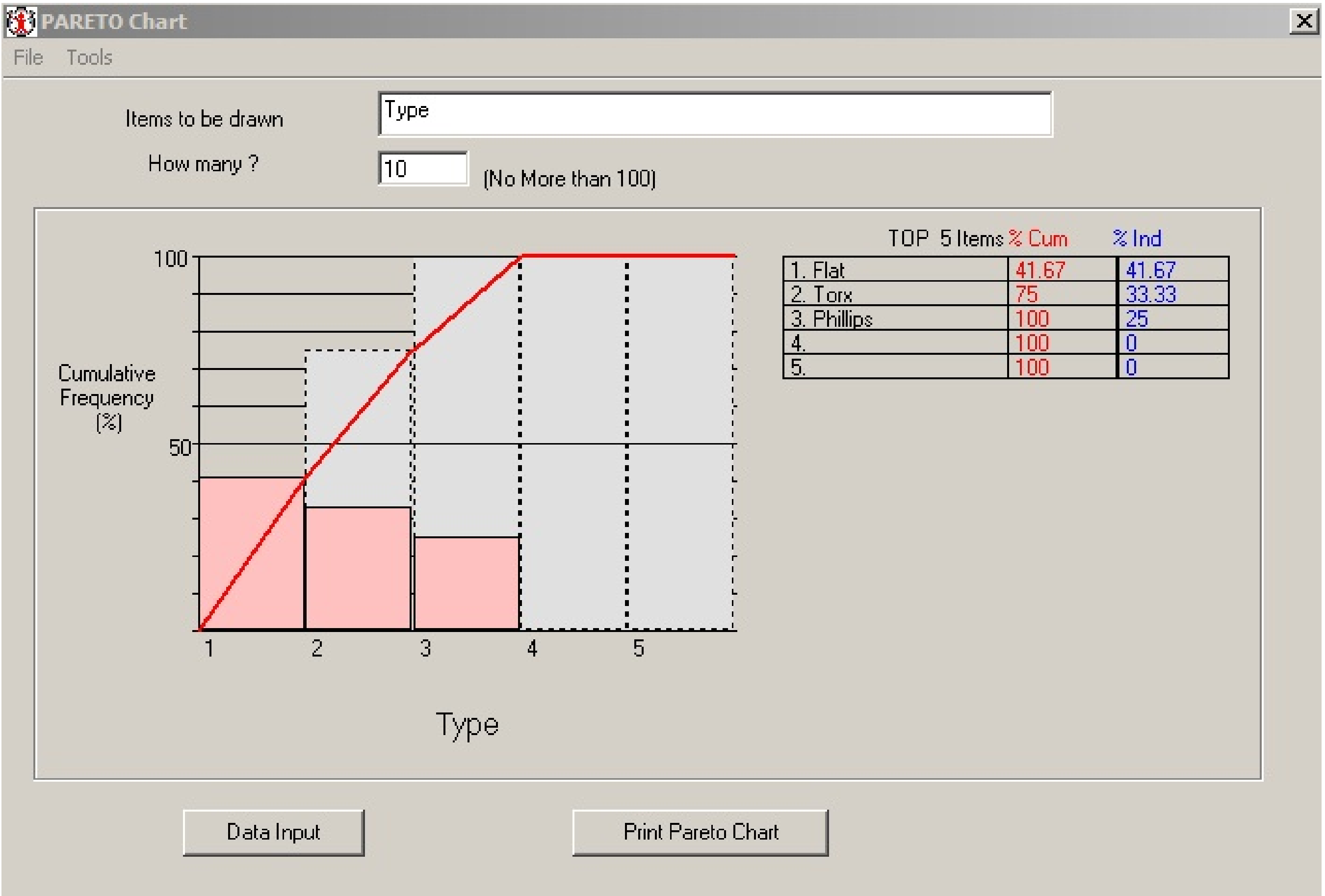
a) The critical path is shown in yellow and takes 30 weeks.

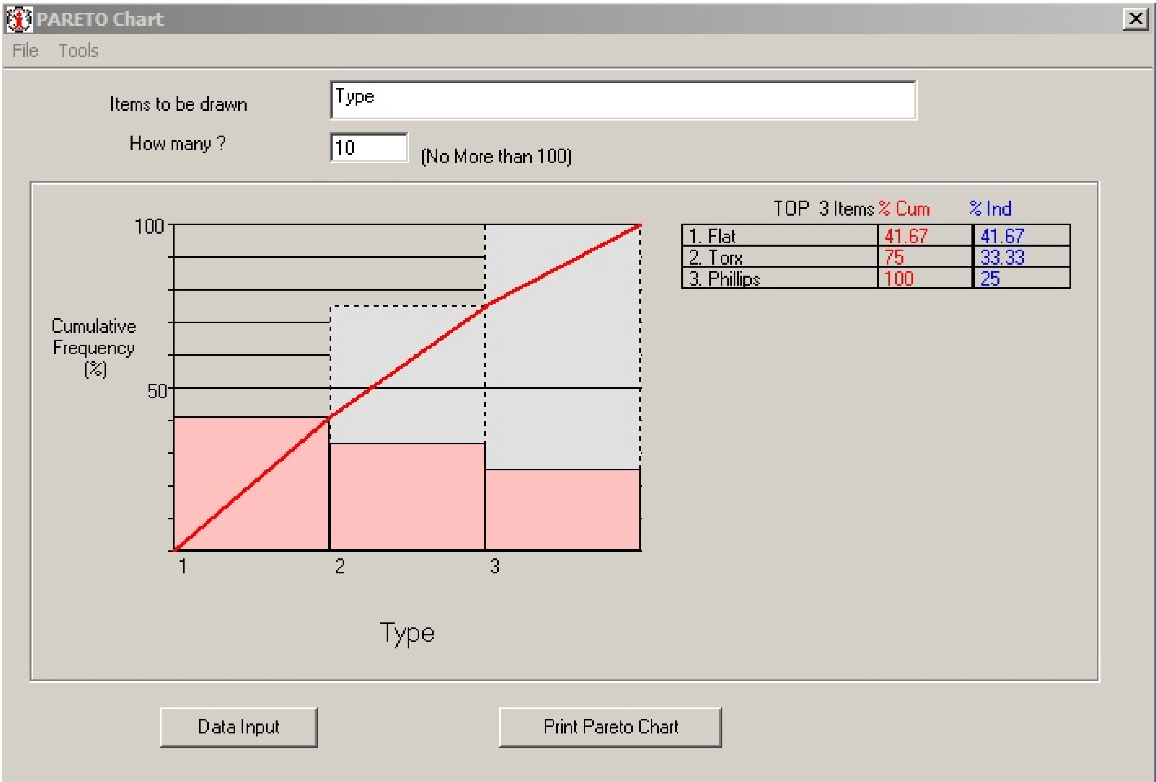
b) Crash #3 for 2 days first for a cost of $6. Next, crash #7 for 1 day for a cost $7. Next crash #9 for 1 day at a cost of $9. Thus for a total cost of $22, the critical path is shortened to 26 days. Note, that path #7 couldn't be shortened further without having an alternate path.

18. *ToolCO manufactures Philips (P), Torx (T) and Flathead (F) screwdrivers in different sizes (1,2,3,4,5). The IE manager is concerned about high product defect rates but has limited resources to address all the problems. Given the following data (defects per batch of 100), identify the product*

problems to be addressed first. Why? What procedures, tools, charts, diagrams, etc. should be used in this case.

Model	Philips	Torx	Flat
1	2	3	4
2	1	0	1
3	0	1	0
4	0	0	0
5	0	0	0



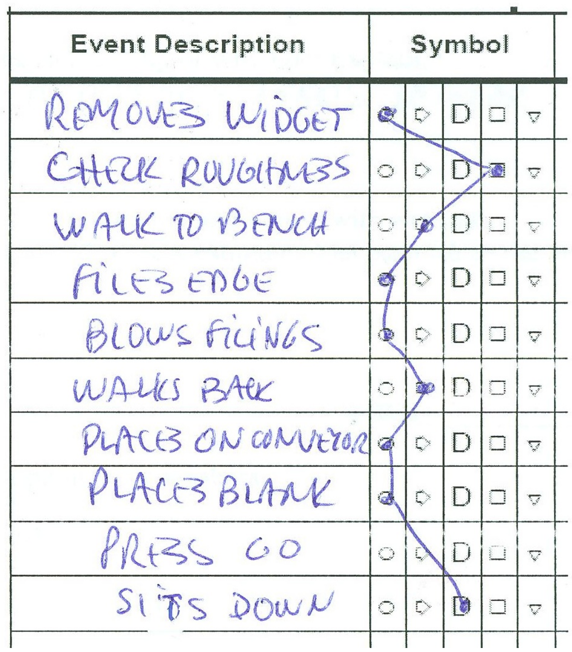


Based on Pareto analyses, the type of screwdriver doesn't show any large deviations. However, Size or Model #1 accounts for 75% of problems (i.e. 20% of models account for 75% or problems, close to the 80/20 rule).

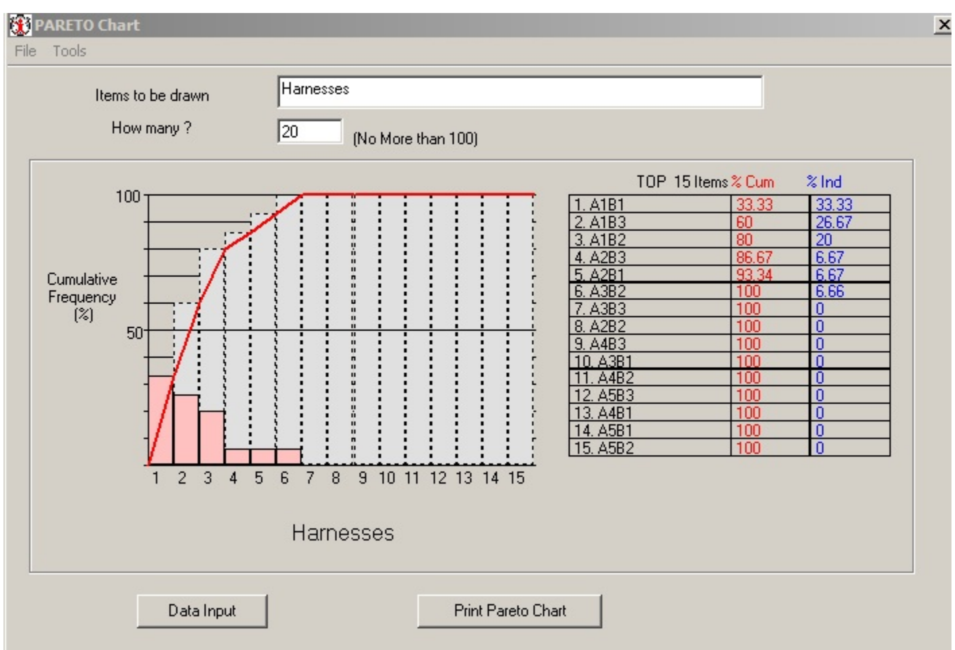
19. *The following activities were observed for a mold operator:*
   a) operator removes molded piece from die,
   b) walks to bench, puts the piece into box and the puts the box on a pallet,
   c) returns to injection molder,
   d) blows out dirt from die (with compressed air) ,
   e) sprays oil into die,
   f) presses START button on molder and sits down,
   g) the machines closes die, injects plastic into die, after set curing time of 2 min opens die,
   h) cycle repeats itself

   Complete a flow process chart for the mold operator. What is one major problem in the job and how can it be improved?

Based on the following flow process chart, there are two unnecessary excess travel distances, that can be reduced or eliminated completely. Also, check on reducing the delay time (1 min) or having the operator run two or more presses (check with worker-machine charting).



20. *Delpack manufactures 15 different wire harnesses for the Big 3 automakers (coded as B1, B2, and B3). The wire harnesses are also coded by their current draw in amps (A1, A2, A3, A4 and A5). Given the following defect data (defects per batch of 100), indicate if there is a problem and where is located. (A1B1=5, A2B2=0, A3B3=0, A1B2=3, A2B3=1, A1B3=4, A2B1=1, A3B2=1, A4B3=0, A3B1=0, A4B2=0, A5B3=0, A4B1=0, A5B1=0, A5B2=0)*



21. *Complete a flow process chart for a press operator:*

1) removes completed widget from press
2) feels widget edges for roughness
3) walks to a work bench and gets file
4) files rough edges on widget
5) uses compressed air to blow away filing
6) walks back to press, places widget on conveyor
7) reaches for blank sheet and places the blank into the press
8) presses "GO", sits down for the 1 minute press cycle
9) the sequence repeats itself

What are obvious problems in the job and how can they be improved?

Extra inspections are wasteful. Work should be done properly, and self-inspected.

Event Description	Symbol				
	○	⇨	D	□	▽
REMOVES WIDGET	●				
CHECK ROUGHNESS				●	
WALK TO BENCH		●			
FILES EDGE	●				
BLOWS FILINGS	●				
WALKS BACK		●			
PLACES ON CONVEYOR	●				
PLACES BLANK	●				
PRESS GO					
SITS DOWN			●		

22. *The following activities and times (in minutes) were recorded for a press operator: removes completed widget from press (0.1), files rough edges on widget (0.4), blows filings from widget (0.3), places widget on conveyor to next station (0.1), places raw blank into press and pushes "GO" (0.1), press cycles automatically for 3.0 min. The cycle then repeats itself. The operator is paid $10.00/hr and it costs $15.00/hr to run the press. What is the optimum number of presses that can be assigned to the operator to produce the widgets at lowest cost? Draw a worker-machine chart. What is the %idle time? What is the unit cost? What is the productivity (widgets/hr)?*

23. An injector machine goes down roughly 20% of the time (the injector gums up and needs to be cleaned, a quick process). One operator is assigned to service three identical such machines. Each machine can produce 100 parts/hr if running properly (i.e. not down). The operator is paid $10.00/hr and each machine costs $20.00/hr to operate. What is the unit cost for this operation? Is it worth hiring another operator at the same rate to assist the first operator, in case more than one machine goes down at the same time? What is the unit cost now?

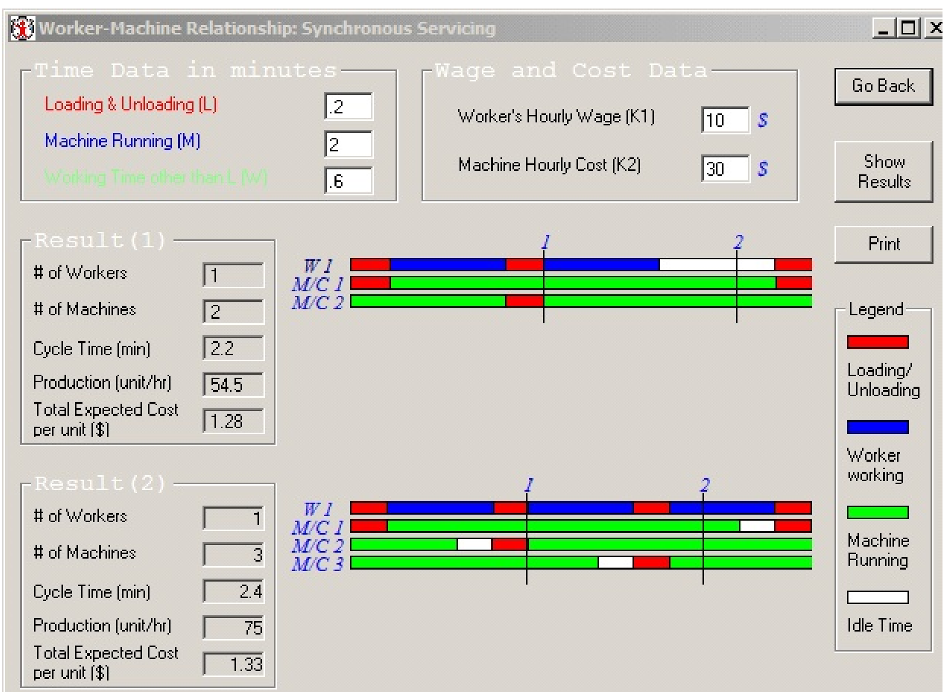
Up	Down		Idle
3	0	$3!(.2^0)(.8^3)/0!3! = 0.512$	0
2	1	$3!(.2^1)(.8^2)/1!2! = 0.384$	0
1	2	$3!(.2^2)(.8^1)/2!1! = 0.096$	0.096x8=0.768
0	3	$3!(.2^3)(.8^0)/3!\ 0! = 0.008$	.008x8x2=0.0128

Productivity is the useful working hours times 100 = (3x8-0.768-0.0128)x100 = 2,310.41 parts
Total cost is 3x8 x \$20 for machines and 8x\$10 for one operator = \$560, yielding a unit cost of \$560/2,310.4 = \$0.242 per part. Adding another operator increases the total cost by \$80 and productivity only by (0.768 + 0.008x8)x100= 83.2 parts for a unit cost of \$640/2393.6 = \$.267, which is greater than before. Therefore, it is not worth adding another operator.

24. *The following activities and times (in minutes) were recorded for a press operator:*

- *removes completed widget from press, 0.1*
- *inspects widget, 0.4*
- *places widget on conveyor to next station, 0.2*
- *places raw blank into press and pushes "GO", 0.1*
- *press cycles automatically for, 2.0*

The cycle then repeats itself. The operator is paid \$10.00/hr, the press costs \$30.00/hr to run. What is the optimum number of machines to insure the lowest unit cost? Draw a worker-machine chart. What is the %idle time? What is the unit cost? What is the productivity (widgets/hr)?



25. *A not-so-well-maintained machine is down roughly 40% of the time. One operator is assigned to service four identical such machines. Each machine can produce 60 widgets/hr if running (i.e. not completely idle). The operator is paid $10.00/hr and each machine costs $20.00/hr for power and supplies.*

a) What is the actual production for the four machines supervised by one operator for an 8-hour shift given the above conditions?

b) What is the unit cost for each widget?

c) Since there is so much lost production due to idle time, management is considering hiring another worker to assist the first operator in servicing these four machines. There are two approaches or choices: i) Assign Machines #1 and #2 to the first operator and Machines #3 and #4 to the second operator, or ii) have both operators help each other and service all four machines as needed. Which choice is best, i.e. lowest unit cost?

Up	Down		Idle
4	0	$4!(.4^0)(.6^4)/0!4! = 0.1296$	0
3	1	$4!(.4^1)(.6^3)/1!3! = 0.3456$	0
2	2	$4!(.4^2)(.6^2)/2!2! = 0.3456$	0.3456x9=2.76
1	3	$4!(.4^3)(.6^1)/3!1! = 0.1536$	0.1536x2 x8=2.46
0	4	$4!(.4^4)(.6^0)/4!1! = 0.0256$	0.0256x8x3=0.61

Productivity is the useful working hours times 60 = (4x8-2.76-2.46-0.61)x60 = 1,570.2 parts.
Total cost is 4x8 x $20 for machines and 8x$10 for one operator = $720, yielding a unit cost of $720/1,570.2 = $0.459 per part. Adding another operator (across all 4 machines or option ii) increases the total cost by $80 and productivity by only (2.76 + 0.1536x8+ 0.0256x8)x60= 251.6 parts for a unit cost of $800/1,821.7 = $.439, but turns out to be a lower cost than before. If the machines are split two and two between the operators (option i), then the only lost times occurs if both machines go down for each operator. This has a probability of $2!(.4^2)(.6^0)/2!0! = 0.16$. Multiplied by 8 this yields 1.28 hours lost out of 16 machine hours for each split, with a productivity of (2x8-1.28)x60 = 883.2 parts. Cost is (2x$20 + $10)x8=$400 per split. Unit cost is $400/883.2 = $.453, which is worse than for option ii.