Product, process and schedule design III.

- Chapter 2 of the textbook
- Schedule design
  - Production quantity
  - Equipment requirements
  - Operator requirements
- Facilities design

Product, process and schedule design II.

	Steps	Documentation
Product design	•Product determination	
	•Detailed design	•Exploded assembly drawing •Exploded assembly photograph •Component part drawing
Process design	•Process identification	•Parts list •Bill of materials
	•Process selection	•Route sheet
	•Process sequencing	•Assembly chart •Operation process chart •Precedence diagram

Schedule Design

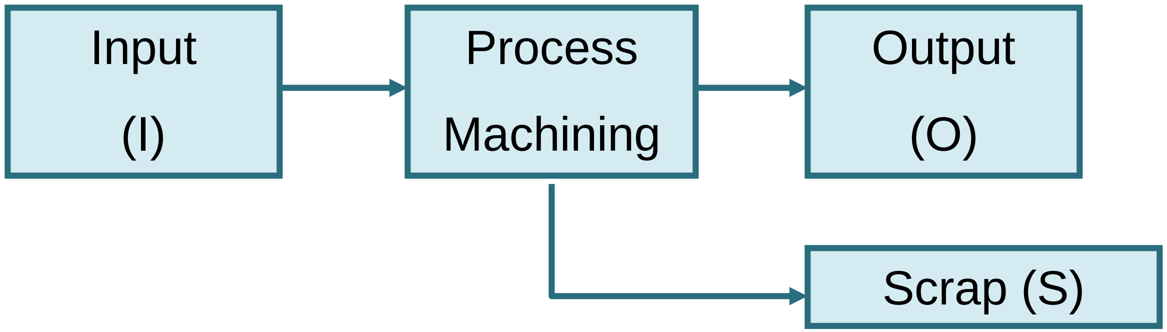
	Steps	Problems
Schedule design	•Quantity of the product	•High volume production (Scrap estimates) •Low volume production (Reject allowance)
	•Equipment requirements	•Equipment fractions
	•Operator requirements	•Machine assignments

Process requirements – Quantity determination

- *Reject Allowance Problem*
  - Determination the number of additional units to allow when the number of items to produce are very few and rejects randomly occur
    - For ***low volume*** production
    - The cost of scrap is very high
- *Scrap Estimates*
  - Determination of the quantity to be manufactured for each component
    - For ***high volume*** production
    - The estimation of scrap

Process requirements – Quantity determination

Scrap estimates – high volume production



$S = I * P_S$

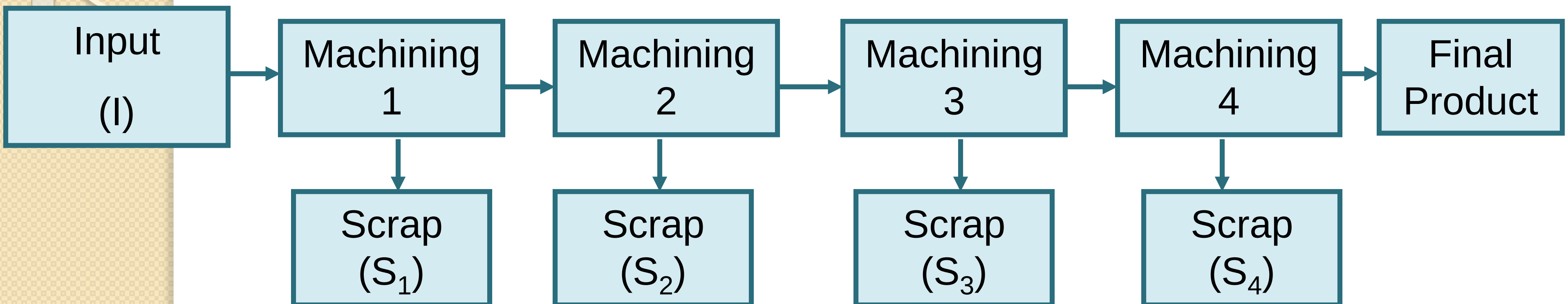
- Based on the given system above, what is the minimum number of inputs required?
- ***I* = *O*+*S***
- If ***S*** is a fraction of ***I***, then

$$I = O + P_S * I \qquad I = \frac{O}{1 - P_S}$$

- Where $\boldsymbol{P_s}$ is the probability of producing scrap items

Process requirements – Quantity determination

Scrap estimates – high volume production



- In order to be able to produce the desired number of final products we have to consider the scraps from the beginning.
- Total needed input can generally be calculated using the following equation

$$Input = \frac{FinalOutput}{(1-P_{s_1})(1-P_{s_2})\dots(1-P_{s_n})}$$

Scrap estimates - problem

- Market estimate of 97,000 components
- 3 operations: turning, milling and drilling
- Scrap estimates: $P_1=0.04$, $P_2=0.01$ and $P_3=0.03$

➤ Total input to the production?

➤ Production quantity scheduled for each operation?

$$Input = \frac{FinalOutput}{(1-P_{s_1})(1-P_{s_2})\ldots(1-P_{s_n})}$$

$$I_1 = \frac{97{,}000}{(1-0.03)*(1-0.01)*(1-0.04)} = 105{,}219$$

Scrap estimates - problem

- Production quantity scheduled for each operation:

$$I_3 = \frac{97{,}000}{1-0.03} = 100{,}000$$

$$I_2 = \frac{100{,}000}{1-0.01} = 101{,}000$$

$$I_1 = \frac{101{,}000}{1-0.04} = 105{,}219$$

Table 2.5 *Summary of Production Requirements for Example 2.1*

Operation	Production Quantity Scheduled (units)	Expected Number of Good Units Produced
Turning	105,219	101,010
Milling	101,010	100,000
Drilling	100,000	97,000

Equipment fractions

- The quantity of equipment required for an operation
- Most of the time facilities need fraction of machines
  - e.g.: 3.5 machine
- How can we determine the number of machines we need in order to produce Q items

$$F = \frac{Total.Time}{Time.Available}$$

$$F = \frac{S * Q}{E * H * R}$$

Where

F… the required number of machines per shift

S … the standard time per unit produced [min]

Q… the number of units to be produced per shift

E …actual performance (as % of standard time)

H … amount of time available per machine [min]

R … reliability of machine (as % "uptime")

Equipment fractions - problem

- A machined part has a standard machinery time of 2.8 min per part on a milling machine. During an 8-hr shift 200 unites are to be produced. Out of the 8 hours available for the production, the milling machine will be operational 80% of the time. During the time the machine is operational, parts are produced at a rate equal to 95% of the standard rate.

➢ How many milling machines are required?

- S=2.8 min, Q=200 units, H=480 min, E=0.95 and R=0.8

$$F = \frac{S*Q}{E*H*R} = \frac{2.8*200}{0.95*480*0.8} = 1.535$$

- We need 1.535 machines per shift.

Total equipment requirements

- Combining the equipment fractions for ***identical*** equipment types
- Problem:

Table 2.9 *Total Equipment Requirement Specification Example*

Operation Number	Equipment Fraction	Next Highest Whole Number
109	1.1	2
206	2.3	3
274	0.6	1

- How many machines do we need?
- Answer: 4, 5 or 6. Other factors need to be considered: setup time, cost of equipment, etc.

Operator Requirements

- If the order quantity (Q) is known
  - Required number of machines can be found
  - How do we find the number of required operators?
- Depending on the nature of the work, determination of the number of required operators might differ
  - Some machines can work alone: CNC machines
  - Some tasks require the involvement of an operator 100% of the time - driving a forklift

Operator Requirements

- It is conceptually the same as the machine requirement

$$F = \frac{Total.Time}{Time.Available}$$

$$N = \frac{T * P}{H * C}$$

Where

N … the required number of operators per shift

T…. the time required for an operation [min]

P … the required number of operations per day

H … amount of time available per day [min]

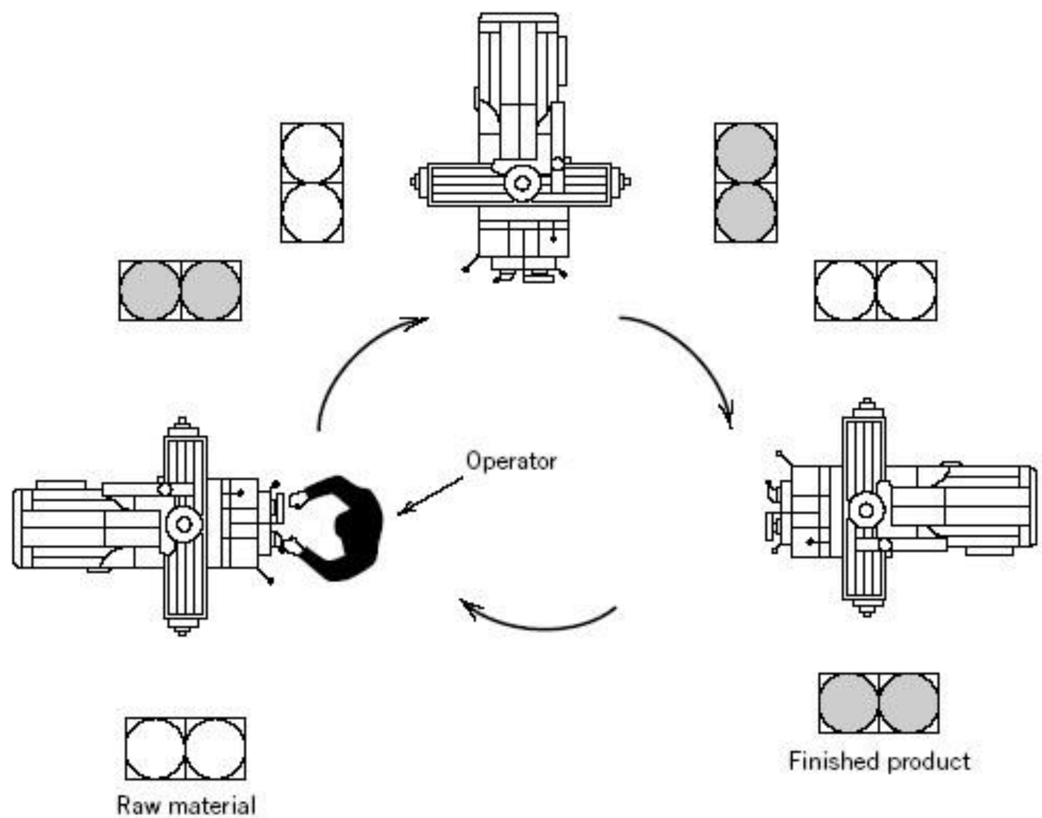
C… time the person is available (% of utilization)

- To perform the exact manpower requirement analysis, we need to know how many machines a worker can operate at the same time.

➔Machine assignment problem

Machine assignment problem

- Decisions regarding the assignment of machines to operators can affect the number of employees



Machine assignment problem

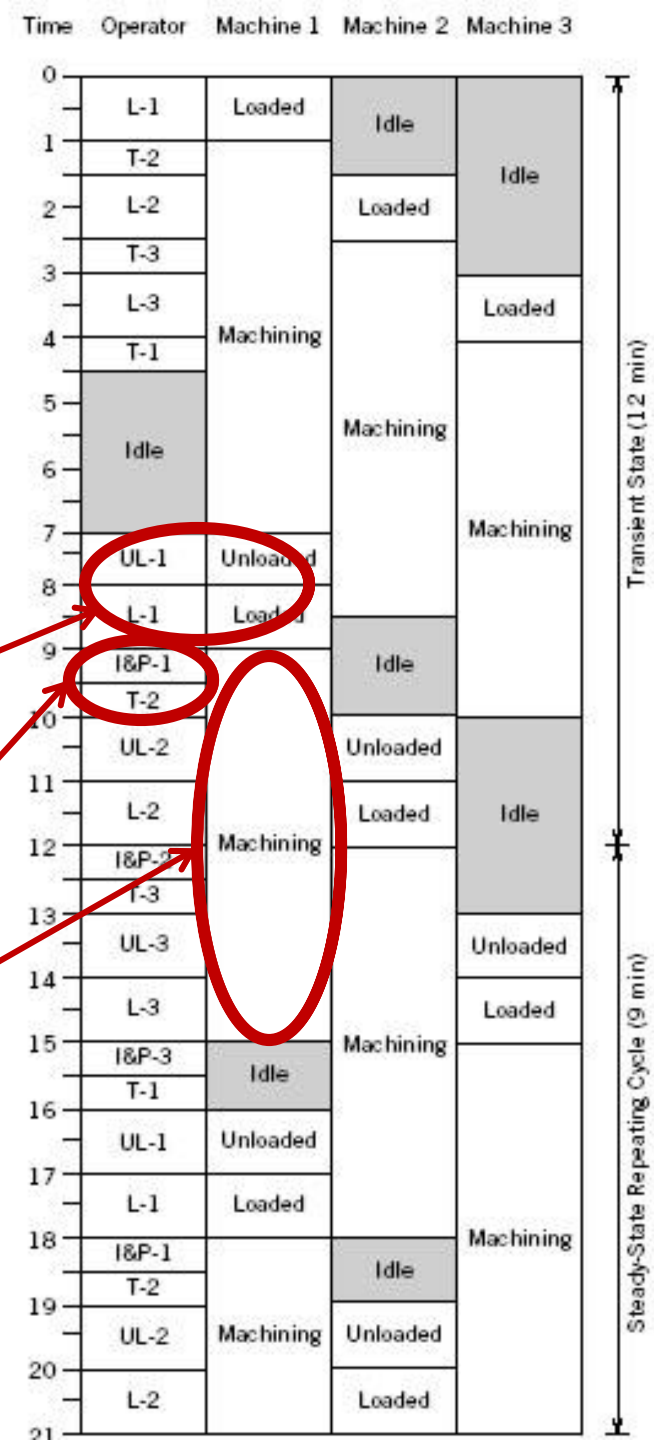
Human-Machine chart
or Multiple Activity chart

a … Concurrent activity (both machine and operator work together: load, unload machines)

b … Independent operator activities (walking, inspecting, packing)

t … Independent machine activities (automatic machining)

L..…Loading
T…..Walking
UL…Unloading
I&P…Inspection & Packing



Machine assignment problem

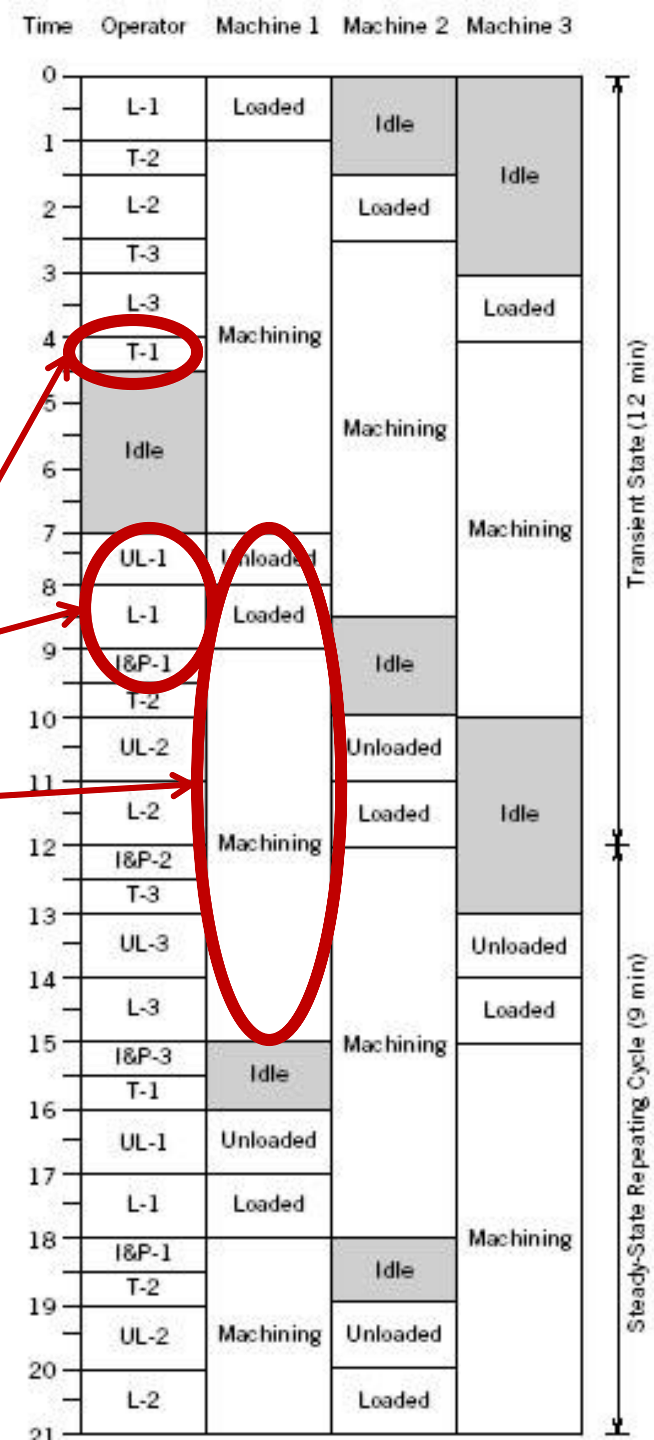
a … Concurrent activity

b … Independent operator activities

t … Independent machine activities

(a+b)…Operator time per machine: time an operator devotes to each machine

(a+t) …Machine cycle time (repeating time): time it takes to complete a cycle



L.….loading
T…..walking
UL…unloading
I&P…inspection & packing

Machine assignment problem – Problem 1

- Three machines: A, B and C
- Loading/Unloading times for each machine are:
  - a_A=2min, a_B=2.5min and a_C=3min
- Machining times
  - t_A=7min, t_B=8, and t_C=9 minutes
- Inspection times
  - b_A=1, b_B=1, and b_C=1.5 minutes

➢ Determine the cycle length (cycle time)

➢ Construct a multiple activity chart

- How can we estimate the minimum cycle length?
  - Compute the **total time operator needs** to work during the full cycle $= \boldsymbol{\Sigma(a_i + b_i)}$

    $T_o = (2+1) + (2.5+1) + (3+1.5) =$ 11minutes

  (the minimum possible cycle length is 11 minutes)
  - Compute **machine cycle time** (total operating time) for each machine ***(a + t)***
    - Machine A: 2+7 = 9 minutes
    - Machine B: 2.5+8 = 10.5 minutes
    - Machine C: 3+9 = 12 minutes

    Machine cycle time is 12 minutes (the minimum possible cycle length is 12 minutes)
  - Cycle time is the higher of the two:

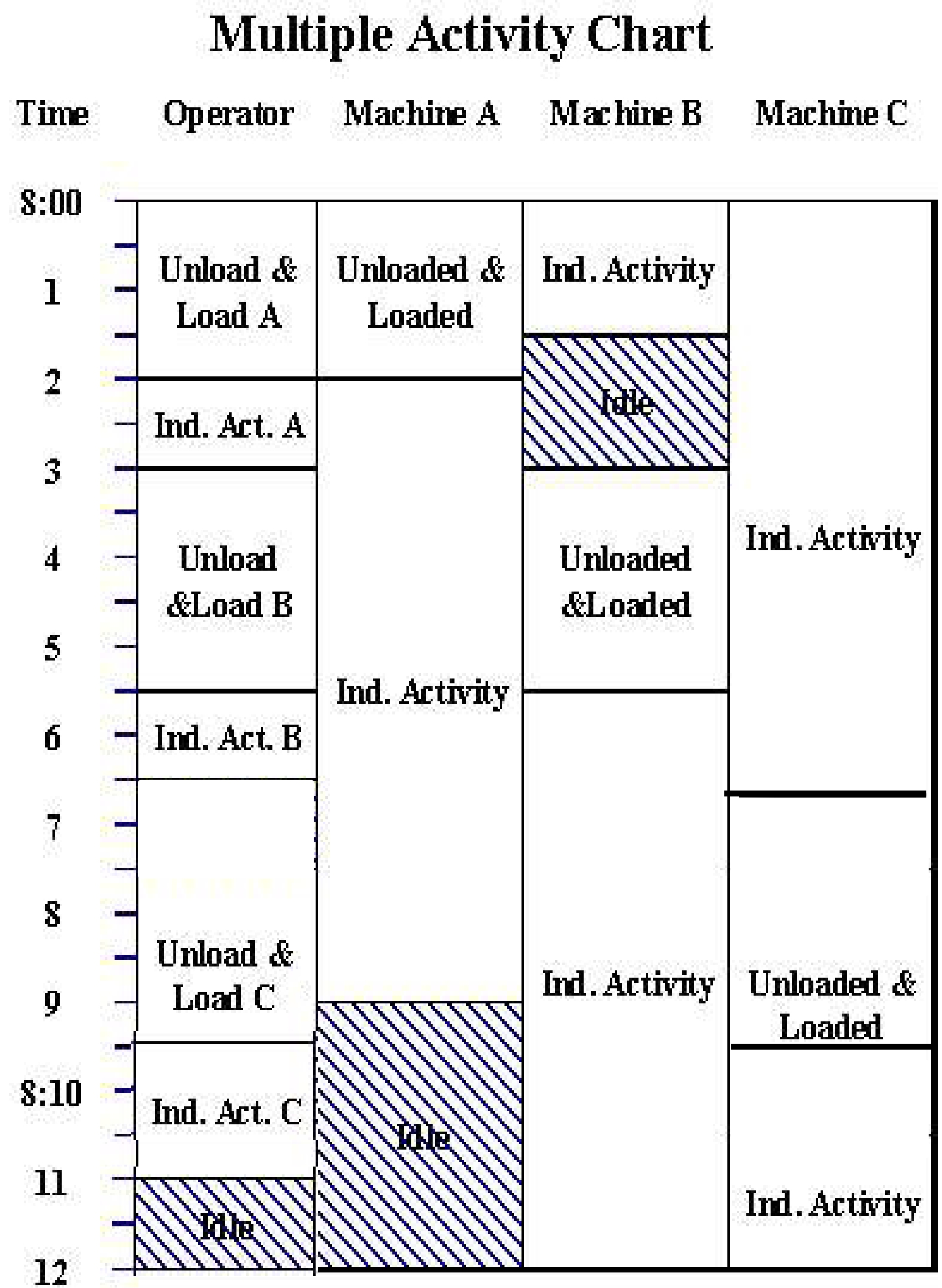
    $\rightarrow T_C = 12$ minutes

Multiple Activity Chart

Loading/Unloading:
- a_A=2min
- a_B=2.5min
- a_C=3min

Machining times
- t_A=7min
- t_B=8min
- t_C=9min

Operator independent times:
- b_A=1min
- b_B=1min
- b_C=1.5 min



Machine assignment problem

- If we know the activities needed and the time required to complete each activity, we can determine the *ideal number of machines per operator* ***n'*** (for identical machines)

$$n' = \frac{\text{Machine cycle time}}{\text{Operator time per machine}} \qquad n' = \frac{(a+t)}{(a+b)}$$

- If found ***n'*** is not an integer value (it will not be in most cases), how do we determine the *number of machine for each person* (***m***)?

If ***m < n'*** then ***operator*** will be idle

If ***m > n'*** then ***machines*** will be idle

- This question can be answered more accurately if we know the cost of machining and of the operator

Machine assignment problem – Problem 2

- Identical machines
- Walking time 0.5 min
- Loading 1 min
- Unloading 1 min
- Automatic machining 6 min
- Inspection and packing 0.5 min

➤ Determine the ideal number of machines per operator ***n'***

- a=1+1=2 min, t=6 min, b=0.5+0.5=1 min

$$n' = \frac{(a+t)}{(a+b)} = \frac{(2+6)}{(2+1)} = \frac{8}{3} = 2.67$$

Machine assignment problem

- T_c …Cycle time
- I_o… Idle operator time
- I_m…Idle time for machines during one cycle (T_c)

$$T_c = \begin{cases} (a+t) & \text{when } m \le n' \\ m(a+b) & \text{when } m > n' \end{cases}$$

(Operator idle)

(Machines idle)

$$I_m = \begin{cases} 0 & \text{when } m \le n' \\ T_c - (a+t) & \text{when } m > n' \end{cases}$$

$$I_o = \begin{cases} T_c - m(a+b) & \text{when } m \le n' \\ 0 & \text{when } m > n' \end{cases}$$

Machine assignment problem – Problem 2 cont.

- a=2 min, t=6 min, b=1 min

➢ Determine the cycle time and idle times for machines and an operator if 3 machines are assigned to an operator

- m>n'   (3>2.67) -> machines will be idle

$$T_C = m(a+b) = 3(2+1) = 9\,\text{min}$$

$$I_m = T_c - (a+t) = 9 - (2+6) = 1\,\text{min}$$

$$I_o = 0$$

Machine assignment problem

- C_o is cost per operator hour
- C_m is cost per machine hour
- $\varepsilon = C_o/C_m$
- ***TC(m)*** is cost per unit produced based on an assignment of **m** machines per operator

$$TC(m) = \begin{cases} (C_o + mC_m)(a+t)/m & \text{when } m \le n' \quad \text{(Operator idle)} \\ (C_o + mC_m)(a+b) & \phantom{\text{when }} m > n' \quad \text{(Machines idle)} \end{cases}$$

Each machine produces one unit during T_c : ➔ *time per unit* T_c/m

If cycle time is *(a+t)* => *(a+t)/m* is time to produce a unit for each machine.

If cycle time is *m(a+b)* => *(a+b)* is the time to produce a unit for each machine.

Based on this equation we may experiment to determine the number of assigned machines

Machine assignment problem

- Let **n** be the integer portion of **n'**

$$\phi = \frac{TC(n)}{TC(n+1)}$$

$$\phi = \frac{(C_o + nC_m)(a+t)}{n[C_o + (n+1)C_m](a+b)}$$

$$Then$$

$$\phi = \left(\frac{\varepsilon + n}{\varepsilon + n + 1}\right)\left(\frac{n^{'}}{n}\right)$$

If ***Φ<1*** then TC(n)<TC(n+1)

If ***Φ>1*** then TC(n)>TC(n+1)

We should assign

n machines

n+1 machine

to each operator

Machine assignment problem – Problem 2

- C_o =$15 per hour
- C_m =$50 per hour

➢ Determine the number of machines assigned to an operator to minimize the cost

$$\varepsilon = \frac{C_o}{C_m} = \frac{15}{50} = 0.3$$

$$\phi = \left(\frac{\varepsilon + n}{\varepsilon + n + 1}\right)\left(\frac{n'}{n}\right) = \left(\frac{0.3+2}{0.3+2+1}\right)\left(\frac{2.67}{2}\right) = 0.93$$

- Since $\Phi<1$ then TC(n)<TC(n+1) and thus only 2 machines should be assigned to an operator

Machine assignment problem – Problem 3

- Loading Mixer: 6 minutes
- Mixing and Unloading: 30 minutes $t = 30$
- Cleaning: 4 minutes $a = 6 + 4 = 10$
- Position for filling: 6 minutes $b = 6$
- Co = \$12/hr
- Cm = \$25/hr

➢ Maximum number of mixers without creating idle time for mixers?

➢ How many mixers to minimize cost?

➢ If 2 machines are assigned per operator, what will be the cost per unit?

➢ If the cost per machine is unknown, for what range of values Cm will the optimum assignment remain the same?

Machine assignment problem – Problem 3

- Maximum number of mixers without idle mixers

a = 6 + 4 = 10; b = 6; and t = 30

$$n' = \frac{(a+t)}{(a+b)} = \frac{(10+30)}{(10+6)} = \frac{40}{16} = 2.5$$

Max of 2 mixers can be assigned to 1 operator without idle mixer time.

- Number of mixers to minimize cost

$$\varepsilon = \frac{C_o}{C_m} = \frac{12}{25} = 0.48$$

$$\phi = \left(\frac{\varepsilon + n}{\varepsilon + n + 1}\right)\left(\frac{n'}{n}\right) = \left(\frac{0.48 + 2}{0.48 + 2 + 1}\right)\left(\frac{2.5}{2}\right) = 0.89$$

Since Φ = 0.89 < 1, only 2 mixers should be assigned to an operator to minimize cost.

Machine assignment problem – Problem 3

➢ If m=2, the cost of a unit?

- Since m<n' (2<2.5)

$$TC(m) = (C_o + mC_m)(a+t)/m$$

$$TC(2) = (12 + 2*25)(\frac{10+30}{60})/2 = 20.66$$

- The cost of a unit will be $20.66.

Machine assignment problem – Problem 3

- If the cost per machine is unknown, for what range of values Cm will the optimum assignment remain the same?

- In order for n=2, Φ≤1

$$\phi = \left(\frac{\varepsilon + n}{\varepsilon + n + 1}\right)\left(\frac{n'}{n}\right)$$

$$(\varepsilon + n) * n' \leq (\varepsilon + n + 1) * n$$

$$(\varepsilon + 2) * 2.5 \leq (\varepsilon + 2 + 1) * 2$$

$$\left(\frac{12}{C_m} + 2\right) * 2.5 \leq \left(\frac{12}{C_m} + 3\right) * 2$$

$$6 \leq C_m$$

- For a machine cost of $6 or more per machine-hour, the optimum assignment will be 2 machines per operator.

Facilities design

- Up to this point
  - We know what we are producing (*Product design*)
  - How we are producing it (*Process design*)
  - How many we are producing (*Schedule design*)

- With the available information we can now start designing the facilities

Facilities design

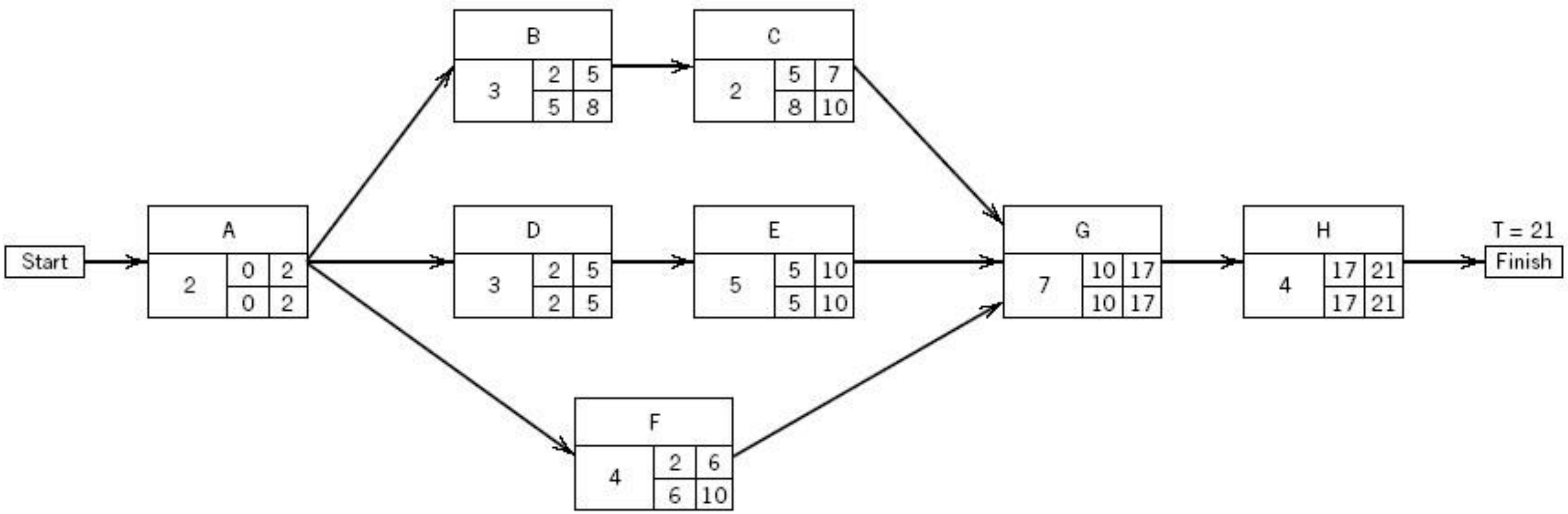
- 7 management and planning tools that are used for system planning and improvement

1. **Affinity diagram**
   - Used to gather verbal data (ideas and issues) and organize into groups.
2. **Interrelationship diagram**
   - Try to relate the items and identify which item impacts the other.
3. **Tree diagram**
   - Detailed study of items that need to be accomplished to reach the goal.
   - Relationship between these items

Facilities design

4. **Matrix diagram**
   - Organize information based on characteristics, functions, and tasks of items to compare and see the relationships
5. **Contingency diagram**
   - Maps the events and possible contingencies that might occur during the implementation of the project
6. **Activity network diagram**
   - Used to develop a work schedule for the facility design effort
   - Used to plan entire design process visually
7. **Prioritization matrix**
   - A tool for comparison of criteria
   - Determines the most important criteria

Activity Network Diagram



Legend:

A: Schedule shutdown periods for equipment movement and installation
B: Interview, evaluate, select, and hire new employees
C: Train new employees
D: Interview, evaluate, and select equipment vendors
E: Order equipment
F: Interview, evaluate, select, and hire construction contractors
G: Meet to review installation plan (Facilities Design Team, contractors, new employees, vendor representatives, and management)
H: Executive installation plan and test system

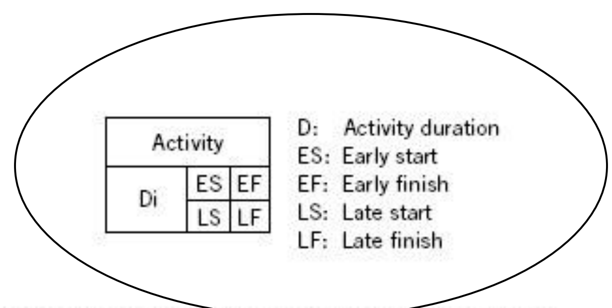


Figure 2.22 Activity network diagram example for a production line expansion facilities design project.

Prioritization matrix

Criteria used to evaluate facilities design alternatives	
A. Total distance traveled	B Manufacturing floor visibility
C. Overall aesthetics of the layout	D. Ease of adding future business
E. Use of current equipment	F. Investment in new equipment
G. Space requirements	H. People requirement
I. Impact on WIP levels	J. Human factor risk
K. Estimated cost of alternatives	

Weights used in comparison of criteria	
1= Equally important	
5 = Significantly more important	1/5 = significantly less important
10 = extremely important	1/10 = extremely less important

Prioritization matrix

Table 2.12 *Prioritization Matrix for the Evaluation of Facilities Design Alternatives*

	Criteria											
	A	B	C	D	E	F	G	H	I	J	K	Row totals (%)
Distance	1	5	10	5	1	1	1	1	1	5	1	32. (9.9)
Visibility	1/5	1	5	1/5	1/5	1/10	1/5	1/5	1/10	1/5	1/5	7.6 (2.4)
Aesthetics	1/10	1/5	1	1/10	1/10	1/10	1/5	1/5	1/10	1/10	1/10	2.3 (0.7)
Fut. Buss.	1/5	5	10	1	1/5	1/5	1/5	1/5	1/10	1/5	1/10	17.4 (5.4)
Current eq.	1	5	10	5	1	1	5	5	1/5	1	1/5	34.4 (10.7)
New eq.	1	10	10	5	1	1	5	5	1	1	1	41. (12.7)
Space	1	5	5	5	1/5	1/5	1	5	1/5	1/5	1/5	23. (7.1)
People	1	5	5	5	1/5	1/5	5	1	1/10	1/5	1/5	22.9 (7.1)
WIP	1	10	10	10	5	1	5	10	1	1	5	59. (18.3)
Human f.r.	1/5	5	10	5	1	1	5	5	1	1	5	39.2 (12.2)
Cost	1	5	10	10	5	1	5	5	1/5	1/5	1	43.4 (13.5)
Column total	7.7	56.2	86.	51.3	14.9	6.8	32.6	37.6	5.	10.1	14.	322.2 Grand total

Prioritization matrix

Layout alternatives

Table 2.13 *Prioritization of Layout Alternatives Based on WIP Levels*

	Layout					
WIP Levels	P	Q	R	S	T	Row totals (%)
P	1	5	1	1/10	1/5	7.3 (9.9)
Q	1/5	1	1/5	1/10	1/10	1.6 (2.2)
R	1	5	1	10	5	22. (30.0)
S	10	10	1/10	1	1/5	21.3 (29.0)
T	5	10	1/5	5	1	21.2 (28.9)
Column Total	17.2	31	2.5	16.2	6.5	73.4 Grand total

Prioritization matrix

- In the previous slide, we compared the different layout alternatives to each other based on WIP levels
- We need to do the comparison for all the selected criteria
- Finally use the following format to determine the best alternative

Prioritization matrix

Table 2.14 *Ranking of Layouts by All Criteria*

								Criteria				Row totals
	A	B	C	D	E	F	G	H	I	J	K	(%)
P									.099 × .183 = .018			Σ (%P)
Q									.022 × .183 = .004			Σ (%Q)
R									.300 × .183 = .055			Σ (%R)
S									.290 × .183 = .053			Σ (%S)
T									.289 × .183 = .053			Σ (%T)
Column									.183			Grand Total

- The ranking of layouts will help determine the best alternative
- Best alternative - serving the objective best
- Best concept might change depending on the company and people.

Facilities design

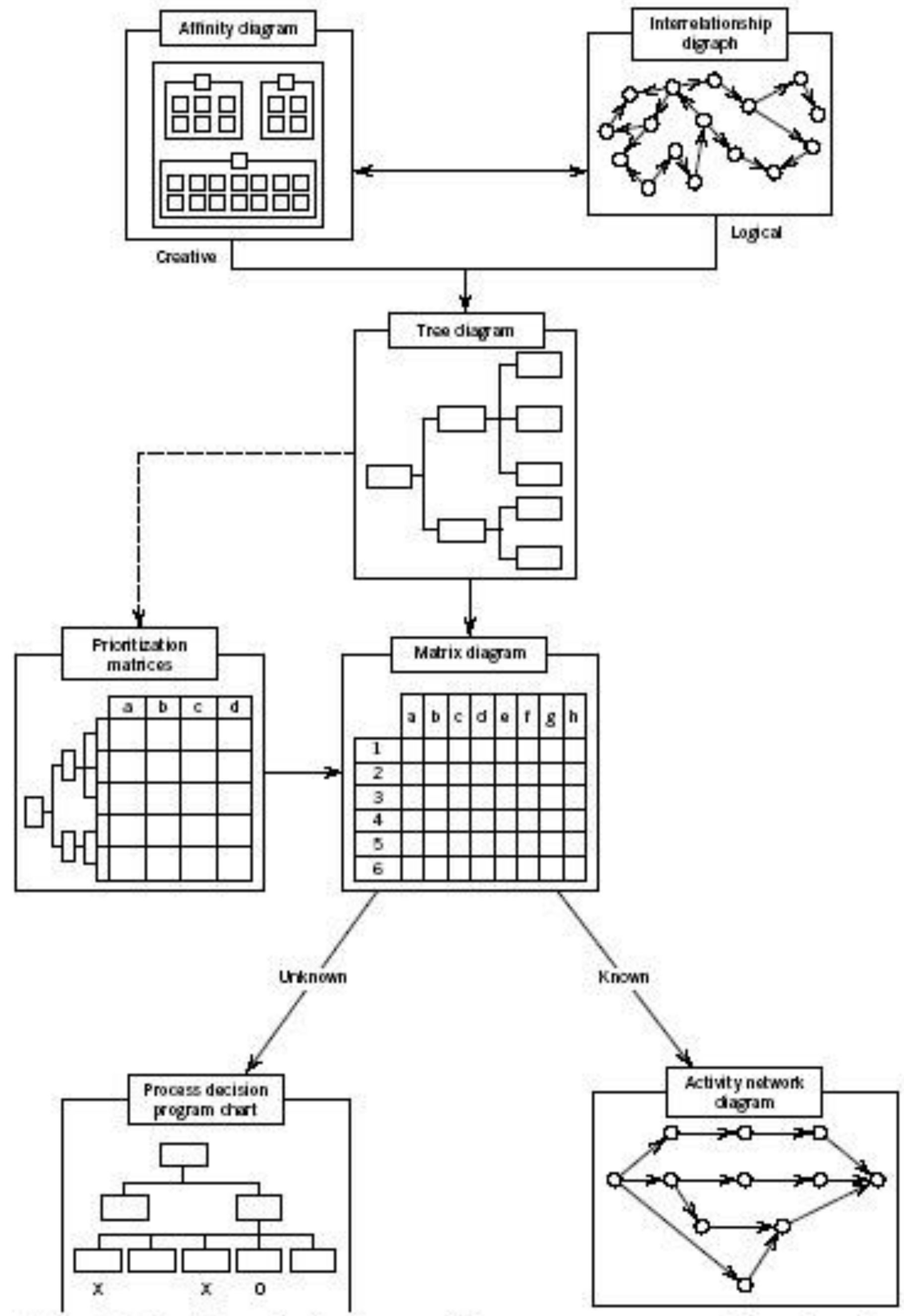


Figure 2.23 Logical application sequence of the seven management and planning tools.

Next lecture

- Flow, space and activity relationships I.