NOTES

Seasonal Index for Quarter 3 = $\frac{722.5}{679}$ = 1.064

Seasonal Index for Quarter 4 = $\frac{890.5}{679}$ = 1.311

***Exponentially moving average with seasonal and trend corrections (Level + Trend + Seasonal)***

If the past data consists of the level, seasonal and trend pattern, then you need three expressions to estimate the three components:-

$$\hat{X}_t = \alpha \qquad + (1 - \alpha)( \qquad _{-1} + T_{t-1})$$

$$Tt = \beta ( \qquad - \hat{X}_{t-1}) + (1 - \beta) T_{t-1}$$

$$I_{t+m} = \qquad + (1 - \gamma) I_t$$

The forecast model

$$= (\hat{X}_t + T_t) I_t$$

To forecast for the 'n' period

$$\hat{Y}_{t+n} = [\hat{X}_t + (n + 1) T_t] I_{t+n}$$

***Exponentially moving average Problem – 5***

Using the data from the last four quarters in the previous problem and the initial seasonal indices computed in the previous problem, determine MAD and bias of an Exponential weighted moving average with $\alpha$ = 0.2, = 0.4, = 0.5, an initial forecast of 720, an initial trend of 65, and an initial level of 801. What is the forecast for quarter 13? For quarter 15? (Assume period 9 as the initial period).

**Given**

**Table 3.9**

| Quarter | $Y_t$ Demand | Forecast Level | Tt Trend | Seasonal Index $I_t$ | Seasonal Index $I_{t+m}$ | Forecast |
|---|---|---|---|---|---|---|
| 9 | 709 | 801 | 65 | 0.83 | | 720 |
| 10 | 715 | | | 0.793 | | |
| 11 | 1794 | | | 1.064 | | |
| 12 | 1242 | | | 1.311 | | |

**NOTES**

= 0.2, = 0.4, = 0.5

New seasonal Index, $I_{t+m}$ 9th quarter is obtained as follows:

New seasonal Index, $I_{t+m} = \gamma \quad + (1 - \gamma) I_t$

$= \quad + 0.5 * 0.83$

$= 0.4425 + 0.415$

$= 0.8575$

Forecast demand level for the 10th quarter is obtained in the following manner:

$\hat{X}_t = \alpha \quad + (1 - \alpha)( \quad _{-1} + T_{t-1})$

$= \frac{0.2*709}{0.83} + 0.8 * (801+65)$

$= 170.84 + 692.8$

$X_{10} = 863.64$

Trend for the 10th quarter is obtained as follows:

$T_t = \beta ( \quad - \hat{X}_{t-1}) + (1 - \beta) T_{t-1}$

$= 0.4 * (863.64 - 801) + 0.6 * (65)$

$T_{10} = 64.056$

Forecast for quarter 10 is

$= (\hat{X}_t + T_t) I_t$

$= (863.64 + 64.056) * 0.793$

$\hat{Y}_{10} = 735.66$

Forecast demand level for the 11th quarter is obtained in the following manner:

$\hat{X}_t = \alpha \quad + (1 - \alpha)( \quad _{-1} + T_{t-1})$

$= \frac{0.2*715}{0.793} + 0.8* (863.64 + 64.056)$

$= 180.32 + 742.156$

$\hat{X}_{11} = 922.47$

Trend for the 11th quarter is obtained as follows:

$Tt = \beta ( \quad - \hat{X}_{t-1}) + (1 - \beta) T_{t-1}$

$= 0.4 * (922.47 - 863.64) + 0.6 * (64.056)$

$T_{11} = 61.96$

NOTES

Forecast for quarter 11 is

$= (\hat{X}_t + T_t)\, I_t$

$= (922.47 + 61.96) * 1.064$

$\hat{Y}_{11} = 1047.43$

Forecast demand level for the 12th quarter is obtained in the following manner:

$\hat{X}_t = \alpha \qquad + (1 - \alpha)( \quad _{-1} + T_{t-1})$

$$= \frac{0.2*1794}{1.064} + 0.8 * (922.47+61.96)$$

$= 337.21 + 787.54$

$X_{12} = 1124.75$

Trend for the 12th quarter is obtained as follows:

$Tt = \beta ( \quad - \hat{X}_{t-1}) + (1 - \beta)\, T_{t-1}$

$= 0.4 * (1124.75 – 922.47) + 0.6 * ( 61.96)$

$T_{12} = 118.08$

Forecast for quarter 12 is

$= (\hat{X}_t + T_t)\, I_t$

$= (1124.75 + 118.08) * 1.311$

$\hat{Y}_{12} = 1629.35$

Forecast demand level for the 13th quarter is obtained in the following manner:

$\hat{X}_t = \alpha \qquad + (1 - \alpha)( \quad _{-1} + T_{t-1})$

$$= \frac{0.2*1242}{1.311} + 0.8 * (1124.75 + 118.08)$$

$= 189.47 + 994.26$

$\hat{X}_{13} = 1183.73$

Trend for the 13th quarter is obtained as follows:

$Tt = \beta ( \quad - \hat{X}_{t-1}) + (1 - \beta)\, T_{t-1}$

$= 0.4*(1183.73 – 1124.75) + 0.6 * (118.08)$

$T_{13} = 93.43$

Forecast for quarter 13 is

$= (\hat{X}_t + T_t)\, I_t$

$= (1183.73 + 93.43) * 0.8575$

$\hat{Y}_{13} = 1096.02$

NOTES

**Forecast for quarter 13 is 1096.02**

New seasonal Index, $I_{t+m}$ for 10th quarter is obtained as follows:

New seasonal Index, $I_{t+m} = \gamma \quad + (1 - \gamma) I_t$

$= \quad + 0.5 * 0.793$

$= 0.413 + 0.396$

$= 0.809$

$I_{t+m}$ for 11th quarter,

$I_{t+m} = \gamma \quad + (1 - \gamma) I_t$

$= \quad + 0.5 * 1.064$

$= 0.972 + 0.532$

$= 1.504$

$I_{t+m}$ for 11th quarter,

$I_{t+m} = \gamma \quad + (1 - \gamma) I_t$

$= \quad + 0.5 * 1.311$

$= 0.552 + 0.655$

$= 1.207$

**Table 3.10**

| Quarter Demand | $Y_t$ Forecast Level | $\hat{X}_t$ | Tt Trend Index | Seasonal | | Forecast |
|---|---|---|---|---|---|---|
| | | | | $I_t$ | $I_{t+m}$ | |
| 9 | 709 | 801 | 65 | 0.83 | 0.8575 | 720 |
| 10 | 715 | 863.64 | 64.056 | 0.793 | 0.809 | 735.66 |
| 11 | 1794 | 922.47 | 61.96 | 1.064 | 1.504 | 1047.43 |
| 12 | 1242 | 1124.75 | 118.08 | 1.311 | 1.207 | 1629.35 |
| 13 | | 1183.73 | 94.43 | 0.8575 | | 1096.02 |

Forecast for Quarter 15 is

$_{t+2} = [1183.73 + 3 * (94.43)] * 1.504$

$= 1467.02 * (1.504)$

$\hat{Y}_{15} = 2206.39$

**NOTES**

**Forecast for quarter 15 is 2206.39**

Mean Absolute Deviation, $MAD = \sum_{i=1}^{n} \frac{Y_i - \hat{Y}_i}{n}$

$$\text{MAD} = \frac{|11 + 20.66 + 746.57 + 387.35|}{4}$$

$$= \frac{1165.58}{4}$$

**MAD = 291.39**

$$\text{Bias} = \frac{\sum_{i=1}^{n} (Y_i - \hat{Y}_I)}{n}$$

$$= \frac{(-11 - 20.66 + 746.57 - 387.35)}{4}$$

=

**Bias = 81.89**

$$\frac{327.56}{4}$$

### 3.2.3.1.2 Econometric models

Econometric models may be designed as social science in which the tools of economic theory, mathematics, and statistical inference are applied to the analysis of economic phenomena.

The traditional econometric methodology proceeds along the following steps:

1. Statement of theory.
2. Development of model.
3. Specification of econometric model.
4. Obtaining the data.
5. Estimation of the parameters of the econometric model.
6. Hypothesis testing.
7. Forecasting.
8. Using the model for central or policy purpose.

The above steps can be explained by an example:-

NOTES

1. Economic theory says, other things remaining the same, a reduction of price of a commodity results in increase of quantity demanded for that commodity.
2. You can find an inverse relationship and a mathematical model can be developed.
3. Use of mathematical model which enables you to develop an economical equation.
4. Get the past data for the price and quantity.
5. Estimate the parameters for the economic model.
6. Use the model as well as parameters.
7. The predicted data further used for decision making purpose.

Thus econometric models are developed and used for decision making purpose.

***3.2.3.1.3 Economic Indicators***

In this kind of model the independent and dependents variables are economic indicators. The variables may be GNP, Personal income, Bank deposits, Inflation, Pre-capita income, Purchasing Power Parity, Wholesale price index, Consumer price index, etc. You should develop a relationship .

$Y = f(x_1, x_2, \ldots, x_p)$

Then develop a model using the variable and treat the problem as simple linear regression or multiple regression model. Then use the model to forecast for the future and test the model and parameters using ANOVA and 't' test. The difference between econometric models and economic indicators are, in econometric model you may have more than one equation which you may get to show the relationship between the economic variables and the parameters estimated and it is used for forecasting, but in the case of economic indicator model you will be having single regression model to predict the future.

***3.2.3.2 Qualitative Methods***

Qualitative methods of forecasting are adopted where you don't have past data for projections. But, these techniques are adopted to forecast for new products. These techniques also adopted to validate the forecast which is derived from the quantitative methods mentioned in the early sections.

***3.2.3.2.1 Market Survey*** is a technique, where the market / consumer are surveyed to estimate the potential market through various techniques like direct survey, questionnaire, interview methods etc.

***3.2.3.2.2 Expert Opinion*** has a method in which the experts are called and they are allowed to discuss to arrive at the decisions related to market potential. This method has a disadvantage of the dominating expert – who may sway away the whole discussion in his way. The docile expert view may not find a remarkable place in the discussion.

NOTES

***3.2.3.2.3 Delphi Technique*** - the short coming of the expert opinion method is eliminated in the Delphi technique method. In this method, the experts are not invited for the discussion, instead the questions is prepared for which is indented and circulated to all experts. The responses of experts are collected and then the reasoning for their response will also be collected and then same such process is continued until the consensus is arrived at. The whole task is carried out by a person called Facilitator.

## Review Questions:

1.List the techniques under qualitative methods.

2.List the different techniques used in the quantitative methods.

### 3.2.4 Forecasting evaluation

Forecasting evaluation tools are many. But each tool is the function of forecast error that is the difference between the actual sales and the forecasted value. The forecasting methods are evaluated based on the forecasting evaluation tool.

The best method is chosen where the forecast error is minimum.Different forecasting evaluation tools are:

1. Sum of squared error
2. Mean squared error
3. Mean absolute deviation
4. Tracking signal

Let us assume that
$F_t$ → Forecast for the period 't'
$A_t$ → Actual for the period 't'
$n$ → number of observation

1. Sum of Squared Error (SSE)

$$= \sum_{t=1}^{n} (F_t - A_t)^2$$

2. Mean Squared Error (MSE)

$$= \sum_{t=1}^{n} (F_t - A_t)^2 / n$$

3. Mean Absolute Deviation (MAD)

$$= \sum_{t=1}^{n} |F_t - A_t| / n$$

NOTES

$|F_t - A_t|$ is the absolute value
Tracking Signal (TS)

$$TS = \frac{\sum_{t=1}^{n} |F_t - A_t|}{MAD}$$

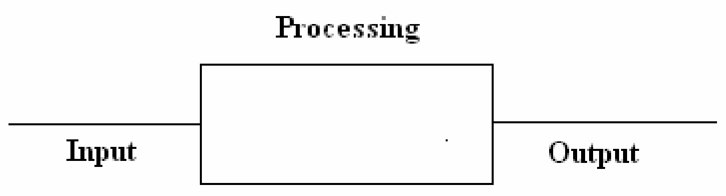
## 3.3 CAPACITY PLANNING

Capacity planning is a process, which is to be carried out after deciding the product and the long range demand for the product. Suppose if you produce custom made product, the demand is not estimated through the product but in terms of hours. Once if you know the long range demand, the effort needed to determine the amount of resources needed to meet the demand requirement is all about capacity planning.

***Capacity Measure***

In this section, you can learn a method of measuring a capacity of system. Consider anything for which you need to measure the capacity, as a system.

**Figure 3.6 – Capacity Measures**




Analyze the system into input, processing and output. When you analyze, see to that, where there is a less variability, choose that side and identify the product, process-resources, the input resources and attach time frame to provide the capacity measure.

***Measure of Capacity through output***

Consider an automobile mass production industry. You can't find much variation in the output side compared to the input resources and processing parts. So the number of cars/time is considered as the measure. Mostly in the case of mass production industry, the output side is considered to measure the capacity.

***Measure of the capacity through Input***

Consider an educational institution; here the output side is not taken into consideration because the number of outgoing students per time may vary depending upon the pass result. But the intake is always constant because the intake depends upon the government approved. So, the capacity of educational institution is measured through the input, namely, the number of students intake.

NOTES

***Measure of the capacity through processing***

Consider a sugarcane industry, the capacity of that industry is not measured in terms of the output and input. There is a variability in terms of yield rate that means some times “y” tons of sugarcane may give “x” tons of sugar or some times same “y” may give more than or less than the “x” tons of sugar. Since variability is existing in both the input side and output side. Inputs and outputs are not considered for measuring the capacity. But in the processing side there is a less variability namely the crushing capacity or the number of tons of sugarcane could be crushed by the crushing machine is considered to be a best measure to measure the capacity of the sugarcane industry from the processing point of view.

In summary, if you want to fix the measure for the capacity, then see the system as input, processing and output. Find where there is a less variability choose that side and correspondingly choose the product or the resources to estimate the measure. The table- 3.11 provides some of the systems and their corresponding measure to measure the capacity.

**Table 3.11 - Capacity planning involves three stages of planning**.

| System | Components of System considered for capacity measure | Unit of Measure |
|---|---|---|
| Automobile Industry | Output | Number of Automobiles |
| Bottling Plant | Output | Gallons / Day |
| University | Input<br>per year | Number of students intake |
| Auto repair shop | Processing<br>day | Number of machines hour per |
| Restaurant | Processing | Seating Capacity |

Stage 1 involves ***resource planning*** this is considered to be long range planning. In the long range planning, mostly the type and amount of man power requirement, the capital equipment requirements are to be decided.

Stage 2 is by considering the resource planning; the ***rough cut capacity planning*** is carried out. Here it is not discussed in detail because it has been discussed in unit II.

Stage 3 is ***capacity requirement planning*** this is lower level planning. This is carried out with the input of rough cut capacity planning. This is also discussed in the unit II.

NOTES

**Review Questions:**

1. How do you measure the capacity planning?
2. Give an example for the capacity measure based on output?

## 3.4 AGGREGATE PRODUCTION PLANNING

### 3.4.1 Introduction

In the operational planning, the long range planning involves capacity planning which involves the determination of long range capacity needs of an organization. Next to the capacity planning is the process of ***aggregate planning*** which comes under intermediate range planning. Aggregate planning is done considering capacity planning as a framework.

***Aggregate Planning***

Aggregate Planning includes identifying different feasible production alternatives and selecting the best one in order to reduce the production cost to minimum. First let us analyze what is meant by aggregate planning? And why this is called aggregate planning? There are organizations which involve the production of various products and each product has its own measurable dimension. For e.g. Assume that an organization produces three products – Product A, Product B and Product C. Product A is measured in terms of tons, product B is measured in terms of length and Product C in terms of number of units. As you know aggregate planning is a medium range planning, you need not plan the capacity of individual products. Instead you should plan the capacity for aggregate demand by converting the different product demand into an aggregate demand. For doing so, you need to find out a common unit, for the above mentioned three products. If possible you can convert into total hours of production. Here the dimension becomes time. Hence time becomes the aggregate unit. After finding the aggregate requirement then you should plan the capacity for the aggregate requirement. This is a planning done at a broader level and does not include details of individual product.

Aggregate planning includes:

**Staffing plan** – related to staff and labor related factors.

**Production plan** – related to production level and inventory.

### 3.4.2 Objectives of Aggregate Planning

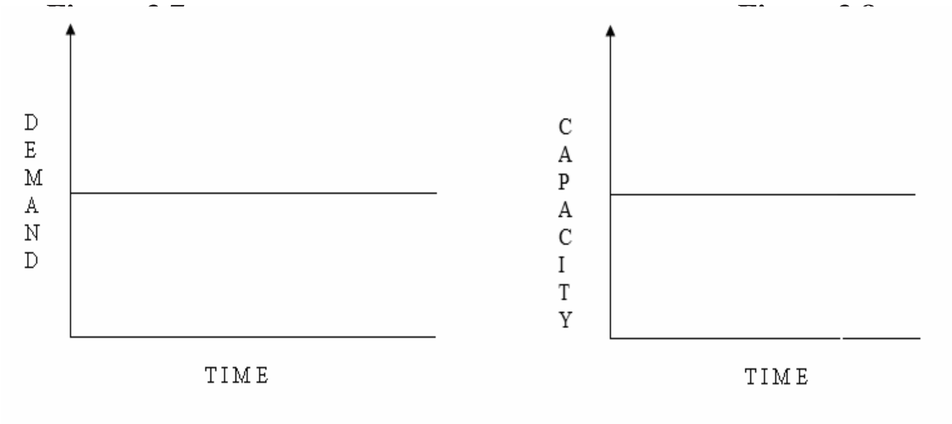
The main objective is to minimize the cost. The others include:

- To maximize
  1. customer service and.
  2. utilization of resources.

- To minimize
  1. changes in workforce and.
  2. changes in production.

### 3.4.3 Strategies to Meet the Demand Fluctuations

Suppose the annual requirement is 1200 units, then you can establish a constant capacity for production as 1200/12 = 100 units per month.




In reality, the demand fluctuates. It could follow seasonal, trend pattern. To meet these demand fluctuations there are certain strategies to be adopted with regard to capacity to meet the demand. They are:

- Inventory carrying through constant workforce.
- Subcontracting.
- Variable workforce.
- Variable Working hours.
- Promotional Activities.
- Backordering.

#### *a. Inventory Carrying Through the Constant Workforce*

In this strategy a constant workforce is maintained throughout the planning period, because of which there is a constant output. But the demand may vary. So during certain periods there will be excess output and at certain times decreased output. The excess demand is met through excess output produced through constant workforce in the previous demands by carrying the inventory.

NOTES

**Figure 3.9 - Inventory Carrying Through Constant Workforce**

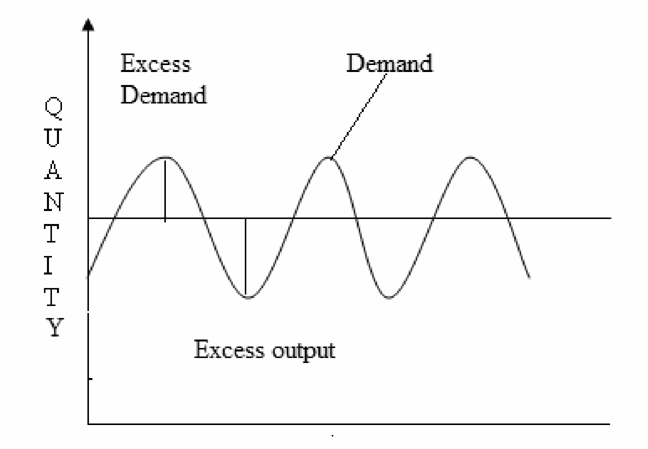
Inventory carrying through constant workforce

- Subcontracting
- Variable workforce
- Variable Working hours
- Promotional Activities
- Backordering

***a. Inventory Carrying Through Constant Workforce***

In this strategy a constant workforce is maintained throughout the planning period, because of which there is a constant output. But the demand may vary. So during certain periods there will be excess output and at certain times decreased output. The excess demand is met through excess output produced through constant workforce in the previous demands by carrying the inventory.

**Figure 3.9 - Inventory Carrying Through Constant Workforce**




***Advantages:***

- This method provides a stable workforce who can give better quality products because of their experience.
- The employees feel secured about their job and hence high productivity level is maintained.
- It avoids hiring and firing cost.

***Disadvantages***

- There will be inventory carrying cost when there is excess output during a period.

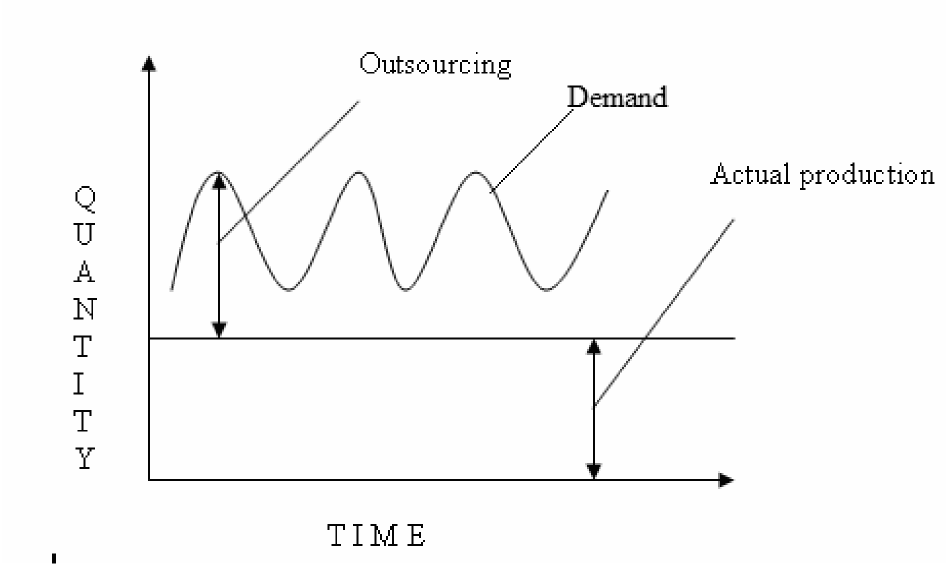
NOTES

- There is a difficulty in finding a stable workforce that will keep the inventory cost at its minimum.
- This strategy cannot be followed for perishable goods.

***b. Subcontracting***

This is one of the strategies to meet demand fluctuation in which a portion of the production is placed with a subcontractor or subcontractors.

***Figure 3.10 - Subcontracting***




***Advantages***

- During the period of the peak demand this is a good alternative if the company is unable to produce the demand needs in a given time period.

***Disadvantages***

- Unless the company has good relations with the suppliers it cannot have much a control on the product quality and delivery time.
- If practiced extensively it will result in increased competition among subcontractors which in turn leads to subcontractors becoming competitors for the firm.

***c. Variable Workforce***

This strategy involves hiring and firing of employees based on demand fluctuations. When the demand increases workforce is hired and when the demand decreases some amount of workforce is fired.

NOTES

**Figure 3.11**

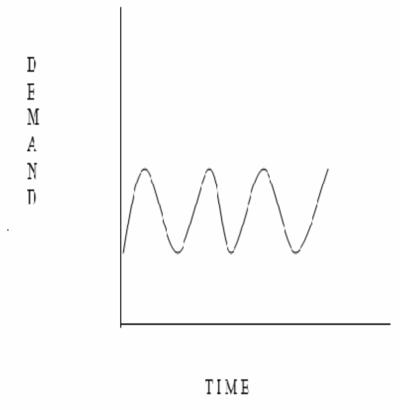
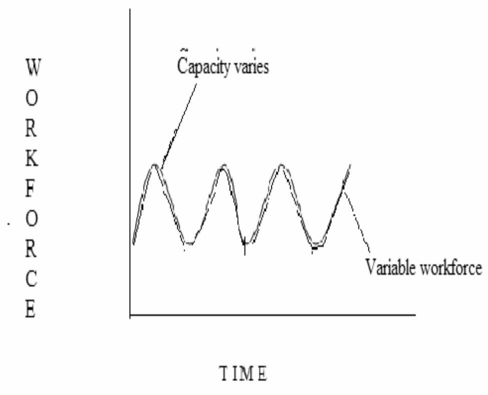



**Figure 3.12**




- Variable workforce enables to match between production quantity and demand because of which inventory cost can be kept at minimum.

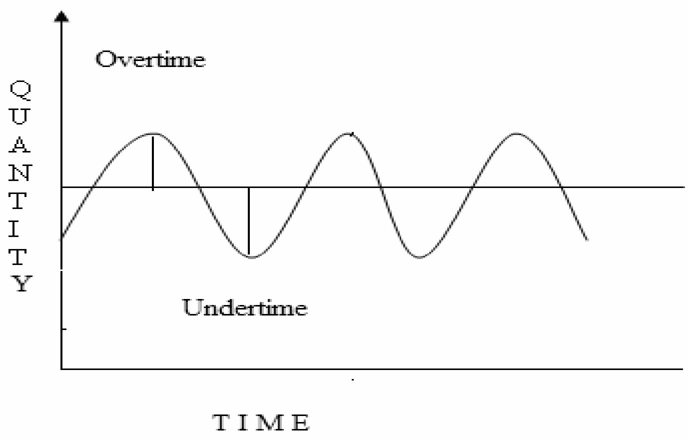
***Disadvantages***

- There is a cost involves in hiring and firing the employees.
- Newly hired employees need training and hence initially productivity might be lowered.
- Workers might feel unsecured about their job which may in turn affect productivity.

***d. Variable Working Hours***

Under this strategy, workforce remains constant but working hours would vary as per the demand. During periods of increased demand employees are made to work overtime. If the demand is low workers are idle but the firm would be paying them full salary. This is a loss to the company.

**Figure 3.13 - Variable Working Hours**



NOTES

***Advantages***

- It helps to maintain a stable workforce.
- The company can save the cost on inventory.

***Disadvantages***

- In case of very large demand it is difficult to follow this strategy.
- Overtime wages are higher than regular time wages.
- Employees are idle during periods of low demand.
- During overtime, if the employees are very much stressed, it will lead to a decrease in their efficiency of working.

***e. Promotional Activities***

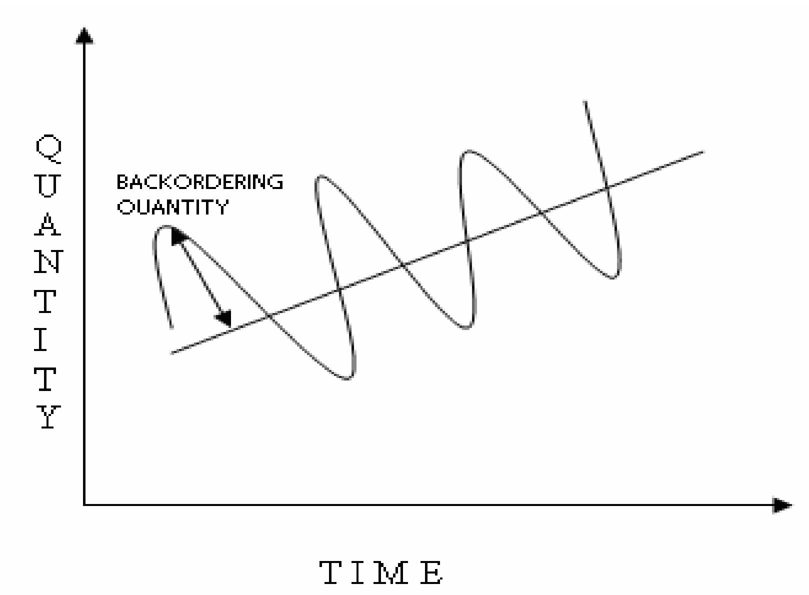
During off seasons, there is a decrease in demand. At such times firms can promote the sales by offering discounts, selling at a lower price, "buy one get one free" sales, etc. This can be adopted to sell the excess inventory.

Example: Giving off-season discounts for soft drinks during winter season.

***f. Backordering***

Here products are supplied to the customers only after a period of waiting time. i.e., customers are made to wait for the product. As soon as the goods are produced they are first supplied to back orders. It is the same as shortage of a product.

**Figure 3.14 - Backordering**



NOTES

If any one of the above strategies is used it is called pure strategy. If a combination of the above strategies are used it is then called mixed strategy.

**The Cost Aspects**

Various costs are associated with aggregate planning strategies. They are explained as follows:

***Production cost***

This includes the fixed cost and variable cost associated with production activities

- Fixed cost – Cost such as rent for the building, salaries, property tax, insurance etc. These cost that does not vary with the volume pf production.
- Variable cost – The cost of labor, material or overhead and this changes according to the change in volumes of unit produced.

***Hiring and Firing cost***

The cost associated with variable workforce size. Costs involved with termination of employee will come under firing cost. Similarly if an employee is recruited temporarily during increased demand there will be cots of training, wages to the new employees. These come under the hiring cost. Hiring cost would include employer expenses on job advertising, screening cost and training of newly hired employees.

For employee lay-off, the firm incurs certain cost such as compensation, expenses on legal advice for settlement, counseling of fired employees, etc.

***Back-order cost***

This is nothing but the shortage cost, when the demand for a product is met later. In other words, customer is made to wait for the product. This may result in any one of the following

- The customer may wait for the product, but there is a cost associated with this which is proportional to the waiting time of the customer.
- The customer may be dissatisfied, and the cost associated with this is independent of waiting time. This is called fixed shortage cost.
- The customer may also switch to competitor's products and hence the sale is lost. This may result in loosing the goodwill of the customer also.

***Overtime Cost***

In case of variable work hours, the employees may be asked to work overtime during periods of peak demand. This results in paying the employee for the overtime. This cost is usually much more than the regular time cost.

**3.4.4 Aggregate Planning Methods**

In this section you can see about the different methods used for aggregate planning. The methods are classified based on the above discussed cost varying linearly

NOTES

or non- linearly against the activities to be measured. It is also based on whether you need optimal solution or non-optimal solution.

The aggregate planning methods can be represented as follows:

**Table 3.12 - Aggregate Planning Methods**

| Solution Requirement | Cost Behavior | |
|---|---|---|
| | **Linear** | **Non-Linear** |
| **Optimal** | Linear Programming<br>- Transportation model<br>- Simplex method | Linear Decision rule<br>Dynamic Programming |
| **Non-Optimal** | Trial and Error method | Heuristic method<br>Computer research |

Real life aggregate planning problem consist of more complex interacting variable and constraints. So it is difficult to formulate the optimal model. Here, planner resorts to non-optimal solution. In this section you can understand the Trial and Error method, Simplex method and Transportation model. Other methods are out of scope and thus not included.

### *3.4.4.1 Error Method*

The following example is solved through the Trial and error method. This method is called as the Trial and Error method because you are following a particular logic to solve the problem, but there is no guarantee that whether the solution that you got is optimal or not.

***Example 3.1***

A company has estimated the demand for each product for 12 months as follows:

**Table 3.13**

| Month | Demand |
|---|---|
| 1 | 1200 |
| 2 | 2400 |
| 3 | 3000 |
| 4 | 3200 |
| 5 | 3500 |
| 6 | 4000 |
| 7 | 4500 |
| 8 | 4700 |
| 9 | 3200 |
| 10 | 2900 |
| 11 | 4800 |
| 12 | 5000 |

NOTES

These demands can be met through Regular Time, Overtime and Subcontracting.

Regular Time capacity – 200 units

Overtime capacity – 1500 units

Subcontracting capacity – infinity

Regular Time cost, $r_t$ = Rs.30 per unit per period

Overtime cost, $o_t$ = Rs.50 per unit per period

Subcontracting cost, $u_t$ = Rs.100 per unit per period

It is possible to carry inventory from one period to another and carrying cost $C_c$ = Rs. 10 per unit. Provide feasible production alternatives.

***Solution:***

Table 3.14

| Month | Demand | $R_T$ (2000) | $O_T$ (1500) | $S_T$ (infinity) |
|---|---|---|---|---|
| 1 | 1200 | **1200, 500 (6), 300 (7) -** 500 units required in 6th month is produced in 1st month and carried as inventory. 300 (7) - 300 units required in 7th month is produced in 1st month. produced in 1st month. | **700 (7), 800 (8)** 700 units required in 7th month is produced in 1st month and carried as inventory. 800 (8) - 800 units required in 8th month is | |
| 2 | 2400 | 2000 | **1400, 400 (8), 700 (11)** 400 units required in 8th month is produced in 2nd month and carried as inventory. 700 (11) - 700 units required in11th month is produced in 2nd month. | |
| 3 | 3000 | 2000 | **1000, 500(11)** 500 units required in11th month is produced in 3rd month and carried as inventory. | |
| 4 | 3200 | 2000 | **1200, 100(11), 200(12)** 100 units required in11th month is produced in 4th month and carried as inventory. 200 (12) - 200 units required in12th month is produced in 4th month. | |
| 5 | 3500 | 2000 | 1500 | |
| 6 | 4000 | 2000 | 1500 | |
| 7 | 4500 | 2000 | 1500 | |
| 8 | 4700 | 2000 | 1500 | |

NOTES

| | | | | |
|---|---|---|---|---|
| **9** | **3200** | **2000** | **1200, 300 (12)** 300 units required in 12th month is produced in 9th month and carried as inventory. | |
| **10** | **2900** | **2000** | **900, 600 (12)** 600 units required in 12th month is produced in 10th month and carried as inventory. | |
| **11** | **4800** | **2000** | **1500** | |
| **12** | **5000** | **2000** | **1500** | **400** |

Total production cost = $\sum_{t=1}^{12} C_t$, where $C_t$ is the cost incurred for the month 't'.

$C_1$ = (2000*30) + (1500*50) = Rs. 135000
$C_2$ = (2000*30) + (1500*50) = Rs. 135000
$C_3$ = (2000*30) + (1500*50) = Rs. 135000
$C_4$ = (2000*30) + (1500*50) = Rs 135000
$C_5$ = (2000*30) + (1500*50) = Rs 135000
$C_6$ = (2000*30) + (1500*50) + (500*50) = Rs 160000
$C_7$ = (2000*30) + (1500*50) + (300*60) + (700*60) = Rs 195000
$C_8$ = (2000*30) + (1500*50) + (800*70) + (400*60) = Rs 215000
$C_9$ = (2000*30) + (1500*50) = Rs 135000
$C_{10}$ = (2000*30) + (1500*50) = Rs 135000
$C_{11}$= (2000*30) + (1500*50) + (700*90) + (500*80) + (100*70) = Rs 245000
$C_{12}$ = (2000*30) + (1500*50) + (200*80) + (300*30) + (600*20) + (400*100)
= Rs 212000

Total Production cost = Rs.19, 721,000

### 3.4.4.2 Linear programming Model

The aggregate planning problem can be formulated as a Linear Programming Model when cost behavior is linear and the optimal solution is required you can Two kinds of linear programming model. One is for constant workforce and the other for variable workforce as shown below.

***Fixed Work Force Model***

The following notation is used to describe the above model.

$v_{it}$ = unit production cost for product I in period t (exclusive of labor cost)
$c_{it}$ = inventory carrying cost per unit of product I held in stock from period

NOTES

t to t+1

$r_t$= cost per man hour of regular labor in period t
$o_t$ = cost per man hour of overtime labor in period t
$d_{it}$ = forecast demand for product i in period t
$k_i$ = man hours required to produce one unit of product i
$(r\,m)_t$ = total man hours of regular labor available i period t
$(o\,m)_t$ = total man hours of overtime labor available i period t
$I_{io}$ = initial inventory level for product i
Wo = initial regular work force level
T= time horizon, in periods
N = total number or products

***Decision variables***

$X_{it}$ = units of product i to be produced in period t
$I_{it}$ = units of product to be left over as inventory in period t
$W_{it}$ = man hours of regular labor used during period t
$O_t$ = man hours of overtime labor used during period t

Fixed work force cost model is:

$$\text{Minimize } Z = \sum_{i=1}^{N} \sum_{t=1}^{T} (v_{it} X_{it} + c_{it} I_{it}) + \sum_{t=1}^{T} (r_t W_t + o_t O_t)$$

Subject to:

$$X_{it} + I_{i,t-1} - I_{it} = d_{it}$$

$$\sum_{i=1}^{N} k_i X_{it} - W_t - O_t = 0$$

$$0 \leq W_t \leq (rm)_t$$

$$0 \leq O_t \leq (om)_t$$

$$X_{it}, I_{it} \geq 0$$

The objective function expresses minimization of variable production, inventory, regular and overtime labor costs.

Constraint one represent production – inventory balance. Second constraint defines total manpower to be used in every period. Last two constraints impose lower and upper bounds on the use of regular and overtime man hours in every time period.

***Variable workforce models***

When there is a change the workforce level to meet demand fluctuations, the workforce becomes a decision variable and hiring and firing cost will be part of objective

NOTES

function. The model below also includes backordering cost.

$H_t$ = man hours of regular work force hired in period t

$F_t$ = man hours of regular work force laid off in period t

$I^+_t$ = units ending inventory of product I in period t

$I^-_t$ = units of product I backordered at the end of period t

$b_t$ = cost per unit of backorder of product i carried from period t to t+1

$h_t$ = cost of hiring one man hour in period t

$f_t$ = cost of laying off one man hour in period t

p = overtime allowed as a fraction of the regular hours

Variable workforce model can be formulated as follows:

$$\text{Minimize } Z = \sum_{i=1}^{N} \sum_{t=1}^{T} ? (v_{it} X_{it} + c_{it} I^+_{it} + b_{it} I^-_{it}) + \sum_{t=1}^{T} (r_t W_t + o_t O_t + h_t H_t + f_t F_t)$$

Subject to

$$X_{it} + I^+_{i,t-1} - I^-_{i,t-1} + I^+_{it} + I^-_{it} = d_{it}$$

$$\sum_{i=1}^{N} K_i X_{it} - W_t - O_t \ ? \ 0$$

$$W_t - W_{t-1} - H_t + F_t = 0$$
$$-pW_t + O_t \ ? \ 0$$
$$X_{it}, I^+_{it}, I^-_{it} \ ? \ 0$$
Wt, Ot, Pt, Ht, Ft ? 0
i = 1,….N
t = 1,…N

The first constraint represents the production inventory balance equation.

The Second constraint limits the production to variable man power. It is possible at some point regular work force $W_t$ will be partially idle therefore is justified.

The Third constraint define the change in workforce during period t i.e. $W_t - W_{t-1} = H_t - F_t$. Labor is added when $H_t > 0$ or subtracted whenever $F_t > 0$.

The Fourth constraint imposes an upper bound on the total overtime available in period t as a function of regular work force size.

***Example 3.2***

The following data pertain to demand forecast, production alternatives, and costs for the XYZ Company which manufactures a cleaning fluid used in hospitals.

NOTES

**Table 3.15**

| Capacity Limit, tons | | | | |
|---|---|---|---|---|
| **Quarter Demand** | **Estimated Production** | **Regular production** | **Overtime per ton** | **Unit cost** |
| 1 | 210 | 210 | 15 | $r_t$ = Rs.2000 |
| 2 | 200 | 210 | 15 | $o_t$= Rs.3000 |
| 3 | 170 | 180 | 10 | $C_c$ = Rs.200 per period |
| 4 | 230 | 210 | 15 | |

Furthermore, the cost of hiring is Rs.4800 per unit increase in output ($h_t$= Rs.4800 per unit) while the cost of firing is Rs.72000 per unit decrease in output ( $f_t$ = Rs.72000 per unit). The starting regular production rate is Po = 220 tons from the work-force level of the previous period.

Formulate the aggregate planning problem as a linear programming problem using simplex method and solve it if computer program is available.

***Solution:***

| Demand data | Regular Time Capacity | Overtime Capacity |
|---|---|---|
| $D_1$ = 210 | $X_1$ = 210 | $O_1$= 15 |
| $D_2$ = 200 | $X_2$ = 250 | $O_2$ = 15 |
| $D_3$ = 170 | $X_3$ = 180 | $O_3$ = 10 |
| $D_4$ = 230 | $X_4$ = 210 | $O_4$ = 15 |

Regular time cost per unit, $r_t$ = Rs. 2000
Over Time cost per unit, $o_t$ = Rs. 3000
Carrying cost per unit per period, $C_c$ = Rs.200
Hiring cost per unit, $h_t$ = Rs. 4800
Firing cost per unit, $f_t$ = Rs. 72000
Starting regular production rate $P_0$ = 220 tons
Initial inventory $I_0$= 0 (assume)

A linear programming problem for the above aggregate planning problem is presented below.
$X_t$, $O_t$ = Units produced during regular time and overtime respectively.
$A_t$, $R_t$ = Number of units increased or decreased respectively during consecutive periods.
$D_{t=}$ Sales forecast

**Minimize z** = 2000 ($X_1$+ $X_2$+ $X_3$) + 4800 ($A_1$+ $A_2$+ $A_3$+ $A_4$) + 7200 ($R_1$+ $R_2$+ $R_3$+ $R_4$) + 3000 ($O_1$+ $O_2$+ $O_3$+ $O_4$) + 200 ($I_1$+$I_2$+ $I_3$+ $I_4$)

**NOTES**

**Subject to constraints:**

$X_1$ ? 210
$X_2$ ? 250
$X_3$ ? 180
$X_4$ ? 210
$O_1$ ? 15
$O_2$ ? 15
$O_3$ ? 10
$O_4$ ? 15
$R_1 + O_1 - I_1 = 210$
$X_2 + O_2 + I_1 - I_2 = 200$
$X_3 + O_3 + I_2 - I_3 = 170$
$X_4 + O_4 + I_3 - I_4 = 230$
$X_1 - A_1$ ? 220
$-X_1 + X_2 - A_2$ ? 0
$-X_2 + X_3 - A_3$ ? 0
$-X_3 + X_4 - A_4$ ? 0
$X_1 + R_1$ ? 220
$-X_1 + X_2 + R_2$ ? 0
$-X_2 + X_3 + R_3$ ? 0
$-X_3 + X_4 + R_4$ ? 0 $X_t$, $R_t$, $A_t$, $O_t$, $I_t$ ?0 where t = 1,2,3,4

The results are given below :

**Table 3.16**

| Quarter I | Quarter II | Quarter III | Quarter IV |
|---|---|---|---|
| $P_1 = 210$ | $P_2 = 210$ | $P_3 = 180$ | $P_4 = 180$ |
| $O_1 = 0$ | $O_2 = 5$ | $O_3 = 10$ | $O_4 = 15$ |
| $I_1 = 0$ | $I_2 = 15$ | $I_3 = 35$ | $I_4 = 0$ |
| $A_1 = 0$ | $A_2 = 0$ | $A_3 = 0$ | $A_4 = 0$ |
| $R_1 = 10$ | $R_2 = 0$ | $R_3 = 30$ | $R_4 = 0$ |

Minimum Cost is = Rs. 19,48000
The above results are shown diagrammatically as follows:

NOTES

**Figure 3.14**

### *3.4.4.3 Transportation Model*

A generalized transportation model for more than one alternative (for production) can be represented as follows:

**Table 3.17 - Aggregate Planning Methods**

| | I | II | III | IV | Cost | Supply |
|---|---|---|---|---|---|---|
| **I** | r | $r_t$ + $C_c$ | $r_t$+2 $C_c$ | $r_t$+3 $C_c$ | $r_t$ | **S1** |
| | o | $o_t$+ $C_c$ | $o_t$+2 $C_c$ | $o_t$+3 $C_c$ | $o_t$ | |
| | u | $u_t$+ $C_c$ | $u_t$+2 $C_c$ | $u_t$+3 $C_c$ | $u_t$ | |
| **II** | $r_t$+ Cs | $r_t$ | $r_t$+ $C_c$ | $o_t$+2 $C_c$ | $r_t$ | S2 |
| | $o_t$ + Cs | $o_t$ | $o_t$+ $C_c$ | $v_t$+2 $C_c$ | $o_t$ | |
| | $u_t$ + Cs | $u_t$ | $u_t$+ $C_c$ | $u_t$+2 $C_c$ | $u_t$ | |
| **III** | $r_t$+ 2Cs | $r_t$ + Cs | $r_t$ | $o_t$ + $C_c$ | $r_t$ | S3 |
| | $_{Ot}$+ 2Cs | $_{Ot}$ + Cs | $o_t$ | $v_t$ + $C_c$ | $o_t$ | |
| | $u_t$+ 2Cs | $u_t$ + Cs | $u_t$ | $u_t$ + $C_c$ | $u_t$ | |
| **IV** | $r_t$+ 3Cs | $r_t$+ 2Cs | $R_t$+ Cs | $r_t$ | $r_t$ | S4 |
| | $_{Ot}$+ 3Cs | $o_t$ + 2Cs | $o_t$ + Cs | $o_t$ | $o_t$ | |
| | $u_t$+ 3Cs | $u_t$+ 2Cs | $u_t$ + Cs | $u_t$ | $u_t$ | |
| **Demand** | D1 | D2 | D3 | D4 | | |

Where

$r_t$ = regular time cost

$o_t$ = over time cost

NOTES

$u_t$ = subcontracting cost
Cs = shortage cost
Cc = carrying cost

In case of back ordering, for three periods in advance the shortage cost will be three times. i.e. 3Cs will be added to the existing labor cost. Similarly for two periods backordering 2Cs will be added to the existing labor cost.

$C_c$ represents carrying cost. Products produced during a period for usage in subsequent periods will have a carrying cost. For e.g. $3C_c$ indicates that product had been carried over three months.

***Example 3.3***

A producer is considering either producing or procuring a certain part. The relevant data are as follows:

**Table 3.18**

| | **PERIOD** | | | |
|---|---|---|---|---|
| | **I** | **II** | **III** | **IV** |
| **Production capacity**<br>In house | 20 | 20 | 20 | 20 |
| Outside Vendor | 40 | 40 | 40 | 40 |
| **Unit cost**<br>In House | 12 | 13 | 15 | 16 |
| Outside vendor | 15 | 15 | 18 | 20 |
| **Demand** | 70 | 40 | 60 | 90 |

Initial inventory is 20 units and the holding cost is Rs.8 per unit per period. What is the optimal aggregate plan?

***Solution:***

**Table 3.19**

| | I | II | III | IV | Supply |
|---|---|---|---|---|---|
| Initial Inventory | 8 | 16 | 24 | 32 | 20 |
| I | 12 | 20 | 28 | 36 | 20 |
| | 15 | 23 | 31 | 39 | 40 |
| II | ∞ | 13 | 21 | 29 | 20 |
| | | 15 | 23 | 31 | 40 |
| III | | | 15 | 23 | 20 |
| | | | 18 | 26 | 40 |
| IV | | | | 16 | 20 |
| | | | | 20 | 40 |
| **Demand** | 70 | 40 | 60 | 90 | |

NOTES

The holding cost is Rs. 8 per period. Therefore for the second, period it will be Rs.16 (8+8), for third period it will be Rs. 24 (8+8+8) and for the fourth period it will be Rs 32.

In a similar manner it is calculate for subsequent periods.

Infinity symbol indicates that product produced during a period is sold during that period or subsequent periods and not in previous periods. i.e. there is no back order.

Solving the above, using Vogel's approximation method

**Table 3.20**

Initial feasible solution:

Transportation cost = (20*8) + (12*20) + (30*15) + (23*10) + (13*20) + (10*15) + (23*30) + (15*20) + (18*10) + (26*30) + (16*20) + (40*20)
= Rs. 4560

**Optimality Test – Modi Method**

Conditions:

- Individual allocated cells should be equal to m+n-1
  - m – number of rows
  - n – number of columns

NOTES

- Test for optimality on initial feasible solutions
- Write the matrix of the cost of allotted cells
- Determine a set of m+n numbers

$U_i = 1,2\ldots.m$

$V_j = 1,2,\ldots.n$

$C_{rs} = u_r+v_s$, r- supply, s-demand

**Table 3.21**

| | I | II | III | IV | $U_i$ |
|---|---|---|---|---|---|
| Initial Inventory | 8 | | | | $U_1 = 0$ |
| | 12 | | | | $U_2 = 4$ |
| I | 15 | 23 | | | $U_3 = 7$ |
| | | 13 | | | $U_4 = -3$ |
| II | | 15 | | | $U_5 = -1$ |
| | | | 15 | | $U_6 = -9$ |
| III | | | 18 | 26 | $U_7 = -6$ |
| IV | | | | 16 | $U_8 = -16$ |
| | | | 20 | $U_9 = -12$ | |
| $V_j$ | $V_1 = 8$ | $V_2 = 16$ | $V_3 = 24$ | $V_4 = 32$ | |

∞

Cost ($C_{ij}$) of un-allotted cells

**Table 3.22**

| | I | II | III | IV |
|---|---|---|---|---|
| Initial Inventory | | 16 | 24 | 32 |
| I | | 20 | 28 | 36 |
| | | | 31 | 39 |
| II | ∞ | | 21 | 29 |
| | | | | 31 |
| III | | | | 23 |
| | | | | |
| IV | | | | |
| | | | | |

$U_i + V_j$ for un-allotted cells

NOTES

**Table 3.23**

| | I | II | III | IV |
|---|---|---|---|---|
| Initial Inventory | | 16 | 24 | 32 |
| I | | 20 | 28 | 36 |
| | | | 31 | 39 |
| II | 5 | | 21 | 29 |
| | 7 | | | 31 |
| III | -1 | 7 | | 23 |
| | -2 | 10 | | |
| IV | -8 | 0 | 8 | |
| | -4 | 4 | 12 | |

$C_{ij} - (U_i + V_j)$ for un-allotted cells

**Table 3.24**

| | I | II | III | IV |
|---|---|---|---|---|
| Initial Inventory | | 0 | 0 | 0 |
| I | | 0 | 0 | 0 |
| | | | 0 | 0 |
| II | | | 0 | 0 |
| | | | | 0 |
| III | | | | 0 |
| | | | | |
| IV | | | | |
| | | | | |

Since there are no negative values in the above table the initial feasible solution is the optimal solution i.e. The optimal transportation cost = (20*8) + (12*20) + (30*15) + (23*10) + (13*20) + (10*15) + (23*30) + (15*20) + (18*10) + (26*30) + (16*20) + (40*20) = Rs. 4560.

**Review Questions:**

1. When do you go for the aggregate planning?

2. Discuss the optimal method when the cost behaves linearly?

3 .Discuss the optimal methods when the cost behaves non linearly?

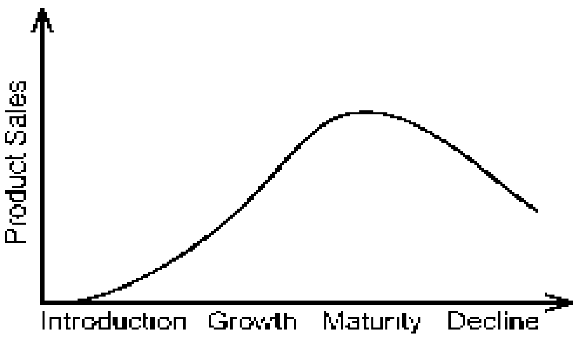
## 3.5 PRODUCT DESIGN AND DEVELOPMENT

The Activity namely the new product design or development in the existing product arises because of an opportunity available to tap the untapped market or a thing required to solve the problem. Like medicine to cure the AIDS or Cancer, these are opportunities to solve the problem. These kind of opportunity problem leads the organization to manufacture new product. Sometimes the demand for the existing product declining. The organization thinks of reviving the product by adding some improvement or the features in the existing product. Both the functions come under the process of product design and development.

### 3.5.1 Product life cycle

Understating in which phase of the product life cycle, the product is there is the basis for the any product design and development activity. As you know any product has many brands, example, if you consider refer generator. You have Samsung, brands. Each brand has the demand pattern the summation of the entire brand's demand pattern provides information in which phase the product is,

**Figure 3.15 - The Pattern of PLC**




## Introduction

In this phase there is a more risk involved there is possibility that the product is not accepted by the customers. This results in early exit of the product. This is all about the acceptability of the product.

In this phase the competition will be less if the product in the introduction phase, you should not think about going for heavy investment because of more chance for infant mortality of the product.

***Growth***

In this phase the people know more about the product that increases the potentiality of the demand. The competition gradually picks up here you should

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concentrate more on the attributes like quality, performance, delivery time, serviceability that helps the organization to establish the product as a leader among the players. At present in Indian cell phone is in the growth stage of PLC. Comparatively the profit the maturity stage will be high.

***Maturity Stage***

In this phase more competitors will be there and here all well established facilities were available and everyone is enjoy is the economy scale. But profit margins of the competitor are less. Because the facilities may be in reality at the end of their life cycle. Because markets are matured, organization finds it difficult to capture a small increase in market share. Packed mass consumption goods, soap are for examples which are in the maturity state of the PLC.

***Decline***

After maturity phase, the product enters into the declining phase. The reasons may be attributed to people would have found another alternative for the product, usually for the most of the time the business cycle and product cycle go together. In this case, if the economy is in the declining stage then there is a chance that product may enter into the declining stage. In such a case the organization has to make all effort to revive the product by adding some features in the product or family declining stage early then this becomes big problem for the organization because you can not utilize facility available. This problem is made in the case of mass production industry. This problem is severe if the industry is of the mass production type because the less demand the investment made in technology becomes turtle. At present the black and white TV is in the declining phase of PLC.

Because of Organization and lot of development in the field of electronic goods the product life cycle is so short may be three or four gems. The organization should be more vigilant in introducing more number of products within short span of time.

With this understanding of product life cycle curve, another activity inter turned with the use product life cycle namely the new product development process in this next section.

### 3.5.2 New Product development process

In the last section you have studied about the product life cycle. Suppose the produce is in the declining stage of life cycle course, if you allow the situation to continue the demand for the product decline and the organizational resources are under utilized. The cost of the product increases and your market share declines at faster rate and you may have to close down the plant soon.

But as soon as the demand for the product starts declining, the organization has to face different problems like-

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1. Under utilization of resources.
2. Cost of the product increase.
3. Price of your product increases.
4. More inventory.
5. Overhead burden etc.

These problems are converted into an opportunity in terms of developing an existing product by adding some features according to the requirement of the customers or you can go for introducing a new product which could use the available facilities. So the starting point for the new product development process is the concept generation.

### 3.5.2.1 Concept Generation

To solve the problem or utilize the opportunity available the idea may come from different sources, the sources may be-

1. The basic research in the field of physics, chemistry and biology etc.
2. Technology innovations.
3. Ideas from the staff in R & D Production, quality control etc.
4. Ideas from competitors consumers.

The above ideas should be in line with the first organization's mission statement, or it should not disturb much the on going marketing or the idea should utilize the existing state of inventory.

### 3.5.2.2 Concept testing

A preliminary analysis different project ideas are screened using scoring models

ATR techniques etc.

In the preliminary analysis different product ideas are screened using the techniques

**Table 3.25**

| FACTORS | SCORE | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| Product superiority, quality, uniqueness | | | | | |
| Overall project firm / resource compatibility | | | | | |
| Market need growth and size | | | | | |
| Newness to the firm | | | | | |
| Technology resource compatibility | | | | | |
| Market competitiveness | | | | | |
| Product score | | | | | |

Product concepts

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ATR MODEL (Awareness – Trial – Repeat) model:

The basic formula is given below:

Profits = Buying units x percent aware x percent trial x percent availability x percent repeat x annual units bought (revenue per unit – costs per unit).

For e.g: Assume that an organization is developing a new cleaning powder for washing sports can

1. Number of owners: 1,00,000
2. Percentage who will become aware of the power: 30 percent
3. Percentage of those aware who will buy it: 10 percent
4. Percentage of the retail outlet store the powder : 30 percent
5. Percentage of the triers who like the product and but more : 40 percent

Number of pockets a typical user will but in a year: 10 pocket
Revenue the unit Rs.1000
Cost Per unit Rs.700
Profit according to ATR model
= 1, 00,000 x .3 x .10 x .3 x .4 x 10m (1000 – 700)
= 10,800
like ATR, scoring model and the best ideas are chosen for

The outcome of the screening is the product definition or the benefits the new item is to yield.

***3.5.2.3 Technical Development***

After concept testing is over, 'you should see that whether you have technical capacity and resources appropriate to produce or provide the product / service.

In technical development, the output is the prototype of the product. In general, in any product design & development activity the product specifications for the product are to be arrived through market survey, for example, the product specification for a car represent the color, the size of the car, fuel efficiency power of the engine. Product specification usually collected from the customer. The customer may not be knowing the technical details about the product, so his/her requirement is obtained through the word of the mouth.

Then the product specifications are converted into engineering specification. To start with, first what kind of material is to be purchased when you purchase the material, it should be economical and the purchased material do not hamper the performance, reliability of the final product were lot of value analysis and value engineering application helps to choose the right material without affecting the function for which it is indented for economically. Here you should see the product where it is

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positioned. For example: if you are manufacturing car for luxury purpose then you may prefer the leather seat rather than vinyl seat. So, when you design a product. To whom the product is targeted for according the material selection and supplier selection take place. When you select the material you should see the process or the resources available because selecting the high quality material may demand high processing requirement that results in high production cost which allows your product to become less competitive.

It is mentioned in the process paragraph now we can develop some time on the product specification, tolerance and allowances.

Allowable deviation from the targeted value is the tolerance, example, shaft diameter designed by the designer to satisfy the final requirement of product aims a target value of 2 cm but you can not produce 2 cm diameter consistently. So because of in built nature of the processing system, there exists variety in the processing. For that you need data like process capability input to fix the tolerance limit etc. for example: the existing process capability of a productive system is to produce 2 ±.05 cm, then it is the design demands for more than 2.05 and less 1.95 cms (10) 2 ±.10. This is the specification required then there is no problem but if you design a shaft of 2 ±.03 cm, then the productive system may produce more back quality product. So in the engineering design one should have the input like process capability to fix tolerance engineering specification.

### *3.5.2.4 Standardization and Inter-changeability*

When you design a product you should not design in such a manner that all the parts sustainability are of your own design because after your product has been purchased by the customer put into use, if there is a problem in the product, it is difficult to service the product because of the components are of you own design and availability of the components become problem. Even there is an availability you need to have more components that result in more inventory cost at the same time the customers also put into lot of trouble in terms of idle time of the product. The problem is a complex one if your product is a capital equipment product. In this case your product design consists of components subassembly of standard product available.

In your product suppose if you have came to use standard components like tin and steel sheets, nuts, bolts, washers transistors, capacitors etc. You try to use the same. Instead you need not design on your own for those components you design should be in such manner that the above mentioned standard products could be transit may use. Usage of the standardized components or products lower the cost of production reduces the inventory cost. It case the maintenance and repair that result in less cost. It also helps in more easier and effective quality control.

The concept of standardization spread to the service industry also, because nowadays for fast food restaurant the standard mix is always speedy according to the

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type of order they mix. Different mix and service requires food at lesser time. Even in the house you need not prepare all the cooking ingredients as it was done in the olden day. Nowadays standard ingredients are available and only mix with less time you can get what you want.

Here we are not saying that all the time your should use the standard components if your product requires. If possible any new design of the components reduces the cost of the product, and then instead of going for standard component you can use your newly designed components. This serves the purpose of continuing innovation and design of the organization.

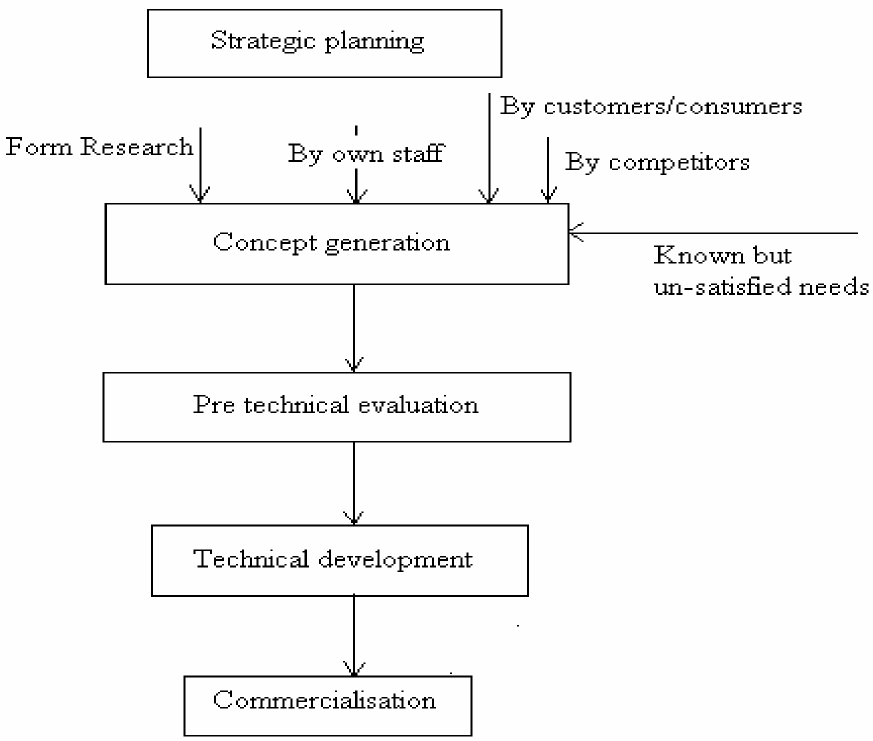
### *3.5.2.5 Commercialization*

In commercialization you must decide to whom this item will be targeted, what will be the value of the product and how do we get the value into it, how it will be positioned relative will be the product's brand, building support around the organization for the marketing actions to follow and overcoming problems that arise in the field and which might cause the firm to fail to achieve the necessary awareness, that and repeat use which are discussed in the concept testing phase.

Once market trial is over, then the products are produced according to the plan. This involves detailed production plan, quality plan, and story and distribution strategy. All the actions are carried out by keeping in the company's strategy objectives and goals.

The above explained new product development process is shown in a flow chart.

**Figure 3.16 : Commercialization**



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**Review Question:**

1. Highlight the stages of Product Life Cycle.
2. Why products fall into maturity stage?
3. How would you expand the life time of saturated product?

## 3.6 EXPERT SYSTEM IN PRODUCT DEVELOPMENT

Strategy planning plays a vital role in defining where a corporation wants to be in the near and long terms, how they will get there, and how they will monitor their progress in getting there. These are derivations of the Total Manufacturing Assurance three **C's: Create, Control, and Critique**.

The same applies to the product development test program. The test program strategy must reflect the overall corporate business strategy.

Combining strategic planning with expert system technology enables the engineer or manager to quickly define the "best" or "optimal" test program for a given product development effort. The expert system makes this happen by using "expert" knowledge derived from its knowledge base of engineering, marketing, and customer requirements.

To make money and enjoy long term survival, a company must be productive and efficient. That statement is very simple and acceptable in light of the evermore competitive business environments being experienced. It thus is imperative to eliminate, or minimize, company bureaucracy. Bureaucracy causes aggravation. It directly correlates to unnecessary company overhead. It is impractical to think that overhead can ever be completely eliminated. It can be optimized and in this case that means minimized. There is still overhead, but it is value-added overhead. To make this happen three things must be readily available in the planning process:

1. Expert knowledge about testing,
2. Expert knowledge about customer market requirements and
3. A mechanism to get all this expert knowledge into one room to quickly make good decision(s).

The expert system facilitates "Optimized strategic test program planning". An engineer or manager defines the "best' or "optimal" test program for a given product development effort. The expert system forces this by using "expert" knowledge derived from its knowledge base of engineering, marketing, and customer requirements.

### 3.6.1 Expert System Development

Product reliability, safety, and quality requirements are a key element of a strategic business plan since they reflect what the customer needs. These product design performance parameters in turn provide a basis for defining the test program necessary as part of the overall product assurance strategy. The product assurance strategic plan balances many interrelated variables and factors.

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These include:

1. Establishing quantitative performance goals (LWBF, MTTR, service-life, defect level, etc.).
2. Implementing a product development management control and tracking activity to ensure timely outputs consistent with major design and program milestones.
3. Performing and implementing analyses and quality checks, audits, and controls to ensure that all test, inspection, and screen data are complete.
4. Performing a fully coordinated product development program, which emphasizes failure analysis and corrective action, and provides growth/ verification of specified design requirements.
5. Exposing design deficiencies and initiating corrective action in a timely manner.
6. Maximizing achieved availability to minimize overall life cycle costs and enhance the probability of commercial success.
7. Identifying, evaluating and eliminating design hazards and risks.
8. Applying historical data and lessons learned into the design process.
9. Minimizing unforeseen impacts on overall project cost and schedule.

It is desirable to assure that the above factors (and others) are adequately considered during a product development test program. It is through the strategic planning that it is possible to initiate the "best" program. That is, one that ensures critical project decisions involving significant investment of resources are keyed to the achievement of specific reliability, safety, and quality requirements, as well as other performance requirements. Obviously, specific test program objectives are dependent on the technology under consideration, the nature of the product, the customer, and other factors as appropriate. But merely defining a test program strategy orients product development, and ultimately manufacture, toward a practical, serviceable, and affordable commercial product.

The expert system output is a baseline test program structure which includes characteristic parameter values and ranges for each of the basic test categories. This strategically defined test program is then tailored, as necessary, to meet the specific product development project's needs while adhering to cost and time constraints. Regardless of which baseline structure is selected, the basic concept of a strategically well-planned, logically structured and phased test program, where each subsequent test is designed to reflect the knowledge gained during the proceeding test and design effort, applies. The expert system provides assurance that the cornerstone (i.e., test program) of a successful product development project is put in place.

### 3.6.2 Putting System Together

The very first task in the expert system development process is to identify the domain, the domain expert and the knowledge expert. The domain of the system must

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be properly scoped out, well defined, sufficiently focused, and capable of solution by the use of expertise. A domain expert, or experts, must be found; either a person who can solve the task, a collection of well documented case studies, or perhaps a good textbook. A knowledge engineer, or someone willing to learn to become one, must be appointed to the task. Finally, the appropriate development platform must be acquired which can be an expert system shell with some sort of development environment. The physical expert system is then developed via the following steps.

Step I—Structural Design

Step 2—Knowledge Acquisition

Step 3—Coding

Step 4—Validation

Step 5—Growth

The result is a working expert system

**Review Questions:**

1. Expand 3C's.
2. Discuss the steps through which the Physical Expert System is developed.

## 3.7 COMPUTER AIDED DESIGN AND DRAWING

### 3.7.1 Introduction

When we think of Computer Aided Design and Drafting (CADD), certain questions arise that we never think of while working on the drawing board. We do not use the essential drawing board tools: paper, pencil, T-square, compass, eraser or scale, yet still have to design or make a drawing. When even one of these tools is missing we know how aggravating it can be. With CADD we don't need even one of them!

CADD is an electronic tool that enables you to make quick and accurate drawings with the use of a computer. Unlike the traditional methods of making drawings on a drawing board, with CADD you can sit back in an easy chair and create wonderful drawings just by clicking the buttons of a keyboard. Moreover, drawings created with CADD have a number of advantages over drawings created on a drawing board. CADD drawings are neat, clean and highly presentable. Electronic drawings can be modified quite easily and can be presented in a variety of formats.

A decade ago, CADD was used only for specific engineering applications that required high precision. Due to CADD's high price, only a few professionals could afford it. In recent years, however, computer prices have decreased significantly and more and more professionals are taking advantage of CADD.

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There are hundreds of CADD programs available in the CADD industry today. Some are intended for general drawing work while others are focused on specific engineering applications. There are programs that enable you to do 2D drawings, 3D drawings, renderings, shadings, engineering calculations, space planning, structural design, piping layouts, plant design, project management, etc. There is a CADD program for virtually every engineering discipline you can think of.

CADD is primarily intended for single-line drafting. It has very limited capabilities to create artistic impressions. However, CADD's 3D and rendering features are fascinating. You can create a 3D model of an object and view it from any angle. With proper shading and rendering, it can be made to look picture perfect!

### 3.7.2 What to Expect from CADD?

You can do amazing things with CADD that you never thought possible while creating drawings with a pen or pencil. The following are some of the important capabilities that make CADD a powerful tool:

- Presentations
- Flexibility in editing
- Units & accuracy levels
- Storage and access for drawings
- Sharing CADD drawings
- Project reporting
- Engineering analysis
- Computer Aided Manufacturing (CAM)
- Design
- Add-on programs

**Presentations**

You can create fine drawings with hundreds of colors, line types, hatch patterns, presentation symbols, text styles, etc. Even if you don't like something about your presentation after you have finished it, you can instantly change it. It takes only a few simple steps to change the text style, color or line type and you can print a fresh copy of the drawing every time. This kind of luxury is available only when working with CADD.

There are a number of ready-made presentation symbols and hatch patterns available in CADD that can be used to enhance the look of drawings. For example, a site planner can instantly add tree symbols, shrubs, pathways, human figures, and other landscape elements to create a site plan. Similarly, an architect can use ready-made symbols of doors, windows, furniture, etc., to make a presentation.

In addition to preparing impressive presentations on paper, you can use CADD to make on-screen presentations. You can plug your computer into a projector and present your ideas on-screen. Advanced CADD programs allow you to created animated images as well. You can illustrate how a building would appear while walking through it, or how a machine assembly will operate when different machine parts move.

**Flexibility in Editing**

CADD provides the flexibility to make quick alterations to drawings. You can erase any portion of a drawing with pinpoint accuracy. It takes only seconds to do a job that could take hours on a drawing board. In many cases, you do not even have to erase to make the change. You can rearrange the existing components of the drawing to fit the new shape. This enables you to analyze design options with minimal effort.

The following are some of the editing capabilities of CADD:

- Move or copy drawing elements.
- Enlarge or reduce parts of a drawing.
- Add one drawing to another.
- Stretch a drawing to fit new dimensions.
- Make multiple copies of a drawing element.
- Change the size, style and fonts of text.
- Change units of measure of dimensions.

**Units & Accuracy Levels**

CADD allows you work with great accuracy. If you need to create highly accurate geometrical shapes, CADD is the answer. It can help avoid time-consuming mathematical calculations.

You can work with different units of measure, such as architectural units, engineering units, scientific units and surveyor's units. These units can be represented in various formats commonly used by professionals.

**Example 3.4:** When working with engineering units, you can specify whether all the dimensions should be represented in inches, feet-inches, centimeters, or meters. Similarly, you can choose angular units of measurement such as decimal degrees, minutes, seconds or radians.

You can set an extremely high accuracy for the units of measurement. You can work with as high precision as 1/1000$^{th}$ of an inch! However, such accuracy is seldom required; you will often need to set it to a lesser accuracy to avoid unnecessary fractions.

In general, when you need to work on a large scale drawing such as a plan of a township, you may want to set a lesser degree of accuracy, say 1'-0". The computer will round off all the measurements to the next foot and you won't see any fractions less than a foot. When you need to work on a minute detail, you can set a higher degree of accuracy such as 1/8$^{th}$ or 1/64$^{th}$ of an inch.

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**Storage and Access of Drawings**

It is quick and convenient to organize for a CADD drawing in the computer. You can have thousands of drawings on a computer's hard disk and can open any one of them within seconds.

A computer's electronic filing system has the following advantages over the traditional filing system:

- o It enables you to create a highly organized environment
- o It contributes to large savings in working space
- o An electronic drawing never gets old and faded. Any time you need a drawing, you can print a new copy from disks.

**Sharing CADD Drawings**

The electronic drawings can be shared by a number of users, allowing them to coordinate their tasks and work as a team. This is accomplished by connecting different computers via a network.

**Example 3.5**: In a building project, different professionals such as architects, engineers and construction managers can use the same electronic drawings to coordinate building services. If a change is made to the drawings, this information becomes available to all the team members instantly.

With the use of modems and the Internet, it has become far easier to share information. Professionals located in different cities can instantly send electronic drawings via telephone lines.

You can publish your drawings on the Internet for anyone to see. Most CADD programs include special functions that allow you to export drawings in a format that can be viewed on the Internet.

**Project Reporting**

The computer can be used to prepare project reports such as records of areas, quantities and cost estimates. Using the database capabilities of CADD, you can link specific non-graphic information (such as text or value) with the graphic elements of the drawing. The non-graphic information is stored in a database and can be used to prepare reports.

**Example 3.6**: An architect can attach text attributes associated with the symbols of doors and windows in a drawing. The attributes can describe the size of the door, material, hardware, cost, etc. Later on the computer can automatically prepare a door schedule listing all the doors and windows in the drawing!

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The non-graphic information is directly linked with the graphics on the screen. When a change is made to the drawing, the values in the reports are updated automatically. This provides a useful means to manage large projects from design through project completion.

There is a special category of software called Computer Aided Facility Management (CAFM) designed for project management. These programs can import information from CADD drawings and allow you to add attributes to drawing elements to build a database. The database can be used to prepare project reports in a number of formats.

**Engineering Analysis**

CADD drawings can be used to perform specific engineering analysis. There is a separate category of programs called Computer Aided Engineering (CAE) that can use CADD drawings for engineering analysis.

**Example3.7**: A structural engineer can use a CAE program to test the design of structural components in different conditions. The engineer can instantly analyze the impact on structural members when a different load is applied to the structure or the spacing between the members is changed. Similarly, there are programs for mechanical engineers to test machine assemblies. The mechanical engineer can create a prototype electronic model and test it without building a physical model.

The advanced engineering programs even provide the ability to link calculations with the geometry on the screen. This capability is known as "parametric design" that allows the computer to automatically update the graphics when the associated calculations are changed and vice versa.

**Computer Aided Manufacturing (CAM)**

CADD extends its power to yet another branch of engineering called Computer Aided Manufacturing (CAM). CAM is a common method of manufacturing used by large corporations. CADD and manufacturing programs are often integrated into one system called CAD-CAM. These systems import CADD drawings into CAM programs to automate the manufacturing process.

**Example 3.8**: An engineer can draw a machine part using CADD. The CADD drawing is brought into a computer aided engineering (CAE) program for engineering analysis. When the design is finalized, the drawing is brought into a CAD-CAM system that uses numerical data from the CADD drawing for actual manufacturing.

**Design**

CADD provides a convenient means to create designs for almost every engineering discipline. It can be used for architectural design, landscape design, interior design, civil and surveying, mechanical design, electrical engineering, plant design,

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industrial design, duct design, electronic circuit design, plumbing design, textile design and product design.

CADD's drafting capabilities provide ample means to create a design scheme. You can create designs with great accuracy and have the flexibility to easily edit them. This allows you to quickly prepare design alternatives.

In addition to the drafting capabilities of CADD, there are special programs that can analyze designs or even create new ones. These programs use artificial intelligence to "think" and make design decisions.

The design capabilities of CADD are available only in advanced CADD programs. There are only a few such programs available. Design programs are usually not generic. They often need to be custom-written to accomplish a specific task. See Chapter 9 "Maximizing CADD" for discussion on design programs.

**Add-on Programs**

There are a number of separate programs available that can enhance the power of CADD. The add-on programs work as an extension of CADD to accomplish specific tasks. Today, there are hundreds of add-on programs available for popular CADD programs.

An architectural add-on program can allow you to instantly draw symbols of doors, windows, kitchens, bathrooms, staircases, etc. Shading and rendering program can be used to enhance the look of 3D images. A plumbing design program includes special functions to draw pipes, drains and plumbing joints. A civil engineering program includes special features to work with contours and land development; the list goes on and on.

Most manufacturers market CADD programs in separate modules. They sell a basic drafting module for a certain price with the options to add on other modules. There are a number of add-on programs available from independent vendors as well.

### 3.7.3 A Look at the CADD Industry

There are hundreds of CADD programs available in the CADD industry today. Most of them are simply drafting programs, while some offer certain engineering analysis, design or database capabilities. Some programs are more elaborate than others. You can purchase a CADD program with just the basic drawing capabilities for as little as $200. These are called low-end programs and are commonly used for general drawing work.

Another category of software is mid-range. This category offers advanced drafting techniques such as layers, 3D, basic database capabilities, advanced dimensioning and many automated drawing features. Architecture and engineering design

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firms commonly use mid-range software. About 80% of all the CADD programs fall into this category and there is immense competition in this market. Their prices vary significantly.

There are a few advanced CADD programs available, which are commonly used by large corporations for manufacturing. These programs include integrated features such as solid modeling, engineering analysis, design, database and project management. These are called high-end programs. Most of the time they are customized to meet the specific requirements of the corporation. These programs are priced quite high.

**Summary**

You would have now understood the differences between the 3 levels of management and usage of CAD and Expert System in the strategic level activity, namely product design and development. In this unit the exponential weighted average method, for all the components of Time series analysis are discussed. In addition your exposed to qualitative technique like Market survey, Expert opinion, Delphi technique. In this section, the different methods of aggregate planning are elucidated for your understanding.

**Review Questions:**

1. What is CADD?

2. List the major capabilities of CADD.

NOTES

# UNIT IV
# SCHEDULING AND PROJECT MANAGEMENT METHODS

# UNIT - 4

NOTES

# SCHEDULING AND PROJECT MANAGEMENT METHODS

## 4.1 INTRODUCTION

This unit deals with the operations levels of management namely scheduling activity. The job shop scheduling and project scheduling are also discussed in detail.

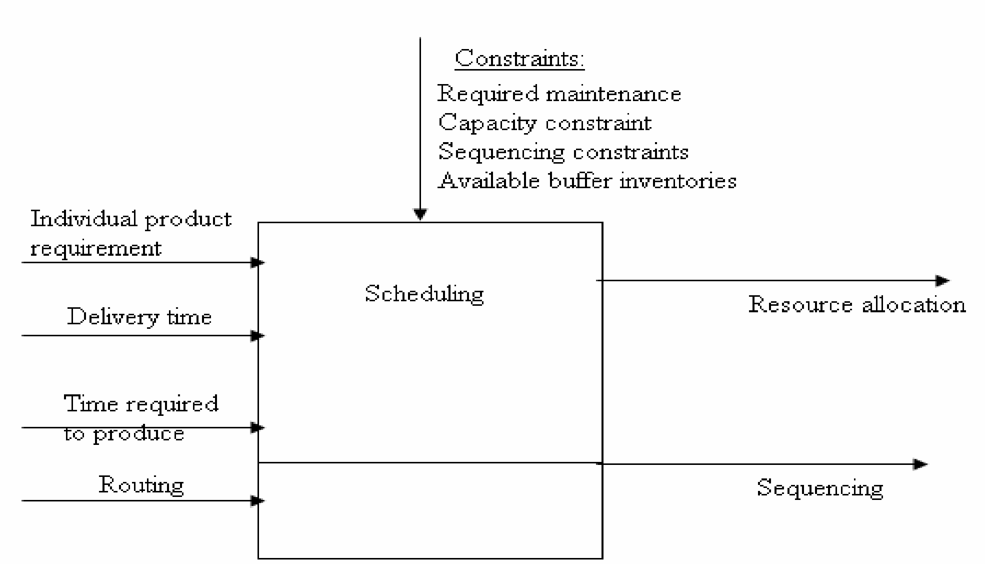
## 4.2 LEARNING OBEJECTIVE

1. To understand the phases of scheduling namely resource allocation and scheduling.
2. To comprehend the resources allocation techniques.
3. To know the various sequencing technique to different job shop types.
4. To understand the project management techniques and their application.

## 4.3 SCHEDULING

This is the lower level activity in the operation planning and control. The output of aggregate planning goes as input to the scheduling activity. The aggregate demand is broken down into individual product requirement.

**Figure 4.1 - Scheduling**



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Based on the information mentioned in the figure, resource allocation and sequencing activities are carried out.

Scheduling is considered to be an important activity because if this activity is not carried out properly, there is more waiting time that results in delayed delivery time which in turn affects the customer satisfaction. The through put time increases because of the more waiting time. Thus the longest through put time may be due to the more waiting time of the product for the operation because the workcenter where the process is demanded is engaged by the other product. The above situation paves the way for more work in progress (WIP) inventory. Thus the scheduling activities determine many important objectives of the organization. So, this is the activity which is getting lot of importance nowadays.

### 4.3.1 Resources Allocation

Based on the process requirement and the available resources, in the first phase of scheduling, resources are allocated for different jobs based on the availability and time requirement when there is no splitting of the orders. This process may be carried out using the Assignment method.

**Assignment Model**

Assignment model is considered to be one of the resource allocation techniques. If you want to apply assignment model for resource allocation, the number of process centers should be equal to the number of jobs to be assigned. This problem could be treated as a maximization or minimization problem, based on the type of entry in the cell. If the entry in the cell is profit etc., then it should be considered as a maximization problem. If the entry is processing time etc., then the problem is considered as a minimization problem. In this model, once a job is assigned to a work center, then the job and the assigned work center should not be considered for further assignment. This kind of problem can be solved by a well known method called Hungarian method. You would have studied Hungarian model in Operation research. Consider the following resource allocation problem.

## 4.4 SEQUENCING

### *4.4.4.1 Sequencing "n" jobs / single machine problem*

Normally, the total number of jobs exceeds the number of work centers. Therefore, **Priority Rules** should be developing to determine the sequencing of machining operations. The Priority Rules come into picture when many jobs or operations are chasing for the same capacity.

Factors to be considered in setting priorities for jobs include:

a. Customer satisfaction.

b. Order urgency

c. Order profitability

d. Impact on capacity utilization

e. Shop performance

The most popular priority rules are

- First come fist served (FCFS)
- Shortest processing time (SPT)
- Earliest due date (EDD)
- Least slack (LS)

An example for working of these rules.

**Example 4.1**

The following table is the required time and due time in days attached to Five jobs waiting in queue to share a same work center.

**Table 4.1**

| Job | Required Time (Days) | Due Date (Days hence) |
|---|---|---|
| A | 2 | 4 |
| B | 5 | 5 |
| C | 1 | 3 |
| D | 4 | 6 |
| E | 6 | 7 |

***Solution***

- ***First come first served rule (FCFS)***

According to this principle, the job which comes first to the workcenter will occupy the machine first.

Table 4.2

| Job Time | Required (Days) | Due Date (Days hence) | Processing Period (Start+Req.) | Completion date | Days Late |
|---|---|---|---|---|---|
| A | 2 | 4 | 0+2 | 2 | 0 |
| B | 5 | 5 | 2+5 | 7 | 2 |
| C | 1 | 3 | 7+1 | 8 | 5 |
| D | 4 | 6 | 8+4 | 12 | 6 |
| E | 6 | 7 | 12+6 | 18 | 11 |
| Sum | 18 | | | 47 | 24 |

NOTES

Average throughput time = 47/5 = 9.4 days
Average number jobs in the work center = 47/18 = 2.611 jobs
Average number of days late= 24/5 = 4.8 days

- ***Shortest processing time (SPT)***

According to this principle, the job which is having shortest processing time will occupy the machine first.

**Table 4.3**

| Job | Required Time (Days) | Due Date (Days hence) | Processing Period (Start+Req.) | Completion date | Days Late |
|---|---|---|---|---|---|
| C | 1 | 3 | 0+1 | 1 | 0 |
| A | 2 | 4 | 1+2 | 3 | 0 |
| D | 4 | 6 | 3+4 | 7 | 1 |
| B | 5 | 5 | 7+5 | 12 | 7 |
| E | 6 | 7 | 12+6 | 18 | 11 |
| Sum | 18 | | | 41 | 19 |

Average throughput time = 41/5 = 8.2 days
Average number jobs in the work center = 41/18 = 2.277 jobs
Average number of days late= 19/5 = 3.8 days

- ***Earliest due date (EDD)***

According to this principle the job with earliest due date will occupy the machine first regardless of job arrival or processing time.

**Table 4.4**

| Job | Required Time (Days) | Due Date (Days hence) | Processing Period (Start+Req.) | Completion date | Days Late |
|---|---|---|---|---|---|
| C | 1 | 3 | 0+1 | 1 | 0 |
| A | 2 | 4 | 1+2 | 3 | 0 |
| B | 5 | 5 | 3+5 | 8 | 3 |
| D | 4 | 6 | 8+4 | 12 | 6 |
| E | 6 | 7 | 12+6 | 18 | 11 |
| Sum | 18 | | | 42 | 20 |

Average throughput time = 42/5 = 8.4 days
Average number jobs in the work center = 42/18 = 2.333 jobs
Average number of days late= 20/5 = 4 days

- ***Least slack (LS)***

Least slack is the time difference between time remaining and work time required. According to this principle, the job with least slack time will occupy the machine first.

Slack = time remaining until due date - process time remaining

**Table 4.5**

| Job | Required Time (Days) | Due Date (Days hence) | Slack Time (Days) | Processing Period (Start+Req.) | Completion date | Days Late |
|---|---|---|---|---|---|---|
| B | 5 | 5 | 0 | 0+5 | 5 | 0 |
| E | 6 | 7 | 1 | 5+6 | 11 | 4 |
| C | 1 | 3 | 2 | 11+1 | 12 | 9 |
| A | 2 | 4 | 2 | 12+2 | 14 | 10 |
| D | 4 | 6 | 2 | 14+4 | 18 | 12 |
| Sum | 18 | | | | 60 | 35 |

Average throughput time = 60/5 = 12 days

Average number jobs in the work center = 60/18 = 3.333 jobs

Average number of days late= 35/5 = 7 days

Summary Table:

Scheduling with Priority Rules

**Table 4.6**

| Performance Dimension | FCFS | SPT | EDD | LS |
|---|---|---|---|---|
| Average throughput time | 9.4 | 8.2 | 8.4 | 12 |
| Average number jobs in the work center | 2.611 | 2.277 | 2.333 | 3.333 |
| Average number of days late | 4.8 | 3.8 | 4 | 7 |

Research has shown that Shortest processing time (SPT) has the good priority rule to follow for job scheduling. This rule results in the shortest manufacturing lead time, therefore, lowest work-in process inventory. It will often minimize the average throughput time so minimum number jobs in the system. The queue position changes with the arrival of new jobs, this makes to follow the Shortest processing time (SPT) in real time scenario. First come first served (FCFS) becomes the only practical solution to the scheduling. Earliest due date (EDD) might prefer when jobs must meet up with other outputs later in an assembly.

### *Critical ratio*

Critical ratio is one of the priority rule which helps the scheduler to know about which job should be given priority for the production in a job shop. The informations required for using the technique are:

1. The number of jobs to be processed.

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2. The production calendar.
3. The requirement date for the jobs.
4. The processing time remaining.

From the above information, you can calculate the critical ratio-

Critical ratio = (date required – today's date) / days needed to complete the job.

This ratio tells you about the urgency attached with the each job. If the critical ratio is a dimensionless index. If the index = 1, that means the job is on schedule, if the index is less than 1 that means that the job is behind the schedule. It needs much attention and priority should be given for the job. If the index is greater than 1 then the job is ahead of the schedule.

***Problem***

1. Suppose there are 6 jobs. Today is the $40^{th}$ day on production calendar other information are given in the table. Provide the sequence in which the jobs are to be processed using critical ratio technique.

**Table 4.7**

| Job | Days required | Processing time remaining (days) |
|---|---|---|
| 1 | 50 | 3 |
| 2 | 48 | 4 |
| 3 | 45 | 3 |
| 4 | 43 | 2 |
| 5 | 42 | 4 |
| 6 | 41 | 3 |

**Solution**

**Table 4.8**

| Job | Critical ratio |
|---|---|
| 1 | (50-40)/3 = 3.3 |
| 2 | (48-40)/3 = 2.0 |
| 3 | (45-40)/3 = 1.6 |
| 4 | (43-40)/3 = 1.0 |
| 5 | (42-40)/3 = 0.5 |
| 6 | (41-40)/3 = 0.3 |

From the above problem, you can conclude that jobs 1,2 and 3 are ahead of schedules. Job 4 is on schedule. But job 5 and 6 are behind the schedules. So job 6 should be given first priority than job 5 should be given next priority.

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### 4.4.2 Sequencing *"n"* jobs / two machines problem - Johnson's Algorithm

The two machine flow shop problem with the objective of minimizing makespan is also known as Johnson's problem. The results originally obtained by Johnson are now standard fundamentals in the theory of scheduling. In the formulation of this problem, job j is characterized by processing time $t_{j1,}$ required on machine 1, and $t_{j2,}$ required on machine 2 after the operation on machine 1 is complete. An optimal sequence can be characterized by the following rule for ordering pairs of jobs.

**Johnson's Rule:**

Job i proceeds job j in an optimal sequence if

$$\text{Min}(t_{i1}, t_{j2}) <= \min(t_{i2}, t_{j1})$$

In practice, an optimal sequence is directly constructed with an adaptation of this result. The positions in sequence are filled by a one- pass mechanism that identifies, at each stage, a job that should fill either the first or last available position.

**Algorithm:**

STEP 1 : Find min $(t_{i1}, t_{i2})$.

STEP 2a: If the minimum processing time requires machine 1, place the associated job in the first available position in sequence. Go to step3.

STEP 2b : If the minimum processing time requires machine 2, place the associated job in the last available position in sequence. Go to step3.

STEP 3 : Remove the assigned job from consideration and return to step 1 until all positions in sequence are filled. (Ties may be broken arbitrarily.)

To illustrate the algorithm, consider the five – job problem shown in table as follows. The accompanying work- sheet shows how an optimal sequence is constructed in five stages using the Algorithm. At each stage, the minimum processing time among unscheduled jobs must be identified. Then step 2 assigns one or more positions in the sequence, and the process is repeated.

***Problem statement:***

The following table shows the five jobs to be allocated in two machines and their respective processing time in the two machines.

**Table 4.9**

| Job j | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **$T_{j1}$(min)** | 3 | 5 | 1 | 6 | 7 |
| **$T_{j2}$(min)** | 6 | 2 | 2 | 6 | 5 |

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***Solution:***

**Table 4.10**

| Stages | Unscheduled jobs | Minimum $t_{ik}$ | Assignment | Partial schedule |
|---|---|---|---|---|
| 1 | 1,2,3,4,5 | $T_{31}$ | 3=[1] | 3 x x x x |
| 2 | 1,2,4,5 | $T_{22}$ | 2=[5] | 3 x x x 2 |
| 3 | 1,4,5 | $T_{11}$ | 1=[2] | 3-1 x x 2 |
| 4 | 4,5 | $T_{52}$ | 5=[4] | 3-1 x 5-2 |
| 5 | 4 | $T_{41} = T_{42}$ | 4=[3] | 3-1-4-5-2 |

The sequence that emerges is 3-1-4-5-2.

### 4.4.3 Extension of Johnson's Rule

***Johnson's Rule to Three machines:***

Consider a three machines and ***n*** jobs problem.

**Table 4.11**

| Job | 1 | 2 | 3 | . | . | i | . | n |
|---|---|---|---|---|---|---|---|---|
| Machine1 | t11 | t21 | t31 | . | . | ti1 | . | tn1 |
| Machine2 | t12 | t22 | t32 | . | . | ti2 | . | tn2 |
| Machine3 | t13 | t23 | t33 | . | . | ti3 | . | tn3 |

Johnson rule can be applied to three machines when the problem exhibits 'Dominance'.

Dominance can be understood when a situation of n jobs with three machines and a processing order requirement of M1, M2, M3 follows for all the jobs, with the following condition holds good

Minimum of $ti1 \geq Maximum\ of\ ti2$

or

Minimum of $ti3 \geq Maximum\ of\ ti2$

Where $tij$ is the operation time for job i in machine j.

If any one of the above conditions satisfied then we say the problem exhibited Dominance.

We will combine the operating times of machines as follows

$t1 = ti1 + ti2$

$t2 = ti2 + ti3$

NOTES

$t1, t2$ are the new operating time of machine1 and machine2.
The optimal solution for the above problem is obtained through Johnson's rule.
***Converting the three machine problem into a two machine problem.***

**Table 4.12**

| Job | 1 | 2 | 3 | . | . | i | . | n |
|---|---|---|---|---|---|---|---|---|
| Machine1 | t11+t12 | t21+t22 | t31+t32 | . | . | ti1+ti2 | . | tn1+tn2 |
| Machine2 | t12+t13 | t22+t23 | t32+t33 | . | . | ti2+ti3 | . | tn2+tn3 |

Now apply Johnson's rule to machine-1 and machine-2 to obtain optimal sequence.

***Practice problem:***

**Table 4.13**

1. A company is faced with five tasks that have to be processed through three work centers. Assume work centers works continuously and that they are using Johnson's rule. Data appear below in minutes:

| Task | A | B | C | D | E |
|---|---|---|---|---|---|
| Workstation 1 | 10 | 8 | 15 | 7 | 12 |
| Workstation 2 | 6 | 4 | 3 | 2 | 5 |
| Workstation 3 | 8 | 11 | 6 | 10 | 9 |

Johnson rule can be applied to three machines when the problem exhibits 'Dominance'.
So check for Dominance.

Minimum of $ti1 \geq Maximum\ of\ ti2$
or
Minimum of $ti3 \geq Maximum\ of\ ti2$

Minimum of $ti1 = 7$
Minimum of $ti3 = 6$
$Maximum\ of\ ti2 = 6$

The above conditions satisfied and the problem exhibited Dominance. We will combine the operating times of machines as follows:

$t1 = ti1 + ti2$
$t2 = ti2 + ti3$

Converting a three machine problem into a two machine problem.

NOTES

Table 4.14

| Task | A | B | C | D | E |
|---|---|---|---|---|---|
| Workstation 1 | 16 | 12 | 18 | 9 | 17 |
| Workstation 2 | 14 | 15 | 9 | 12 | 14 |

By applying Johnson's rule the optimal sequence is as follows:

D - B - A - E - C (or) D - B - E - A - C

Finding of Make span is as follows :

**Table 4.15**

| Task | Time | D | B | A | E | C | |
|---|---|---|---|---|---|---|---|
| Workstation1 | In | 0 | 7 | 15 | 25 | 37 | |
| | Out | 7 | 15 | 25 | 37 | 52 | |
| Workstation2 | In | 7 | 15 | 25 | 37 | 52 | |
| | Out | 9 | 19 | 31 | 42 | 55 | |
| Workstation3 | In | 9 | 19 | 31 | 42 | 55 | |
| | Out | 19 | 30 | 39 | 51 | 61 | |
| Idle Time of | | | | | | | Total Idle time |
| W/S 2 | | 7 | 6 | 6 | 6 | 10 | 35 |
| W/S 3 | | 9 | 0 | 1 | 3 | 4 | 17 |

The Make span of the above optimal sequence is 61 minutes.

### 4.4.4 *M* machines and *N* jobs:

***Johnson's algorithm and Multiple Machines***

Johnson's method only works optimally for two machines. However, since it is optimal, and easy to compute. Johnson's rule can be tried to adopt it for M machines, (M > 2). All the methods developed for the *m* machines and *n* jobs are heuristic in nature. The heuristics methods are based on a logic based and thumb rules.

Which may not be an optimal solution, but a better solution will be provide.

For jobs scheduled in flow shop of more than three machines, no optimal solution except exhaust search has ever been proposed. ***Campbell, Dudek and Smith*** proposed a heuristic method named CDS algorithm to achieve a nearly minimum make span in the CDS method.

NOTES

***Assumptions:***

1. Jobs are not preemptive.
2. Each job has ***m* tasks** to be executed in sequence on ***m.***
3. Given a set of *n* independent jobs, each having *m* executed in the same sequence on m machines

*(PI, Pz, ...,P,.),* scheduling seeks the minimum completion time of the last job.

***Algorithm:***

1. Create (m-1) stages.
2. Each stage should have 2 workstations.
3. Apply Johnson's rule for each pair of workstations created by certain conditions.
4. From all the (m-1) sequences find out the make span of each sequence.
5. Choose the best among the (m-1) sequences which yields low make span or flow time.

NOTE: We should be careful in determining the make span. The original processing time required by the job on ***m*** machines are to be taken into consideration in evaluating the make span but not the converted time for the workstations.

Let us consider a four machines and ***n*** jobs problem.

**Table 4.16**

| Job | 1 | 2 | 3 | . | . | i | . | n |
|---|---|---|---|---|---|---|---|---|
| Machine1 | t11 | t21 | t31 | . | . | ti1 | . | tn1 |
| Machine2 | t12 | t22 | t32 | . | . | ti2 | . | tn2 |
| Machine3 | t13 | t23 | t33 | . | . | ti3 | . | tn3 |
| Machine4 | t14 | t24 | t34 | . | . | ti4 | . | tn4 |

Follow the CDS algorithm step by step.
In this problem the numbers of machines are 4.
We should generate (4-1) =3 sequences.

The first sequence will come from workstation-1 and workstation2. Here workstation-1 is equals to machine-1 and workstation-2 equals to machine-4 in operating time.

**Table 4.17**

| Job | 1 | 2 | 3 | . | . | i | . | n |
|---|---|---|---|---|---|---|---|---|
| Workstation1 | t11 | t21 | t31 | . | . | ti1 | . | tn1 |
| Workstation2 | t14 | t24 | t34 | . | . | ti4 | . | tn4 |

NOTES

The second sequence will come from workstation-1 and workstation2. Here workstation-1 is equals to machine-1&2 and workstation-2 equals to machine-4&3 in operating time.

**Table 4.18**

| Job | 1 | 2 | 3 | . | . | i | . | n |
|---|---|---|---|---|---|---|---|---|
| Workstation 1 | t11+t12 | t21+t22 | t31+t32 | . | . | ti1+ti2 | . | tn1+tn2 |
| Workstation 2 | t14+t13 | t24+t23 | t34+t33 | . | . | ti4+ti3 | . | tn4+tn3 |

The third sequence will come from workstation-1 and workstation2. Here workstation-1 is equals to machine-1+2+3 and workstation-2 equals to machine-4+3+2 in operating time.

**Table 4.19**

| Job | 1 | 2 | 3 | . | . | i | . | n |
|---|---|---|---|---|---|---|---|---|
| Workstation1 | t11+t12+t13 | t21+t22+t23 | t31+t32+t33 | . | . | ti1+ti2+ti3 | . | tn1+tn2+tn3 |
| Workstation2 | t14+t13+t12 | t24+t23+t22 | t34+t33+t32 | . | . | ti4+ti3+ti2 | . | tn4+tn3+tn2 |

Apply Johnson's rule to the above feasible sequences. Choose the least make span among the above sequences.

***Practice problem:***

1. A company is faced with four jobs that have to be processed through four machines. Assume machines works continuously. Data appear below in minutes

**Table 4.20**

| Job | A | B | C | D |
|---|---|---|---|---|
| Machine1 | 3 | 2 | 1 | 4 |
| Machine2 | 3 | 2 | 4 | 3 |
| Machine3 | 3 | 1 | 4 | 3 |
| Machine4 | 3 | 2 | 2 | 2 |

Follow the CDS algorithm step by step.
This problem is a 4 of machines. So we should generate (4-1) =3 sequences.

The first sequence will come from workstation-1 and workstation2. Here workstation-1 is equals to machine-1 and workstation-2 equals to machine-4 in operating tim.

NOTES

**Table 4.21**

| Job | A | B | C | D |
|---|---|---|---|---|
| Workstation1 | 3 | 2 | 1 | 4 |
| Workstation2 | 3 | 2 | 2 | 2 |

By applying Johnson's rule the optimal sequence for the above setup is

C - B - A – D

The second sequence will come from workstation-1 and workstation2. Here workstation-1 is equals to machine-1&2 and workstation-2 equals to machine-4&3 in operating time.

**Table 4.22**

| Job | A | B | C | D |
|---|---|---|---|---|
| Workstation1 | 6 | 4 | 5 | 7 |
| Workstation2 | 6 | 3 | 6 | 5 |

By applying Johnson's rule the optimal sequence for the above setup is

C - A – D – B

The third sequence will come from workstation-1 and workstation2. Here workstation-1 is equals to machine-1+2+3 and workstation-2 equals to machine-4+3+2 in operating time.

**Table 4.23**

| Job | A | B | C | D |
|---|---|---|---|---|
| Workstation1 | 9 | 5 | 9 | 10 |
| Workstation2 | 9 | 5 | 10 | 8 |

By applying Johnson's rule the optimal sequence for the above setup is

B - A – C – D

Find out the make span of each sequence obtained above.
For the first sequence C - B - A – D

NOTES

**Table 4.24**

| Job | Time | C | B | A | D |
|---|---|---|---|---|---|
| Machine1 | In | 0 | 1 | 3 | 6 |
| | Out | 1 | 3 | 6 | 10 |
| Machine2 | In | 1 | 5 | 6 | 10 |
| | Out | 5 | 7 | 9 | 13 |
| Machine3 | In | 5 | 9 | 10 | 13 |
| | Out | 9 | 10 | 13 | 16 |
| Machine4 | In | 9 | 11 | 13 | 16 |
| | Out | 11 | 13 | 16 | 18 |

The make span time is 18. For the second sequence C - A – D – B

**Table 4.25**

| Job | Time | C | A | D | B |
|---|---|---|---|---|---|
| Machine1 | In | 0 | 1 | 4 | 8 |
| | Out | 1 | 4 | 8 | 10 |
| Machine2 | In | 1 | 5 | 8 | 11 |
| | Out | 5 | 8 | 11 | 13 |
| Machine3 | In | 5 | 9 | 12 | 15 |
| | Out | 9 | 12 | 15 | 16 |
| Machine4 | In | 9 | 12 | 15 | 17 |
| | Out | 11 | 15 | 17 | 19 |

The make span time is 19. For the third sequence B - A – C - D

**Table 4.26**

| Job | Time | B | A | C | D |
|---|---|---|---|---|---|
| Machine1 | In | 0 | 2 | 5 | 6 |
| | Out | 2 | 5 | 6 | 10 |
| Machine2 | In | 2 | 5 | 8 | 12 |
| | Out | 4 | 8 | 12 | 15 |
| Machine3 | In | 4 | 8 | 12 | 16 |
| | Out | 5 | 11 | 16 | 19 |
| Machine4 | In | 5 | 11 | 16 | 19 |
| | Out | 7 | 14 | 18 | 21 |

The make span time is 21.

NOTES

Decision Table

**Table 4.27**

| S.no. | sequence | Make span | Selection |
|---|---|---|---|
| 1 | C-B-A-D | 18 | v |
| 2 | C-A-D-B | 19 | õ |
| 3 | B-A-C-D | 21 | õ |

Among the feasible sequences C-B-A-D is the best sequence with the make span of 18 minutes.

**Review Question:**

1. Explain the two phases of scheduling.
2. Which priority rule is the best rule for sequencing for a single machine problem where the customer satisfaction is an important objective?

## 4.5 PROJECT SCHEDULING

In the previous sections you have seen how do you schedule the mass production, job shop production. In this section you can see how do you schedule project type of production. To schedule project type of production, during the World War II US defense people developed a technique known as PERT, stands for Program Evaluation and Review Technique to develop a missile.

Here the development of a missile is a project and to plan and schedule the above said project, US defense personnel developed a PERT technique. After developing PERT technique, US defense people developed another technique known as CPM. CPM stands for Critical Path Method to plan and schedule of certain type of projects.

**PERT** techniques is a applied mainly for new project at which you don't have any experience that is why the time estimate for each activity of the project revolves around three time estimate (e.g.) PERT usually applied for the following projects,

- Planning and scheduling of new product.
- Development of missile.
- Development of launching of rockets.

But **CPM** is applied for known projects like

- The construction of building.
- The manufacture and assembly of motors.
- The maintenance project.

NOTES

*Difference between PERT and CPM*

**Table 4.28**

| S.No | Characteristics | CPM | PERT |
|---|---|---|---|
| 1. | Type of projects | Known | Unknown |
| 2. | Time estimate | Single time estimate | Three time estimate |
| 3. | Time | Non random variable | Random variable |
| 4. | Nature of the time estimate | Deterministic | Probabilistic |
| 5. | Type of network | Activity oriented network | Event oriented network |

A project as already mentioned consists of many activities. The activities are interlinked together to achieve the common objectives like time, cost and standard of performance. CPM and PERT techniques are considered to be project management techniques which enable the project manager to plan and schedule the project. They are also called project network planning and scheduling technique. In the next section you can know about the network planning and scheduling.

### 4.5.1 Planning

Jobs to be carried out in the planning

1) List the activities involved in the project,
2) Estimate the time requirement and cost requirement for each activity,
3) Find the relationship between the activities,
4) Based on the relationship draw the precedence diagram,
5) Draw the network based on the precedence diagram.

The output of the planning activities will be as follows :

Precedence relation with time and cost data

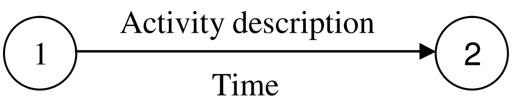
**Table 4.29**

| Activities | Immediate predecessor | Cost | Time |
|---|---|---|---|
| a. | - | 5000 | 4 |
| b. | - | 4000 | 5 |
| c. | - | 10,000 | 1 |
| d. | a, b | 7000 | 3 |
| e. | c | 6000 | 2 |
| f. | e | 10,000 | 5 |

In a project, the activity is represented as follows:

**NOTES**

**Figure 4.2**

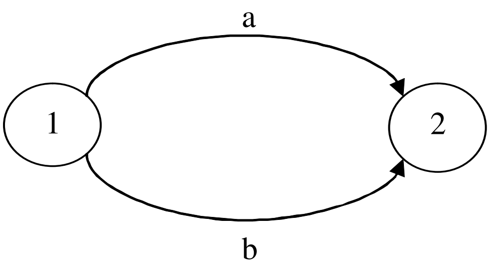



Suppose an activity consists of test marketing. This is represented as

**Figure 4.3**

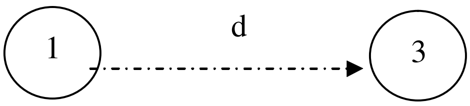

1. The tail node of the arrow should carry small number than the head of the arrow. In this case tail node carry number1 and the head node carry number2.
2. Two activities should not have common initial node and common end node.

**Figure 4.4**




This is not permitted if this kind of situation arises, then you should introduce a dummy activity as follows:

**Figure 4.5**

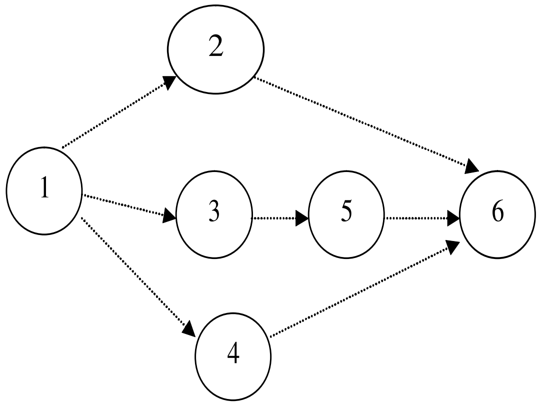



'd' is the dummy ,it does not consume any resources. It is introduced just to show the relationship.

1. When you draw the network, all the starting activities should start at one starting node. Similarly at the end all the ending activities should culminate at one node.

NOTES

**Figure 4.6**




In the above network, all the starting activities are emanating from node 1 and all the ending activities are namely (2 - 6, 5 - 6, 4 - 6) are culminated at node 6.

**4.5.2 Project network scheduling**

In this phase, you should decide about whether the network is treated as an activity oriented network or event oriented network.

An event is nothing but, a milestone of a network. A project network could be treated as an activity oriented network, only when, as a project manger, you should know in detail about the every activity of the project, namely, the estimated time of the each activity, and how to complete each activity etc. Otherwise, if you are not so experienced with the project, then you should treat the project as an event oriented project. In the event oriented project, you don't bother about the progress of the activity. You should bother about the starting and completion time of the activity and then the project. For example- Test marketing. If you treat this job as an activity then the description is test marketing. Then you should find out the earliest starting time, latest starting time, earliest finishing time and latest finishing time. Suppose you treat the test marketing as an event oriented one, then you should find out the earliest and latest starting time, the earliest and latest finishing time of the test marketing event.

With this information, now you can see what you should do in the scheduling of the project network.

**Steps:**

1. Find the earliest starting time, earliest finishing time for activity, and latest starting time and latest finishing time for activity oriented network.
2. Find the earliest starting time, earliest finishing time for event, and latest starting time and latest finishing time for event, for event oriented network.

NOTES

***Forward pass Method***

In forward pass method, the earliest starting time and earliest finishing time are calculated.

$$EF_{ij} = ES_{ij} + t_{ij}$$

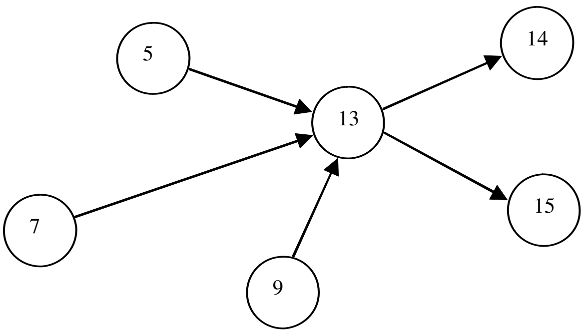
= Earliest finish time of activity *i,j*

$ES_{ij}$ = Earliest starting time of activity *i,j*

$t_{ij}$ = Time duration of the activity *i,j*

You may have problem in calculation of ES of scheduled activity only when many activities lead into a particular node and one or many activities emanating from that particular node as shown below:

**Figure 4.7**




$EF_{ij}$

Assume

**Table 4.30**

| Activity | Earliest Start (ES) | Earliest Finish (EF) | Time Duration |
|---|---|---|---|
| 5-13 | 4 | 7 | 3 |
| 7-13 | 7 | 11 | 4 |
| 9-13 | 6 | 8 | 2 |

Earliest start of activity 13 – 14

(i.e) $$ES_{13-14} = \max\begin{Bmatrix} EF_{5-3} \\ EF_{7-13} \\ EF_{9-13} \end{Bmatrix} = \max\begin{Bmatrix} 7 \\ 11 \\ 14 \end{Bmatrix} = 14$$

NOTES

The reason for considering the maximum time is that as per the technological constraint the succeeding activity will be started only after the completion of all the preceding activities.

***Backward pass method***

In the backward pass method, from the end node of the project the latest start and the latest finish are calculated. You should start with the earliest completion time of the project as the latest completion time of the project then you should work backward, so that you can deduce the latest starting time for each activity.

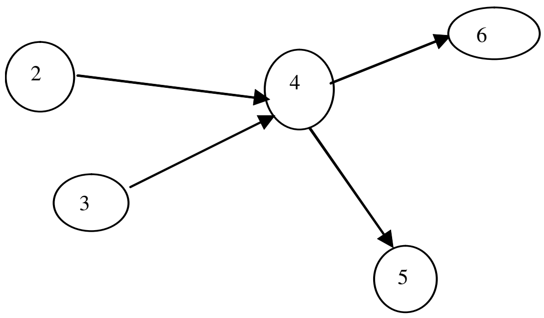
$$LS_{IJ} = LF_{ij} - t_{ij}$$

$LS_{IJ}$ = Latest starting time for the activity ***i-j***

$LF_{ij}$ = Latest finishing time for the activity ***i-j***

$t_{ij}$ = Time duration of the activity ***i-j***

In the latest finish time calculated, you may face some problem because many activities may emanate from a particular node as shown in the diagram.




Assume

**Table 4.31**

| Activity | Latest Start (LS) |
|---|---|
| 4-6 | 15 |
| 4-7 | 20 |
| 4-5 | 18 |

Now, to find the latest finish of activity 2-4 and 3-4, consider all the latest start time of all the activities emanating from the node four and consider the minimum latest starting time because, In the worst case, if all the succeeding activities starts at the latest starting time then the lowest latest starting time of the succeeding activity becomes latest finishing time of the preceding activities.

NOTES

(i.e)

Similarly $LF_{34} = \min \begin{Bmatrix} LS_{4-6} = 15 \\ LS_{4-7} = 20 \\ LS_{4-5} = 18 \end{Bmatrix} = LF_{2-4} = 15$

3. Identify the critical path. ***The critical path is the longest path in the network.***
4. Identify the float or slack for each activity/ event of the network.
5. Carry out the time- cost trade off and if possible crash the project.
6. Carry out the resource scheduling.

In scheduling to carry out the above activity, you need to apply (PERT/ CPM) techniques. First you can see the application of the critical path method in the following example. ***Why a manger should know about latest start and latest finish of each activity of a project?*** This is because sometimes more than one activity may compete for one resource. In this case, if you know the latest start and latest finish, the resource which is in question will be immediately allocated to the activity which could not be delayed, rather than to the activity which could be delayed. This is one of the reasons for the usage of float.

$$LF_{2-4} = \min \begin{Bmatrix} LS_{4-6} = 15 \\ LS_{4-7} = 20 \\ LS_{4-5} = 18 \end{Bmatrix} = LF_{2-4} = 15$$

***Identification of float:***

Float is the leeway available for the manager to schedule the scarce resources to the activity based on the float availability. This means, if an activity has zero float, that activity should be given preference in terms of allocating the resources, that too, when the other activities which possess float compete for the same resources.

Now, you can see how the above explained project network planning and scheduling is elucidated with an example.

***Problem statement***

**Table 4.32**

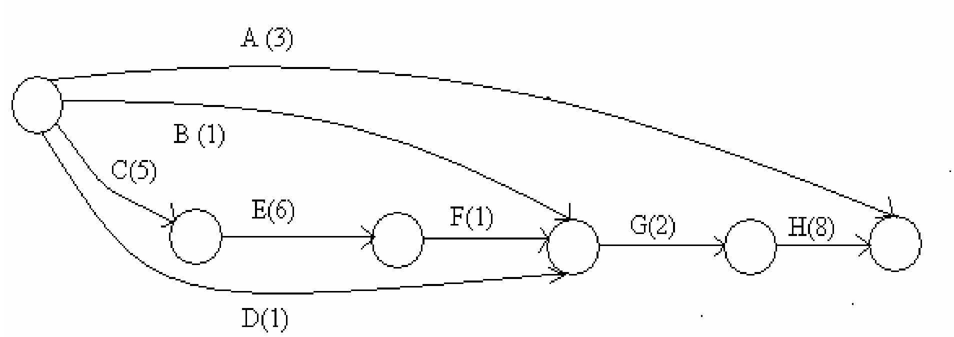
Consider the product development project. This project consists of following activities.

| Activity | Symbol | Preceding Activity | Time estimate (days) |
|---|---|---|---|
| Demand estimation | A | - | 3 |
| Development of pricing strategy | B | - | 1 |
| Product design | C | - | 5 |
| Conduct, promotional cost analysis | D | - | 1 |
| Manufacture prototype model | E | C | 6 |
| Perform product cost analysis | F | E | 1 |
| Perform final pricing analysis | G | B,D,F | 2 |
| Conduct Market test | H | G | 8 |

NOTES

**Solution**

**Figure 4.9**




Earliest starting and finishing time calculation using forward pass method:
$ES_i = \max [ 0, ES_{(i-1)}]$, $EF_i = ES_i +$ time duration.

**Table 4.33**

| Activity | Early start ($ES_i$) | Early finish ($EF_i$) |
|---|---|---|
| A | 0 | 3 |
| B | 0 | 1 |
| C | 0 | 5 |
| D | 0 | 1 |
| E | 5 | 11 |
| F | 11 | 12 |
| G | 12 | 14 |
| H | 14 | 22 |

Since three activities B,F and D are to be completed before G, we have to select the maximum of all the three early finish time of the predecessors. $ES_g = \max [ EF_b, EF_f, EF_d]$
Latest starting and finishing time calculation using forward pass method:
$LS_a =$ Total completion time of the project - $T_a$, $LF_a = TC_a$

**Table 4.34**

| Activity | Latest start ($LS_i$) | Latest finish ($LF_i$) |
|---|---|---|
| A | 19 | 22 |
| B | 10 | 11 |
| C | 0 | 5 |
| D | 10 | 11 |
| E | 5 | 11 |
| F | 11 | 12 |
| G | 12 | 14 |
| H | 14 | 22 |

NOTES

Total float for each activity 'i' = $LS_i - ES_i$ (or) $LF_i - EF_i$

**Table 4.35**

| Activity | Total Float |
|---|---|
| A | 19 |
| B | 10 |
| C | 0 |
| D | 10 |
| E | 0 |
| F | 0 |
| G | 0 |
| H | 0 |

The above method of planning and scheduling a network is called **Critical Path Method**. The critical path for the mentioned problem is C- E- F-G-H. (The path in the project which has the maximum completion time).

**PERT:**

Suppose, if a project planner treats the problem, which is discussed in the previous section, as an unknown project in some other new product launch, the project planner has to estimate "three time estimate", instead of "one time estimates". The three time estimates for each activity are called optimistic time ($t_o$), the most likely time ($t_m$), pessimistic time ($t_p$).

- Optimistic time($t_o$): It is the minimum time taken to complete the activity, if every thing goes well.
- Pessimistic time($t_m$): This is the maximum time to complete an activity, if most of the things go wrong.
- Most likely time ($t_p$): In real life situation, not everything goes completely right or wrong. The most likely is the time with a more chance to complete the activity.

For example, consider the following activity.

NOTES

**Figure 4.10**

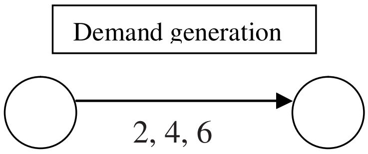



**Table 4.36**

| Symbol | Activity | Probability |
|---|---|---|
| $t_o$ | 2 | 0.2 |
| $t_m$ | 4 | 0.7 |
| $t_p$ | 6 | 0.1 |

**Beta distribution**

**Figure 4.11**

It is proved that the time estimate in the PERT method follows a Beta distribution. So the mean of the Beta distribution is

$$T_{expected} = T_e = (t_o + 4 \text{ x } t_m + t_{p)} / 6$$

Variance for the activity,

á$^2$ = $((t_p - t_o) / 6)^2$

2

A project planner, in addition to the estimation of standard, should know the variance of each activity; variance is a measure to measure the uncertainty about that activity. If the variance is high, this means that the project manager may not have much idea about the progress and completion of the activity.

Let us see the application of PERT – model for the previous problem, with the information provided in the following table.

NOTES

**Table 4.37**

| Activity | Symbol | Time estimate (days) | | |
|---|---|---|---|---|
| | | Optimistic (to) | Most likely ($t_m$) | Pessimistic ($t_p$) |
| Demand estimation | A | 1 | 3 | 4 |
| Development of pricing strategy | B | 1 | 1 | 2 |
| Product design | C | 4 | 5 | 9 |
| Conduct, promotional cost analysis | D | 1 | 1 | 1 |
| Manufacture prototype model | E | 4 | 6 | 12 |
| Perform product cost analysis | F | 1 | 1 | 2 |
| Perform final pricing analysis | G | 1 | 2 | 3 |
| Conduct Market test | H | 6 | 8 | 10 |

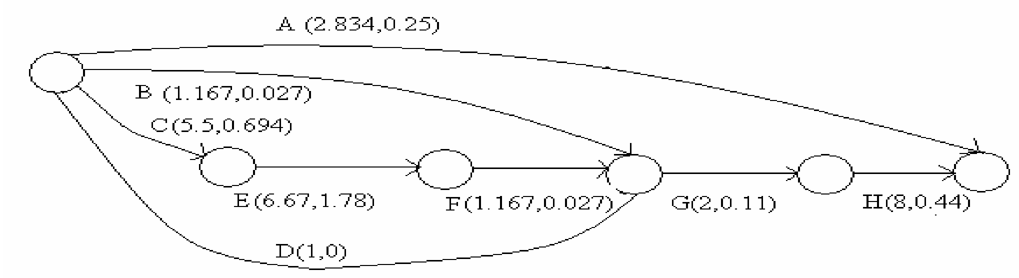
Step 1: Estimate the expected time and variance for each activity. Using 1 and 2 Table 4.38

**Table 4.38**

| Activity | $E_T$ | $V_T$ |
|---|---|---|
| A | 2.834 | 0.25 |
| B | 1.167 | 0.027 |
| C | 5.5 | 0.694 |
| D | 1 | 0 |
| E | 6.67 | 1.78 |
| F | 1.167 | 0.027 |
| G | 2 | 0.11 |
| H | 8 | 0.44 |

**Step 2: Network model:**

**Figure 4.12**



NOTES

**Step 3:**

Earliest starting and finishing time calculation using forward pass method:
$ES_i = \max [0, ES_{(i-1)}]$, $EFi = ES_i$ + time duration.

**Table 4.39**

| Activity | Early start ($ES_i$) | Early finish ($EF_i$) |
|---|---|---|
| A | 0 | 2.834 |
| B | 0 | 1.167 |
| C | 0 | 5.5 |
| D | 0 | 1 |
| E | 5.5 | 12.17 |
| F | 12.17 | 13.34 |
| G | 13.34 | 15.34 |
| H | 15.34 | 23.34 |

Since three activities B,F and D are to be completed before G, we have to select the maximum of all the three early finish time of the predecessors. $ES_g = \max [EF_b, EF_f, EF_d]$
Latest starting and finishing time calculation using forward pass method:
$LS_a$ = Total completion time of the project - $T_a$, $LF_a = TC_a$

Latest starting and finishing time calculation using backward pass method:
$LS_a$ = Total completion time of the project - $T_a$, $LF_a = TC_a$

**Table 4.40**

| Activity | Latest start ($LS_i$) | Latest finish ($LF_i$) |
|---|---|---|
| A | 20.50 | 23.34 |
| B | 11.00 | 12.17 |
| C | 0 | 5.5 |
| D | 11.17 | 12.17 |
| E | 5.5 | 12.17 |
| F | 12.17 | 13.34 |
| G | 13.34 | 15.34 |
| H | 15.34 | 23.34 |

**Step 4:**

Identify the critical path. The critical path is the longest path in the network. The expected critical path is C – E - F – G – H. The duration is 23.34 days. The variance of the critical path is 3.051 days. Therefore standard deviation is equal to 1.746.

NOTES

**Step 5:**

Identify the float or slack for each activity/ event of the network.
Identification of float:

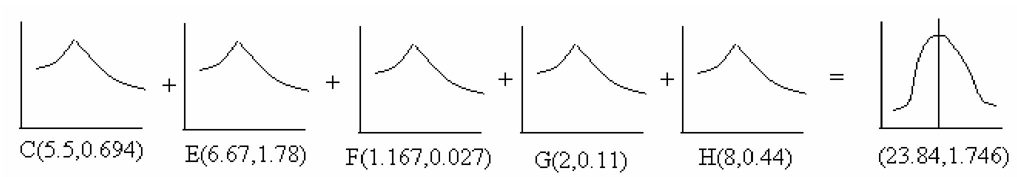
Total float for each activity 'i' = $LS_i - ES_i$ (or) $LF_i$ - $EF_i$

**Table 4.41**

| Activity | Total Float |
|---|---|
| A | 20.50 |
| B | 11.00 |
| C | 0 |
| D | 11.17 |
| E | 0 |
| F | 0 |
| G | 0 |
| H | 0 |

You cannot claim that, the completion time of the project is 23.34 days in this case, because this is the expected completion time attached with the probability. The expected completion time is the sum of the expected completion time of the activity C, E, F, G and H. But timing of each activity follows beta distribution. Now the summation of all the time follows the normal distribution with the summation of all variance. This principal is arrived based on the central limit theorem. It is shown in the figure4.13.

**Figure 4.13**




From this above figure; you can answer for the following questions.

1. What is the probability that the project will be completed within the mean time?
2. What is the probability that the project will be completed within the specified time period?
3. What is the probability that the project will be completed above the specified time period?
4. To complete within the particular probability, how much time will be required?

NOTES

5. To complete above the particular probability, how much time will be required?

Let us determine the following probabilities for the above mentioned problem.

A. The project will be completed in 22 days or less.

B. The project will be completed by its earliest expected completion date.

C. The project will be completed in more than 30 days.

D. The project will be completed between 25 and 30 days.

To answer the above problems you should find the Z- values using normal distribution tables as follows.

**Solution:**

A. $X_i = 22$, ($X_i$ = Project due date)

$\bar{X} = 23.34$ ($\bar{X}$ = Project completion time)

= 1.746 (  = standard deviation of the project completion time)

$Z = (X_i - \bar{X}) /$

$Z = (22 – 23.34) / 1.746$

$= -1.053$

Corresponding value for this Z from the normal tables is 0.1469

So the probability of completing the project with in 22 days is 14.69%

B. $X_i = 23.34$,

$\bar{X} = 23.34$

= 1.746

$Z = (X_i - \bar{X}) /$

$Z = (23.34 – 23.34) / 1.746$

$= 0.00$

Corresponding value for this Z from the normal tables is 0.5

So the probability of completing the project with in expected completion time is 50 %.

C. $X_i = 30$,

$\bar{X} = 23.34$

= 1.746

$Z = (X_i - \bar{X}) /$

$Z = (30 – 23.34) / 1.746$

$= 3.5281$

Corresponding value for this Z from the normal tables is 0.99978.

Therefore to complete the project beyond 30 days = 1-0.99978 (ie) = 0.00022

So the probability of completing the project beyond 30 days is 0.022%

D. $X_i = 30$,
$\bar{X} = 23.34$
$= 1.746$
$Z = (X_i - \bar{X}) /$
$Z = (25 - 23.34) / 1.746$
$= 0.66437$

Corresponding value for this Z from the normal tables is 0.7357.
Therefore to complete the project between 25 and 30 days = 0.99978 – 0.7357 = 0.26408
So the probability of completing the project beyond 30 days is 26.41%

## 4.6 RESOURCE SCHEDULING

As it is mentioned in the project scheduling, resource scheduling is another important activity of project scheduling. As resource are scares, the project manager efficiency and effectiveness can be measured through the way in which he allocate the resource in various activities of the project but not much extending the completion time of the project. Resource scheduling consists of two phases. Phase 1, deals about the resource allocation and Phase 2 deals about the resource leveling.

### *Resource allocation*

It is the allocation of the resources for the activities that are critical in nature. If some resources are required by more than one activity at a time, the resources are to be allocated to the activity which is critical in nature and thereby delaying non critical activity. Any how you should see that the critical activities are getting importance in allocating the resources rather than the non critical activity. This is done based on the availability of the float for each activity and this does not effect the project completion time. If you proceed in this manner you will come across the situation in which all activities become critical and resources allocation becomes a problem. In such a situation, the efficiency of a project manager even could be measured through how judiciously he allocates the resources and at the some time without much extending the completion time of the project.

### Resource leveling

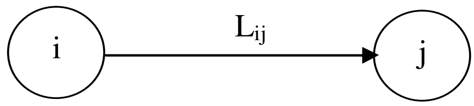
As the name indicates if you draw a curve between the time Vs resource requirement, the profile of the curve is almost constant then you need not carry out the leveling of the resources because all the time almost you need to make use of a constant resource requirement. This paves the way for continuous employment for the people involved in the project. Suppose the profile of the resource requirement Vs time has more peak & valley then you have to level the peak & valley of the resource requirement in such a manner that throughout the project period you are going to use constant

NOTES

resources with little variation. The process of doing so is called Project leveling. In this the case of project leveling the project completion time should not be extended but the objective of allocating constant workforce in all the days is achieved through a simple logic that the activities which are having floats are to be moved front and back without violating the precedence relationship. This is done with an objective of having constant resource in all the project days. When you move the activity front and back based on the availability of free float of each activity, that means the highest free float activity is moved front and back to ensure constant
resources in all the days.

Free float for an activity is calculated as follows

**Figure 4.14**




Free float for activity i-j= $t_j$- ($t_i$+$L_{ij}$)

Where $t_i$- is the earliest end time of the event i
$t_j$- is the earliest end time of the event j
$L_{ij}$- time duration of the activity i and j

Example 4.2
Consider the following network

**Table 4.42**

| Activity | Immediate predecessor | Manpower requirement | Time duration |
|---|---|---|---|
| A | - | 9 | 4 |
| B | - | 3 | 2 |
| C | - | 6 | 2 |
| D | - | 4 | 2 |
| E | B | 8 | 3 |
| F | C | 7 | 2 |
| G | F, D | 2 | 3 |
| H | E, G | 1 | 4 |

Step1: -Draw the network and post the network in a time scale.

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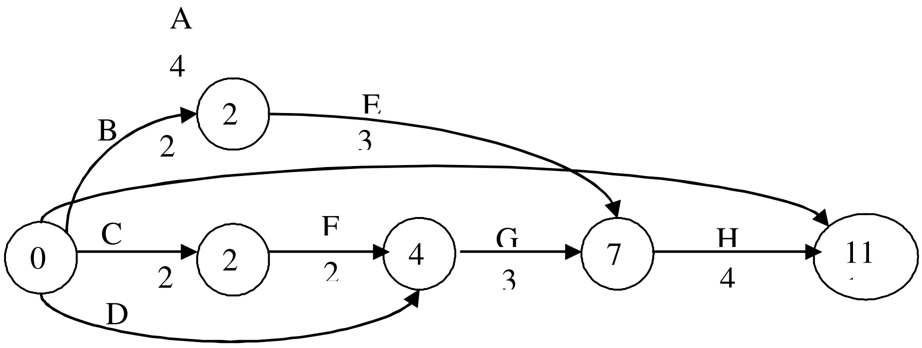
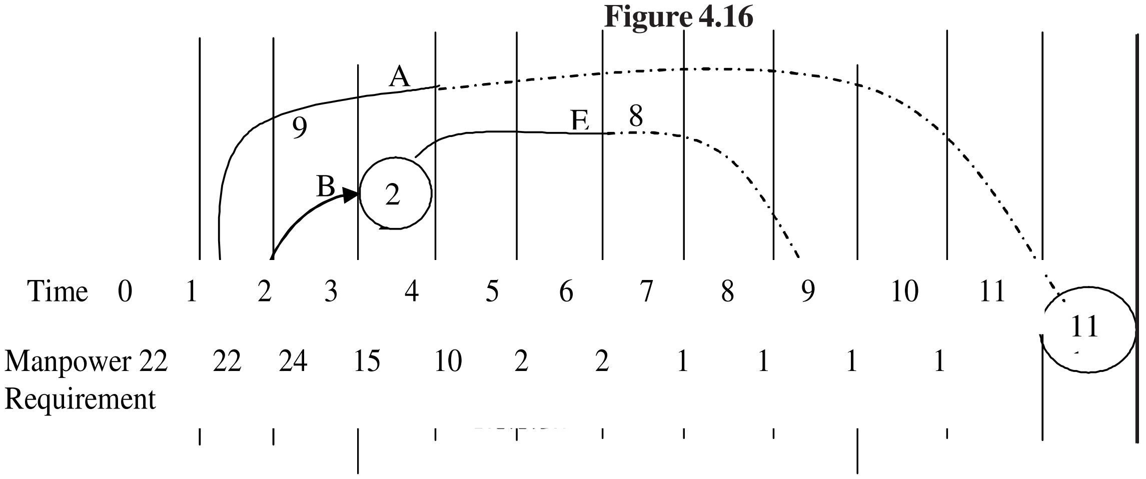
**Figure 4.15**




You can verify that the path C-F-G-H is the critical path. Next you should draw it in time scale. To draw this, first you should post the critical path.

**Figure 4.16**




The number appears above the arrow indicates that the manpower requirement.

Step2: - Draw the resource requirement Vs time profile

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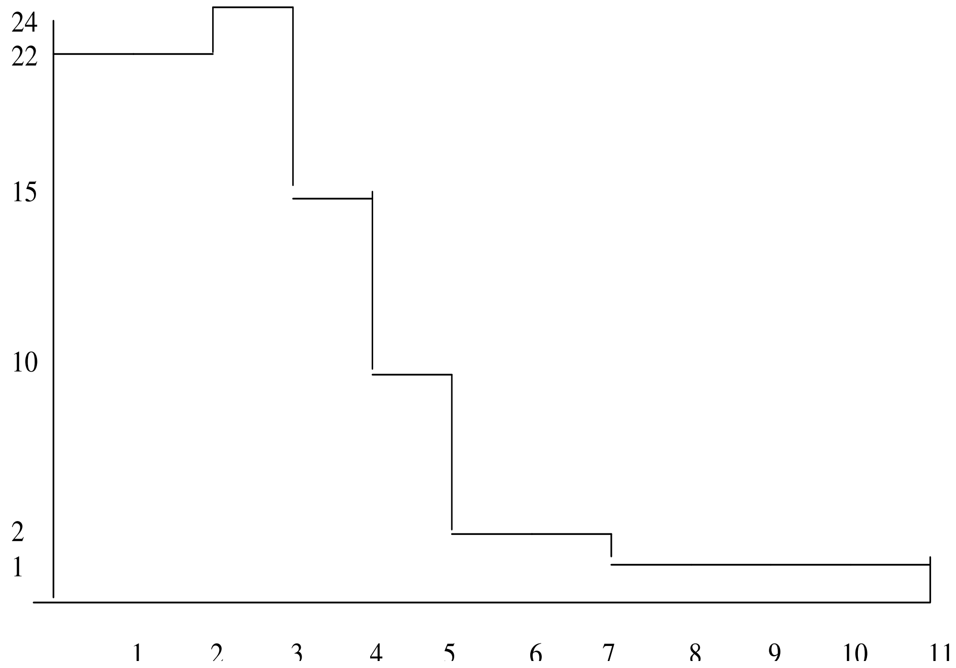
**Figure 4.17**




If you see the above resource requirement profile, this profile has more peak & valley. So this is to be leveled to have constant work force requirement.

Step3: - Find the float using the formula mentioned already for all the activities .This is shown in the table.

**Table 4.43**

| Activities | Free float |
|---|---|
| A | 7 |
| B | 0 |
| C | 0 |
| D | 2 |
| E | 2 |
| F | 0 |
| G | 0 |
| H | 0 |

Step 4: - Find the total requirement for all the days, this is equal to 101.Now divide this by the number of days to find constant resource requirement

Constant resource requirement = 101/11=9.1

Every day you should see that the number of resources requirement should not exceed 10. For doing so, you should give preference for the activity which has least free float.

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**Day1**
**Table 4.44**

| Activity | Free float requirement | Resource performed | Action to be |
|---|---|---|---|
| B | 0 | 3 | Scheduled |
| C | 0 | 6 | Scheduled |
| D | 2 | 4 | Postponed |
| A | 7 | 4 | Postponed |

In the day1, even though the free float for activity D is more than B. You should give preference to D because if you allot 'D' and 'C' on day1 it perfectly matches the maximum resources requirement 10.

**Day2**
**Table 4.45**

| Activity | Free float requirement | Resource performed | Action to be |
|---|---|---|---|
| B | 0 | 3 | Postponed |
| C | 0 | 6 | Continued |
| D | 2 | 4 | Continued |
| A | 6 | 9 | Postponed |

**Day3**
**Table 4.46**

| Activity | Free float requirement | Resource performed | Action to be |
|---|---|---|---|
| F | 0 | 7 | Scheduled |
| B | 0 | 3 | Scheduled |
| E | 2 | 8 | Postponed |
| A | 5 | 9 | Postponed |

**Day4**
**Table 4.47**

| Activity | Free float | Resource requirement | Action to be performed |
|---|---|---|---|
| F | 0 | 7 | Continued |
| B | 0 | 3 | Continued |
| E | 1 | 8 | Postponed |
| A | 4 | 9 | Postponed |

NOTES

Day5

**Table 4.48**

| Activity | Free float requirement | Resource performed | Action to be |
|---|---|---|---|
| E | 0 | 8 | Scheduled |
| G | 0 | 2 | Scheduled |
| A | 3 | 9 | Postponed |

**Day6**

**Table 4.49**

| Activity | Free float requirement | Resource performed | Action to be |
|---|---|---|---|
| E | 0 | 8 | Continued |
| G | 0 | 2 | Continued |
| A | 2 | 9 | Postponed |

**Day 7**

**Table 4.50**

| Activity | Free float requirement | Resource performed | Action to be |
|---|---|---|---|
| E | 0 | 8 | Continued |
| G | 0 | 2 | Continued |
| A | 2 | 9 | Postponed |

**Day 8**

**Table 4.51**

| Activity | Free float requirement | Resource performed | Action to be |
|---|---|---|---|
| A | 0 | 8 | Scheduled |
| H | | 0 | 2 Scheduled |

**Day 9**

**Table 4.52**

| Activity | Free float requirement | Resource performed | Action to be |
|---|---|---|---|
| A | 0 | 8 | Continued |
| H | 0 | 2 | Continued |

NOTES

**Day10**
**Table 4.53**

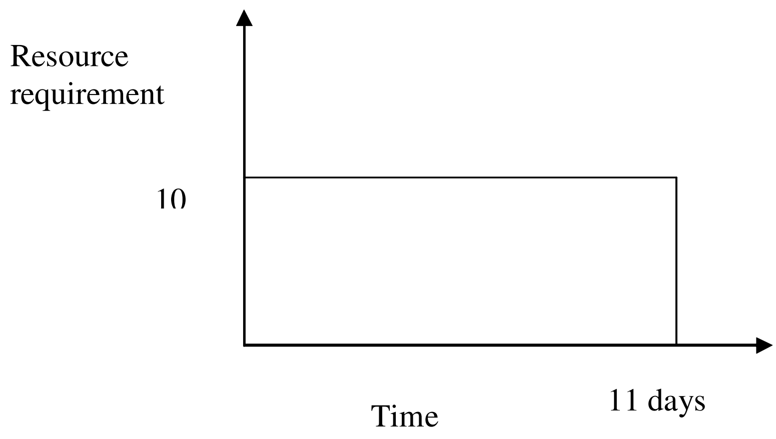
| Activity | Free float requirement | Resource performed | Action to be |
|---|---|---|---|
| A | 0 | 8 | Continued |
| H | 0 | 2 | Continued |

**Day11**
**Table 4.54**

| Activity | Free float requirement | Resource performed | Action to be |
|---|---|---|---|
| A | 0 | 8 | Continued |
| H | 0 | 2 | Continued |

Since for all the days the resources are scheduled as per the procedure mentioned. The requirement Vs time profile graph is as follows:

**Figure 4.18**



NOTES

## Summary

In this unit, the job shop scheduling for single machine n jobs, two machine n jobs, 3 machine n jobs and n job m machine are discussed. The project scheduling techniques namely the critical path method, program evaluation review technique are elaborated. The application of float is interpreted and appreciated. The resource leveling is also highlighted.

**Review Questions:**

1. Draw the network for the given precedence diagram.

**Table 4.55**

| Activities | Immediate predecessor |
|---|---|
| a | - |
| b | - |
| c | b |
| d | a,c |

2. How would you calculate the expected time and variance in the PERT model?
3. Expand CPM and PERT?

NOTES

# UNIT V

# FACILITY, LAYOUT LOCATION AND WORK MEASUREMENT

NOTES

# UNIT - 5

# FACILITY, LAYOUT LOCATION AND WORK MEASUREMENT

## 5.1 INTRODUCTION

The unit deals about one of the strategic decisions in the operations management, namely plant location decision, the characteristics of different layouts are discussed. The different techniques available to design the layout are also introduced. Work measurement technique like time study, work sampling and methods time measurement are elaborated to fix the standards for organizational activities. The impact of learning curve on the standard and productivity improvement is also discussed.

## 5.2 LEARNING OBJECTIVES

1. To comprehend the factors to be considered for selecting the location.
2. To know the characteristics of different types of layout.
3. Understand the techniques to be adopted in designing the layout.
4. To establish the standards for different activities using standard techniques.
5. To construct learning curve and to comprehend the impact of learning curve in standards and productivity.

## 5.3 FACILITY LOCATION

Facility location i.e. identifying the best location is a strategic decision in operation management. This is a decision like any other strategic decisions like identifying the product, choosing the technology, deciding the capacity etc. It is a long term decision. Once the resources are committed taken back the resources involves more cost because of change in the decision later. So you should be careful while identifying the various locations and choosing the best one.

**Need for the Decision**

1. Research and development department of an organization come up with a new product, to manufacture the product you need to incur the decision.

2. For the existing product, there is a lot of market potential so to tap the untapped market you have to expand the capacity. To expand the capacity, you have to identify the location.
3. Markets are served in a particular region, more competitions and high escalation of cost. It is difficult to survive then identifying the location where there is untapped market in the different regions.
4. Relocation required because of Tsunami, fire, flood, earthquake natural holocaust etc.

### 5.3.1 Selection of location

Selection of the best location involves two phases:

#### *5.3.1.1 Phase 1*

In the phase I a preliminary feasibility study is carried out to assess the production input, process technology, infrastructural facilities, social and cultural conditions and legal and government considerations.

**Production Input:**

***Raw material:***

It is important to assess the availability of raw material. The assessing is to be carried out in the point of view of the transportation cost and the amount or deposit. Suppose if you start a cement or aluminium industry the deposit of ore and how long it will be lost, that is to be assessed. You have to see the present requirements and future requirements and choose the place where the above conditions are fulfilled. The raw material supplier is for away then the transportation cost dominates the price that makes you less competitive.

***Labour inputs:***

When you assess the labour input, the quality of the labour is important. You may find the labours with fewer wages but the productivity of that labour may be low. So in addition to bothering about that wages, you should assess then the skill level also.

You can see now more foreign IT companies sources India. The main reasons are those companies identify abundant IT skills in India at comparatively lesser cost. So they sources India.

***Process Technology:***

Some times the technology restricts the choice of location e.g. to start a pulp and paper mills. You need water for processing so most of the pulp and paper mill industry are started in the river banks.

NOTES

***Infrastructural facilities:***

A study is very much required to asses well connected and land roads, parts, out parts, railway lines telecommunication facilities etc. This is important because it reduces the transportation cost and lead time. Lend time reduction show lot of saving in other costs. It helps the organization to be a cost competitive.

***Legal and political considerations:***

Governments woo the corporate to start industry in their respective countries or state through providing free land, exemption of taxes, subsided power tariffs, less cumbersome licensing procedures. In addition, the prospective person has to see that the legal formalities and complication. He / she has to study the government stipulation about the pollution standards to be exercised, zoning codes to be adopted import and export regulations prescribed and construction specifications etc.

***Social and cultural conditions:***

This is the process of exploring the attitude of the people towards the plant to be started over there. This study involves the skill availability and accessibility.

This study also involves the study about their demographic variables like the age distribution, income distribution, their status, their life conditions their tradition. Here, you should explain in detail to make them aware of the usefulness of plant to up lift them both economically and socially. At present, in India, since this process not carried out systematically and scientifically, many important projects are stalled by the people in many states like West Bengal, Orissa, Tamil Nadu, to state a few.

**5.3.1.2 Phase – II**

It there is a problem in the first phase, the second phase may not see the lime light. In the phase 1 macro analysis is over, in the second phase the region, community and site selection take place. Region include country to country or state-to-state within a country or within a state different regions. The factors to be considered in the selection of region, community and site are shown in the table.

The factors are considered under different major heading like infrastructure, market, supply, and environment and internal. You should note that most of the factors are considered in all the regional, community and site selection. For example, customer concentration and trends are considered in all region, community and site selection.

NOTES

Table 5.1

| Regional selection | Community Decision Infrastructure | Site Decision |
|---|---|---|
| Transportation network and their costs | Transportation network and their costs | Proximity to transpor tation system |
| Utilities supply and costs | Utilities supply and costs | Utilities supply and costs |
| | **Market** | |
| Customer concentration and trends. | Customer concentration and trends. | Customer concentration and trends. |
| | **Supply** | |
| Materials and supplies availability & accessibility | Materials and supplies availability & accessibility | Materials and supplies availability & accessibility |
| Labour availability & accessibility | Labour availability & accessibility | |
| Land and construction cost | Site availability cost & construction cost | |
| | | Size of the site |
| | | Site costs |
| | **Environment** | |
| The intensity of unionization towards the new facilities | Community attitudes | Zoning restrictions |
| Climate taxes | Community service & industry | Proximally to related |
| | Banking services | Environmental impact |
| Government SOPS | Government SOPS | |
| Environmental regulations | Environmental regulations | |
| | **Internal** | |
| | Preference of the management | |

## 5.4 PLANT LOCATION SELECTION

The selection of the plant is characterized by the subjective factors as well as the objective factors. But it is very difficult to quantify subjective factors. The plant location evaluation is done by considering both subjective and objective factors through a subjective evaluation known as Rating Plan Method. You can see in the following section, how the rating plan is applied to choose a place, where to start a Bio technology plant, in India.

NOTES

***To start a biotechnology plant what factors you consider and how do you evaluate the same using rating plan method.***

**Selection Criteria**

The important considerations for selecting a suitable location are given as follows:

a. Natural or climatic conditions.
b. Availability and nearness to the sources of raw material.
c. Transport costs-in obtaining raw material and also distribution or marketing finished products to the ultimate users.
d. Access to market: small businesses in retail or wholesale or services should be located within the vicinity of densely populated areas.
e. Availability of Infrastructural facilities such as developed industrial sheds or sites, link roads, nearness to railway stations, airports or sea ports, availability of electricity, water, public utilities, civil amenities and means of communications are important, especially for small scale businesses.
f. Availability of skilled and non-skilled labour and technically qualified and trained managers.
g. Banking and financial institutions are located nearby.
h. Locations with links: to develop industrial areas or business centers result in savings and cost reductions in transport overheads, miscellaneous expenses.
i. Strategic considerations of safety and security should be given due importance.
j. Government influences: Both positive and negative incentives to motivate an entrepreneur to choose a particular location are made available. Positive includes cheap overhead facilities like electricity banking transport, tax relief, subsidies and liberalization. Negative incentives are in form of restrictions for setting up industries in urban areas for reasons of pollution control and decentralization of industries.
k. Residence of small business entrepreneurs want to set up nearby their homelands.

One study of the locational considerations from the small-scale units revealed that the native place or homelands of the entrepreneur was the most important factor.

Heavy preference to homeland suggests that small-scale enterprise is not freely mobile. Low preference for Government incentives suggests that concessions and incentives cannot compensate for poor infrastructure.

In the rating plan method, ideal rating is considered for the factors, then how much rating each location scores against each factor is assessed and best location is chosen based on the highest total point.

NOTES

**Table 5.2 - Rating Plan Method To Evaluate The Factors For Plant Location:**

| Factors | Ideal Point | Lucknow | Bangalore | Pune |
|---|---|---|---|---|
| • Availability of technically qualified skilled labor. | 30 | 25 | 28 | 20 |
| • Availability and nearness to the source of material. | 20 | 15 | 17 | 15 |
| • Market Potential | 15 | 13 | 11 | 10 |
| • Access to the market | 5 | 4 | 5 | 4 |
| • Competitive Analysis | 5 | 5 | 2 | 3 |
| • Site Economics | 10 | 10 | 5 | 6 |
| • Positive Govt. Influences | 10 | 10 | 6 | 6 |
| • Strategic consideration of safety and security | 2 | 2 | 2 | 2 |
| • Rent or buy the property | 3 | 3 | 2 | 1 |
| **TOTAL POINT** | **100** | **87** | **78** | **67** |

In the above table, Lucknow scores more than the Pune and Bangalore.

### 5.4.2 Cost analysis method:

In the previous section, you saw how the rating plan method is applied, to choose the location. In this section, you can see a method, where only the objective factor is considered, namely the cost factors i.e., to start a plant in a particular location, based on the labour availability and accessibility, material availability and accessibility, you may have different variable cost as well as fixed cost for each location. Now based on the estimated fixed cost and variable cost, you can formulate for each location, a different a total cost equation. Once the total cost equation is arrived for each location by applying the cost volume profit analysis, you can estimate the range of production quantity at which the locations are preferred. You can understand above method through exapmle5.1.

**Example 5.1**

Consider a corporate office, which wants to identify the best location. They have identified 3 locations after a preliminary survey. They are locations A, B and C. The corporate has estimated the variable cost and fixed cost and then the total cost for the each location against the production quantity. This is shown in the table.

NOTES

**Table 5.3**

| SITE | Fixed cost **(Rupees in lakhs)** | **Variable cost (Rupees per unit)** |
|---|---|---|
| A | 2.5 | 1000 |
| B | 3 | 750 |
| C | 4 | 500 |

**Solution:**

Considering site A and B,

the total cost for site A for 'x' quantities = 250000 + 1000x. —— (1)
the total cost for site B for 'x' quantities = 300000 + 750x. —— (2)
Therefore from (1) and (2),

x = (300000 – 250000)/(1000-750)
= 200 units.

Considering site B and C,

the total cost for site B for 'x' quantities = 300000 + 750x. ——— (3)
the total cost for site C for 'x' quantities = 400000 + 500x. ——— (4)
Therefore from (3) and (4),

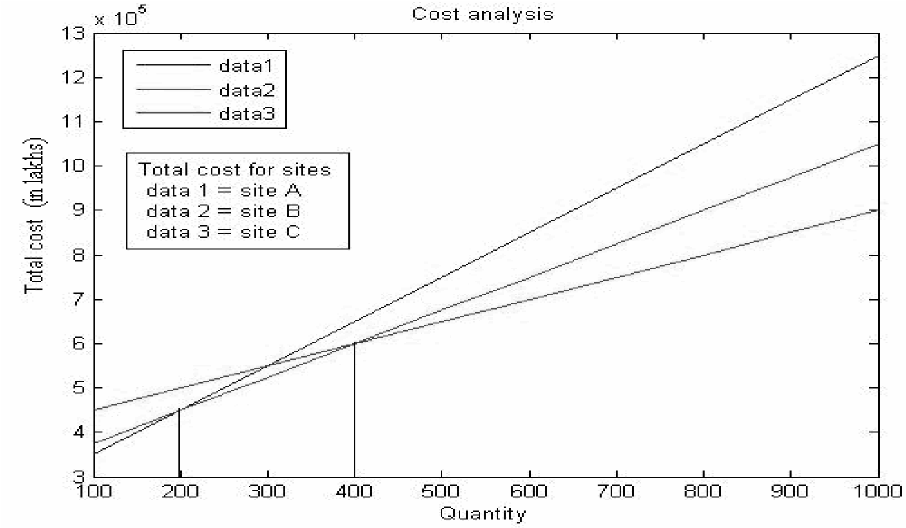
x = (400000 – 300000)/(750-500)
= 400 units.

Result,

If 'x' < 200 units, select site A as it has minimum fixed value.
If 200 < 'x' < 400 units, select site B as it has minimum variable cost compared to A and minimum total cost compared to C.

If 'x' > 400 units, select site C as it has the least variable cost.

**Graphical representation:**
**Figure 5.1**



NOTES

**Review Questions:**

1) Define facility location.
2) When will you go for facility location?
3) What are the phases in the facility location?
4) What the methods used for plant location selection?

## 1.3 TYPES OF LAYOUT

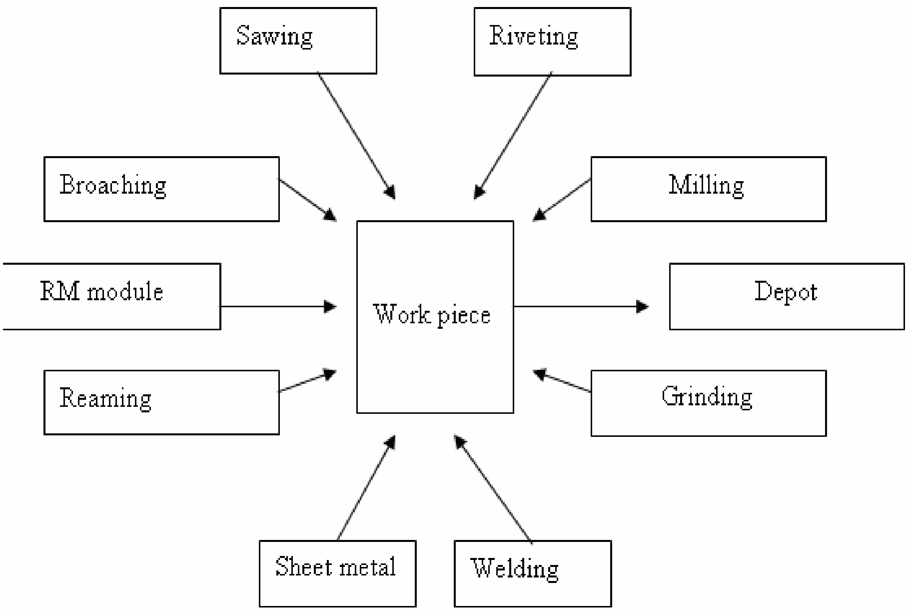
After selecting the plant location, based on the type of production system to be adopted, the layout has to be decided. The types of layout are:

1. Fixed product layout
2. Product layout
3. Group (flexible) layout
4. Process layout

### 5.5.1 Fixed Product Layout

The fixed product layout is developed by locating the workstations or production centers on the fixed job. Fixed layout type is used when the job size is large. Logistics are involved in ensuring that the right processes are brought to the product at the right time and at the right place. This has been mainly used in electronic industry to support computer systems integration and test; materials, sub assemblies, components, peripherals are brought to the single workstation where finished system is built. This type of layout requires generally higher number of personnel and equipments than the other types, since the work piece remains stationary.

**Figure 5.2 – Fixed Product Layout**



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**Advantages**:

1. This method is highly flexible and any changes in product design and product mix can be easily accommodated.
2. Since work centers are independent, scheduling results in achieving minimum total production time.
3. The teams of personnel are responsible for continuity of operations.
4. Movement of materials is reduced.
5. Job enlargement could be promoted by allowing individuals or teams to perform the whole job.

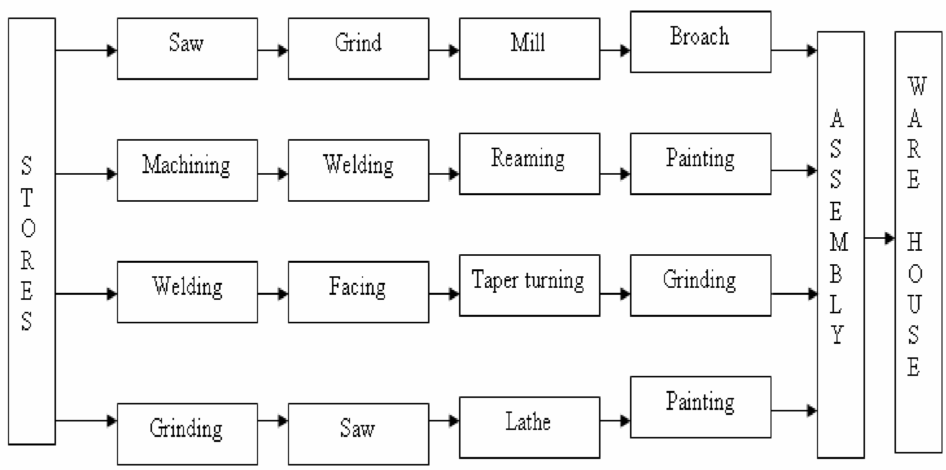
**Limitations:**

1. Skilled labour is required.
2. Supervision is required.
3. Positioning of material and machinery is costly and complex.
4. Equipment duplication may occur.
5. Utilization of equipment is required.

### 5.5.2 Product Layout

In this layout the machines are arranged according to the processing sequence of the product. Material flows directly from one workstation to other workstation. Machines are not shared by the products. This type of layout is used for high volume production. For proper utilization of machines sufficient production volume is required. Since the processes are located closed together in the production sequence, the layout minimizes the distance between the work center.

**Figure 5.3 – Product Layout**




**Advantages:**

1. The total production time is short.
2. The material handling is reduced because of the location of the machines to minimize the distances between the consecutive operations.

NOTES

3. Less skilled operator is required. Thus training is simple and short.
4. Less space is occupied by work in transit and temporary storage.
5. The flow is smooth and logical flow line results.
6. Small in process inventory as the work is directly fed from one process to other.

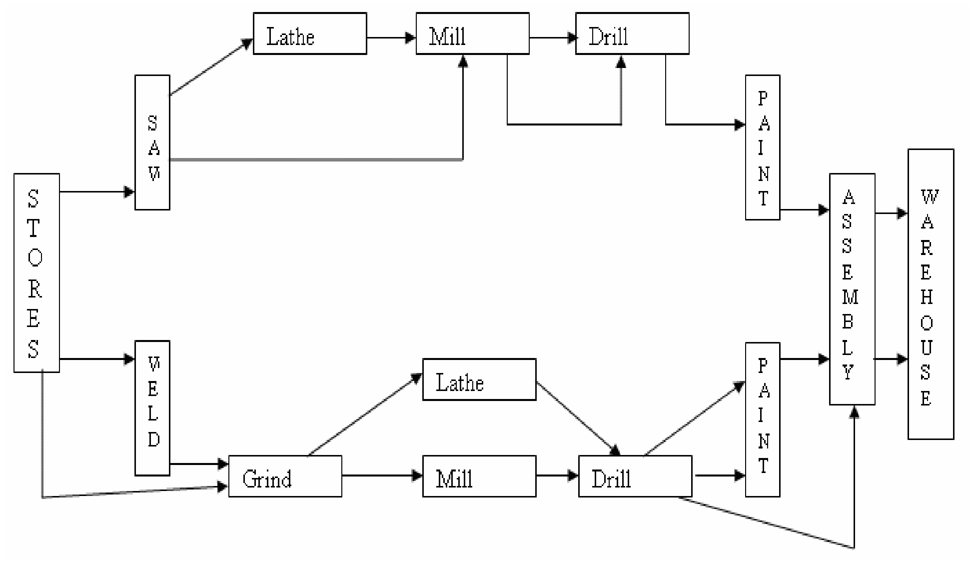
**Limitations**:

1. The production time is determined by the slowest machine.
2. A general supervision is required.
3. Since identical machines are arranged at various locations, initial investment is high.
4. A change in the product design requires an entire change in the layout.
5. A break down of one machine lead to complete stoppage of entire production.

### 1.5.3 Group Layout

When production volume is not sufficient for product layout, group layout is used. Here products are grouped in to logical product families. The groups of processes are called **cells**. So it is also called as **cellular layout**. It is a compromise between product and process layout. Since products are grouped into families this technology is also called as group technology with each individual cells are called GT cells.

**Figure 5.4 – Group Layout**




**Advantages:**

1. This supports the use of general purpose equipments.
2. This is a compromise between product and process layout.
3. Shorter travel distances and smoother flow lines than process layout.

NOTES

4. Team attitude and job enlargement tend to occur.
5. Utilization of each machine is increased.

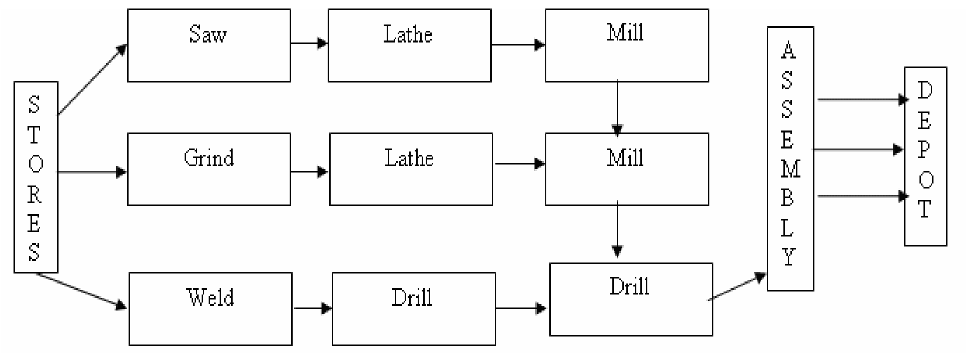
**Limitations:**

1. Higher skilled employees are required
2. General supervision is required.
3. It depends on the balanced material flow through the cell otherwise buffers and WIP storage are required.

### 1.5.3 Process Layout

In this type the machine are grouped and the product passes from one group to other group based on the sequence of production. The groups of processes are called cells. The process layout is used in the rapid changes in the product mix or production volume as well as when both product and group layout cannot be used. Typically job shop employs process layout due to the variety of products manufactured and their low production volume. It has high degree of inter departmental flow.

**Figure5.5 – Process Layout**




**Advantages:**

1. Since the machines are grouped, only fewer machines are required; thus minimum investment is required.
2. Better utilization of machines could be achieved.
3. High degree of flexibility exists.
4. Supervision could be specialized.
5. The working personnel find the job more satisfying and interesting since there is a diversity of tasks.

**Limitations:**

1. Highly skilled labour is required.
2. Work in process inventory is increased.

NOTES

3. Total production time is longer
4. Planning and control of production system turns out to be tedious.
5. Space and capital are tied up by the work in process.
6. Material handling is more expensive because of longer flow line.

### 5.5.5 Design of Process Layout

To design a process layout there are some computerized techniques available. Computerized techniques are classified into:

- Techniques which select the best process layout based on the material cost comparison.
- Other computerized techniques which select the best process layout based on the qualitative factors namely the closeness between the departments.

Closeness ratings are as follows:

A – Absolutely essential
E - Ordinary closeness
I – Important
O – Ordinary importance
U – Un important
X – Not desirable.

**CRAFT (Computerized Relationship Allocation of Facilities Techniques)**

CRAFT algorithm was originally developed by Armour and Buffa. CRAFT is more widely used than ALDEP and CORELAP. It is an improvement algorithm. It starts with an intial layout and improves the layout by interchanging the departments pairwise so that the transportation cost is minimized. The algorithm continues until no further interchanges are possible to reduce the transportation cost. The result given by CRAFT is not optimum in terms of minimum in majority of applications. Hence, CRAFT is mainly a heuristic algorithm.Unfortunately, plant layout problem comes under combinatorial category. So, usage of efficient heuristic like CRAFT is inevitable for such problem.

CRAFT Requirements:

1. Initial layout.
2. Flow data.
3. Cost per unit distance.
4. Total number of departments.
5. Fixed departments.
   Number of such departments
   Location of those departments
6. Area of departments.

NOTES

**CRAFT Procedure**

The steps of CRAFT algorithm are summarized below:

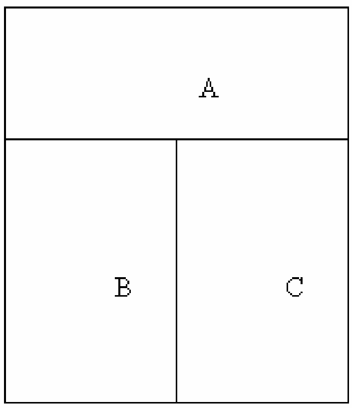
Step 1. Input: 1. Number of departments
2. Number of interchangeable departments
3. Intial layout
4. Cost matrix
5. Flow matrix
6. Area of departments

Step 2. Compute centroids of departments in the present layout.
Step 3. Forum distance matrix using the centroids.
Step 4. Given data on flow, distance and cost, compute the total handling cost of the present layout.

Step 5. Find all the possible pairwise interchanges of departments based on common border or eqal area criterion. For each possibility, interchange the corresponding centroids and compute approximate costs.

Step 6. Find the pair of departments corresponding to the minimum handling cost from among all the possible pairs of interchanges.
Step 7. Is the cost in the previous step less than the total cost of the present layout? If yes, go to step 8.If not go to step 11.
Step 8. Interchange the selected pair of departments.Call this as the NEW LAYOUT. Compute centroids, distance matrix and total cost.
Step 9. Is the cost of new layout less than the cost of the present layout? If yes, go to Step 10.If not, go to Step 11.
Step 10.The new layout is hereafter considered as the present layout.its data on centroids, layout matrix and the total cost is retained. Go to step 5.
Step 11. Print the present layout as the FINAL LAYOUT.
Step 12. Stop

**LAYOUT:**
**Figure 5.6**



NOTES

**Figure 5.8**

| | | | |
|---|---|---|---|
| | A | B | C |
| A | | 100 | 100 |
| B | 100 | | 25 |
| C | 100 | 25 | |

| | | | |
|---|---|---|---|
| C | 2 | 1 | |

Flow matrix:

| | | | |
|---|---|---|---|
| | A | B | C |
| A | | 1 | 1 |
| B | 1 | | 1 |
| C | 1 | 1 | |

1) Iteration 1: calculate the distance matrix.

Distance between two departments = |x1-x2| + |y1-y2|

Where,

(X1, y1) is the centre of department 1

Centroids of A,B and C,

A(50,125)
B(25,50)
C(75,50)

DISTANCE MATRIX:

**Figure 5.9**

| | | | |
|---|---|---|---|
| | A | B | C |
| A | | 100 | 100 |
| B | 100 | | 25 |
| C | 100 | 25 | |

1) Determine the total cost for all possible movements between each department.

Cost between two departments = Distance matrix X Cost matrix

NOTES

**Figure 5.10**

| | A | B | C | |
|---|---|---|---|---|
| A | | 400 | 100 | 500 |
| | 200 | | 50 | 250 |
| C | 200 | 25 | | 225 |
| | 400 | 425 | 150 | 975 |

TOTAL COST : 975

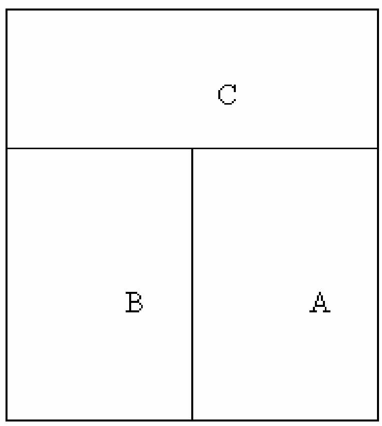
1) Re allocation of departments,
   In this step the departments are interchanged. For interchanging
   1. Both departments should have the same area (or)
   2. Both departments should share common boundary
2) After reallocating find the new centroid and repeat step 2 and 3.

**ITERATION 2**

Interchange A and C (Because A and C have common border and same area)
Therefore new Centroids are,

C (50,125)
B (25,150)
A (75, 50)

**Figure 5.11**



NOTES

**DISTANCE MATRIX:**
**Figure 5.12**

| | A | B | C |
|---|---|---|---|
| A | | 25 | 100 |
| B | 25 | | 100 |
| C | 100 | 100 | |

**COST MATRIX:**
**Figure 5.13**

| | A | B | C | |
|---|---|---|---|---|
| A | | 100 | 100 | 200 |
| | 50 | | 200 | 250 |
| C | 200 | 100 | | 300 |
| | 250 | 200 | 300 | 750 |

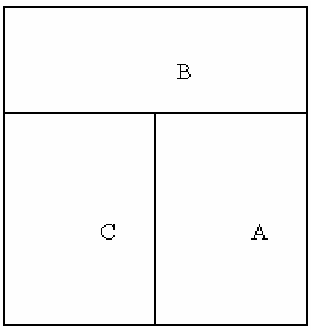
TOTAL COST: 750

**ITERATION 3:**

Interchange B and C (Because B and C have common border and same area). Therefore new centroid are,

B (50,175)
C (25, 50)
A (75, 50)

**Figure 5.14**



**DISTANCE MATRIX:**
**Figure 5.15**

| | A | B | C |
|---|---|---|---|
| A | | 100 | 25 |
| B | 100 | | 100 |
| C | 25 | 100 | |

**COST MATRIX:**
**Figure 5.16**

| | A | B | C | |
|---|---|---|---|---|
| A | | 400 | 25 | 425 |
| | 200 | | 200 | 400 |
| C | 50 | 100 | | 150 |
| | 250 | 500 | 225 | 975 |

**TOTAL COST: 975**

5) Check total cost for all the possible reallocations and select the layout with minimum total cost.
6) Repeat the iterations till the least total cost is achieved. This layout is optimum solution.

In the given problem layout seems to be optimal compared to other two layouts. Now taking layout 2 as base layout, continue further iterations to find the least cost. That layout is the optimal solution.

**Corelap Algorithm**

**Input data requirement**

1. Relationship chart and closeness rating.
2. Building description is given by maximum length to width ratio.

**Objective**

1. Maximizing overall closeness rating.

**How the software programs works**

First he found out the closeness rating between the departments. It has to be placed in layout. If there is any type select the department which is high in closeness rating. If there is again tie select the department which is larger in area. If the tie still exists then select any department randomly.

**Output**

Computer printout shows final layout.

**Determination of placement order of department:**

For the purpose of finding the order of placing the departments the following data are needed.

**REL- chart and closeness ratings:**

REL –chart:

**Table 5.4**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | - | | | | | | |
| 2 | E | - | | | | | |
| 3 | O | U | - | | | | |
| 4 | I | E | U | - | | | |
| 5 | O | I | U | I | - | | |
| 6 | U | I | O | U | | - | |
| 7 | U | U | U | U | I | E | - |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

CLOSENESS VALUES:

A=6, E-5, I=4, O=3, U=2, and X=1

Using the closeness rating TCR (total closeness rating) is calculated thus:

NOTES

**Table 5.5**

| Dep. | Closeness relationship. | | | | | | TCR |
|---|---|---|---|---|---|---|---|
| 1 | E | O | I | O | U | U | 19 |
| 2 | E | U | E | I | I | U | 22 |
| 3 | O | U | U | U | O | U | 14 |
| 4 | I | E | U | I | U | U | 19 |
| 5 | O | I | U | I | A | I | 23 |
| 6 | U | I | O | U | A | E | 22 |
| 7 | U | U | U | U | I | E | 17 |

The following steps are carried out to select the placement order of the departments.

1. Department with the largest TCR is selected for the first placement. In case of ties, the department with the largest area is selected. Department 5 is selected.
2. Review the closeness relationship of department 5 with other departments to find the department that has the highest closeness relationship with department 5.

**Table 5.6**

| 1 | 2 | 3 | 4 | 6 | 7 |
|---|---|---|---|---|---|
| O | I | U | I | A | I |

Department 6 has the highest closeness relationship with the department 5. So it has to be placed next to department 5.

3. Check the closeness relationship for both the departments.

**Table 5.7**

| Departments | 1 | 2 | 3 | 4 | 7 |
|---|---|---|---|---|---|
| Closeness with 5. | O | I | U | I | I |
| Closeness with 6. | U | I | O | U | E |

NOTES

In the above study department 7 has high closeness rating with 6. Thus it has to be placed in the layout next.

Similarly, if there is a tie in closeness rating, then select the department with the highest TCR.

If there is a tie again, then select a department with larger area. In case of tie in both conditions, then select a department randomly. Order of placement:

5 → 6 → 7 → 2 → 1 → 4 → 3

**PLACEMENT OF DEPARTMENTS IN THE LAYOUT:**

**Table 5.8**

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | 5 | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |

1. The first department to be placed is 5. it is placed in the centre of a (7x 15) layout. Each cell has an area of 6000 sq.mt.
2. The second department from the list is department 6. It is thus placed.

**Table 5.9**

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |
| | | | | 6 | 6 | | | | | | | | | |
| | | | | | 5 | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |

(Department 6 has two squares. It can be placed thus…)

NOTES

3. Department 7 has to be placed. It has two squares. It can be placed thus in three ways.

**Table 5.10**

| | | | |
|---|---|---|---|
| 7 | 7 | | |
| | 6 | 6 | |
| | 5 | | |
| | | | |

**Table 5.11**

| | | | |
|---|---|---|---|
| | | | |
| | 6 | 6 | 7 |
| | | 5 | 7 |
| | | | |

**Table 5.12**

| | | | |
|---|---|---|---|
| | | | |
| | 6 | 6 | |
| 7 | 7 | 5 | |
| | | | |

In the above case we have to find the weighted rating for each department.

WEIGHTED DEPARTMENT RATING

**Table 5.13**

| Closeness relationship | Weighted rating. |
|---|---|
| A | 243 |
| E | 81 |
| I | 27 |
| O | 9 |
| U | 1 |
| X | -729 |

a. Department 7 with department 6 = E = 81,
Therefore placement rating = 81.
b. Weighted rating of 7 with 6 = 81
Weighted rating of 7 with 5 = 27

Total = 108

Similarly, for the other layout also, the rating is 108.
Thus we have to select either b. or c. layouts… let us take c. layout…

1. Next department 2 has to be placed.

**Table 5.14**

| | | | |
|---|---|---|---|
| | | | |
| 2 | 6 | | 6 |
| 7 | 7 | | 5 |
| | | | |

NOTES

PLACEMENT RATING = (27+1) = 28.
No other allocation has maximum placement rating…

2. Next department 1 has to be placed. It has the following four possibilities.

**Table 5.15**

| | | | |
|---|---|---|---|
| 1 | 1 | | |
| 2 | 6 | 6 | |
| 7 | 7 | 5 | |
| | | | |

a.

**Table 5.16**

| | | | |
|---|---|---|---|
| | | | |
| 2 | 6 | 6 | |
| 7 | 7 | 5 | |
| | 1 | 1 | |

b.

**Table 5.17**

| | | | |
|---|---|---|---|
| | | | |
| 1 | 2 | 6 | 6 |
| 1 | 7 | 7 | 5 |
| | | | |

c.

**Table 5.18**

| | | | |
|---|---|---|---|
| | | | |
| 2 | 6 | 6 | 1 |
| 7 | 7 | 5 | 1 |
| | | | |

d.

PLACEMENT RATING:

A. Weighted rating with department 6 and 2 = 82
B. Weighted rating with department 6 and 5 = 10
C. Weighted rating with department 7 and 5 = 10
D. Weighted rating with department 7 and 2 = 82

**Table 5.19**

| | | | |
|---|---|---|---|
| 1 | 1 | | |
| 2 | 6 | 6 | |
| 7 | 7 | 5 | |
| | | | |

The above arrangement is selected randomly (between A. & D.)

6. Next department 4 has to be placed. It has the following five possibilities.

NOTES

**Table 5.20**

| | | | |
|---|---|---|---|
| 4 | 1 | 1 | |
| 4 | 2 | 6 | 6 |
| | 7 | 7 | 5 |
| | | | |

**Table 5.21**

| | | | |
|---|---|---|---|
| | 1 | 1 | |
| 4 | 2 | 6 | 6 |
| 4 | 7 | 7 | 5 |
| | | | |

**Table 5.22**

| | | | |
|---|---|---|---|
| | 1 | 1 | |
| | 2 | 6 | 6 |
| | 7 | 7 | 5 |
| | | 4 | 4 |

**Table 5.23**

| | | | |
|---|---|---|---|
| 1 | 1 | | |
| 2 | 6 | 6 | 4 |
| 7 | 7 | 5 | 4 |
| | | | |

**Table 5.24**

| | | | |
|---|---|---|---|
| 1 | 1 | 4 | 4 |
| 2 | 6 | 6 | |
| 7 | 7 | 5 | |
| | | | |

e.

PLACEMENT RATING:

A. Weighted rating with department 1 and 2 = 108
B. Weighted rating with department 2 and 7 = 82
C. Weighted rating with department 7 and 5 = 28
D. Weighted rating with department 6 and 5 = 28
E. Weighted rating with department 1 and 6 = 28

**Table 5.25**

| | | | | |
|---|---|---|---|---|
| 4 | 1 | 1 | | |
| 4 | 2 | 6 | 6 | |
| | 7 | 7 | 5 | |
| | | | | |

The above arrangement is selected.(A.)

1. The last department to be placed is department 3.

**Table 5.26**

| | | | | |
|---|---|---|---|---|
| 4 | 1 | 1 | 3 | |
| 4 | 2 | 6 | 6 | |
| 7 | 7 | 5 | | |
| | | | | |

The above placement of department 3 has maximum placement rating. (Based on REL). Thus the layout is allocated with all the departments as follows.

**Table 5.27**

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |
| | | | | 4 | 1 | 1 | 3 | | | | | | | |
| | | | | 4 | 2 | 6 | 6 | | | | | | | |
| | | | | | 7 | 7 | 5 | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |

**Total Score of The Layout:**

Total score of the layout is the sum of the products found by multiplying the length of the shortest path between all departments and the numerical closeness value for the pairs.

$$\text{Total score} = \Sigma_{\text{For all pairs}} (\text{Closeness rating x length of shortest path})$$

The path is calculated by the rectilinear distance from the border of one department to the border of the other one.

Therefore, if two departments are adjacent, they will have common border. The path length will be zero.

Total score of the above layout is given as follows:

NOTES

**Table 5.28**

| | Department to | Distance | Closeness | Score |
|---|---|---|---|---|
| 1 | 2 | 0 | - | - |
| 1 | 3 | 0 | - | - |
| 1 | 4 | 0 | - | - |
| 1 | 5 | 2 | 3 | 6 |
| 1 | 6 | 0 | - | - |
| 1 | 7 | 1 | 2 | 2 |
| 2 | 3 | 2 | 2 | 4 |
| 2 | 4 | 0 | - | - |
| 2 | 5 | 2 | 4 | 8 |
| 2 | 6 | 0 | - | - |
| 2 | 7 | 0 | - | - |
| 3 | 4 | 2 | 2 | 4 |
| 3 | 5 | 1 | 2 | 2 |
| 3 | 6 | 0 | - | - |
| 3 | 7 | 2 | 2 | 4 |
| 4 | 5 | 3 | 4 | 12 |
| 4 | 6 | 1 | 2 | 2 |
| 4 | 7 | 1 | 2 | 2 |
| 5 | 6 | 0 | - | - |
| 5 | 7 | 0 | - | - |
| 6 | 7 | 0 | - | - |
| Total | | | | 46 |

Thus the procedure to find the total score ends with this step. One can repeat the procedure with different scales and pick up the best layout with the **MINIMUM TOTAL SCORE…**

**ALDEP** (**Automated layout Programming**):

ALDEP is a construction type algorithm .This algorithm uses basic data on facilities and builds a design by successively placing the departments in the layout. After placing all the departments in the layout, a score is computed .This is nothing but the sum of the closeness rating values of different neighbouring departments in the layout. This algorithm is repeated for a prespecified number of times and the best layout is selected based on the maximum layout score.

The basic data required for this algorithm are listed below.

1. Total number of departments.
2. Area of each department .
3. Length and width of layout.
1. Closeness ratings of various pairs of departments in the form of Relationship Chart.
2. Minimum department preference (MDP) value.
3. Sweep width.
4. Number of iterations to be performed.
5. Location and size of each restricted area in the layout if present.

**Steps to be followed**:

Step 0.INPUT:

1) Number of departments in the layout.
2) Area of each department.
3) Length and width of the layout.
4) REL-CHART (Relationship chart).
5) MDP value.
6) Sweep width.
7) Number of iterations to be carried (N).
8) Current iteration number(I),1.
9) 9.Locations and sizes of fixed departments if present.
10) 10.score of the current layout (It is assumed as a very high negative value before performing the first iteration).

Step 1. Select a department randomly and place it in the layout.
Step 2. Scan the relationship (REL) – chart and classify the unselected departments into two lists, namely List A and List B.

List A contains the unselected departments whose relationship values in relation to the lastly selected department are less than the MDP value.
List B contains the unselected departments whose relationship values in relation to the lastly selected department are greater than or equal to the MDP value.
Step 3. Is the List B empty? If so , go to step 4;otherwise,go to step 5.
Step 4. Select a department randomly from List A and place it in the layout. go to step 6
Step 5. Select a department from List B which has the maximum REL value in relation to the lastly selected department and place it in the layout.
Step 6. Whether all the departments are placed in the layout? If not go to step 2; if yes, go to step 7.
Step 7. Compute the score of the layout.

NOTES

Step 8. Is the score of the layout more than the score of the current best layout? If yes, update the new layout as the current best layout and store the corresponding score. otherwise, drop the new layout.

Step 9. Is the current iteration number I =N? if yes, go to step 10; otherwise, increment the iteration number by one (I =I+1) and then go to step 1.

Step 10. Print the current best layout and the corresponding score.

**STEPS OF ALDEP:**

1. Get the inputs. (REL chart, Department area, layout plan)

(A=64, E=16, I=4, O=1, U=0, X=-1024)

The REL diagram for a plant with 11 departments is as follows:

**Table 5.29**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | |
| 2 | A | | | | | | | | | | |
| 3 | E | E | | | | | | | | | |
| 4 | U | E | U | | | | | | | | |
| 5 | O | U | O | O | | | | | | | |
| 6 | U | U | U | E | O | | | | | | |
| 7 | X | U | O | O | U | U | | | | | |
| 8 | U | U | O | O | U | O | A | | | | |
| 9 | U | U | O | O | U | I | O | O | | | |
| 10 | U | U | O | O | I | O | O | O | O | | |
| 11 | U | O | U | A | I | E | A | A | E | I | |

1) Based on the area of all the departments, fix an appropriate scale. Based on the scale divide the departments in to number of square blocks.

NOTES

**Table 5.30**

| DEPARTMENT | AREA | NO. OF SQUARES |
|---|---|---|
| 1 | 600 | 12 |
| 2 | 400 | 8 |
| 3 | 350 | 7 |
| 4 | 150 | 3 |
| 5 | 350 | 7 |
| 6 | 150 | 3 |
| 7 | 200 | 4 |
| 8 | 800 | 16 |
| 9 | 200 | 4 |
| 10 | 350 | 7 |
| 11 | 5000 | 50 |

(SCALE: 1: 50, i.e. each cell in the layout is assumed to be a square of area 50 sq. units).

1. Draw an initial layout based on the layout area or based on the total area of all the departments. Divide the departments in to the basic number of squares. (Sum of all department squares).

1) **ITERATION-1:**

   a. Initially assume a closeness rating of "0".
   b. Fix a cut-off value for the department selection. (i.e.) "A" or "E" or "I"...
   c. Initially place a department randomly or the department with the max. area.
   d. Then from the candidate (remaining) departments, select a department with the maximum cut-off value with the previously placed department.

2) **SERPENT TYPE ALLOCATION:**

While allocating/placing each department in the layout, it has to be laid out in the following sequence. (Each cell is area of 50 in sq. units… based on the scale).

**NOTES**

**Table 5.31**

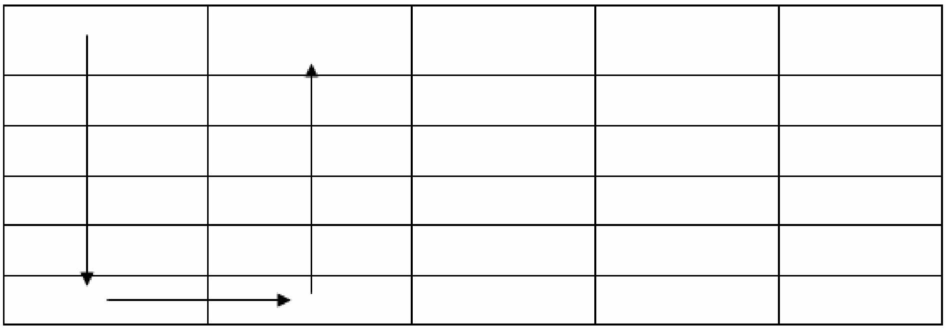


**Table 5.32**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 11 | 11 | 9 | 10 | 2 | 2 | 7 | 7 | 0 | 0 |
| 11 | 11 | 11 | 9 | 10 | 2 | 2 | 7 | 0 | 0 | 0 |
| 11 | 11 | 11 | 9 | 10 | 2 | 2 | 7 | 0 | 0 | 0 |
| 11 | 11 | 11 | 9 | 10 | 2 | 2 | 8 | 0 | 0 | 0 |
| 11 | 11 | 11 | 6 | 10 | 1 | 3 | 8 | 0 | 0 | 0 |
| 11 | 11 | 11 | 6 | 10 | 1 | 3 | 8 | 0 | 0 | 0 |
| 11 | 11 | 11 | 6 | 10 | 1 | 3 | 8 | 0 | 0 | 0 |
| 11 | 11 | 11 | 4 | 5 | 1 | 3 | 8 | 0 | 0 | 0 |
| 11 | 11 | 11 | 4 | 5 | 1 | 3 | 8 | 0 | 0 | 0 |
| 11 | 11 | 11 | 4 | 5 | 1 | 3 | 8 | 0 | 0 | 0 |
| 11 | 11 | 11 | 11 | 5 | 1 | 3 | 8 | 0 | 0 | 0 |
| 11 | 11 | 11 | 11 | 5 | 1 | 8 | 8 | 0 | 0 | 0 |
| 11 | 11 | 11 | 11 | 5 | 1 | 8 | 8 | 0 | 0 | 0 |
| 11 | 11 | 11 | 11 | 5 | 1 | 8 | 8 | 0 | 0 | 0 |
| 11 | 11 | 11 | 11 | 1 | 1 | 8 | 8 | 0 | 0 | 0 |

6) If in there is a tie or no department satisfies the cut-off value during the selection of candidate department, then place a department randomly.

7) Calculation of TCR (Total Closeness Rating):

a. Once all the departments are placed, then the next step is to calculate TCR.

NOTES

b. Make a note of all the pair of departments sharing common border with each other. (Note a pair only once i.e. either 1-3 or 3-1).

c. Now add up all the pairs' REL points…

d. Then multiply it by 2.

**Table 5.33**

| Pairs | REL points |
|---|---|
| 11-1 | 0 |
| 11-9 | 16 |
| 11-6 | 16 |
| 11-4 | 64 |
| 11-5 | 4 |
| 9-10 | 1 |
| 9-64 | |
| 6-10 | 1 |
| 6-4 | 16 |
| 4-5 | 1 |
| 10-2 | 0 |
| 10-5 | 4 |
| 5-1 | 1 |
| 2-8 | 0 |
| 2-3 | 16 |
| 2-1 | 64 |
| 1-3 | 16 |
| 1-8 | 0 |
| 3-8 | 1 |
| 7-8 | 64 |
| 2-7 | 0 |
| | 290 |

Thus the Total Closeness Rating is (290*2) = 580

7) This is the TCR value for the initial layout.

8) Keeping this as the minimum value continue the steps (4-7) for all the possible layouts and calculate the TCR value for all the layouts. Once iteration results in a TCR value less than the immediately previous layout's TCR value then that layout is the optimal solution.

NOTES

**Table 5.34**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 11 | 11 | 8 | 8 | 6 | 9 | 1 | 1 | 0 | 0 |
| 11 | 11 | 11 | 8 | 8 | 6 | 9 | 1 | 0 | 0 | 0 |
| 11 | 11 | 11 | 8 | 8 | 6 | 9 | 1 | 0 | 0 | 0 |
| 11 | 11 | 11 | 8 | 8 | 4 | 9 | 1 | 0 | 0 | 0 |
| 11 | 11 | 11 | 8 | 8 | 4 | 3 | 1 | 0 | 0 | 0 |
| 11 | 11 | 11 | 8 | 8 | 4 | 3 | 1 | 0 | 0 | 0 |
| 11 | 11 | 11 | 7 | 8 | 5 | 3 | 1 | 0 | 0 | 0 |
| 11 | 11 | 11 | 7 | 8 | 5 | 3 | 1 | 0 | 0 | 0 |
| 11 | 11 | 11 | 7 | 8 | 5 | 3 | 1 | 0 | 0 | 0 |
| 11 | 11 | 11 | 7 | 8 | 5 | 3 | 1 | 0 | 0 | 0 |
| 11 | 11 | 11 | 11 | 10 | 5 | 3 | 1 | 0 | 0 | 0 |
| 11 | 11 | 11 | 11 | 10 | 5 | 2 | 2 | 0 | 0 | 0 |
| 11 | 11 | 11 | 11 | 10 | 5 | 2 | 2 | 0 | 0 | 0 |
| 11 | 11 | 11 | 11 | 10 | 10 | 2 | 2 | 0 | 0 | 0 |
| 11 | 11 | 11 | 11 | 10 | 10 | 2 | 2 | 0 | 0 | 0 |

Total Closeness Rating:

**Table 5.35**

| **Pairs** | **REL points** |
|---|---|
| 11-8 | 64 |
| 11-7 | 64 |
| 11-10 | 4 |
| 8-7 | 64 |
| 8-10 | 1 |

NOTES

| | |
|---|---|
| 8-6 | 1 |
| 8-4 | 1 |
| 8-5 | 0 |
| 10-5 | 4 |
| 10-2 | 0 |
| 6-9 | 4 |
| 6-4 | 16 |
| 4-5 | 1 |
| 4-9 | 1 |
| 4-3 | 0 |
| 5-2 | 0 |
| 5-3 | 1 |
| 9-1 | 0 |
| 9-3 | 1 |
| 3-2 | 16 |
| 3-1 | 16 |
| 1-2 | 64 |
| | 319 |

Thus the Total Closeness Rating is (319*2) = 638.

Thus Iteration 2 shows that layout 2 has high TCR value compared to layout 1. Thus layout 2 is an optimal one compared to layout 1. Similarly, iterations are continued to find the optimal layout.

### a. LINE BALANCING

This is a technique applied to design workplace of a plant, which adopts flow line production system. You know that the productive system of flow line production produces less variety and standardized products. So the capacity of the system is to be established first or the no. of units produced per day.

NOTES

**Figure 5.17 – Line Balancing**


**Objective:** To design an effective and efficient workplace.

**Input:**
**Capacity:**

The capacity as it is mentioned already that the capacity is measured through the output. In an automobile industry it may be number of cars to be produced in a day. To decide the capacity you need to have the information about the demand for the product. Yearly demand has been converted into day to day capacity requirement.

**Technological constraints:**

Technological constraint that means when you are manufacturing a product, there is a sequence in which the operation on the components is to be carried out then the produced components are assembled according to the particular sequence. For example in the case of electric motor manufacturing activity the activities and immediate predecessor activity to be carried out are given below:

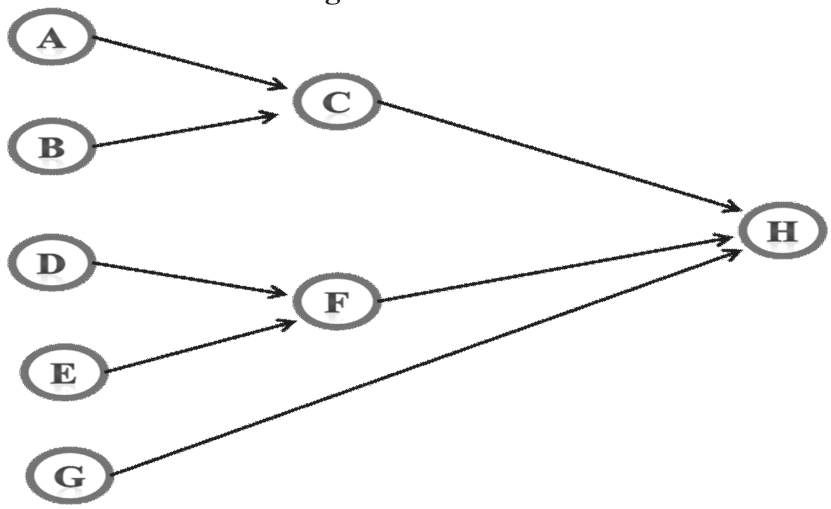
**Table 5.36**

| Activities | | ImmediateActivities | Min |
|---|---|---|---|
| A | Axile manufacturing | - | 700 |
| B | Rotar manufacturing | - | 800 |
| C | Rotar assembly | A, B | 400 |
| D | Stator manufacturing | - | 200 |
| E | Stator cashing manufacturing | - | 400 |
| F | Stator assembly | D, E | 300 |
| G | Protective shield manufacturing | - | 500 |
| H | Final assembly | C, E, F | 300 |

The above relationship could be shown in a network form as follows for clear understanding.

NOTES

**Figure 5.18**




**Available Working time:**

The available working time is the total working hours available based on the time frame. Example: if the capacity calculation is done for the day then the available hour's calculation is done for day. If there is one shift of 8 hours duration then the available time in seconds is calculated as 8 x 60 x 60 second.

= 28,800 seconds

**Technological constraint continuation**:

Each activity is considered to be an element. An element is a distinct that of a specified job. This is done for the purpose of observation, measurement and analysis. Against each element the time for completing the activity is also estimated.

**Output:**
**Number of stations:**

Based on the available working time per day, the no. of units to be manufactured, and the total work content, the no. of stations are calculated as follows:

No. of stations = 3600 x 35 units

$$= \frac{\text{[Total work content per unit] [Desired no. of units per day]}}{\text{Total productive time available per day}}$$

= 8 x 60- x 60

= 4.375

= 5 stations

NOTES

**Maximum allowable time:**

From this you can calculate the maximum allowable time for each station

$$= \frac{\text{Total available hours}}{\text{Desired no. of units per day}}$$

= 8 x 60 x 60 /35
= 823 seconds.

**Minimum Allowable time:**

This is the highest elemental time. In this example the highest elemental time is 800 seconds. The maximum and minimum allowable time helps you to assess the efficiency and effectiveness of the proposed designs.

**Assignment of the job elements to the workstations**:

A method is to be adopted to assign the jobs to workstations. The method may be an optimal method or heuristic method. In heuristic method, you may get best solution but there is no guarantee that you may get a solution. But it helps to get nearer to best solution. One such a procedure is the longest operation time (LOT) Remaining. Longest Operation time remaining means after assigning a particular task to a work station. You should find out the remaining unassigned elements and choose the element with highest operation time. Then add the element with the already assigned element. You should be careful enough that the total element time in a particular workstation should not exceed the cycle time established. Suppose the element considered for assigning could not be assigned because the total elemental time at the workstation increased beyond the cycle time, then in such case, you should look for the next highest remaining elemental time. The above mentioned caution is to be followed before assigning the element to the work station. Thus process is continued till all the elements are assigned.

Assignment of elements for 823 seconds work station cycle time

**Table 5.37**

| | | | | |
|---|---|---|---|---|
| B | A | C & E | D & F | G & H |
| I WS | II | III | IV | V |
| | WS | WS | WS | WS |

WS – Work

**Station I:**

Consider the highest elemental time. This is element B it could be straight away assigned to station because it does not have any predecessor. Next 5 highest elemental time is 700 that is element A. But element A could not be assigned because if you assigned A the stations sum of elemental time exceeds the time cycle time 823 seconds. This reason holds good for other remaining elemental times.

**Station II:**

In Station II you can assign element A. This has elemental time of 700 second. You can not assign any remaining elements to station II because the total elemental time exceeds the cycle time.

**Station III:**

In Station III the remaining highest elemental time is 500 minutes that is of element G. But before assigning the activities, you should complete other activities as per the technological constraints. So next highest operational elements are C & E, so C & E are
assigned to station III. No. other elemental could be assigned to station III.

**Station IV:**
**Table 5.38**

Line design for 800 seconds

| B | 1<br>A | 2<br>C&D | 3<br>E&F | 4<br>G&H | 5<br>Goal | Effectiveness<br>accomp-lishment | Efficiency<br>Utilization of employee | |
|---|---|---|---|---|---|---|---|---|
| **Time required per unit in each station** | 800 | 700 | 600 | 720 | 800 | 28800/800 = 36 Units | 3620 | |
| **Available time each work station** | 800 | 800 | 800 | 800 | 800 | | 4000<br>90.5% | Utilization = 3620/4000 = |
| **Idle time per cycle** | 0 | 100 | 200 | 80 | 0 | | 380 | Idle time = 380/4100 = 9.26% |

Next highest unassigned element is G. For the same reason spelt out previously. They are not allotted to station IV then you can go for allocating next highest elements namely D & F.

NOTES

**Station IV:**

Then In the remaining unallotted elements, element G is allotted first and then H.

**The efficiency and effectiveness**

The efficiency and effectiveness of the LOT method is shown below:

Suppose if you adopt minimum allowable cycle time 800 seconds. On the basis for the allocation of elements, then the elements to be assigned will be as shown as below:

Next highest unassigned element is G. For the same reason spelt out previously. They are not allotted to station IV then you can go for allocating next highest elements namely D & F.

**Station V:**

Then In the remaining un allotted elements, element G is allotted first and then H.

**The efficiency and effectiveness**

The efficiency and effectiveness of the LOT method is shown below:

Suppose if you adopt minimum allowable cycle time 800 seconds. On the basis for the allocation of elements, then the elements to be assigned will be as shown as below:

**Table 5.40**

| | | | | |
|---|---|---|---|---|
| B | A | C & D | E & F | G & H |
| I | II | III | IV | V |

**Table 5.41**

Line design for 800 seconds

| B | 1 A | 2 C&D | 3 E&F | 4 G&H | 5 Goal | Effectiveness accomp-lishment | Efficiency Utilization of employee | |
|---|---|---|---|---|---|---|---|---|
| **Time requi-red per unit in each station** | 800 | 700 | 820 | 500 | 800 | 28800/800 = 35 Units | 3620 | |
| **Available time each work station** | 820 | 820 | 820 | 820 | 820 | | 4100<br>88.29% | Utilization = 3620/4100 = |
| **Idle time per cycle** | 20 | 120 | 0 | 320 | 20 | | 480 | Idle time = 480/4100 = 11.71% |

NOTES

As you have seen the second design consists of 800, as the cycle time stands better in terms of efficiency and effectiveness compound to the first design. Employee idleness could be reduced tasks. Thus results in reduction in no. of the employee.

Till now it is assumed that the elemental time is deterministic but there is a possibility that the more manual elements involved in the task you can't get the single elemental time, in this case usually the elemental time follows certain distribution. You can design the workplace or product layout by considering the stochastic time elements also.

**Review Question:**

1. What are the types of layout?
2. What are the techniques used in layout planning?
3. Define line balancing and why is it required?
4. What is minimum allowable time?

## 5.7 TIME STUDY AND WORK MEASUREMENT

Work study consists of two major phases namely method study and work measurement. In an industry method study is applied with an objective of simplifying the job and finding the best method of doing work. Method study paves the way to reduce the work content due to bad working methods, bad layout, wrong selection of tools etc. Work measurement is applied with an objective to reduce the ineffective time and to set the standards. Usually in the industry the method study is applied to ensure the correct methods, process etc. Then, for the best method - the measurement of the method is carried out.

According to **ILO**, Work measurement is defined as follows:

***"Work measurement is the application of techniques designed to establish the time for a qualified worker to carry out the job at a defined level of performance***" Now each key term requires a kind of explanation:

**Who is qualified worker?**

Qualified worker is one who has the requisite physical attributes, requisite intelligence and education, requisite skill and knowledge. With the above mentioned qualities, he can complete the work to meet the satisfactory standards of safety, quality and quantity.

**Average worker:**

All the recruited workers are qualified workers. But if you analyze their performance. The performance may be the time taken per unit by the worker. Assume that

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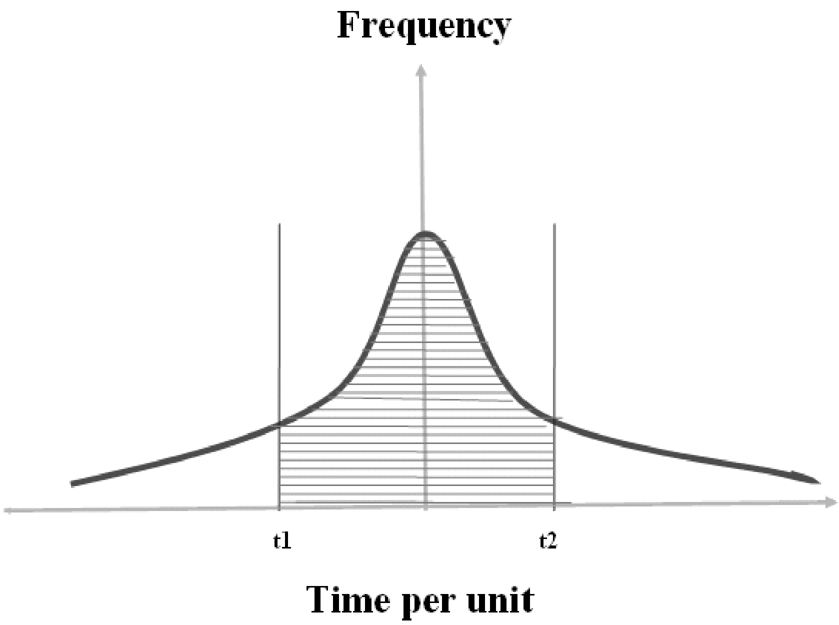
there are 500 workers; if you analyze their performance; the performance against the frequency mostly follows the normal distribution.

**Figure 5.19**

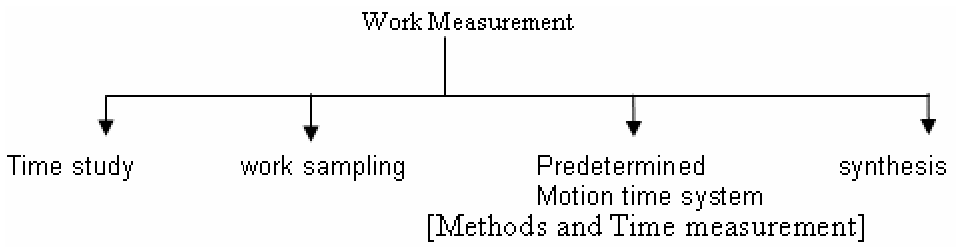



The shaded portion represents the majority of the worker that means more workers take time to produce one unit between t1 and t2. The no. of employee fall in the region you can consider as the qualified average workers. The unshaded portions in the left side represent above average performance and the unshaded portion of the right side represent the below average performer. Since most of the workers performance falls in the shaded area. The organization has to set the time standard for the average workers.

**Work Measurement Techniques**

There are many techniques available to measure the work. The techniques are listed below:

**Figure 5.20**




**Procedures to conduct work measurement technique:** According to ILO

NOTES

| | | |
|---|---|---|
| SELECT | : | Select the job to be studied. |
| RECORD | : | Record all the relevant facts by direct observations or by means of suitable recording technique. |
| EXAMINE | : | Examine critically the recorded elements. |
| MEASURE | : | Measure each element by time measurement. |
| COMPILE | : | Arrive at the normal time and standard time by adding allowance. |
| INSTALL | : | Implement the established standard time. |

### 5.7.1 Time Study

**Select:**

First you should select the job to be studied. Situations may lead you to conduct the time study to fix the time standard.

a) **SITUATION:**

1. Organization requires time standard to introduce incentive scheme
2. To determine the no. of equipment and no. of workers, you need to conduct work measurement technique.
3. To fix the standard cost, particularly to determine the labor cost, you need time standard.
4. To determine the selling price, tender price and to promise the delivery time you need to have time standard.

**Record:**

After selecting the job you should note down the surrounding conditions like working place, layout condition and see to that the worker adhere to the methods suggested by the method study.

**Examine:**

Next you should divide the job into different elements. Suppose you have to fix time standard for the job which involves drilling operation. The elements are:

1. Selecting the work piece and placing it in jig.
2. Tightening the screw.
3. Advancing the drill towards the work piece.
4. Drilling.
5. Withdrawing the drill from the operation.
6. Loosening the screw.
7. Removing piece from jig.
8. Removing the chips.

NOTES

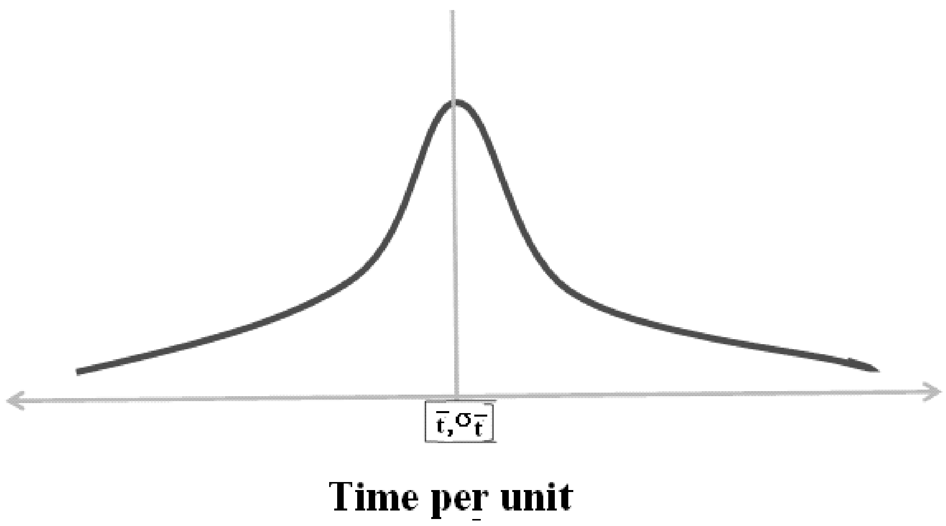
The purposes of the dividing jobs into different elements are to time the elements accurately and also to have a distinguishable starting and ending points for each element.

**Measure:**

After dividing the jobs into different elements, the number of observations to be made on each elements is to be determined. Here a trade off is to be made between the accuracy of the result and the cost of the time / study. If you take more observations, results in more accuracy in the result. You can know now, how do you determine the sample size statistically.

To determine the sample size statistically you have to specify the desired accuracy and the confidence level. Suppose you need 5 % accuracy result and 95 % confidence level. Assume that the sampling mean follows normal distribution. $\bar{t}$ is the mean.

**Figure 5.21**




Of the elemental time, t is the standard error of the sampling distribution. **A 95 % confidence level and ± 5% accuracy level means that the changes are at least 95 out of 100 that the average value for the element will not be in error when you allow more or less 5 % of true element time.**

The above bold statements showed pictorially as below:

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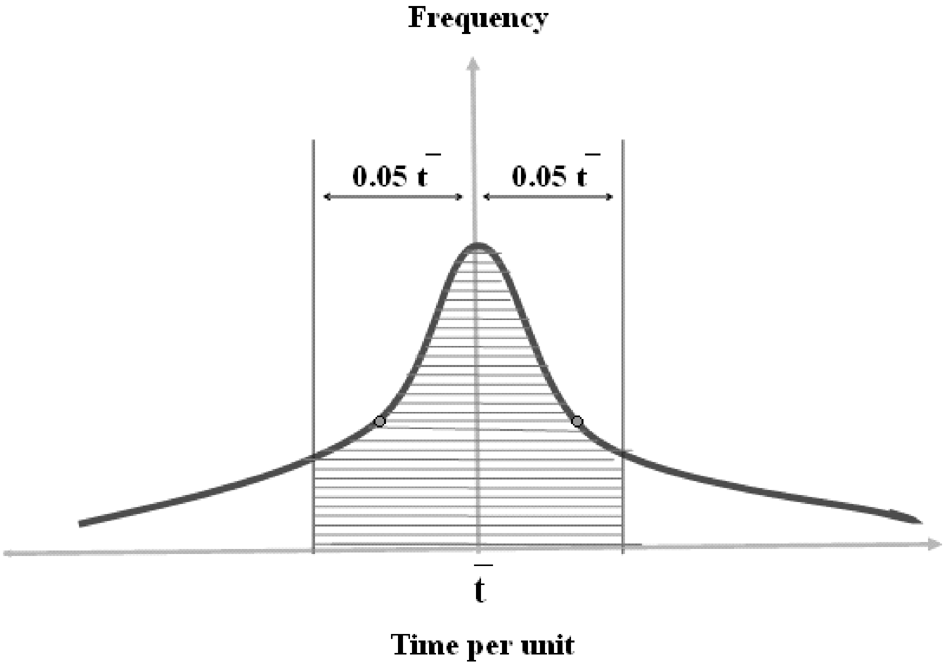


From the above figure, you can arrive $Z \sigma_{\bar{t}}$ = (accuracy level) X ( $\bar{t}$ )

At 95% confidence limit and 5% accuracy level, the Z value from the normal distribution is 1.96.

$\sigma$

$$1.96\, \sigma_{\bar{t}} = .05\, \bar{t} \qquad \text{——— 1}$$

You know the relationship between the population standard deviation and standard error of the sampling distribution.

$$\sigma_{\bar{t}} = \sigma / \sqrt{n} \qquad \text{——— 2}$$

Where n is the sample size, $\sigma$ is the population standard deviation. Substitute the value of in equation 1.

$$1.96\, \sigma / \sqrt{n} = .05\, \bar{t}$$

$$1.96\, \sigma / .05\, \bar{t} = \sqrt{n}$$

$$n = (1.96\, \sigma / .05\, \bar{t})^2$$

Here, usually the population standard deviation is not known. In this cases is estimated from the pilot study. Suppose the number of samples to be taken is less than pilot study, then you need not go for further sample collection. But the number of samples to

NOTES

be determined is more than the pilot study samples, then more sample need to be collected.

This process is continued for each element. But there is a possibility that in each element you may end up with different sample size requirements. In this case you can fix the number of cycles for the all the elements based on the element which demands the highest sample size requirement.

**Measure:**

In this phase, the elemental time is recorded using stop watch which is specifically designed for the **time study**.

**Rating:**

While measuring the time for each element, the time study person has to take note of the **pace** in which the operator does the job. The accuracy of the judgment towards the pace of the operator depends upon the experience and training of the time study person. **Rating is defined as the workers rate of working relative to the time study person's concept corresponding to the standard pace.**

Rating is an adjustment factor, because when a time study person choose a qualified, experience, trained worker there is a possibility that the operator may belong to the below average group of that company in this case he may take more time to complete the element. So to bring the time related to the average worker, which observed time has to be multiplied with the adjustment factor i.e. or other wise to lessen the observed time. In this case rating will be less than 1. This case becomes opposite while the supposed selected operator is above average worker. In this case the rating factor takes more than 1 to have higher observed time than what is available.

**Rating = Observed rating / standard rating**
**Standard rating = 100**

**Compile:**

After obtaining the observed time, rating for each element Normal time is calculated.

**Normal time for element = observed time for the element x rating factor**

All the normal elemental times are added to arrive at the normal time for the operation.

You should not consider this time as standard time because you should add allowances with the normal time. Because allowances are to be given to compensate for the energy that the operator spent while doing the job and also allowances are to be added for meeting his / her personal needs like going for toilets etc. Allowance for these reasons is beyond his control.

NOTES

Allowances are personal allowances, fatigue allowances and delay allowances. Personal allowances for meeting his / her personal needs, fatigue allowances are allowed for physical exertion. Delay allowances are due to lack of materials, random inspection visits etc.

Now the standard time is arrived as follows:
**Standard time = Normal time x 100 / [100 - % allowance]**

**5.7.2 Work sampling:**

Work sampling is another work measurement technique for measuring the following:

- To measure & control the percentage of idle time of an activity or productive resource
- To established the standard time
- To determine the performance index of the operator / department / unit

When do you apply work sampling technique:

- Jobs consists of longer lead time
- To measure the team work

**Let us consider the first application namely to measure & control the percentage of idle time of an activity or productive resources.**

Usually in any organization, the management bothers very much about the utilization of key productive resources. Work sampling study used to identify the percentage of idle time and it helps the management to correct the excessive idle time. It helps in fixing idle time control chart so that management can control the idle time percentage of the so called critical resources every time.

Consider in a hospital X- ray equipment is very critical. The management of the hospital wants to establish a control chart to monitor and control the idleness of the X- ray machine.

To fix this standard, first nothing has to determine how many observations to be made. To determine the no. of observations you should analyze the process of conducting this study. This study is nothing but a random process. There are two out comes of this random process, one is the X ray machine is working, and another outcome is X- ray machine is not working. So there is every possibility that the outcome to follow a binomial distribution. Based on the percentage of occurrence of activity (in this case idle) ‘P’ and the no. of trails ‘n’ binomial distribution is approximated into a normal distribution.

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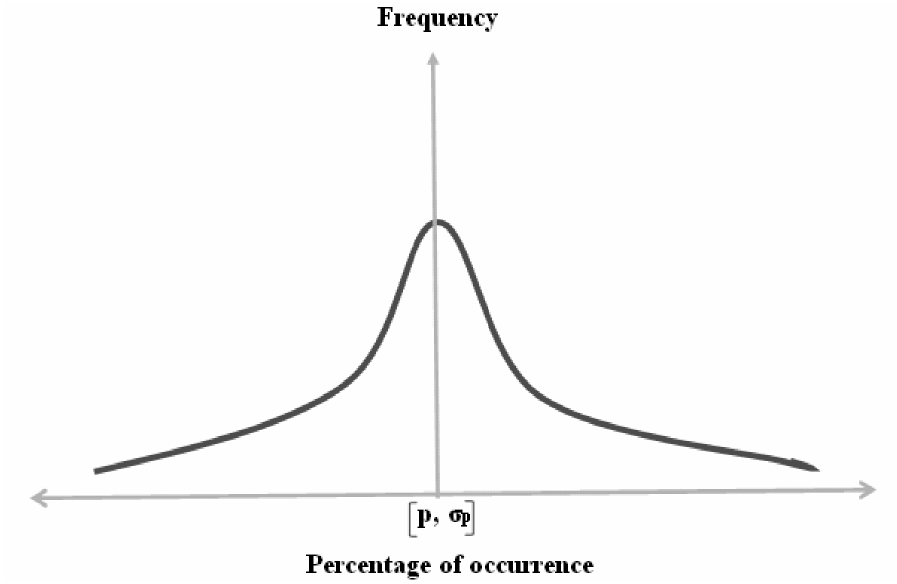
**Figure 5.23**




$\sigma_p$ is the stand error of this sampling distribution

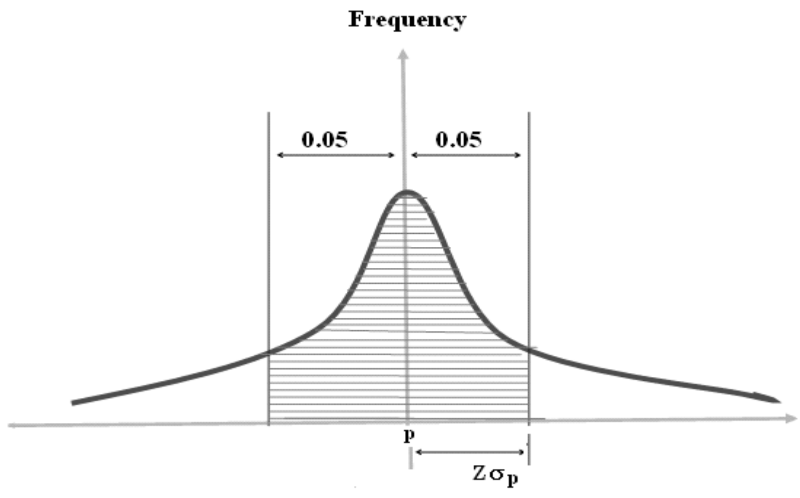
$\sigma_p$ = ? P (1-P)/n

n = sample size

p = percentage of occurrence of the activity to be measured.

As it is required in the Time study, here also to determine the no. of cycles to be determined, you need to specify the two parameters namely the confidence interval and accuracy. Assume 95% confidence limit and 10% accuracy value. 'P' is estimated from the past record that p = 20% suppose 'P' is not available, then you should conduct a pilot study to determine the 'P' then the sample size is determined as follows:

**Figure 5.24**



NOTES

General formula

$$Z . \sigma_p = SP$$

Where S = accuracy level

Z . ? P (1 – p) / n = SP

$$n = Z^2 P (1- p) / P^2S^2$$

$$= [Z^2/S^2] (1-p) / p$$

For 95% confidence limit and 10% accuracy value

$$n = [1.96/.10]^2 \quad [1 - .20/.20]$$

n = 1537 observation

**Timing of the activity to be measured**

Next you should decide to schedule the timing of the observation to be measured. For this you should generate random numbers through the computer or random number tables. Assume that the hospital is working for 16 hours. Then generate three digit random numbers. Working time of the hospital is given as below:

**Table 5.42**

| Shifts | Starting time | Break | Ending time |
|---|---|---|---|
| I | 8 A.M. | 12- 1 P.M. | 5 P.M. |
| II | 5 P.M. | 9- 10 P.M. | 2 A.M. |

First digit represents the number of hours after 8 A.M. Second and third digit help us to find the minutes. The following table shows the conversion of random numbers in to timing.

**Table 5.43**

| Random Number | Hours after start | Observation time | Chronological order |
|---|---|---|---|
| 712 | 7.12 | 3.07 | 3 |
| 473 | 4.73 | 12.44 | Lunch hour |
| 482 | 4.82 | 12.49 | Lunch hour |
| 116 | 1.16 | 9.01 | 1 |
| 311 | 3.11 | 11.07 | 2 |

**NOTES**

You can know how do you convert the random number 712 into 3.07 AM. 7 represents the time after the starting of the factory. Namely, 8 AM then it is 3'o clock. Second and third digit represents 1 and 2 represents 0.12 X 60 minutes 7.2 minutes, that means the observer has to observe the position of X ray machine after 3.07 Hrs. Similarly the no. of random numbers are converted into observer observable time. Suppose you have got the results as shown in the table

**Table 5.44**

| Activity | No.of observation |
|---|---|
| X Ray machine is working | 1227 |
| X Ray machine is not working | 310 |
| Total Observation | 1537 |

The percentage of idle time is calculated as follows:

'p' = 310/1537 = 20%

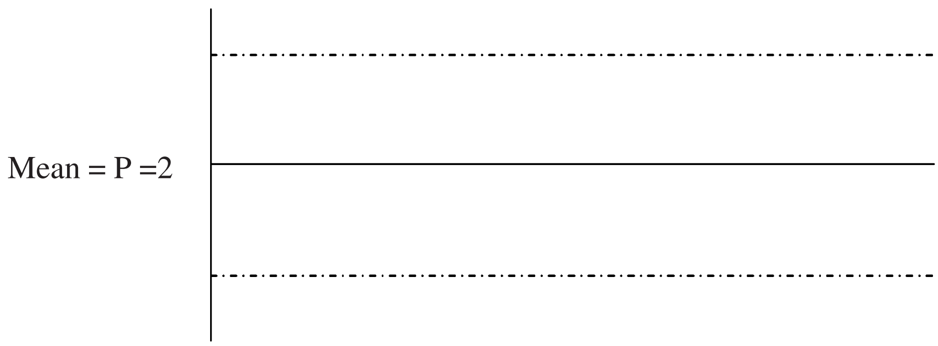
In this case you need not go for further observations. Suppose the obtained 'p' value is more than the allowable limit, then you need to rework to find the no. of observations to be taken. Suppose, if it comes around 1600,m then further (1600 -1537) so 63 observations has to be taken to fix the standard

Now $\sigma_p = \sqrt{\frac{-2X.8}{1537}} = 0.1$

You can fix the control limit using P and $\sigma_p$ value as follows:

**Figure 5.25**

**Upper control limit P + 3 $\sigma_p$ = 0.23**




Lower control limit P – 3 $\sigma_p$ = 17

NOTES

This is kept as a standard and any particular day, proportion of idle time exceeds the limit you have fixed, then the reasons has to be analyzed and corrected. Thus the work sampling techniques used to fix the standard to monitor and control the key resources.

**Establishing Time Standard by Work sampling:**

Work sampling study in addition to finding the performance index, fixing the control limits for delay and percentage of utilization of activities, it also used for establishing the time standard for operation or for the job.

**Data required to be collected:**

Assume that an operator does a turning operation in a part. By work-sampling study to determine the time standards the following information is to be collected.

- The percentage of working.
- The total working time.
- The Number of pieces to be produced.
- The average performance index.
- The allowance.

The normal time per unit is calculated using the following formula.

Normal Time = (The percentage of working) (Total working time) / No. of

Pieces product) x Average performance index.

Then standard time is calculated follow as:

**Standard time**

= Normal time (100/100 - % Allowances)

E.g.: An operator does a turning operation in a product. An observer collected the following information.

- The percentage of working = 85%
- The total working time = 480 min.
- The no. of pieces produced = 300 units
- The average performance index = 120
- Allowances from the time study manual is arrived at 15%

Normal time = (0.85 x 480)/300 (120/100)

= 1.632 min.

Standard time = 1.632 x 100/ (100-15) = 1.632 x 100/85

= 1.92 min.

**Work Sampling study to establish the performance index:**

This study is applied to establish the average performance index. This average performance index of the labour or department helps the management to control the

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labour cost. Let us see how you calculate the average performance index. The work sampling study may be carried out for many periods for data collection. Then from the data collected you can calculate the average performance index as follows:

**Average Data per period from the data collected during the study.**

- Average no. of pieces produced during the period
- Standard time per unit.
- Average working time.

Performance index = [(Average no. of pieces produced during the period x Standard time

per piece in minutes) / Average hours worked during the period x 60] x 100

E.g. Assume that a drilling operation is carried out on a product. The organization interested in knowing the average performance index of the operator who does the drilling operation. Work sampling study has been conducted for several weeks. The average data collected from the study are given below:

Average no of pieces produced during a week = 1500
Standard time per piece per min. = 5 min.
Average hours worked during the period = 36 hours
Performance index = [500 x 5 /36 x 60] x 100
= 115 %

The average performance index helps the organization to control the labour cost.

**a. LEARNING CURVE**

In the case of more labour intensive mass production industry, mostly the labour do repetitive type of job, that results in more learning due to experience of doing the same job because of this, the time taken to produce subsequent units gets reduced compared to the previous units. This phenomenon will not lose for longer period, at some point of the time this learning effect ceases. After the learning effect ceases, the time required to produce one unit or one batch will be the same irrespective of the number of units or batches. The organization has to cash in the relevant range period, the period in which the learning effect is there. During the learning effect period, the standard time per unit is not constant it varies depends upon the quantity of the order you get. Since the learning effect has impact on the standard time that is the reason to study this concept in this section .

**Learning Curve Model:**

Consider the past data of a company manufacturing Aircraft components. For a particular component the data are taken for ten situations.

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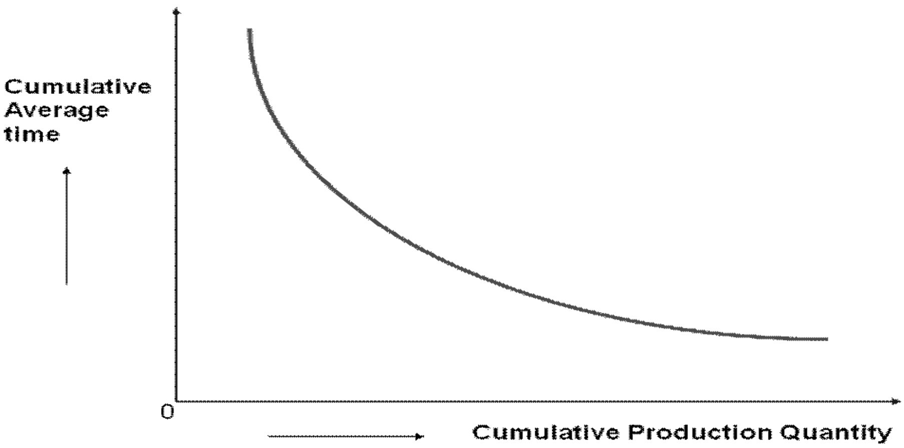
**Table 5.45**

| Situation | Quantity (Q) | Production Time (tp) | Cumulative batches (1) Time (2) | Cumulative Production (3)=(2) / (1) | Cumulative Average Time |
|---|---|---|---|---|---|
| 1 | 20 | 164 | 20 | 164 | 8.2 |
| 2 | 30 | 228 | 50 | 392 | 7.84 |
| 3 | 50 | 340 | 100 | 732 | 7.32 |
| 4 | 80 | 453 | 180 | 1185 | 6.58 |
| 5 | 120 | 655 | 300 | 1840 | 6.13 |
| 6 | 150 | 767 | 450 | 2607 | 5.79 |
| 7 | 210 | 863 | 660 | 3470 | 5.26 |
| 8 | 260 | 1115 | 920 | 4595 | 5 |
| 9 | 330 | 1488 | 1250 | 6083 | 4.86 |
| 10 | 380 | 1311 | 1630 | 7394 | 4.37 |

Using (1) and (3) if you draw the curve, it appears as follows

**Figure 5.26**




Since the nature of the curve is exponential, the general equation for exponential curve is

**$Y = a \times X^b$**

**Y**= cumulative average time

**X**= Cumulative production quantity

**a** = The time required to produce the first quantity

**b** = Exponent

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'**b**' depends upon the operating condition. In the above model, for the particular cumulative production quantity what will be the cumulative average time? This could be easily calculated provided, if you know the two parameters namely '**a**' and '**b**'. Since the curve is exponential in nature, if you take the logarithm for the **X** value and **Y** value then you can get a linear curve as follows:

$$\text{Log}(Y) = \text{Log}(a) + b \times \text{Log}(X)$$

Thus the curve is of the form

$$Y = a + bx$$

Where

y= Log (Y)

x= Log(X)

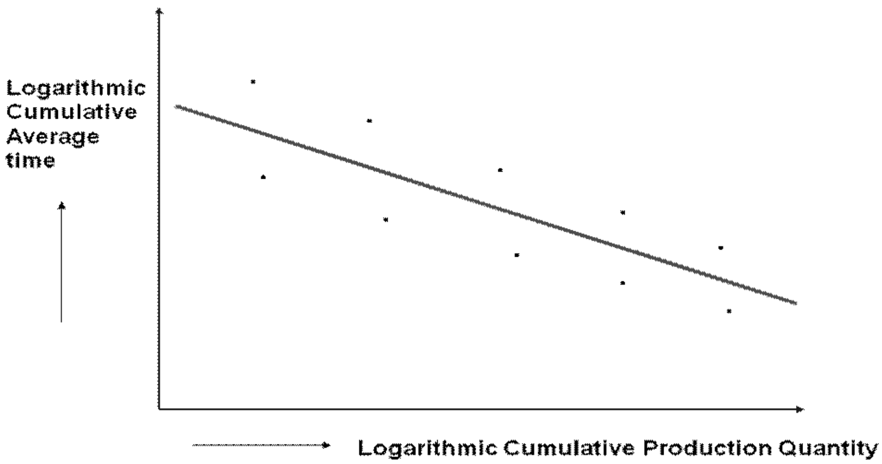
So using the simple regression analysis you can find the values of 'a' and 'b'. For the given data, shown in the table, let us try to estimate the regression model,

**Table 5.46**

| log X | log Y |
|---|---|
| 2.995 | 2.104 |
| 3.401 | 2.059 |
| 3.912 | 1.99 |
| 4.382 | 1.884 |
| 4.787 | 1.813 |
| 5.01 | 1.756 |
| 5.347 | 1.66 |
| 5.56 | 1.609 |
| 5.799 | 1.581 |
| 5.94 | 1.513 |

If we solve

**Figure 5.27**



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$\log Y = 2.7555 - 0.263 \ln x.$

Where,

$R^2$ = Coefficient of determination = 0.985

$R^2_{adjusted} = 0.983$

Since $R^2$ value is approximately 99%, which means 99% of the variations in the original data have been captured by the estimated regression line. Thus show that the estimated line is the best fit for the original data.

Cumulative average time

$\ln Y = 2.7555 - 0.203 \ln X$

You know that

b = ln learning curve percent / ln2.

-0.203 = ln learning curve percent / ln 2.

ln learning curve percent = ln 2 * (-0.203)

= 0.6931 * (-0.203)

= -0.1407.

Learning curve percent = Antilog of [-0.1407]

= 86.88%

= 87%.

The practical meaning of learning effect or the learning curve percent is that if the production quantity becomes double, then corresponding required time to produce one unit of that doubled quantity gets reduced to that extent of (1- learning curve percent). This is shown in the following table for the problem discussed already.

**Table 5.47**

| **UNIT** Assume 20 units = 1 units | Cumulative average time (Y = a * b) |
|---|---|
| 20 = 1 units | Y = 164 (1-0.203) |
| 40 = 2 units | Y = 164 (2-0.203) |
| 60 = 3 units | Y = 164 (3-0.203) |
| 80 = 4 units | Y = 164 (4-0.203) |

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From the above table you can easily identify that when the production quantity becomes double; the average time per unit gets reduced to the extent of 13%. So this is to be taken into account while calculating the standard time for the product. Thus way the standard time gets reduced.

**Application of learning curve:**

As it is mentioned already the reduced standard time could be made use of estimating the following,

1. Learning curve concept could be applied in pricing the product.
2. This concept could be applied in standard costing.
3. This is applied in budgeting and production planning.

## 5.9 PRODUCTIVITY

Productivity is the ratio between the output and input. This is an index, the output may be sales and input is the recourses utilized for getting the output. Example: the output is sales value and the input is cost of goods sold.

$$\text{Productivity} = \frac{\text{Sales}}{\text{Cost of goods sold}}$$

If the Productivity Index is more than one, you can say that the performance of the organization is good. If it is less than one you can say that the organization is not doing well.

**Impact of Learning Curve on the Productivity**

Cost of the goods sold is the function of labour, material and overhead cost because of learning effect the time required to produce one unit in the relevant range decreases as the number of units produce is more. The result is less labour and variable over heads. So the denominator decreases that leads to higher productivity. There are many reasons for the improvement in the productivity. The increase may due to quality, methods, materials, better management etc. in addition learning effect also have a source for the productivity improvement.

## Summary

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This unit would have helped you to know the factors to be considered while selecting a location. The kind of system design, like layout design, work measurement standards are exposed with an objective of complete understanding the nuances of the system design techniques. At last, you are exposed to the construction and the impact of the learning curve on the productivity.

## Review Questions:

1. List the various work measurement techniques.
2. List out the procedures to carry out the work measurement.
3. What is time study?
4. Define work sampling?
5. What is impact of learning curve on productivity?

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