# Operations Planning 2

**This Module Includes**

# Operations Planning

**SLOB Mapped against the Module**

To attain knowledge on techniques and tools to be applied for product and process designing, capacity planning and production line balancing; and job designing; in operations management.

**Module Learning Objectives:**

After studying this module, the students will be able to:

- Comprehend the challenges faced by the operations manager.
- Understand the characteristics of capacity Planning and requirement
- Understand the different forecasting techniques used in planning.
- Understanding the inventory management.

# Demand Forecasting

# 2.1

"Demand" is in a simpler way defined as the requirement and desire of consumers to purchase products and services and willingness and abilities to pay for availing the same.

Example of product: Household durable products like television, daily use products like soap. Example of service: Pathological tests by medical service providing laboratories like Drs. Ray & Trivedi Lab.

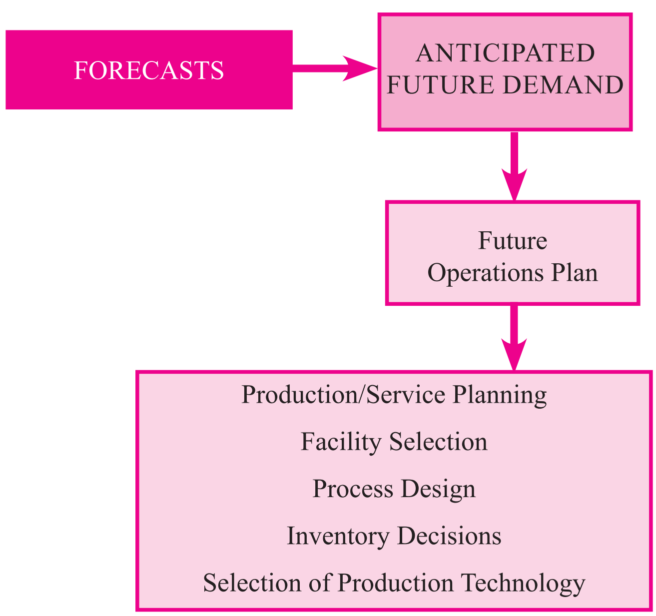
The products/services demanded are of two categories such as industrial purpose products like machines and consumers, specific products like confectionaries

"Forecasting" is the process of making prediction about future happenings and/or requirements based on available information and/evidences. Example, forecasting of product requirements, forecasting of weather, forecasting of fashion trends, forecasting of tourist inflow, forecasting of patient admission, forecasting of technology etc.

A forecast is an estimate about the future value of a variable such as demand.

Forecasts of demand are a basic input in the decision processes of operations management.

The primary goal of operations management is to match supply to demand. Therefore, demand forecasting is essential for determining how much capacity or supply will be needed to meet demand.




In this segment we shall restrict our discussions mainly on forecasting of demand of products.

**Source of Information (used for forecasting)**

There are a number of sources from where past information and/or evidences are gathered to facilitate forecasting of demand such as

- Market Report
- Sales force opinion
- Experts' views
- Industry report
- Point of Sales data
- Structured customer survey
- Field report etc.

**Range of period**

Forecasting is done on short, medium and long term basis. The underlying objectives are explained below.

Forecasting can have both near and distant horizons. This period of forecasting, that is the time range selected for forecasting depends on the purpose for which the forecast is made. For example demand for a product can have both near and distant horizons but replacement of plant, other than due to obsolescence, is bound to have a distant horizon. The period may vary from one week to some years. Depending upon the period, the forecast can be termed as

- Short range forecasting
- Medium range forecasting
- Long range forecasting

Short range forecasting period may be one week, two weeks or a couple of months. Medium range forecasting period may vary from 3 to 6 months. Long range forecasting period may vary from one year to any period. The objective of above said forecast is naturally different.

In general, short term forecasting will be more useful in production planning. The manager who does short range forecast must see that they are very nearer to the accuracy.

Short run forecasting (usually for highly innovative products with shorter life cycle like smartphones; usually spanning over 6-8 months)

- In case of short-term forecast, following purposes are generally served:
- To estimate the inventory requirement
- To provide transport facilities for dispatch of finished goods
- To decide workloads for men and machines
- To find the working capital needed
- To set-up of production run for the products
- To fix sales quota
- To find the required overtime to meet the delivery promises.

Medium run forecasting (usually for consumer durable products, medicines, period may extend over to one or two years)

The purpose of this type of forecasting is:

- To determine budgetary control over expenses
- To determine dividend policy
- To find and control maintenance expenses
- To determine schedule of operations
- To plan for capacity adjustments

Long run forecasting (usually for daily used routine household product like Aata, the normal period used is generally 5 years, in some cases it may extends to 10 to 15 years also. )

The purpose of long range forecast is:

- To work out expected capital expenditure for future developments or to acquire new facilities,
- To determine expected cash flow from sales
- To plan for future manpower requirements
- To plan for material requirement
- To plan for Research and Development. Here much importance is given to long range growth factor.

**Forecasting Methods (How to forecast demand?)**

There are two types of approaches such as

- Qualitative
    - ► Delphi method
- An iterative group process which employs group of experts, staff, respondents to obtain forecasts
    - ► Sales force composite
- Group comprising members from sales force of company are asked to estimate the likely demand in respective sales zones
    - ► Consumer panel Survey
- Group of consumers are asked about their purchase plans to ascertain future demand forecast
- Quantitative
    - ► Causal/Regression analysis

Forecast of a dependent variable is made with the help of its variability nature with an independent variable Follows Simple regression equation $Y = a + bX$

- a = y axis intercept of the regrssion line
- b = slope of the regrssion line
- X = the independent variable
- Y = the forecast value of dependent variable

$$b = \frac{\Sigma XY - n * \overline{X} * \overline{Y}}{\Sigma X^2 - n\overline{X}^2}$$

$a = \overline{Y} - b\overline{X}$

$\overline{Y}, \overline{X}$ are mean of respective variables

n = no of data items in X and Y series

Example: A manufacturer has held road side exhibition which exhibited on the introduction of a new product of its smart phone product. The number of sales personnel employed at each of a sample of 10 exhibitions and the no of smart phones booked at each one are given below:

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No of sales person | 15 | 18 | 16 | 18 | 19 | 13 | 15 | 14 | 16 | 16 |
| No of smart phone booked | 30 | 60 | 50 | 60 | 70 | 52 | 50 | 80 | 72 | 80 |

If the manufacturer employs 20 salesmen in an exhibition then forecast no of Smartphones that could be booked in that exhibition.

Answer: Here number of smartphones booked needs to be predicted on the basis of no. of salesmen involved

So No of sales person is independent variable: X and

No of smartphones booked is dependent variable: Y

Therefore we will apply simple regression analysis under following steps:

- Find out the value of a,b
- Form the regression equation i.e. Y= a+bX
- Hence find the value of Y,putting X = 20 in the above regression line

Detail computation are as follows:

| Sr. No. | X | Y | XY | $X^2$ |
|---|---|---|---|---|
| 1 | 15 | 30 | 450 | 225 |
| 2 | 18 | 60 | 1080 | 324 |
| 3 | 16 | 50 | 800 | 256 |
| 4 | 18 | 60 | 1080 | 324 |
| 5 | 19 | 70 | 1330 | 361 |
| 6 | 13 | 52 | 676 | 169 |
| 7 | 15 | 50 | 750 | 225 |
| 8 | 14 | 80 | 1120 | 196 |
| 9 | 16 | 72 | 1152 | 256 |
| 10 | 16 | 80 | 1280 | 256 |
| Total | 160 | 604 | 9718 | 2592 |

$$\overline{X} = \frac{\Sigma X}{n} = \frac{160}{10} = 16, \ \overline{Y} = \frac{\Sigma Y}{n} = \frac{604}{10} = 60.4$$

$$\text{Hence } b = \frac{\Sigma XY - n * \overline{X} * \overline{Y}}{\Sigma X^2 - n\overline{X}^2} = \frac{9718 - 10 * 16 * 60.4}{2592 - 10 * 16 * 16} = 1.6875$$

Hence a = $\overline{Y}$ - b$\overline{X}$ = 60.4 - 1.6875 * 16 33.4

Hence Y = a + bX i.e.Y = 33.4 + 1.6875X

Hence required forecast Y = 33.4 + 1.6875 * 20 = 67.15 = 67 (Approx)

- Quantitative
  - ➢ Time Series analysis
    - ⦿ Under this method to make forecast of future, time series data of actual demand for historical previous periods are taken
    - ⦿ A time ordered sequence of observations taking at regular intervals (e.g. hourly, daily, weekly, monthly etc.)
    - ⦿ Period wise actual demand data (Y) fluctuates
    - ⦿ These fluctuations in any time series demand data are caused by four components—Trend(T), Seasonality (S), Cyclical (C) and Irregular (I) or Random(R)
    - ⦿ These components are related either Additively or Multiplicatively
    - ⦿ Under Additive model Y=T+S+C+I
    - ⦿ Under Multiplicative model Y=T*S*C*I
    - ⦿ Forecast is made by forming trend equation or by average method

Methods of forecasting by forming Trend equation

- Trend (T)
  - ➢ Refers to a long term upward or downward movement in the data mainly due to seasonal variations in the time duration
  - ➢ The trend component may be linear or may be non-linear.
  - ➢ Linear trend is fairly common and measured by forming the equation F_t=a+bt
  - ➢ $F_t$ = Forecast for period t, a = value of $F_t$ at t = 0 i.e. y axis intercept, b = slope of the linear trend equation shown above,t = specified no of time periods from t = 0
  - ➢ $b = \dfrac{\Sigma tY - n * \overline{t} * \overline{Y}}{\Sigma t^2 - n\overline{t}^2} = \dfrac{n\Sigma tY - \Sigma t * \Sigma Y}{n\Sigma t^2 - (\Sigma t)^2}$
  - ➢ $a = \overline{Y} - b\,\overline{t}$
  - ➢ $\overline{t}$, $\overline{Y}$ are mean of respective variables
  - ➢ n = no of data items in t and Y series
  - ➢ Very similar to causal method discussed earlier

Methods of forecasting by averaging

- Can be found by
  - ➢ Simple moving average method
  - ➢ Weighted moving average method

Forecast by Simple moving average method is done by

➢ $F_t = MA_n = \frac{\sum_{t=1}^{n} A_{t-i}}{n}$

Where $F_t$ = Forecast for period t, $MA_n$ = n period moving average, $A_{t-i}$ = Actual demand in period t - i & n = no of period (data points)in the time series

➢ Forecast by weighted moving average method is done by

$F_t = WMA_n = \sum_{i=1}^{n} W_{t-i} * A_{t-i}$

Where $F_t$ = Forecast for period t, $WMA_n$ = n period weighted moving average, $A_{t-i}$ = Actual demand in period t - i, $w_t$ = weight assigned to period t - i & n = no of period (data points)in the time series

- Seasonality (S)
  - ➢ Refers to short term fairly regular variations in the data
- Cycles (C)
  - ➢ Refer to wave like variations in the data of more than one year's duration due to cyclical variations in the economy during the time period
- Irregular (I)
  - ➢ Random unexplained variations in the time series data

Example: Monthly sales of ABC Company for a seven month period are as follows:

| Month | Feb | Mar | April | May | June | July | August |
|---|---|---|---|---|---|---|---|
| Sales (000 units) | 24 | 23 | 20 | 25 | 23 | 27 | 25 |

a) Plot the data;

b) Forecast September sales volume using each of the following:

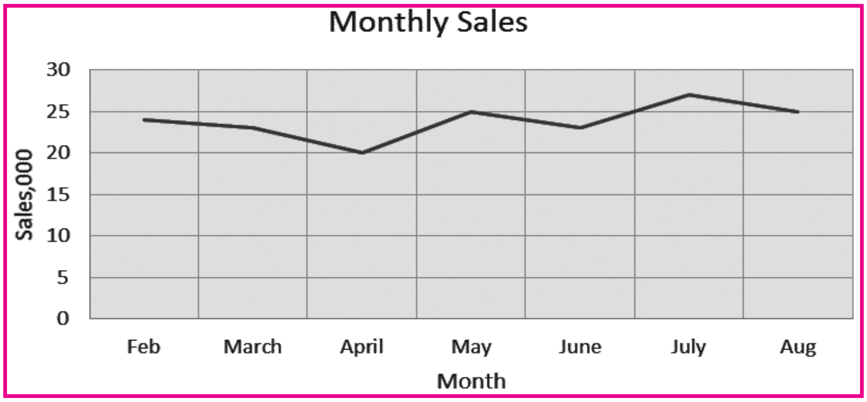
i) A five month moving average;

ii) A weighted average using 0.60 for August, 0.30 for July and 0.10 for June

iii) A linear trend equation

Answer:

(a)



(b) A 5 month moving average : Our formula will be

$$F_t = MA_n = \frac{\sum_{i=1}^{n} A_{t-i}}{n}$$

$$\text{Or} = \frac{A_{t-n} \ldots + A_{t-2} + A_{t-1}}{n}$$

Where

$F_t$ = Forecast for time period t. Here time period t = 8 from February month

n = Number of periods (data points) in the moving average = 5 here

$MA_n$ = n period moving average

$A_{t-i}$ = Actual value in period t-i

Since here we are calculating with t = 8, so we require 8 - 1 = 7th, 8 - 2 = 6th, 8 - 3 = 5th, 8 - 4 = 4th & 8 - 5 = 3rd month data respectively from February.

Therefore the concerned months and actual data will be as follows:

| | |
|---|---|
| $A_{t-5}$ = April | 20 |
| $A_{t-4}$ = May | 25 |
| $A_{t-3}$ = June | 23 |
| $A_{t-2}$ = July | 27 |
| $A_{t-1}$ = August | 25 |
| Sum | 120 |

So forecast sales for the month of September $MA_5$ = 120/5 = 24 (in 000)

(c) In case of weighted average the heaviest weights are assigned to the most recent values. And for September our forcast will be

$F_t$ = 0.6 * Sales of August + 0.3 * Sales of July + 0.1 * Sales of June

Or, = 0.6 * 25 + 0.3 * 27 + 0.1 * 23 = 25.4 (in 000)

(d) For computation of trend we have to use the following two parameters:

$$b = \frac{n\Sigma tY - \Sigma t * \Sigma Y}{n\Sigma t^2 - (\Sigma t)^2} \quad \& \quad a = \frac{\Sigma Y - b\Sigma t}{n}$$

Where Y represents sales value and t represents time period & n number of items. Trend equation is $F_t = a + bt$, where $F_t$ = forecast for period t, a = value of $F_t$ at t = 0 & b = slope of the line

Computations are:

| t = Month | Y = Sales | t*Y | $t^2$ |
|---|---|---|---|
| 1 | 24 | 24 | 1 |
| 2 | 23 | 46 | 4 |
| 3 | 20 | 60 | 9 |
| 4 | 25 | 100 | 16 |
| 5 | 23 | 115 | 25 |
| 6 | 27 | 162 | 36 |
| 7 | 25 | 175 | 49 |
| Sum 28 | 167 | 682 | 140 |

So b = 0.5 & a = 21.86

For September t = 8

So forecast for September = 21.86 + 0.5 * 8 = 25.857 (in 000)

In time series analysis Seasonality(S) refers to regular annual variation. Well known examples of seasonality is rush hour rate of UBER cab booking, holiday influenced demand like puja shopping etc.

We have learnt that fluctuation in time series due to Seasonality is smoothen out by averaging. Therefore Seasonality in time series is expressed in terms of the amount that actual demand values deviate from the average value of the series. If trend is present, seasonality is expressed in terms of the trend value.

- In additive model, seasonality is expressed as a quantity which is added to or subtracted from the series average in order to incorporate seasonality
- In multiplicative model, seasonality is expressed as a percentage of the average (or trend) which is then used to multiply the value of a series to incorporate seasonality
- In practice, businesses use multiplicative model much more than additive model

  Seasonality expressed as a percentage of the average (or trend) is termed Seasonal relative (Seasonal Index)
- If seasonality relative to Christmas month is 1.60 and a trader has monthly average of 300 units of sales then in December the trader could expect a sales demand around 480 (i.e.300*1.6)
- Seasonal Relatives are used for forecasting in two ways
  - To deseasonalise the forecast by dividing the forecast data by respective seasonal relative e.g. Christmas month's total demand forecast / Seasonal relative of Christmas month = Actual forecast resulted by following trend pattern of the underlying product/service
  - To seasonalise a forecast by multiplying the forecast data by respective seasonal relative e.g. Christmas month's demand forecast as per trend pattern of the underlying product * Seasonal relative of Christmas month = Christmas month's total demand resulted from trend and seasonality
  - Seasonal Relatives can be found by i) Simple average; ii) Centered moving average;

Example: Yearly sales of a company for last 8 years are as follows:

| Year | Q1 | Q2 | Q3 | Q4 | Total |
|---|---|---|---|---|---|
| 2016 | 28 | 37 | 33 | 24 | 122 |
| 2017 | 27 | 40 | 30 | 23 | 120 |
| 2018 | 31 | 36 | 33 | 30 | 130 |
| 2019 | 31 | 39 | 36 | 26 | 132 |
| 2020 | 29 | 38 | 32 | 24 | 123 |
| 2021 | 32 | 40 | 36 | 26 | 134 |
| 2022 | 34 | 42 | 34 | 29 | 139 |
| 2023 | 31 | 39 | 39 | 23 | 132 |

| Year | t | Y | $t_y$ | $t_2$ |
|---|---|---|---|---|
| 2016 | 1 | 122 | 122 | 1 |
| 2017 | 2 | 120 | 240 | 4 |
| 2018 | 3 | 130 | 390 | 9 |
| 2019 | 4 | 132 | 528 | 16 |
| 2020 | 5 | 123 | 615 | 25 |
| 2021 | 6 | 134 | 804 | 36 |
| 2022 | 7 | 139 | 973 | 49 |
| 2023 | 8 | 132 | 1056 | 64 |
| Total | 36 | 1032 | 4728 | 204 |

Form a trend line and find yearly forecast for 2024 and 2025. Hence compute average quarterly forecast for these two years. Hence seasonalise the quarterly forecast of 2024 and 2025. Apply simple average method

Answer: For computation of trend we have to use the following two parameters:

$$b = \frac{n\Sigma tY - \Sigma t * \Sigma Y}{n\Sigma t^2 - (\Sigma t)^2} \ \& \ a = \frac{\Sigma Y - b\Sigma t}{n}$$

Detail computations are as follows from where we get

b = 2 & a = 120 and the trend equation is Y = 120 + 2t

So for year 2024, t = 9 and hence yearly forecast = 120 + 2 * 9 = 138

So for year 2025, t =10 and hence yearly forecast = 120 + 2 * 10 = 140

Hence Average quarterly forecast for 2024 = 138/4 = 34.5

Hence Average quarterly forecast for 2025 = 140/4 = 35

To seasonalise these quarterly forecast we have to find Seasonal Relative w.r.t each quarter as follow through simple average

| Year | Q1 | Q2 | Q3 | Q4 | Total |
|---|---|---|---|---|---|
| 2016 | 28 | 37 | 33 | 24 | 122 |
| 2017 | 27 | 40 | 30 | 23 | 120 |
| 2018 | 31 | 36 | 33 | 30 | 130 |
| 2019 | 31 | 39 | 36 | 26 | 132 |
| 2020 | 29 | 38 | 32 | 24 | 123 |
| 2021 | 32 | 40 | 36 | 26 | 134 |
| 2022 | 34 | 42 | 34 | 29 | 139 |
| 2023 | 31 | 39 | 39 | 23 | 132 |
| Total | 243 | 311 | 273 | 205 | |
| Average | 30.375 | 38.875 | 34.125 | 25.625 | |
| Seasonal Relative | (30.375/32.25) *100 = 94.19 | (38.875/32.25) *100 = 120.54 | (34.125/32.25) *100 = 105.81 | (25.625/32.25) *100 = 79.46 | |

*(30.375+38.875+34.125+25.625)/4 = 32.25

Hence seasonalised quarterly forecast for 2024 & 2025 are

| Quarter | 2024 | | | 2025 | | |
|---|---|---|---|---|---|---|
| | Quarterly Average | Seasonal Relative (%) | Seasonalised Quarterly forecast | Quarterly Average | Seasonal Relative | Seasonalised Quarterly forecast |
| Q1 | 34.5 | 94.19 | 32.5 | 35 | 94.19 | 32.97 |
| Q2 | 34.5 | 120.54 | 41.59 | 35 | 120.54 | 42.19 |
| Q3 | 34.5 | 105.81 | 36.50 | 35 | 105.81 | 37.03 |
| Q4 | 34.5 | 79.46 | 27.41 | 35 | 79.46 | 27.81 |

Seasonalised Quarterly forecast = Quarterly average (available from trend) * Seasonal Relative

Seasonal relative can also be found by Centered Moving average. It gives more accurate result compared to simple average method. Simple average method however could be used for finding Seasonal relative when ratio of intercept to the slope is large.

Example: Quarterly demand data for a manufacturer are as follows. Compute Seasonal relative for each quarter by centered moving average (Apply even numbered moving average say 4)

| Year | Q1 | Q2 | Q3 | Q4 |
|---|---|---|---|---|
| 1 | 34 | 38 | 55 | 66 |
| 2 | 48 | 56 | 80 | 91 |
| 3 | 65 | 74 | 104 | 108 |
| 4 | 78 | | | |

Answer: First we have to calculate $MA_4$. Since the computed centered values are not corresponding to actual data point, we have to find $MA_2$ and the computed centered values correspond to actual data point. With $MA_2$ we could find Demand/$MA_2$. Detail computation are as follows:

| Year | Quarter | Demand | MA4 | MA2 | Demand/MA2 |
|---|---|---|---|---|---|
| 1 | 1 | 34 | | | |
| | 2 | 38 | | | |
| | 3 | 55 | 48.25 | | |
| | 4 | 66 | 51.75 | 50 | 1.10 |
| 2 | 1 | 48 | 56.25 | 54 | 1.22 |
| | 2 | 56 | 62.5 | 59.38 | 0.81 |
| | 3 | 80 | 68.75 | 65.63 | 0.85 |
| | 4 | 91 | 73 | 70.88 | 1.13 |
| 3 | 1 | 65 | 77.5 | 75.25 | 1.21 |
| | 2 | 74 | 83.5 | 80.50 | 0.81 |
| | 3 | 104 | 87.75 | 85.63 | 0.86 |
| | 4 | 108 | 91 | 89.38 | 1.16 |
| 4 | 1 | 78 | | | |

| | Demand/MA2 | | | | Total |
|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | |
| | | | 1.10 | 1.22 | |
| | 0.81 | 0.85 | 1.13 | 1.21 | |
| | 0.81 | 0.86 | 1.18 | | |
| Total | 1.62 | 1.71 | 3.41 | 2.43 | |
| Average | 0.81 | 0.855 | 1.137 | 1.215 | 4.017 |
| Relative | 0.81*4/4.017= 0.807 | 0.855*4/4.017= 0.851 | 1.137*4/4.017= 1.132 | 1.215*4/4.017= 1.210 | |

For repopulating understanding on time series paper 3 under foundation curriculum could be well referred

## Illustration 1

From the following time series data of sale project the sales for the next three years.

| Year | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|---|---|
| Sales (₹000 units) | 80 | 90 | 92 | 83 | 94 | 99 | 92 |

**Solution:**

Computation of Trend Values

| Years | Time Deviation from 2020 X | Sales in (₹ 000 units) Y | Squares of time dev. $X^2$ | Product of time deviations and sales XY |
|---|---|---|---|---|
| 2017 | –3 | 80 | 9 | –240 |
| 2018 | –2 | 90 | 4 | –180 |
| 2019 | –1 | 92 | 1 | –92 |
| 2020 | 0 | 83 | 0 | 0 |
| 2021 | +1 | 94 | 1 | +94 |
| 2022 | +2 | 99 | 4 | +198 |
| 2023 | +3 | 92 | 9 | +276 |
| n = 7 | $\sum X = 0$ | $\sum Y = 630$ | $\sum X^2 = 28$ | $\sum XY = +56$ |

Regression equation of Y on X

$Y = a + bX$

To find the values of a and b

$$a = \frac{\sum Y}{n} = \frac{630}{7} = 90$$

$$b = \frac{\sum XY}{\sum X^2} = \frac{56}{28} = 2$$

Hence regression equation comes to Y = 90 + 2X. With the help of this equation we can project the trend values for the next three years, i.e., 2024, 2025 and 2026.

$Y_{2024}$ = 90 + 2(4) = 90 + 8 = 98 (000) units.

$Y_{2025}$ = 90 + 2(5) = 90 + 10 = 100 (000) units.

$Y_{2026}$ = 90 + 2(6) = 90 + 12 = 102 (000) units.

### Illustration 2

With the help of following data project the trend of sales for the next five years:

| Years | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|---|
| Sales (in lakhs) | 100 | 110 | 115 | 120 | 135 | 140 |

**Solution:**

**Computation of trend values of sales**

| Year | Time deviations from the middle of 2020 and 2021 assuming 6 months = 1 unit | Sales (in lakh ₹) | Squares of time deviation | Product of time deviation and sales |
|---|---|---|---|---|
| | X | Y | $X^2$ | XY |
| 2018 | -5 | 100 | 25 | -500 |
| 2019 | -3 | 110 | 9 | -330 |
| 2020 | -1 | 115 | 1 | -115 |
| 2021 | +1 | 120 | 1 | +120 |
| 2022 | +3 | 135 | 9 | +405 |
| 2023 | + 5 | 140 | 25 | +700 |
| n = 6 | ΣX = 0 | ΣY = 720 | $\Sigma X^2 = 70$ | ΣXY = 280 |

Regression equation of Y on X:

Y = a + bX

To find the values of a and b

$$a = \frac{\sum Y}{n} = \frac{720}{6} = 120$$

$$b = \frac{\sum XY}{\sum X^2} = \frac{280}{70} = 4$$

Hence regression equation comes to Y = 120 + 4X

Sales forecast for the next years, i.e., 2024-28

$Y_{2024}$ = 120 + 4 (+7) = 120 + 28 = ₹ 148 lakhs

$Y_{2025}$ = 120 + 4 (+9) = 120 + 36 = ₹ 156 lakhs

$Y_{2026}$ = 120 + 4 (+11) = 120 + 44 = ₹ 164 lakhs.

$Y_{2027}$ = 120 + 4 (+13) = 120 + 52 = ₹ 172 lakhs.

$Y_{2028}$ = 120 + 4 (+15) = 120 + 60 = ₹ 180 lakhs.

**Illustration 3**

An investigation into the demand for colour TV sets in 5 towns has resulted in the following data:

| | | | | | | |
|---|---|---|---|---|---|---|
| **Population of the town (in lakhs)** | X: | 5 | 7 | 8 | 11 | 14 |
| **No of TV sets demanded (in thousands)** | Y: | 9 | 13 | 11 | 15 | 19 |

Fit a linear regression of Y on X and estimate the demand for CTV sets for two towns with a population of 10 lakhs and 20 lakhs.

**Solution:**

**Computation of trend values**

| Population (in lakhs) | Sales of CTV (in thousands) | Squares of the population | Product of population and sales of colour TV |
|---|---|---|---|
| X | Y | $X^2$ | XY |
| 5 | 9 | 25 | 45 |
| 7 | 13 | 49 | 91 |
| 8 | 11 | 64 | 88 |
| 11 | 15 | 121 | 165 |
| 14 | 19 | 196 | 266 |
| $\Sigma X = 45$ | $\Sigma y = 67$ | $\Sigma X^2 = 455$ | $\Sigma XY = 655$ |

Regression equation of Y on X

$Y = a + bX$

To find the values of a and b, the following two equations are to be solved

$\Sigma Y = na + b\Sigma X$ ... (i)

$\Sigma XY = a\Sigma X + b\Sigma X^2$ ... (ii)

By putting the values we get

$67 = 5a + 45b$ ... (iii)

$655 = 45a + 455b$ ... (iv)

Multiplying equation (iii) by 9 and putting it as no. (v) we get,

$603 = 45a + 405b$ ... (v)

By deducting equation (v) from equation (iv); we get 52 = 50b

$b = \frac{52}{60} = 1.04$

By putting the value of b in equation (iii), we get

$$67 = 5a + 45 \times 1.04$$

or, $67 = 5a + 46.80$

or, $67 - 46.80 = 5a$

or, $5a = 20.20$

or, $a = \frac{20.20}{5}$

or $a = 4.04$

Now by putting the values of a and b the required regression equation of Y on X, is

$$Y = a + bX \quad \text{or, } Y = 4.04 + 1.04X$$

When X = 10 lakhs than

$$Y = 4.04 + 1.04\,(10)$$

or, $Y = 4.04 + 10.40$ or 14.44 thousand CTV sets.

Similarly for town having population of 20 lakhs, by putting the value of X = 20 lakhs in regression equation

$$Y = 4.04 + 1.04\,(20)$$

$$= 4.04 + 20.80 = 24.84 \text{ thousands CTV sets.}$$

Hence expected demand for CTV for two towns will be 14.44 thousand and 24.84 thousand CTV sets.

### Illustration 4

An investigation into the use of scooters in 5 towns has resulted in the following data: Population in town

| | | | | | | |
|---|---|---|---|---|---|---|
| **Population in town (in lakhs)** | (X) | 4 | 6 | 7 | 10 | 13 |
| **No. of scooters** | (Y) | 4,400 | 6,600 | 5,700 | 8,000 | 10,300 |

Fit a linear regression of Y on X and estimate the number of scooters to be found in a town with a population of 16 lakhs.

**Solution:**

**Computation of trend value**

| Population (in lakhs) X | No. of scooters demanded Y | Squares of population $X^2$ | Product of population and No. of scooters demanded XY |
|---|---|---|---|
| 4 | 4,400 | 16 | 17,600 |
| 6 | 6,600 | 36 | 39,600 |
| 7 | 5,700 | 49 | 39,900 |
| 10 | 8,000 | 100 | 80,000 |
| 13 | 10,300 | 169 | 1,33,900 |
| $\Sigma X = 40$ | $\Sigma Y = 35,000$ | $\Sigma X^2 = 370$ | $\Sigma XY = 3,11,000$ |

Regression equation of Y on X

Y = a + bX

To find the values of a and b we will have to solve the following two equations

$$\Sigma Y = na + b\Sigma X \quad \text{... (i)}$$

$$\Sigma XY = a\Sigma X + b\Sigma X^2 \quad \text{....(ii)}$$

By putting the values, we get

$$35,000 = 5a + 40b \quad \text{... (iii)}$$

$$3,11,000 = 40a + 370b \quad \text{... (iv)}$$

By multiplying equation no. (iii) by 8 putting as equation (v) we get,

$$2,80,000 = 40a + 320b \quad \text{... (v)}$$

By subtracting equation (v) from equation (iv), we get

$$31,000 = 50b$$

or, $50b = 31,000$

or, $b = \frac{310}{50} = 620$

By substituting the value of b in equation no. (iii), we get

$$35,000 = 5a + 40b$$

or $35,000 = 5a + 40 \times 620$

or $35,000 = 5a + 24,800$

or $10,200 = 5a$

or $a = \frac{10200}{5} = 2040$

Now putting the values of a and b the required regression equation of Y on X, is

$Y = a + bX$ or, $Y = 2040 + 620\ X$

When X = 16 lakhs then $Y = 2040 + 620\ (16)$

or $Y = 2040 + 9920$

or $Y = 11,960$

Hence, the expected demand of scooters for a town with a population of 16 lakhs will be 11,960 scooters.

# Capacity Planning

# 2.2

Capacity is the maximum amount of output a productive unit could produce within a stated time. So capacity is the rate of productive capability of a facility and it is usually expressed as volume of output per period of time.

Capacity refers to the maximum load an operating unit can handle. The operating unit might be a plant, a department, a machine, a store or a worker. Capacity of a plant is the maximum rate of output (goods or services) the plant can produce.

The production capacity of a facility or a firm is the maximum rate of production the facility or the firm is capable of producing. It is usually expressed in terms of units produced per period of time (i.e., hour, shift, day, week, month etc.). But when firms are producing different types of products, it is difficult to use volume of output of each product to express the capacity of the firm. In such cases, capacity of the firm is expressed in terms of monetary value (production value) of the various products produced put together

While producing output if the production process consists of many sub processes, then the capacity of the productive unit is governed by the capacity of the weakest link.


**Productive Unit**

If sub process 2 is the weakest link then capacity of the productive unit is governed by the capacity of weakest link.

But no single capacity measure is best for all situations.

- A retailer measures capacity as annual sales rupees generated per square ft;
- An airline measures capacity as available seat miles per month;
- A theater measures capacity as number of seats;
- A car manufacturer measures capacity as number of cars produced per day;

In general capacity can be expressed in one of two ways:

Output measures of capacity –

Are best utilized when applied to individual processes within the firm or when the firm provides a relatively small number of standardized services and products;

- High volume processes such as car manufacturers are a good example;
- Capacity is expressed as number of cars produced per day;

- This method is less applicable when the amount of customization and variety in the product mix increases;

Input measures of capacity –

- Are generally used for low volume, flexible processes such as furniture maker;
- Capacity is usually expressed as number of workstations or number of workers;

Capacity can be:

- Installed Capacity--It represents capacity in terms of machines actually installed. Productive machines procured for installation have some defined capacity, as provided in their printed literatures. Summation of such capacity gives a total installed capacity.
- Rated Capacity--This denotes the highest output established by the actual trial runs of the productive machines installed. (However, deciding the capacity rate based on the single one-time highest achievement may not be always correct. It is necessary to assume the average of performance rate of machines over a time period for more effective rating decision)
- Licensed Capacity--This denotes the actual capacity licensed by the concerned government authorities**.**
- Design capacity -The maximum output rate or service capacity an operation, process or facility is designed for achieving under ideal condition
- Effective capacity -Design capacity minus allowances such as personal time, maintenance etc.

Effective Capacity can be determined by giving due consideration to the following factors

- **Facilities -** design, location, layout and environment
- **Product -** Product design and product-mix.
- **Process -** Quantity and quality capabilities of the process or to be followed.
- **Human factors -** Job content, Job design, motivation, compensation, training and experience of labour, learning rates and absenteeism and labour turn over.
- **Operational factors -** Scheduling, materials management, quality assurance, maintenance policies, and equipment break-downs.
- **External factors -** Product standards, safety regulations, union attitudes, pollution control standards.

Effective capacity is always less than design capacity owing to changing product mix, the need for periodic maintenance of facilities, tiffin breaks, lunch breaks etc.

Actual output can never exceed effective capacity and is usually less because of machine breakdown, absenteeism, shortages of materials etc.

These different measures are useful in defining two measures of effectiveness of a system:

- Capacity Utilisation
- Efficiency

Capacity Utilisation –

Is the degree to which a resource such as equipment, space or the workforce is currently being used and is measured as the ratio of average output rate to maximum capacity (expressed as a percent).

The average output rate and the maximum capacity needs to be measured in the same terms – that is time, customers, units or rupees.

$$\text{Utilisation} = \frac{\text{Actual output}}{\text{Design Capacity}} \times 100\%$$

The utilization rate indicates the need for adding extra capacity or eliminating unneeded capacity. Utilisation can be increased by increasing actual output and hence effective capacity since actual output is born out of effective capacity

$$\text{Efficiency} = \frac{\text{Actual output}}{\text{Effective Capacity}} \times 100\%$$

Capacity planning is concerned with finding answers to the basic questions regarding capacity such as:

- What kind of capacity is needed?
- How much capacity is needed?
- When this capacity is needed?

Capacity planning is a Long term strategic decision that establishes a firm's overall level of resources.

The goal of capacity planning of an organisation is to achieve a match between its long term supply capabilities and the predicted level of long term demand.

Capacity decisions often involve long term irrevocable commitment of resources

Capacity decisions affect—

- Product lead times ( Duration between receipt of order for the product and readiness of the product);
- Customer Responsiveness;
- Operating Costs;
- Firm's ability to compete;

Capacity decisions are strategic because this decisions can affect competitiveness.

The objective of capacity planning and control of capacity, is to match the level of operations to level of demand. Out of Balance Capacity occurs when there is a gap between current and desired capacity. This depletes the competitiveness.

Capacity decisions are made in light of several long term issues such as the firm's economies and diseconomies of scale, capacity cushions, timing, trade offs between customer service and capacity utilisation etc.

Because of the aforesaid long term factors there are risks involved and Capacity strategies should consider all these.

Therefore while taking capacity decisions concerns are on factors

**Flexibililty:**

- *Flexibility* is introduced into the system
    - *Provisions for future requirments* must be there in the system

      If future expansion of an education institute is most likely, then during initial construction of the the institute's building water lines, power lines etc must be provided with adequate capacity commesurate with future need
    - Besides provisions for future requirements, flexibility also incorporated
        - While designing Location & Layout of equipments

- While making Productin planning, Scheduling & Inventory policies

**Life Cycle:**

Capacity requirements are often closely linked to the stage of the *Life Cycle* that a product or service is in.

*The product life cycle is the process a product goes through from when it is first introduced into the market until it declines or is removed from the market. The life cycle has four stages - introduction, growth, maturity and decline.*

- At introduction phase of a product---size of the overall market and organisation's share of the market is uncertain----large and inflexible capacity planning needs to be avoided
- At growth phase of a product---size of the overall market grows—
  - Rate of growth of individual organisation's market share influences its capacity planning
  - Influences individual organisation's level of production, level of investment
  - Opens opportunities to all organisations to bring competitive advantage through introduction of distinguished features into product (product differentiation) by investing in technology and process improvements
  - Brings risks of overcapacity in the market and result in higher unit costs of the output
- At maturity phase of a product---size of the market levels off
  - Organisations tend to have stable market share
  - Organisations could increase profitability through cost reduction and full capacity utilisation
  - Organisations with lower capacity in earlier phases of life cycle could go for capacity addition if maturity stage is thought to be prolonged
- At decline phase of a product---overall market demand declines
  - Organisations face underutilisation of capacity
  - Excess capacity could be sold off
  - Excess capacity could be used for producing other products or services

**Interrelation:**

- Parts of any system are always interrelated
- Capacity of one part has impacts on other parts and so capacity planning must consider these interrelations
  - Increasing the number of routes from an airport must have influence on security check-in capacity of the station.
- Capacity decisions related to a process has a role on the supply chain of the organisation as a whole
  - Increasing production capapcity may require more raw material supllies and supllier require time to adjust this change requirement
- So capapcity planning decsions must be made with collaboration among all the interelated players including supllier, distributos, transporters etc

**Bottleneck:**

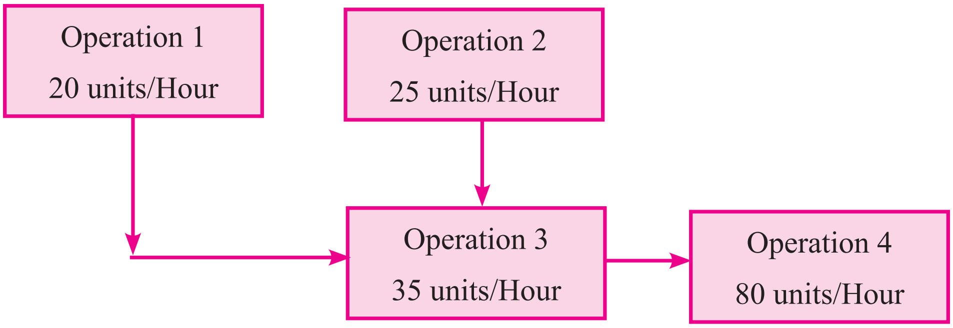
- Capacity planning decision must not encouarge *Bottleneck Operation*

Bottleneck operation is an operation in a sequence of operations whose capacity is lower than the capacities of other operation in the sequence.

- Bottleneak operation limits the capacity utilisation of the previous and successive operation in the whole sequence of opertion
- Capacity utilisation of the whole system is thereby reduced

Supoose there are four operations named Operations 1, Operation 2, Oepartion 3 & Operation 4

Production capacities and and their interrealtion is shown in the following figure:




Operation 3 can handle only 35 units/hour. But Operation 1 and Operation 2 at its full capacity could produce a total of 45 units /hour which Operation 3 cannot handle. So although operation 4 has enough capacity overall capacity of the system is restricted to 35 units per hour

**Chunk:**

- Capacities are available in Chunks
- Creates mismatch between desired capacity and available capacity
- Creates either shortfall or surplus in production

**Variability:**

- Demand is variable
- Variability can be seasonal, chance random, cyclical etc.
- Variable demand brings unevenness in capacity requirements
- Capacity strategies should provide allowances for these
- Capacity should be for complementary products & services to cater seasonality

**Optimal Operating level:**

- Production units always have an ideal or optimal level of operation in terms of unit cost of output
- This brings Economies of scale and Diseconomies of scale

Economies of scale

- States that the average unit cost of a good or service can be reduced by increasing its output rate

Diseconomies of scale

- A level of operation at which average cost per unit increases as the facility's size increases

**Miscellaneous:**

- Incremental Expansion or single step expansion of capacity considering
  - Competitive pressure
  - Market Opportunities
  - Costs and availability of funds
  - Disruption of operation
  - Training requirements

Capacity planning is required for the following:

- Sufficient capacity is required to meet the customers demand in time,
- Capacity affects the cost efficiency of operations,
- Capacity affects the scheduling system,
- Capacity creation requires an investment
- Post selection of required capacity, decisions regarding the facility location and process technology selection etc. starts

Capacity planning is mainly of two types:

- **Long-term capacity plans** which takes into account investments in new facilities and equipment. These plans cover a time horizon of more than two years.
- **Short-term capacity plans** which takes into account work-force size, overtime budgets, inventories etc.

Capacity planning involves activities such as:

- Assessing the capacity of existing facilities.
- Forecasting the long-range future capacity needs.
- Identifying and analysing sources of capacity for future needs.
- Evaluating the alternative sources of capacity based on financial, technological and economic considerations
- Selecting a capacity alternative most suited to achieve strategic mission of the firm.

An operating unit in its life may face any of the following two situations:

- An excess or surplus capacity situation where the present capacity exceeds the expected future demand
- A capacity shortage situation where present capacity is not enough to meet the forecast demand for the product

Capacity planning takes concern on these two cases.

**The over capacity is preferred when:**

- Fixed cost of the capacity is not very high.
- Subcontracting is not possible because of secrecy of design and/or quality requirement.
- The time required to add capacity is long.
- The company cannot afford to miss the stipulated delivery date and cannot afford to lose the customer.
- There is an economic capacity size below which it is not economical to operate the plant.

Excess capacity –

- Drain company's resources;
- Prevent investments in other more lucrative ventures;

**The under capacity is preferred when:**

- Fixed cost of the capacity is very high.
- Shortage of products does not affect the company (i.e., lost sales can be compensated).
- The technology changes fast, i.e., the rate of obsolescence of plant and equipment are high.
- The cost of creating the capacity is prohibitively high.

Inadequate capacity –

- Loss of customers;
- Restricts growth;

Two kinds of factors affecting capacity planning are:

- **Controllable Factors:** amount of labour employed, facilities installed, machines, tooling, shifts of work per day, days worked per week, overtime work, subcontracting, preventive maintenance and number of production set ups.
- **Less Controllable Factors:** absenteeism, labour performance, machine break-downs, material shortages, scrap and rework, strike, lock-out, fire accidents, natural calamities (flood, earthquake etc.) etc.

**Forms of capacity planning:**

- Based on time-horizon
  - Long-term capacity planning - which takes into account investments in new facilities and equipment. These plans cover a time horizon of more than two years.
  - Short-term capacity planning - which takes into account work-force size, overtime budgets, inventories etc.
- Based on amount of resources employed
  - Finite capacity planning and
  - Infinite capacity planning

Operations managers must examine three dimensions of capacity strategy before making capacity decisions:

- Sizing capacity cushions;
- Timing and sizing expansion;
- Linking Capacity decisions with other operating decisions;

**(1)** Sizing capacity cushions

*Capacity Cushion* is the amount of reverse capacity a process uses to handle sudden increases in demand or temporary losses of production capacity.

Capacity Cushion = 100% - Average utilisation rate (%)

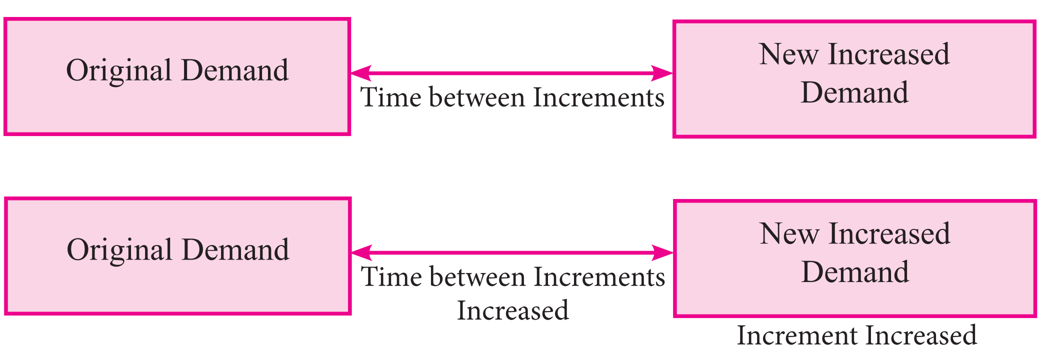
The appropriate size of the cushion varies by industry—capital intensive industries prefer under 10% cushion where less capital intensive can run with 40 to 30% cushion

- Unused capacity costs money and brings low return on investment
  - Business keeps large cushion when demand varies or when future demand is uncertain or with a changing product mix
  - In the long run it buffers the organisation against uncertainty as do resource flexibility, inventory and longer customer lead times
  - Any change in any decision area needs change in capacity cushion
- Capacity cushions for a process can be lowered if competitive priorities are given
- Capacity cushions can be lowered if the company is willing to smooth the output rate by raising prices when inventory is low (since inventory is low, raising price could restrict demand becomes greater than production) and decreasing prices when it is high

Highly variable demand – In certain service industries (e.g. Grocery) demand on some days of the week is predictably higher than on other days. Long customer waiting times are not acceptable because customer goes impatient if they have to wait in a supermarket checkout line for more than a few minutes. Prompt customer service requires supermarkets to maintain a capacity cushion large enough to handle peak demand.

**(2)** Timing and sizing expansions

- Has concern when to adjust capacity levels and by how much
- Two extreme strategies for expanding capacity---
  - Expansionist strategy----involves large, infrequent jumps in capacity
- Stays ahead of demand, minimises the chance of sales lost to insufficient capacity
  - Wait and see strategy ---involves smaller more frequent jumps
- Lags behind demand and therefore to meet any shortfalls it relies on short term options such as use of overtime, temporary workers, subcontractors, stock-outs and postponement of preventive maintenance of equipment
- Timing and sizing of expansion are related
  - If demand is increasing and the time between increments increases, the size of the increments must also increase



Factors favouring expansionist strategy:

- It results economies of scale;
- It results reducing cost of operation;
- It facilitates a firm to compete on price;
- It might increase the firm's market share;

Factors favouring wait and see strategy:

- It reduces the risks of overexpansion;
- It facilitates firms to avoid obsolete technology;
- It guards against inaccurate assumptions regarding competition;

Advantages/disadvantage of Expansionist strategy---

- It can result in economies of scale and faster rate of learning
- This helps a firm to reduce its costs and compete on price
- This might increase firm's market share
- It may bring risk of overexpansion

Advantages/disadvantage of Wait & see strategy---

- It reduces the risks of overexpansion
- It is unable to respond if demand is unexpectedly high
- It fits the short term outlook but can erode market share over the long run

*Managers may choose one of these two strategies or one of the many between these extremes*

Three basic strategies for the timing of capacity expansion in relation to a steady growth in demand are

***Capacity Lead Strategy:*** Capacity is expanded in anticipation of demand growth. This aggressive strategy is used to lure customers from competitors who are capacity constrained ot to gain a foothold in a rapidly expanding market

***Capacity Lag strategy:*** Capacity is increased after an increase in demand has been documented. This conservative strategy produces a higher return on investment but may lose customers in the process. It is used in industries with standard products and cost based or weak competition. The strategy assumes that lost customers will return from competitors after capacity has expanded

***Average Capacity strategy:*** Capacity is expanded to coincide with average expected demand. This is a moderate strategy in which mangers are certain they will be able to sell at least some portion of the additional output

**(3)** Linking process capacity and other operating decisions

- Capacity decisions should be closely linked to processes and supply chains throughout the organisation
- Capacity decisions must link backward as well as forward channels in the whole operation chain

**Level capacity plan**

- Based in "produce-to-stock and sell" approaches wherein the production systems are operated at uniform production levels and finished goods inventories rise and fall depending upon whether production level exceeds demand or vice versa from time period to time period (say every quarter).

**Matching capacity with demand plan.**

- In this plan, production capacity is matched with the demand in each period (weekly, monthly or quarterly demand). Usually, material flows and machine capacity are changed from quarter to quarter to match the demand. The main advantages are low levels of finished goods inventory resulting in lesser inventory carrying costs. Also, the back-ordering cost is reduced. The disadvantages are high labour and material costs because of frequent changes in workforce (hiring, training and lay-off costs, overtime or idle time cost or subcontracting costs).

A higher capacity plant offers some economies of scale:

- Automation is possible in a high capacity plant;
- Labour economies – lower variable cost/unit – increase of skill of worker;
- Managerial economies, technical competence;
- Marketing economies – Purchase in bulk;
- Financial economies – better security, attract investment at lower cost;

Economies of scale – occur when it costs less per unit to produce or operate at high levels of output. This is true when:

- Fixed costs can be spread over a larger number of units;
- Production or operating costs do not increase linearly with output levels;
- Quantity discounts are available for material purchases;
- Operating efficiency increases as workers gain experience;

Economies of scale do not continue indefinitely. Above a certain level of output diseconomies of scale can occur like:

- Overtaxed machines and material handling equipment break down;
- Slowing of service time;
- Quality suffers requiring more rework
- Labour costs increase with more overtime;
- Increase in difficulties in coordination and management activities;

Once long term forecast is found out additions of increments to existing capacity can be done:

- Add capacity increments but more often (less new capacity at a time);
- Add capacity increments but less often (high new capacity at a time);
- Add capacity before the requirements exceed the capacity available;
- Add capacity after the requirements has overtaken the available capacity;

A systematic approach to Long term decisions for capacity would typically include:

(a) Whether to add a new plant

(b) Whether to add a new workstations

(c) Whether to reduce the number of existing workstations/warehouses etc.

Some of these can take years to become operational and so a systematic approach is required to plan for long term capacity decisions. The four step systematic approach involves:

(1) Estimate future capacity requirements

(2) Identify gaps by comparing requirements with available capacity

(3) Develop alternative plans for reducing the gaps

(4) Evaluate each alternative, both qualitatively and quantitatively, and making a final choice

Out of Balance Capacity occurs when there is a gap between current and desired capacity

When just one service or product is processed, then capacity requirement of a single capacity per year is:

$$\text{Capacity Requirement (M)} = \frac{\text{Processing hours required to meet year's demand}}{\text{Hours available from a single capacity unit per year after deducting desired cushion}}$$

[Single capacity means an employee, a machine, a computer etc.]

$$= \frac{D_p}{N[1 - (\frac{C}{100})]} \text{ .............................. (1)}$$

Where

D = demand forecast for the year (number of customers serviced or units of product)

p = processing time (in hours per customer served or unit product)

N = total number of hours per year during which the process operates

C = desired capacity cushion (expressed as a percent)

After accounting for both processing and setup times equation (1) above for multiple products/services can be modified as

Capacity Requirement (M)

$$= \frac{\text{Processing \& Set up hours required to meet year's demand summed over all services / products}}{\text{Hours available from a single capacity unit per year after deducting desired cushion}}$$

$$= \frac{[Dp + (\frac{D}{Q})s]_{product1} + [Dp + (\frac{D}{Q})s]_{product2} + \text{...............} + [Dp + (\frac{D}{Q})s]_{productn}}{N[1 - (\frac{C}{100})]} \text{ .................. (2)}$$

Where

Q = number of units in each lot.

s = set up time (in hours) per lot

**Example1**: For your company capacity measures is in number of machines. The company produces three product A, B and C. Processing and Set up times (Time standard), lot sizes and demand forecasts are given in the following table. The firm operates 3-8hour shifts, 5 days week, 50 weeks per year. A capacity cushion of 5% is sufficient.

| Product | Time standard | | Lot Size (units/lot) | Demand Forecast (units/year) |
|---|---|---|---|---|
| | Processing(hr/unit) | Setup(hr/unit) | | |
| A | 2 | 0.5 | 300 | 18000 |
| B | 5 | 1 | 500 | 50000 |
| C | 3 | 1 | 1000 | 9000 |

(i) How many machines are needed?

(ii) If the operation currently has fifty machines, what is the capacity gap?

**Answer:**

(i) The number of hours of operation per year, $N = \frac{3 \text{ shifts}}{\text{Day}} = \frac{8 \text{ hours}}{\text{shift}} = \frac{5 \text{ day}}{\text{week}} * 50 \text{ week} = 6000 \text{ hours}$

The number of machines required M is the sum of machine hour requirements for all three products divided by the number of productive hours available for one machine

Capacity Requirements (M)

$$= \frac{\text{Processing \& Set up hours required to meet year's demand summed over all services / products}}{\text{Hours available from a single capacity unit per year after deducting desired cushion}}$$

$$= \frac{[Dp + (\frac{D}{Q})s]_A + [Dp + (\frac{D}{Q})s]_B + [Dp + (\frac{D}{Q})s]_C}{N[1 - (\frac{C}{100})]}$$

$$= \frac{[18000 * 2 + (\frac{18000}{300})0.5] + [50000 * 5 + (\frac{50000}{500})1] + [9000 * 3 + (\frac{9000}{1000})1]}{6000[1 - \frac{5}{100}]}$$

$$= \frac{313139}{5700} = 54.9 \cong 55 \text{ machines}$$

(ii) The capacity gap is 55 - 50 = 5 machines. 20 more machines should be purchased unless management decides to use short term options, if any available, to fill the gap

**Example 2:** The base case for a cloud kitchen company whose details are given below is to do nothing. The capacity of the kitchen in the base case is 100,000 meals per year. A capacity alternative is a two stage expansion. This alternative expands the kitchen at the end of the year 0, raising its capacity from 80,000 meals per day to that of the dining area (105,000 meals per year).

If sales in year 1 and 2 live up to expansions, the capacities of both the kitchen and dining room will be expanded at the end of the year 3 to 150,000 meals per year. This upgraded capacity level should suffice up through year 5. The initial investments would be ₹1,20,000 at the end of year 0 and an additional investment of ₹ 2,00,000 at the end of year 3. The pretax profit is ₹15/meal. The owner expects to sale 80,000 meals in the current year. Forecasted Demand for the next 5 years is 90,000 meals for the next year, followed by a 10,000 units increase in each of the succeeding years. What are the pretax cash flows for the alternative through year 5, compared with the base case? Find NPV at 10%

**Answer:**

| Year | 0 (Current year) | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Forecasted sale (meals) | 80000 | 90000 | 1,00,000 | 1,10,000 | 1,20,000 | 1,30,000 |
| Increamental sale Compared to base i.e., current year (units) | | 10000 | 20000 | 30000 | 40000 | 50000 |
| Average profit per unit | | 15 | 15 | 15 | 15 | 15 |
| Increamental profit flow (Rs.) | | 150000 | 300000 | 450000 | 600000 | 750000 |

| | Year | 0 (Current year) | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| 1 | Initial Investment | -120000 | | | | | |
| 2 | Incremental profit flow on investment | | 150000 | 300000 | 450000 | 600000 | 750000 |
| 3 | Additional Investment | | | | -200000 | | |
| 4 | Net cash flows (Inflows/Outflows) | -120000 | 150000 | 300000 | 250000 | 600000 | 750000 |
| 5 | PV Factor $(1/1.10)^n$ (Since cost of fund 10%, n = no of years) | 1 | 0.909 | 0.826 | 0.751 | 0.683 | 0.621 |
| 6 | PV (4 * 5) | -120000 | 136363.6 | 247933.9 | 187828.7 | 409808.1 | 465691 |
| 7 | NPV (Sum of Row 4) | 1327625.286 | | | | | |

**Example 3**: Up, Up and Away is a producer of kites and wind socks. Relevant data on a bottleneck operation in the shop for the upcoming fiscal year are given in the following table:

| Item | Kites | Wind Socks |
|---|---|---|
| Demand forecast | 30000 units/year | 12000 units/year |
| Lot size | 20 units | 70 units |
| Standard processing time | 0.3hours/unit | 1.0 hour/unit |
| Standard setup time | 3hours/lot | 4hours/lot |

The shop works for two shifts per day, 8 hours per shift, and 200 days per year. Currently, the company operates four machines and desires a 25% capacity cushion. How many machines should be purchased to meet the upcoming year's demand without resorting to any short term capacity solution?

**Answer:**

The number of hours of operation per year, $N = \frac{2 \text{ shifts}}{\text{Day}} = \frac{8 \text{ hours}}{\text{shift}} * 200 \text{ days} = 3200 \text{ hours}$

The number of machines required is the sum of machine hour requirements for all two products divided by the number of productive hours available for one machine

Capacity Requirements (M)

$$= \frac{\text{Processing \& Set up hours required to meet year's demand summed over all services / products}}{\text{Hours available from a single capacity unit per year after deducting desired cushion}}$$

$$= \frac{[Dp + (\frac{D}{Q})s]_K + [Dp + (\frac{D}{Q})s]_W}{N[1 - (\frac{C}{100})]}$$

$$= \frac{[30000 * 0.3 + (\frac{30000}{20})3] + [12000 * 1 + (\frac{12000}{70})4]}{3200[1 - \frac{25}{100}]}$$

$$= \frac{26185.71}{2400} = 10.91 \cong 11 \text{ machines}$$

So another 11 - 4 = 7 machines are to be purchased

**Example 4:** Turf-Rider Inc. manufactures touring bikes and mountain bikes in a variety of frame sizes, colors and component combinations. Identical bicycles are produced in lots of 100. The projected demand, lot size and time standards are shown in the following table:

| Item | Touring | Mountain |
|---|---|---|
| Demand forecast | 5000 units/year | 10000 units/year |
| Lot size | 100 units | 100 units |
| Standard processing time | 25hours/unit | 5 hour/unit |
| Standard setup time | 2hours/lot | 3hours/lot |

The shop currently works 3shift 8 hours a day, 5 days a week, 50 weeks a year. It operates hundred workstations, each producing one bicycle in the time shown in the table. The shop maintains a 15% capacity cushion. How many workstations will be required next year to meet expected demand without using overtime and without decreasing the firm's current capacity cushion?

**Answer:**

The number of hours of operation per year, $N = \frac{3 \text{ shifts}}{\text{Day}} = \frac{8 \text{ hours}}{\text{shift}} = \frac{5 \text{ day}}{\text{week}} * 50 \text{ week} = 6000 \text{ hours}$

The number of machines required M is the sum of machine hour requirements for all two products divided by the number of productive hours available for one machine

Capacity Requirements (M)

$$= \frac{\text{Processing \& Set up hours required to meet year's demand summed over all services / products}}{\text{Hours available from a single capacity unit per year after deducting desired cushion}}$$

$$= \frac{[Dp + (\frac{D}{Q})s]_r + [Dp + (\frac{D}{Q})s]_m}{N[1 - (\frac{C}{100})]}$$

$$= \frac{[5000 * 25 + (\frac{5000}{100})2] + [10000 * 50 + (\frac{10000}{100})3]}{6000[1 - \frac{15}{100}]} = \frac{625400}{5100} = 122.63 \cong 123 \text{ workstations}$$

**Example 5:** Amrita is considering expanding the floor area of her high-fashion import clothing store, The Frantic, by increasing her leased space in the upscale Acropolis mall from 2000 square feet to 3000 square feet. The Acropolis mall boasts one of the country's highest ratios of sales value per square ft. Rents (including utilities, security and similar costs) are Rs 110 per Sq.ft per year. Salary increases related to Frantic's expansion are shown in the following table, along with projection of sales per square ft. The purchase cost of goods sold average 70% of the sales price. Sales are seasonal, with an important peak during the year-end holiday season.

| Year | Quarter | Sales (per Sq.ft) | Salaries |
|---|---|---|---|
| 1 | 1 | Rs 90 | Rs 120,000 |
| | 2 | 60 | 80,000 |
| | 3 | 110 | 130,000 |
| | 4 | 240 | 240,000 |
| 2\ | 1 | 99 | 120,000 |
| | 2 | 66 | 80,000 |
| | 3 | 121 | 140,,000 |
| | 4 | 264 | 240,000 |

(i) If Amrita expands Frantic at the end of year 0, what will her quarterly pretax cash flows be through year 2?

(ii) Will the expansion be accepted?

**Answer:**

| | | POST EXPANSION RESULT | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1st year | | | | 2nd year | | | |
| | 0 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| | EXPANSION | | | | | | | | |
| 1. Sq feet | | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 |
| 2. Sales per Sq ft (Rs/Sq ft) | | 90 | 60 | 110 | 240 | 99 | 66 | 121 | 264 |
| 3. Sales (Rs) | | 270000 | 180000 | 330000 | 720000 | 297000 | 198000 | 363000 | 792000 |
| 4. Cost of goods sold at 70% of sales | | 189000 | 126000 | 231000 | 504000 | 207900 | 138600 | 254100 | 554400 |
| 5. Rent of the space @ Rs.110/sq ft | | 330000 | 330000 | 330000 | 330000 | 330000 | 330000 | 330000 | 330000 |
| 6. Salaries | | 120000 | 80000 | 130000 | 240000 | 120000 | 80000 | 140000 | 240000 |
| 7. Pretax cash flows (3-4-5-6) | | -369000 | -356000 | -361000 | -354000 | -360900 | -350600 | -361100 | -332400 |

The project will not be accepted as negative pretax cash flows in all periods will generate a negative NPV

When demand is uncertain and sequential decisions are involved then a decision tree can be particularly valuable for evaluating different capacity expansion alternatives.

Suppose on the basis of forecast demand position at time t = 0 a business unit decided to expand. During further studies during course of operation with expanded establishment if it is found that future demand will be more compared to demand forecast available at t = 0, then additional expansion will be required to cater the changed demand.

Expanding twice is likely to be much more expensive than building a larger facility from the outset. However, making a large expansion now, when demand growth is low, means poor facility utilisation. Under this type of situation decision tree model will be used.

**Optimum Plant Capacity:**

Plant capacity has a great influence on cost of production with increasing volume of production, economies of scale arises which results in reduction in average cost per unit produced.

As the volume of output increases outward from zero in a particular production facility, average unit costs fall. These declining costs are because of the following reasons: (i) Fixed costs are spread over more units produced, (ii) Plant construction costs are less, (iii) Reduced costs of purchased material due to quantity discounts for higher volume of materials purchased and (iv) Cost advantages in mass production processes

So for a given production facility, there is an optimum volume of output per year that results in the least average unit cost. This level of output is called the "best operating level" of the plant.

**Balancing the Capacity:**

In firms manufacturing many products (a product line or a product-mix) the load on different machines and equipment vary due to changes in product-mix. When the output rates of different machines do not match with the required output rate for the products to be produced, there will be an imbalance between the work loads of different machines. This will result in some machine or equipment becoming a "bottleneck work centre" thereby limiting the plant capacity which will in-turn increase the production costs per unit.

To overcome problem of imbalance between different machines, additional machines or equipment are added to the bottleneck work-centre to increase the capacity of the bottle-neck work centre to match with the capacity of other work centre. Adding new machines or equipment to bottleneck work centres to remove the imbalance in capacity between various work centres is found to be economical than giving excessive overtime to workers working in bottle-neck centres which increases production costs. Another method to remove imbalance is to subcontract excess work load of bottleneck centres to outside vendors or subcontractors. Another way to balance capacities is to try to change the product mix by manipulating the sales for different products to arrive at a suitable product-mix which loads all work centres almost uniformly.

**Illustration 5**

A department works on 8 hours shift, 250 days a year and has the usage data of a machine, as given below:

| Product | Annual demand (units) | Processing time (standard time in hours) |
|---|---|---|
| X | 300 | 4.0 |
| Y | 400 | 6.0 |
| Z | 500 | 3.0 |

Determine the number of machines required.

**Solution:**

**Step 1:** Calculate the processing time needed in hours to produce product x, y and z in the quantities demanded using the standard time data.

| Product | Annual demand (units) | Standard processing time per unit (Hrs.) | Processing time needed (Hrs.) |
|---|---|---|---|
| X | 300 | 4.0 | 300 x 4 = 1200 Hrs. |
| Y | 400 | 6.0 | 400 x 6 = 2400 Hrs. |
| Z | 500 | 3.0 | 500 × 3 = 1500 Hrs. |
| | | | Total = 5100 Hrs |

**Step 2 :** Annual production capacity of one machine in standard hours = 8 × 250 = 2000 hours per year

**Step 3 :** Number of machines required

$$= \frac{\text{Work load per year}}{\text{Production capacity per machine}} = \frac{5100}{2000} = 2.55 \text{ machines} = 3 \text{ machines.}$$

## Illustration 6

A steel plant has a design capacity of 50,000 tons of steel per day, effective capacity of 40,000 tons of steel per day and an actual output of 36,000 tons of steel per day. Compute the efficiency of the plant and its utilisation.

**Solution:**

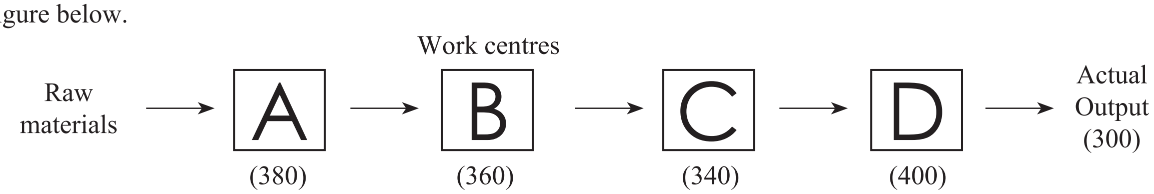
Actual output

$$\text{Efficiency of the plant} = \frac{\text{Actual output}}{\text{Effective capacity}} = \left(\frac{36000}{40000}\right) \times 100 = 90\%$$

$$\text{Utilisation} = \left(\frac{\text{Actual output}}{\text{Design capacity}}\right) = \left(\frac{36000}{50000}\right) \times 100 = 72\%$$

## Illustration 7

A firm has four work centres, A, B, C & D, in series with individual capacities in units per day shown in the figure below.




(i) Identify the bottle neck centre.

(ii) What is the system capacity?

(iii) What is the system efficiency?

**Solution:**

(i) The bottle neck centre is the work centre having the minimum capacity. Hence, work centre 'C' is the bottleneck centre.

(ii) System capacity is the maximum units that are possible to produce in the system as a whole. Hence, system capacity is the capacity of the bottle neck centre i.e., 340 units.

(iii) $\text{System efficiency} = \frac{\text{Actual output}}{\text{System capacity}} = \frac{300}{340} \times 100$ (i.e., maximum possible output) = 88.23%

## Illustration 8

A manager has to decide about the number of machines to be purchased. He has three options i.e., purchasing one, or two or three machines. The data are given below.

| Number of machine | Annual fixed cost | Corresponding range of output |
|---|---|---|
| One | ₹ 12,000 | 0 to 300 |
| Two | ₹ 15,000 | 301 to 600 |
| Three | ₹ 21,000 | 601 to 900 |

Variable cost is ` 20 per unit and revenue is ` 50 per unit

(a) Determine the break-even point for each range

(b) If projected demand is between 600 and 650 units how many machines should the manager purchase?

**Solution:**

(i) Break-even point

Let Q be the break even point.

FC = Fixed cost, R = Revenue per unit, VC = Variable cost

At, BEP, TR = FC + TVC

or, Revenue p.u × Q = FC + VCp.u. × Q

$$Q\,(R - VC) = FC$$

$$Q = \frac{FC}{R - VC}$$

Let Q1 be the break-even-point for one machine option

$$\text{Then, } Q1 = \frac{1200}{(50 - 20)} = \frac{1200}{30} = 400 \text{ units}$$

(Not within the range of 0 to 300)

Let Q2 be the break-even-point for two machines option.

$$\text{Then, } Q2 = \frac{1500}{(50 - 20)} = \frac{1500}{30} = 500 \text{ units}$$

(within the range of 301 to 600)

Let Q3 be the break-even-point for three machines option.

$$\text{Then, } Q3 = \frac{21000}{(50 - 20)} = \frac{21000}{30} = 700 \text{ units}$$

(with in the range of 601 to 900)

(ii) The projected demand is between 600 to 650 units.

The break even point for single machine option (i.e., 400 units) is not feasible because it exceeds the range of volume that can be produced with one machine (i.e., 0 to 300).

Also, the break even point for 3 machines is 700 units which is more than the upper limit of projected demand of 600 to 650 units and hence not feasible. For 2 machines option the break even volume is 500 units and volume range is 301 to 600.

Hence, the demand of 600 can be met with 2 machines and profit is earned because the production volume of 600 is more than the break even volume of 500. If the manager wants to produce 650 units with 3 machines, there will be loss because the break even volume with three machines is 700 units. Hence, the manager would choose two machines and produce 600 units.

# Facility Location and Layout

# 2.3

For any manufacturing unit operations management starts with "What to produce?" followed by "How much to produce" and then followed by Where to produce"

Where to produce--- results in this topic "Facility location and layout"

**Definition of a Facility and Facility Location**

- In a simpler term, facility means any type of set-up that an organisation requires to run its operations and produce required products and/or delivers intended services to the customers. Location, on the other hand is the place or region where the above-mentioned facility may be established.

**Facility location involves following decision:**

- Where to establish the set-up?

**Need for an appropriate facility location**

The need for selecting an appropriate facility location stems from the following concerns of an organisation such as

- When an organisation wants to start a new business and/or expand the existing business by entering into a new market and/or increases the scale of operations
- When the business faces some complexities and/or difficulties in terms of resource shortage, expiry of lease agreement, socio-cultural problems, legal and political issues and other economic and social issues that force the organisations to change the location.

**Benefits from a Good Facility Location**

- Cost benefit in terms reduced fixed and variable cost, transportation cost.
- Proximity to market and source
- Easy and hassle free transport facility

In short, a good facility location is one that enables the organisations to strike a balance between cost (cost of production and service) and service and intends to maximize the service quality while minimizing the cost to the extent possible and remain competitive at the market place (in terms of visibility, proximity to source and market). It is a strategic decision that organisation takes.

**Factors affecting location selection decision**

- Sourcing
    - Availability of raw materials
    - Availability of natural resources, energy and waters

- Availability of internet connectivity
- Proximity to the key suppliers
- Connectivity to alternate vendors
- Opportunity to cross-docking and utilizing milk vans

- Markets
  - Proximity to market
  - Coverage of wide geographical area (with close proximity to target customers) keeping the facility at focal point
  - Connectivity with a large customer base
  - Lesser time to market
  - Connectivity
- Cost
  - Lesser transportation cost and well availability of various transportation modes
  - Lesser lease and/or rental cost
  - Tax, and other duties
  - Other hidden cost
- Socio-cultural, community and Political issues
  - Supportive community
  - Familiarity with language, rituals and culture
  - Level of crime and other disturbances
  - Availability of prospective employees
  - Quality of living
  - Statutory and regulatory rules and regulations
  - Availability of medical facilities, fire and police
- Environmental concerns
- Availability of skilled labours
- Competitive pressure

Some approaches for facility location selection

An organisation follows certain steps to make a correct location choice. These Steps are:

- Decide on the criteria for evaluating location alternatives
- Identify important factors
- Develop location alternatives
- Evaluate the alternatives

- Make a decision and select the location

Some of the popular approaches are:

- Factor Rating Method
- Centre of Gravity Technique
- Transportation Model
- Optimization and Heuristic Models

Let us consider some situations of facility location selection problems

### Illustration 9

Suppose, an E-Commerce company wants to open Central order fulfilment center in Kolkata South in West Bengal. The possible locations are say $L_1$, $L_2$, and $L_3$. The company form a group of experts. The team identifies say 6 actors such as $F_1$, $F_2$, $F_3$, and $F_4$ to evaluate $L_1$ to $L_3$.

**Solution:**

This situation can be solved using Factor Rating Method. The steps are:

In the first stage the expert team needs to give weightage to the factors. This can be done in many ways. In the following one simple way is explained.

A possible approach:

Suppose, the experts rate each factor on a scale 1 to 5 (1: least important and 5: Most important)

| **Factor** | **Rating** | | | | | | |
|---|---|---|---|---|---|---|---|
| | E-1 | E-2 | E-3 | E-4 | E-5 | **Row** | **Weight** |
| $F_1$ | 4 | 3 | 4 | 4 | 3 | 18 | 18/68 |
| $F_2$ | 5 | 5 | 5 | 5 | 4 | 24 | 24/68 |
| $F_3$ | 3 | 4 | 4 | 3 | 5 | 19 | 19/68 |
| $F_4$ | 2 | 1 | 2 | 1 | 1 | 7 | 7/68 |
| | | | | | | 68 | |

There may be other ways (e.g., AHP method). Let us now come back to our problem. Let us assume the factors are following weights.

| **Factors** | **Weight** |
|---|---|
| $F_1$ | 0.3 |
| $F_2$ | 0.2 |
| $F_3$ | 0.1 |
| $F_4$ | 0.4 |
| | Total 1.0 |

The experts are requested to rate each of the location alternatives with respect to the factors, e.g., 10: Most beneficial and 1: Least beneficial

| Factors | Alternatives | | |
|---|---|---|---|
| | $L_1$ | $L_2$ | $L_3$ |
| $F_1$ | 10 | 9 | 7 |
| $F_2$ | 7 | 3 | 10 |
| $F_3$ | 7 | 5 | 10 |
| $F_4$ | 6 | 8 | 5 |

So the complete table becomes

| Factors | Weight | Alternatives | | |
|---|---|---|---|---|
| | | $L_1$ | $L_2$ | $L_3$ |
| $F_1$ | 0.3 | 10 | 9 | 7 |
| $F_2$ | 0.2 | 7 | 3 | 10 |
| $F_3$ | 0.1 | 7 | 5 | 10 |
| $F_4$ | 0.4 | 6 | 8 | 5 |
| | Best Location | 7.5 | 7 | 7.1 |

Example of calculation

for L1 : 0.3 × 10 + 0.2 × 7 + 0.4 × 6 = 3 + 1.4 + 0.7 + 2.4 = 7.5

As per the weighted score Location L1 is the best location

### Illustration 10

Suppose, XYZ Ltd wants to open a retail shop in Kolkata, West Bengal.

It first selects the 4 locations such as L1, L2, L3 and L4. The coordinates of the locations (i.e., latitudes and longitudes) and volume of customers (i.e., average number of customers in a day in '000) are given in the following table

| | | Coordinates | |
|---|---|---|---|
| Location | Volume | X | Y |
| $L_1$ | 200 | 30 | 100 |
| $L_2$ | 100 | 90 | 120 |
| $L_3$ | 100 | 130 | 130 |
| $L_4$ | 200 | 60 | 40 |

Find out the best location using Center of Gravity (COG) method.

**Solution:**

| Loc | $V_1$ | $x_i$ | $y_i$ | $v_i x_i$ | $v_i y_i$ |
|---|---|---|---|---|---|
| $L_1$ | 200 | 30 | 100 | 6000 | 20000 |
| $L_2$ | 100 | 90 | 120 | 9000 | 12000 |
| $L_3$ | 100 | 130 | 130 | 13000 | 13000 |
| $L_4$ | 200 | 60 | 40 | 12000 | 8000 |
| | 600 | | Total | 40,000 | 53,000 |

Therefore, $SV_i = 600$; $Sv_i x_i = 40000$

$Sv_i y_i = 53000$

COG location is given by (X, Y)

$$X = \frac{\sum V_i X_i}{\sum V_i} = 40000/600 = 200/3$$

$$Y = \frac{\sum V_i Y_i}{\sum V_i} = 53000/600 = 265/3$$

## Facility Layout

Plant Layout, also known as layout of facility refers to the configuration of departments, work-centres and equipment and machinery with focus on the flow of materials or work through the production system.

Plant layout or facility layout means planning for location of all machines, equipments, utilities, work stations, customer service areas, material storage areas, tool servicing areas, tool cribs, aisles, rest rooms, lunch rooms, coffee/tea bays, offices, and computer rooms and also planning for the patterns of flow of materials and people around, into and within the buildings. Layout planning involves decisions about the physical arrangement of economic activity centres within a facility. An economic activity centre can be anything that consumes space, a person or group of people, a machine, a work station, a department, a store room and so on. The goal of layout planning is to allow workers and equipments to operate more effectively.

The questions to be addressed in layout planning are:

- How much space and capacity does each centre need?
- How should each center's space be configured?
- What centres should the layout include?
- Where should each centre be located?

The location of a centre has two dimensions:

- Absolute location or the particular space that the centre occupies within the facility.
- Relative location i.e., the placement of a centre relative to other centers.

**The importance of layout decisions:**

The need for layout planning arises both in the process of designing new plants and the redesigning existing plants or facilities.

Most common reasons for design of new layouts are:

(i) Layout is one of the key decisions that determine the long-run efficiency in operations.

(ii) Layout has many strategic implications because it establishes an organisation's competitive priorities in regard to capacity, processes, flexibility and cost as well as quality of work life, customer contact and image (in case of service organisations).

(iii) An effective layout can help an organisation to achieve a strategic advantage that supports differentiation, low cost, fast response or flexibility.

(iv) A well designed layout provides an economic layout that will meet the firm's competitive requirements.

**Need for redesign of layout arises because of the following reasons:**

- Accidents, health hazards and low safety,
- Changes in environmental or legal requirements,
- Changes in processes, methods or equipments,
- Changes in product design/service design,
- Changes in volume of output or product-mix changes,
- Inefficient operations (high cost, bottleneck operations),
- Introduction of new products/services,
- Low employee morale.

**Good Plant layout- Objectives:**

- Efficient utilisation of labour reduced idle time of labour and equipments,
- Higher flexibility (to change the layout easily),
- Higher utilisation of space, equipment and people (employees),
- Improved employee morale and safe working conditions,
- Improved flow of materials, information and people (employees),
- Improved production capacity,
- Reduced congestion or reduced bottleneck centers,
- Reduced health hazards and accidents,
- To allow ease of maintenance,
- To facilitate better coordination and face-to-face communication where needed,
- To improve productivity,
- To provide ease of supervision,
- To provide product flexibility and volume flexibility,
- To utilise available space efficiently and effectively.

**Choices of Layout:**

Layout choices can help greatly in communicating an organisation's product plans and competitive priorities. Layout has many practical and strategic implications. Altering a layout can affect an organisation and how well it meets its competitive priorities by:

- Facilitating the flow of materials and information,
- Improving communication,
- Improving employee morale,
- Increasing customer convenience and sales (in service organisations such as retail stores),
- Increasing the efficient utilisation of labour and equipment,
- Reducing hazards to employees.

The type of operations carried out in a firm determines the layout requirements.

Some of the fundamental layout choices available to managers are:

- Whether to plan the layout for the current or future needs?
- Whether to select a single-story or multistory building design?
- What type of layout to choose?
- What performance criteria to emphasise?

**Factors influencing layout choices:**

Primarily the layout of a plant is influenced by the relationship among materials, machinery and men. Other factors influencing layout are type of product, type of workers, the type of industry, management policies etc.

Some of these factors are discussed in detailed below:

- **Location:** The size and type of the site selected for the plant, influences the type of buildings (single story or multi story) which in turn influences the layout design. Also, the location of the plant determines the mode of transportation from and into the plant (such as by goods trains, truck, or ships) and the layout should provide facilities for mode of transport used. Also, the layout should provide for storage of fuel, raw materials, future expansion needs, power generation requirements etc.
- **Machinery and Equipments:** The type of product, the volume of production, type of processes and management policy on technology, determines the type of machines and equipments to be installed
- **Managerial Policies:** regarding volume of production, provision for future expansion, extent of automation, make-or-buy decisions, speed of delivery of goods to customers, purchasing and inventory policies and personnel policies influence the plant layout design.
- **Materials:** Plant layout includes provision for storage and handling of raw materials, supplies and components used in production. The type of storage areas, racks, handling equipments such as cranes, trolleys, conveyors or pipelines etc., used - all depend on the type of materials used - such as solid, liquid, light, heavy, bulky, big, small etc.
- **Product:** The type of product i.e., whether the product is light or heavy, big or small, liquid or solid etc., it influences the type of layout. For example, Ship building, Aircraft assembly, Locomotive assembly etc., requires a layout type different from that needed to produce refrigerators, cars, scooters, television sets, soaps, detergents, soft drinks etc. The manufacturing process equipments and machines used and the processing steps largely depend on the nature of the product and hence the layout design depends, very much on the product.

**Type of Industry:**

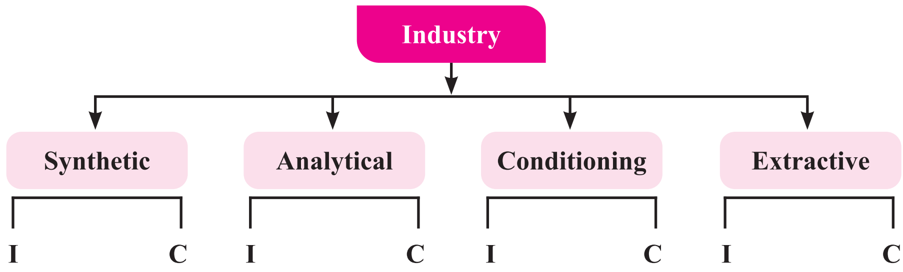



**Figure 2.1: Type of Industry Process**

I is intermittent type of industry

C is continuous type of industry

Whether the industry is classified under (a) Synthetic, (b) Analytical, (c) Conditioning and (d) Extraction industries and again whether the industry has intermittent production or continuous production has a relevance to the type of layout employed.

- **Workers :** The gender of employees (men or women), the position of employees while working (i.e., standing or sitting), employee facilities needed such as locker rooms, rest rooms, toilets, canteens, coffee/tea bays etc., are to be considered while designing the plant layouts.

**Plant Layout- Principles:**

The layout selected in conformity with layout principles should be an ideal one. These principles are:-

- **Principle of Minimum Travel:** Men and materials should travel the shortest distance between operations so as to avoid waste of labour and time and minimise the cost of materials handling.
- **Principle of Sequence:** Machinery and operations should be arranged in a sequential order. This principle is best achieved in product layout, and efforts should be made to have it adopted in the process layout.
- **Principle of Usage:** Every unit of available space should be effectively utilised.
- **Principle of Compactness:** There should be a harmonious fusion of all the relevant factors so that the final layout looks well integrated and compact.
- **Principle of Safety and Satisfaction:** The layout should contain built in provisions for safety for the workmen. It should also be planned on the basis of the comfort and convenience of the workmen so that they feel satisfied.
- **Principle of Flexibility:** The layout should permit revisions with the least difficulty and at minimum cost.
- **Principle of Minimum Investment:** The layout should result in savings in fixed capital investment, not by avoiding installation of the necessary facilities but by an intensive, use of available facilities.

**Types of Layout:**

A layout essentially refers to the arranging and grouping of machines which are meant to produce goods. Grouping is done on different lines. The choice of a particular line depends on several factors. The methods of grouping or the types of layout are:

(i) Process layout or functional layout or job shop layout;

(ii) Product layout or line processing layout or flow-line layout;

(iii) Fixed position layout or static layout;

(iv) Cellular manufacturing (CM) layout or Group Technology layout and

(v) Combination layout or Hybrid layout.

**Process Layout:**

Also called the functional layout, layout for job lot manufacture or batch production layout, the process layout involves a grouping together of similar machines in one department. For example, machines performing drilling operations are installed in the drilling department; machines performing turning operations are grouped in the turning department; and so on. In this way, there would be an electroplating department, a painting department, a machining departments and the like, where similar machines or equipments are installed in the plants which follow the process layout. The process arrangement is signified by the grouping together of like machines based upon their operational characteristics. For example, centre lathes will be arranged in one department, turret lathes in a second department, and milling machines in a third departments.

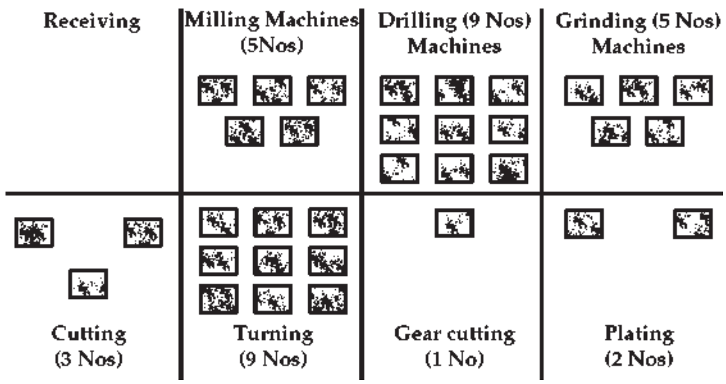



**Figure 2.2: Process Layout**

A quantity of raw material is issued to a machine which performs the first operation. This machine may be situated anywhere in the factory. For the next operation, a different machine may be required, which may be situated in another part of the factory. The material should be transported to the other machine for the operation. Thus, material would move long distances and along crisscrossing paths. At one stage, the material may be taken to a separate building, say, for heat treatment, and then brought back for grinding. If machines in one department are engaged, the partly finished product awaiting operations may be taken to the store and later reissued for production. Partly finished goods would be waiting for processing in every department, like commuters waiting for buses in a city.

Machines in each department attend to any product that is taken to them. These machines are, therefore, called general purpose machines. Work has to be allotted to each department in such a way that no machine in any department is idle. In a batch production layout, machines are chosen to do as many different jobs as possible, i.e., the emphasis is on general purpose machines. The work which needs to be done is allocated to the machines according to loading schedules, with the objective of ensuring that each machine is fully loaded. The process layout carries out the functional idea of Taylor and from the historical point of view, process layout precedes product layout. This type of layout is best suited for intermittent type of production.

While grouping machines according to the process type, certain principles must be kept in mind. These are:

- Convenience for inspection.

- Convenience for supervision. Process layout may be advantageously used in light and heavy engineering industries, made-to-order furniture industries and the like.
- The distance between departments needs to be as short as possible with a view to avoiding longdistance movement of materials.
- Though similar machines are grouped in one department, the departments themselves should be located in accordance with the principle of sequence of operations. For example, in a steel plant, the operations are smelting, casting; rolling etc. These different departments may be arranged in that order to avoid crossovers and backtracking of materials.

**Product Layout:**

Also called the straight-line layout or layout for serialised manufacture. The product layout involves the arrangement of machines in one line depending upon the sequence of operations. Material is fed into the first machine and finished products come out of the last machine. In between, partly finished goods move from machine to machine. The output of one machine becoming the input for the next. In a sugar mill, sugar cane, fed at one end of the mill comes out as sugar at the other end. Similarly, in paper mill, bamboos are fed into the machine at one end and paper comes out at the other end.

In product layout, if there are more than one, line of production, there are as many, lines of machines. The emphasis here, therefore, is on special purpose machines in contrast to general purpose machines, which are installed in the process layout. Consequently, the investment on machines in a straight line layout is higher than the investment on machines in a functional layout.

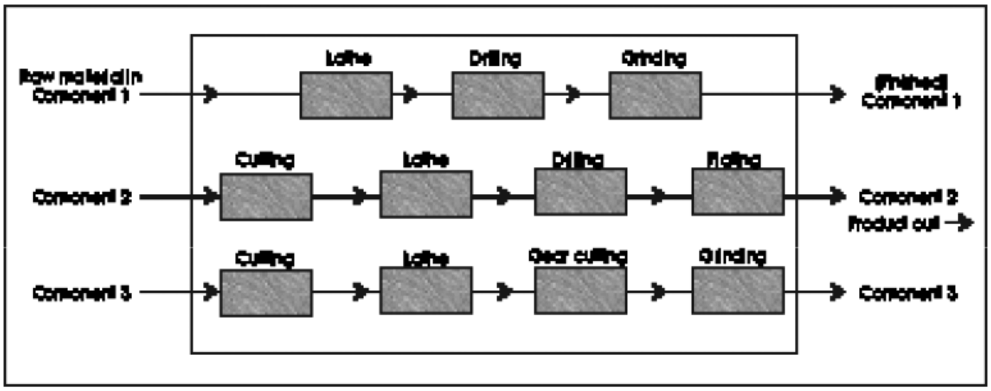


**Figure 2.3: Product Layout**

The grouping of machines should be done, on product line, keeping in mind the following principles:

- All the machine tools or other types of equipment must be placed at the point demanded by the sequence of operations.
- All the operations, including assembly, testing and packing should be, included in the line.
- Materials may be fed where they are required for assembly but not necessarily all at one point; and
- There should be no points where one line crosses another line;

The product layout may be advantageously followed in plants manufacturing standardised products on a mass scale such as chemical, paper, sugar, rubber, refineries and cement industries.

**Layout in the form of Fixed Position:**

As the term itself implies, the fixed position layout involves the movement of men and machines to the product which remains stationary. In this type of layout, the material or major component remains in a fixed location, and tools, machinery and men as well as other pieces of material are brought to this location. The movement of men and machines to the product is advisable because the cost of moving them would be less than the cost of moving the product which is very bulky.

Also called static layout, this type is followed in the manufacture, if bulky and heavy products, such as locomotives, ships, boilers, air crafts and generators.

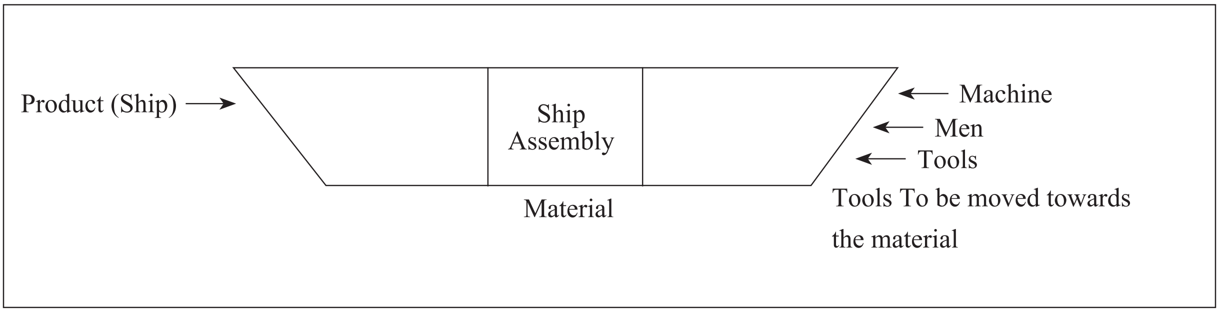



**Figure 2.4: Fixed Position Layout**

**Mixed Layout or Combined Layout**

The application of the principles of product layout or process layout in their strict meanings is difficult to come across. A combination of the product and process layouts, with an emphasis on either, is noticed in most industrial establishments. Plants are never laid out in either pure form. It is possible to have both types of layout in an efficiently combined form if the products manufactured are somewhat similar and not complex.

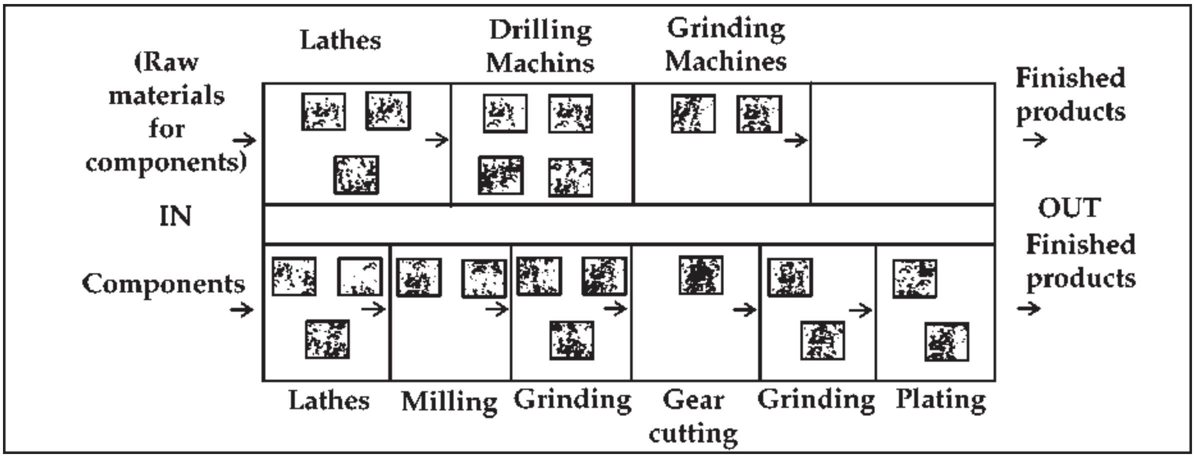



**Figure 2.5: Component flow in combined layout**

**Layout of Service Facility:**

The fundamental difference between service facility and manufacturing facility layouts is that many service facilities exist to bring together customers and services. Service facility layouts should provide for easy entrance to these facilities from freeways and busy thoroughfares. Large, well organized and amply lighted parking areas and well designed walkways to and from parking areas are some of the requirements of service facility layouts.

Because of different degree of customer contact, two types of service facility layouts emerge, viz., those that are almost totally designed around the customer receiving and servicing function (such as banks) and those that are designed around the technologies, processing of physical materials and production efficiency (such as hospitals).

**Other facilities with reference to Plant Layout:**

A plant layout involves, besides the grouping of machinery, an arrangement for other facilities as well. Such facilities include receiving and shipping points, inspection facilities, employee facilities and storage. Not all the facilities are required in every plant. The requirements depend on the nature of the product which is manufactured in a particular plant.

**Importance of layout:**

The importance of a layout can be described as under:

- **Avoidance of Bottlenecks:** Bottlenecks refer to any, place in a production process where materials tend to pile up or produced at rates of speed less rapid than the previous or subsequent operations. Bottlenecks are caused by inadequate machine capacity, inadequate storage space or low speed on the part of the operators. The results of bottlenecks are delays in production schedules, congestion, accidents and wastage of floor area. All these may be overcome with an efficient layout.
- **Avoidance of Unnecessary and Costly Changes:** *A* planned layout avoids frequent changes which are difficult and costly. The incorporation of flexibility elements in the layout would help in the avoidance of revisions.
- **Better Production Control:** Production control is concerned with the production of a product of the right type at the right time and at reasonable cost. A good plant layout is a requisite of good production control and provides the plant control officers with a systematic basis upon which to build organisation and procedures.
- **Better Supervision:** A good plant layout ensures better supervision in two ways: (a) Determining the number of workers to be handled by a supervisor and (b) Enabling the supervisor to get a full view of the entire plant at one glance. A good plant layout is, therefore, the first step in good supervision.
- **Economies in Handling:** Nearly 30 per cent to 40 per cent of the manufacturing costs are accounted for by materials handling. Every effort should, therefore, be made to cut down this cost. Long distance movements should be avoided and specific handling operations must he eliminated.
- **Effective Use of Available Area:** Every unit of the plant area is valuable, especially in urban areas. Efforts should therefore, be made to make use of the available area by planning the layout properly.
- **Improved Employee Morale:** Employee morale is achieved when workers are cheerful and confident. This state of mental condition is vital to the success of any organisation. Morale depends on better working conditions; better employee facilities; reduced number of accidents; and increased earnings.
- **Improved Quality Control:** Timely execution of orders will be meaningful when the quality of the output is not below expectations. To ensure quality, inspection should be conducted at different stages of manufacture. An ideal layout provides ample space to carryout inspection to ensure better quality control.
- **Improved Utilisation of Labour:** A good plant layout is one of the factors in effective utilisation of labour. It makes possible individual operations, the process and flow of materials handling in such a way that the time of each worker is effectively spent on productive operations.
- **Minimisation of Production Delays:** Repeat order and new customers will be the result of prompt execution of orders. Every management should try to keep to the delivery schedules by minimising delays in production.
- **Minimum Equipment Investment:** Investment on equipment can be minimised by planned machine balance and location, minimum handling distances, by the installation of general purpose machines and by planned machine loading. A good plant layout provides all these advantages.

**Illustration 11**

The present layout is shown in the figure. The manager of the department is intending to interchange the departments C and F in the present layout. The handling frequencies between the departments is given. All the departments are of the same size and configuration. The material handling cost per unit length travel between departments is same. What will be the effect of interchange of departments C and F in the layout?

| | | |
|---|---|---|
| A | C | E |
| B | D | F |

| From / To | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| A | – | 0 | 90 | 160 | 50 | 0 |
| B | – | – | 70 | 0 | 100 | 130 |
| C | – | – | | 20 | 0 | 0 |
| D | – | – | – | _ | 180 | 10 |
| E | | – | – | – | – | 40 |
| F | – | – | – | – | – | – |

**Solution:**

The distance matrix of the present layout:

| From / To | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| A | | 1 | 1 | 2 | 2 | 3 |
| B | | | 2 | 1 | 3 | 2 |
| C | | | | 1 | 1 | 2 |
| D | | | | | 2 | 1 |
| E | | | | | | 1 |
| F | | | | | | – |

(ii) Computation of total cost matrix (combining the inter departmental material handling frequencies and distance matrix.

| From / To | A | B | C | D | E | F | Total |
|---|---|---|---|---|---|---|---|
| A | | 0 | 90 | 320 | 100 | 0 | 510 |
| B | | | 140 | 0 | 300 | 260 | 700 |
| C | | | | 20 | 0 | 0 | 20 |
| D | | | | | 360 | 10 | 370 |
| E | | | | | | 40 | 40 |
| F | | | | | | | – |
| Total | | | | | | | 1,640 |

If the departments are interchanged, the layout will be represented as shown below.

| | | |
|---|---|---|
| A | F | E |
| B | D | C |

The distance matrix and the cost matrix are represented as shown.

| From / To | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| A | | 1 | 3 | 2 | 2 | 1 |
| B | | | 2 | 1 | 3 | 2 |
| C | | | | 1 | 1 | 2 |
| D | | | | | 2 | 1 |
| E | | | | | | 1 |
| F | | | | | | |

Total cost matrix for the modified layout.

| From / To | A | B | C | D | E | F | Total |
|---|---|---|---|---|---|---|---|
| A | – | 0 | 270 | 320 | 100 | 0 | 690 |
| B | | | 140 | 0 | 300 | 260 | 700 |
| C | | | | 20 | 0 | 0 | 20 |
| D | | | | | 360 | 10 | 370 |
| E | | | | | | 40 | 40 |
| F | | | | | | | – |
| Total | | | | | | | 1,820 |

The interchange of departments C and F increases the total material handling cost. Thus, it is not a desirable modification.

### Illustration 12

A defence contractor is evaluating its machine shops current process layout. The figure below shows the current layout and the table shows the trip matrix for the facility. Health and safety regulations require departments E and F to remain at their current positions.

| | | |
|---|---|---|
| E | B | F |
| A | C | D |

Current Layout

| From / To | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| A | | 8 | 3 | | 9 | 5 |
| B | | - | | 3 | | |
| C | | | - | | 8 | 9 |
| D | | | | - | | 3 |
| E | | | | | - | 3 |
| F | | | | | | - |

Can layout be improved? Also evaluate using load distance (ld) score.

**Solution:**

Keep the departments E and F at the current locations. From the Trip Matrix, C is having maximum no. of trips from E&F. So C must be as close as possible to both E and F, put C between them. Place A directly south of E, and B next to A. All of the heavy traffic concerns have been accommodated. Department D is located in the remaining place. The proposed layout is shown in figure below. The load distance (ld) scores for the existing and proposed layout are shown below. As Id score for proposed layout is less, the proposed layout indicates improvement over existing.

| | | |
|---|---|---|
| E | C | F |
| A | B | D |

**Comparative Analysis : Current and Proposed Layout :-**

| Dept. Pair | No. of Trips (1) | Existing plan | | Proposed plan | |
|---|---|---|---|---|---|
| | | Distance (2) | Load × Distance (1 × 2) | Distance (3) | Load × Distance (1 × 3) |
| A–B | 8 | 2 | 16 | 1 | 8 |
| A–C | 3 | 1 | 3 | 2 | 6 |
| A–E | 9 | 1 | 9 | 1 | 9 |
| A–F | 5 | 3 | 15 | 3 | 15 |
| B–D | 3 | 2 | 6 | 1 | 3 |
| C– E | 8 | 2 | 16 | 1 | 8 |
| C–F | 9 | 2 | 18 | 1 | 9 |
| D–F | 3 | 1 | 3 | 1 | 3 |
| E–F | 3 | 2 | 6 | 2 | 6 |
| Total | | | 92 | | 67 |

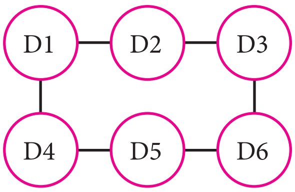
As 'ld' score of the proposed layout is lower than the existing one, there is an improvement in the new layout.

## Facility Layout Decision

### Illustration 13

Suppose a hospital has 6 major departments namely D1, D2, D3, D4, D5 and D6. The initial layout of the hospital is given below.

Initial Layout




The average traffic movement to and fro each department is given in the following table.

**Table – Average traffic flow (Direct)**

| | D1 | D2 | D3 | D4 | D5 | D6 |
|---|---|---|---|---|---|---|
| **D1** | – | 10 | 20 | 0 | 5 | 6 |
| **D2** | 8 | – | 6 | 10 | 0 | 2 |
| **D3** | 10 | 6 | – | 20 | 7 | 8 |
| **D4** | 0 | 25 | 5 | – | 10 | 3 |
| **D5** | 15 | 10 | 1 | 20 | – | 6 |
| **D6** | 0 | 6 | 0 | 3 | 4 | – |

The hospital wants to find out an optimum layout.

**Soluton:**

We notice quite obviously that from Di to Di (i = 1, 2….6), there is no movement.

From D2 to D1, the average movement is 10 (circle) and from D1 to D2 the average movement is 8 (circle)

Therefore, the combined average traffic movement from D1 to D2 is = (10 + 8) = 18

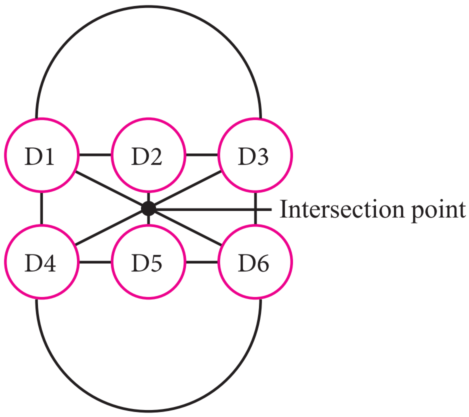
Let us now take another pair, e.g., D4 and D2

| Movement | Avg traffic |
|---|---|
| D4 →D2 | 10 (red circle) |
| D2 →D4 | 25 (Green circle) |

Therefore, the combined average traffic movement is 35. Proceeding in the same way, we get the combined average traffic movement for all pairs as follows:

| | D1 | D2 | D3 | D4 | D5 | D6 |
|---|---|---|---|---|---|---|
| **D1** | – | 18 | 30 | 0 | 20 | 6 |
| **D2** | | – | 12 | 35 | 10 | 8 |
| **D3** | | | – | 25 | 8 | 8 |
| **D4** | | | | – | 30 | 7 |
| **D5** | | | | | – | 10 |
| **D6** | | | | | | – |

Let us now draw the initial layout again.




Looking at the diagram we can find the adjacent and non-adjacent pairs.

| Adjacent Pairs | Non-adjacent Pairs |
|---|---|
| D1 & D2 | D1 & D3 |
| D2 & D3 | D1 & D6 |
| D3 & D6 | D3 & D4 |
| D6 & D5 | D4 & D6 |
| D5 & D4 | |
| D2 & D5 | |
| D1 & D4 | |
| D1 & D5 | |
| D3 & D5 | |
| D2 & D4 | |
| D2 & D6 | |

Let us now concentrate on the non-adjacent pairs

| Non-adjacent Pair | Distance |
|---|---|
| D1 & D3 | (D1 → D2; D2 → D3)<br>D1 → D3 : 2 nodal points<br>Hence, distance is 2 |
| D1 & D6 | D1 → D6<br>= D1 → P & P → D6<br>Distance = 2 |
| D3 & D4 | D3 → D4<br>= D3 → P & P → D4<br>Distance = 2 |
| D4 & D6 | D4 → D6<br>= D4 → D5 & D5 → D6<br>Distance = 2 |

The combined average traffic movement between any two non-adjacent nodes is called the load distance. Our objective is to reduce the load distance.

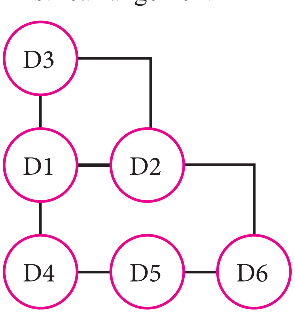
| Non-adjacent Pair | Load distance |
|---|---|
| D1 & D3 | 30 × 2 = 60 |
| D3 & D4 | 25 × 2 = 50 |
| D1 & D6 | 6 × 2 = 12 |
| D4 & D6 | 7 × 2 = 14 |
| | Total = 136 |

Note that for getting the load values, please refer table (Solution).

To meet our objective, we find the highest load distance, i.e., 60. Therefore, we need to rearrange the nodes.

We notice that from D1 to D3 and back, the highest traffic is involved. Therefore, we need to rearrange their positions to make them adjacent as follows:

First rearrangement

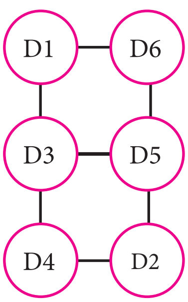


The revised non-adjacent pairs and load distance calculation is given below

| Non-adjacent Pair | distance | Load distance |
|---|---|---|
| D4 & D6 | 2 | 14 |
| D1 & D6 | 2 | 12 |
| D3 & D6 | 2 | 16 |
| D3 & D5 | 2 | 16 |
| D3 & D4 | 2 | 50 |
| | | 108 |

We notice that there is an improvement. However, now the pair of D3 and D4 creates the problem. Therefore, we need to make them adjacent through rearrangement as follows:

2nd Arrangement




The revised non-adjacent pairs and load distance (after second arrangement) is given below

| Non-adjacent Pair | Load | distance | load-distance |
|---|---|---|---|
| $D_1D_4$ | 2 | 0 | 0 |
| $D_6D_2$ | 2 | 8 | 16 |
| $D_1D_2$ | 2 | 18 | 36 |
| $D_6D_4$ | 2 | 7 | 14 |
| | | | 66 |

Through trial and error approach we arrive at a considerable improvement. Therefore, the above layout (2nd Arrangement) is the acceptable one.

# Resource Aggregate Planning 2.4

Production planning in the intermediate range of time is termed Aggregate Planning. It is the process of planning the quantity and timing of output over the intermediate time horizon (3 months to one year).

It is thus called because the demand on facilities and available capacities are specified in aggregate quantities e.g aggregate quantitates of thousands of litres of paint or no of automobiles etc. That is in aggregate planning the total expected demand is measured without regard to the product mix (Maruti Dzire, Maruti Alto, Maruti Swift etc) that makes up this figure.

For this planning horizon the physical plant and equipment and its capacity are fixed. So the sales orders have to be met by different strategies.

Steps in aggregate planning:

- Development of some logical overall unit for measuring output----gallons of paint in paint industry, rooms occupied in hotel etc.;
- Forecast of demand for the planning period;
- Identification and measurement of Relevant costs;

Aggregate planning increases the range of alternative use for capacity for management for getting answers to following type questions:

- To what extent should inventory be used to absorb the fluctuations in demand that will occur over the next 6 to 12 months?
- Why not maintain a fairly stable work force size and absorb the fluctuations by changing activity rates by varying work hours?
- Why not maintain a fairly stable work force and let subcontracts be engaged for demand fluctuations?

If demand for a company's products or services are stable over time or its resources are unlimited, the aggregate planning is trivial. Under this case---

- Demand forecasts are converted to resource requirements;
- Resources necessary to meet demand over the time horizon are acquired;
- Minor variations in demand are handled with overtime or under time;

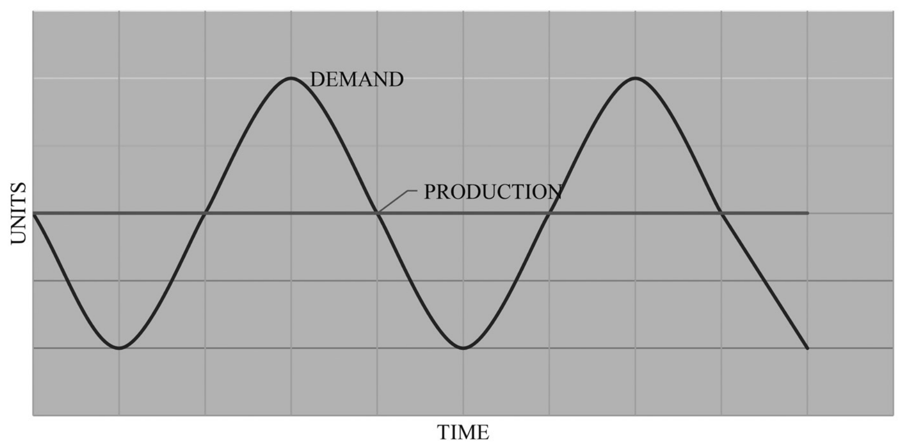
But Aggregate Resource Planning becomes a challenge when demand fluctuates over the planning horizon. Under this case alternatives are---

- Producing at a constant rate and using inventory to absorb fluctuations in demand (level production);
- Hiring and firing workers to match demand (chase demand);
- Maintaining resources for high demand levels;

- Increasing or decreasing working hours (overtime and under time);
- Subcontracting work to other firms;
- Using part time workers;
- Providing the service or product at a later time period (backordering);

When one of these is selected, a company is said to have a Pure Strategy for meeting demand. When two or more are selected, a company has a Mixed Strategy.

Level Production: Refer following figure.

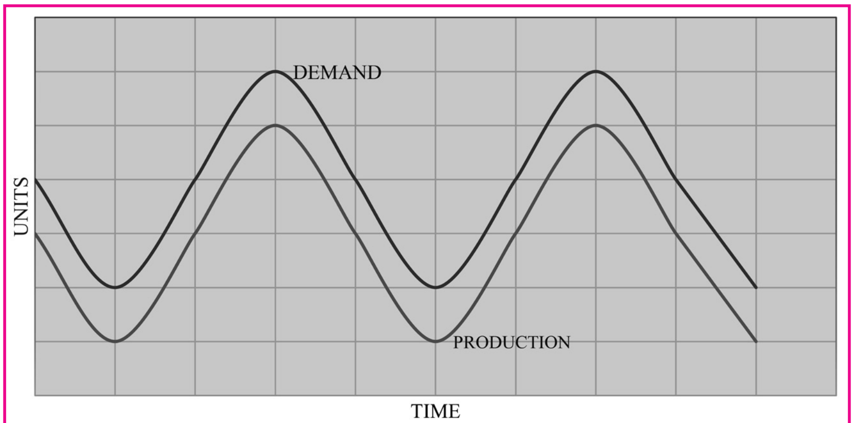



Level production sets production at a fixed rate (usually to meet average demand) and uses inventory to absorb variations in demand. During periods of low demand, overproduction is stored as inventory, to be depleted in periods of high demand. The cost of this strategy is the cost of holding inventory, including the cost of obsolete or perishable items that may have to be discarded.

Chase Demand: Refer the following figure

It matches the production plan to the demand pattern and absorbs variations in demand by hiring and firing workers.

During periods of low demand production is cut back and workers are laid off. During periods of high demand production is increased and additional workers are hired. The cost of this strategy is the cost of hiring and firing workers.



When skilled labour is scarce or when competition for labor is intense, this strategy is not applicable. During period of high unemployment and for industries requiring low skilled labours, this strategy is very much applicable.

Maintaining resources for high demand levels ensures high levels of customer service but very costly in terms of the investment in extra workers and machines that remain idle during low demand period. This strategy is most suitable when superior customer services are required and to get this customers are ready to pay extra for the availability of critical staff or equipment.

When demand fluctuations are not extreme Overtime/Under-time are common strategies. Under this strategy a competent staff is maintained, hiring and firing costs are avoided and demand is met temporarily without investing in permanent resources. Disadvantages include the premium paid for the overtime. But overtime alone may not be sufficient to meet the peak demand and overtime premium may be enjoyed by less efficient and tired workforce.

Subcontracting or outsourcing is a feasible alternative if a reliable supplier is available both in terms of quality and time for supply. This is a very common strategy when demand of final products exceeds expectations and required components are to be made ready through outsourcing to meet the demand. This strategy needs a strong tie with possible subcontractors and first-hand knowledge of their work. Disadvantages of subcontracting include reduced profits, loss of control over production, long lead times and the potential that the subcontractor may become a future competitor.

Using part time workers is feasible for unskilled jobs or in areas with large temporary labour pools (such as students, home makers etc.). Part time workers are less costly than full time workers and they have more flexibility so far as working hours and time are concerned.

Backordering is a viable alternative only if the customer is willing to wait for the product or service.

One aggregate planning strategy is not always preferable to another. The most effective strategy depends on the demand distribution, competitive position and cost structure of the firm or product line. Mixed strategy, the combination of strategies, rather than a single strategy, usually results in the most economical plan.

Each of these strategies has a cost factor associated with it. Some of the cost items that may be relevant are:

- Payroll costs;
- Costs of overtime, second shifts and subcontracting;
- Costs of hiring and laying off workers;
- Costs of excess inventory and backlog;
- Costs of production rate changes;

The cost items that are to be included in the strategy should vary with changes in the decision variables. If a cost item such as the salary of a manufacturing manager is incurred no matter which aggregate plan is chosen, then this cost is excluded from consideration.

Aggregate planning guidelines:

- Determine corporate policy regarding controllable variables.
- Use a good forecast as a basis for planning.
- Plan in proper units of capacity.

- Maintain the stable workforce.
- Maintain needed control over inventories.
- Maintain flexibility to change.
- Respond to demand in a controlled manner.
- Evaluate planning on a regular basis.

Properties of Aggregate Planning:

- Both output and sales should be expressed in a logical overall unit of measuring. For example, an automobile manufacturing company can say 1000 vehicles per year, without giving the number of each variety of vehicle. Similarly a paint industry can say 10,000 litres of paint and does not mention the quantities of each variety of colour.
- Acceptable forecast for some reasonable planning period, say one year.
- A method of identification and fixing the relevant costs associated with the plant. Availability of alternatives for meeting the objective of the organisation.
- Facilities that are considered fixed to carry out the objective.

### Illustration 14

ABC. Co. has developed a forecast for the group of items that has the following demand pattern

| Quarter | Demand | Cumulative demand |
|---|---|---|
| 1 | 270 | 270 |
| 2 | 220 | 490 |
| 3 | 470 | 960 |
| 4 | 670 | 1630 |
| 5 | 450 | 2080 |
| 6 | 270 | 2350 |
| 7 | 200 | 2550 |
| 8 | 370 | 2920 |

The firm estimates that it costs ₹ 150 per unit to increase production rate ₹ 200 per unit to decrease the production rate, ₹ 50 per unit per quarter to carry the items in inventory and ₹100 per unit if subcontracted. Compare the costs of the pure strategies.

**Solution:**

**Different pure strategies are**

**Plan I** In this pure strategy, the actual demand is met by varying the work force size. This means that during the period of low demand, the company must fire the workers and during the period of high demand the company must hire workers. These two steps involve associated costs. In this strategy, the production units will be equal to the demand and values in each period. The cost of the plan is computed in the table below,

| Quarter | Demand | Cost of increasing Production level (₹) | Cost of decreasing Production level (₹) | Total cost of plan (₹) |
|---|---|---|---|---|
| 1 | 270 | — | — | — |
| 2 | 220 | — | 50 × 200 = 10,000 | 10,000 |
| 3 | 470 | 250 × 150 = 37,500 | — | 37,500 |
| 4 | 670 | 200 × 150 = 30,000 | — | 30,000 |
| 5 | 450 | — | 220 × 200 = 44,000 | 44,000 |
| 6 | 270 | — | 180 × 200 = 36,000 | 36,000 |
| 7 | 200 | — | 70 × 200 = 14,000 | 14,000 |
| 8 | 370 | 170 × 150 = 25,500 | — | 25,500 |
| | Total | | | 1,97,000 |

**Plan II** In this plan, the company computes the average demand and sets its production capacity to this average demand. This results in excess of units in some periods and also shortage of units during some other periods. The excess units will be carried as inventory for future use and shortage of units can be fulfilled using future inventory. The cost of the plan II is computed in the table below. The plan incurs a maximum shortage of 255 units during quarter 5. The firm might decide to carry 255 units from the beginning of period 1 to avoid shortage. The total cost of the plan is ₹ 96,500.

| Quar-ter | Demand forecast | Cumu lative demand | Production level =Av. demand =2920÷8 | Cumu. prod. level | Inventory = (Cum. Production – Cum. Demand) | Adjusted inventory with 255 at beginning of period 1 | Cost of holding inven-tory (₹) |
|---|---|---|---|---|---|---|---|
| 1 | 270 | 270 | 365 | 365 | 95 | 350 | 17,500 |
| 2 | 220 | 490 | 365 | 730 | 240 | 495 | 24,750 |
| 3 | 470 | 960 | 365 | 1095 | 135 | 390 | 19,500 |
| 4 | 670 | 1630 | 365 | 1460 | –170 | 85 | 4,250 |
| 5 | 450 | 2080 | 365 | 1825 | –255 | 0 | 0 |
| 6 | 270 | 2350 | 365 | 2190 | –160 | 95 | 4,750 |
| 7 | 200 | 2550 | 365 | 2555 | 5 | 260 | 13,000 |
| 8 | 370 | 2920 | 365 | 2920 | 0 | 255 | 12,750 |
| | Total | | | | | | 96,500 |

**Plan III**

Normal Production Capacity is assumed to be 200 units i.e. Minimum of the demand values. The additional demand other than the normal capacity is met by subcontracting. The cost of the plan III amounts to ₹ 1,32,000 as shown in table below.

| Quarter | Demand forecast | Production units | Subcontract units | Incremental cost @ ₹ 100/units |
|---|---|---|---|---|
| 1 | 270 | 200 | 70 | 70 × 100 = 7,000 |
| 2 | 220 | 200 | 20 | 20 × 100 = 2,000 |
| 3 | 470 | 200 | 270 | 270 × 100 = 27,000 |
| 4 | 670 | 200 | 470 | 470 × 100 = 47,000 |
| 5 | 450 | 200 | 250 | 250 × 100 = 25,000 |
| 6 | 270 | 200 | 70 | 70 × 100 = 7,000 |
| 7 | 200 | 200 | 0 | 0 |
| 8 | 370 | 200 | 170 | 170 × 100 = 17,000 |
| | | | Total | = 1,32,000 |

The total cost of pure strategies is given below. On observation Plan II (Changing inventory levels) has the least cost.

| Plan | Total cost (₹) |
|---|---|
| Plan I | 1,97,000 |
| Plan II | 96,500 |
| Plan III | 1,32,000 |

### Illustration 15

A firm has developed the following forecast (units) for an item which has a demand influence by seasonal factors.

| Month | Forecasted Demand | Production Days |
|---|---|---|
| Jan | 220 | 22 |
| Feb | 90 | 18 |
| Mar | 210 | 21 |
| Apr | 396 | 22 |
| May | 616 | 22 |
| Jun | 700 | 20 |
| Jul | 378 | 21 |
| Aug | 220 | 22 |
| Sep | 200 | 20 |
| Oct | 115 | 23 |
| Nov | 95 | 19 |
| Dec | 260 | 20 |

(a) Prepare a chart showing the daily demand requirements.

(b) Determine the production rate required to meet average demand.

(c) Determine the monthly inventory balance required to follow a plan with:

1. Constant workforce
2. No idle time or overtime
3. No Backorder
4. No use of Sub-Contractor
5. No capacity adjustment

(d) The firm has determined that to follow a plan of meeting demand by varying the size of the workforce strategy

Put result in hiring and lay-off cast estimated at ₹12000. If the unit cost is ₹100 each to produce, carrying cost per year are 20% of the average inventory value and storage cost (based upon maximum inventory) are ₹0.90 per unit which plan results in the lower cost, varying inventory or varying employment? [Where Plan 1 indicates varying inventory and Plan 2 indicates varying Employment]

(e) Suppose the firm wishes to investigate two other plans (alternatives). A third plan is to produce at a rate of 10 units per day and sub-contract the additional requirements at a delivered cost of ₹107 per unit.

Any accumulated inventory is carried forward at a 20% carrying cost (No extra Storage cost).

The Fourth Plan is to produce at a steady rate of 10 units per day and use overtime to meet the additional requirement at a premium of ₹10 per unit. Accumulated inventory is again carried forward at a 20% cost.

(f) Compare 4 plans given in Question (d) and (e) and comment which plan gives the minimum cost.

**Solution:**

**Chart of Production Requirement**

| Month | Forecasted Demand | Production Days | Demand/ Day | Cumulative Production Days | Cumulative Demand |
|---|---|---|---|---|---|
| Jan | 220 | 22 | 10 | 22 | 220 |
| Feb | 90 | 18 | 5 | 40 | 310 |
| Mar | 210 | 21 | 10 | 61 | 520 |
| Apr | 396 | 22 | 18 | 83 | 916 |
| May | 616 | 22 | 28 | 105 | 1532 |
| Jun | 700 | 20 | 35 | 125 | 2232 |
| Jul | 378 | 21 | 18 | 146 | 2610 |
| Aug | 220 | 22 | 10 | 168 | 2830 |
| Sep | 200 | 20 | 10 | 188 | 3030 |
| Oct | 115 | 23 | 5 | 211 | 3145 |
| Nov | 95 | 19 | 5 | 230 | 3240 |
| Dec | 260 | 20 | 13 | 250 | 3500 |
| **Total** | 3500 | | | | |

(a) Average Requirement = Total Demand / Total Production Days = 3500/25 = 140 units/day

(b) Inventory Balance = ∑Production – ∑Demand

**Showing the ending Inventory Balance and Ending Balance with Negative Shortage.**

| Month | Production at 14/day | Forecasted Demand | Inventory Change | Ending Inventory Balance | Ending Balance adjusted in the month of Jan |
|---|---|---|---|---|---|
| Jan | 308 | 220 | 88 | 88 | 654 |
| Feb | 252 | 90 | 162 | 250 | 816 |
| Mar | 294 | 210 | 84 | 334 | 900 |
| Apr | 308 | 396 | -88 | 246 | 812 |
| May | 308 | 616 | -308 | -62 | 504 |
| Jun | 280 | 700 | -420 | -482 | 84 |
| Jul | 294 | 378 | -84 | -566 | 0 |
| Aug | 308 | 220 | 88 | -478 | 88 |
| Sep | 280 | 200 | 80 | -398 | 168 |
| Oct | 322 | 115 | 207 | -191 | 375 |
| Nov | 266 | 95 | 171 | -20 | 546 |
| Dec | 280 | 260 | 20 | 0 | 566 |

(c) Maximum Inventory required in storage = 900 units (in the above table Column 6)

Average Inventory Balance = 460 units

**Solution to Plan 1 (Varying Inventory):**

Inventory Cost = Carrying Cost + Storage Cost

Carrying Cost = 0.20 × 460×100 = 9200

Storage Cost = 900 × 0.90 = 810

Inventory Cost = ₹10010

**Solution to Plan 2 (Varying Employment):**

₹12000 (Given)

**Comparing Plan 1 and Plan 2 we see that Plan 1 is lower.**

**In case of Plan 3:**

it is given that Produce at 10 units per day, vary inventory and sub-contract.

A production rate of 10 units per day exceeds demand only 3 months (Feb, Oct, Nov)

| Month | Production at 10/day | Forecasted Demand | Inventory Change |
|---|---|---|---|
| Jan | 220 | 220 | 0 |
| **Feb** | **180** | **90** | **90** |
| Mar | 210 | 210 | 0 |
| Apr | 220 | 396 | -176 |
| May | 220 | 616 | -396 |
| Jun | 200 | 700 | -500 |
| Jul | 210 | 378 | -168 |
| Aug | 220 | 220 | 0 |
| Sep | 200 | 200 | 0 |
| **Oct** | **230** | **115** | **115** |
| **Nov** | **190** | **95** | **95** |
| Dec | 200 | 260 | -60 |

The Inventory Accumulated During these Years must be carried at a cost of (20%) (₹100) /12 Months = ₹**1.67** per unit month. Units are Carried until they can be used to help meet demand in a subsequent month

Assume, an equilibrium condition where the excess production from OCT and NOV (150 Units) is on hand JAN 1.

| Month | Demand | Production at 10/day | Inventory to carry | Inventory carried until | No. of Months | Cost at $1.67 per unit month |
|---|---|---|---|---|---|---|
| Initial | | | 150 | 150 units to April | 3 | 750 |
| Feb | 90 | 180 | 90 | 26 units to April | 2 | 87 |
| | | | | 64 units to May | 3 | 320 |
| Oct | 115 | 230 | 115 | 60 units to Dec | 2 | 200 |
| | | | | 55 units to Year End | 3 | 275 |
| Nov | 95 | 190 | 95 | 95 units to Year End | 2 | 317 |
| | | | | | Total | 1952 |

Therefore, Inventory Cost from above = ₹1952

Calculating Marginal Cost of Sub-contracting:

The marginal cost of sub-contracting

Number of units = Demand – Production = 3500 – (10 × 250) = 1000 units for sub-contracting

Therefore, Cost per unit = ₹107 – ₹100 = ₹7 per unit

Therefore, Marginal Cost = 1000 units × ₹7 per unit = ₹7000

The total Cost of Plan 3 = Inventory Cost + Sub-contracting cost = 1952 + 7000 = ₹8952

**Plan 4:**

This plan differs from plan 3 only in the marginal cost which is now due to overtime rather than sub-contracting. So, Inventory cost (same as plan 3) i.e., ₹1952 and Marginal cost of Overtime = 1000 units × rate of ₹10 per unit = ₹10,000

Therefore, total cost of Plan 4 = ₹10,000 + ₹1952 = ₹11952

Table: Comparison of Plans

| Plan | Strategy | Cost |
|---|---|---|
| Plan 1 | Pure Strategy (Vary Inventory) | ₹10010 |
| Plan 2 | Pure Strategy (Vary Employment) | ₹12000 |
| Plan 3 | Mixed Strategy (Sub-contract and Vary Inventory) | ₹8952 |
| Plan 4 | Mixed Strategy (Overtime and Vary Inventory) | ₹11952 |

# Material Requirements Planning 2.5

In this issue we will discuss on Material Requirement Planning (MRP).

Material Requirement Planning is a methodology used for planning the production of assembled products.

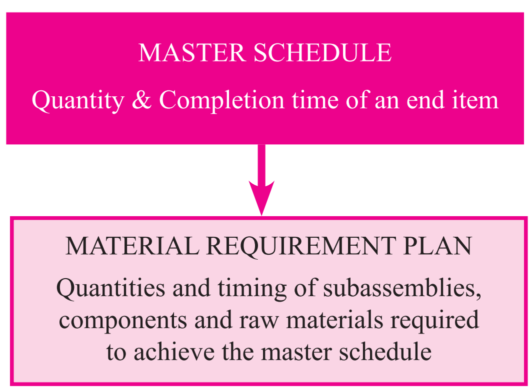
It is a computerised inventory control system that would facilitate determination of demand for component items, keep track of when they are needed and generate work orders and purchase orders that take into account the lead time required to make the item in-house or buy them from a supplier.

MRP begins with a Master Schedule.

Master Schedule designates the quantity and completion time of an assembled product, often referred to as end item.

This Master schedule for end items is translated into time-phased requirements for subassemblies, components and raw material.

The main objective of any inventory system is to ensure that material is available when needed. MRP does this by determining when component items are needed and scheduling them to be ready at that time, no earlier and no later.

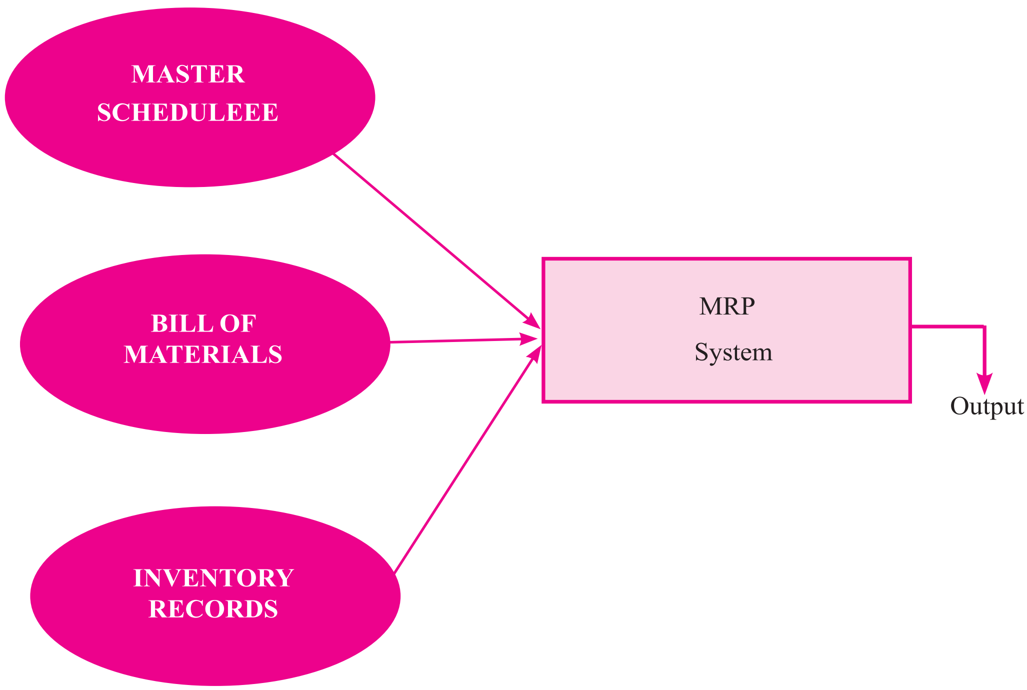



MRP answers three questions—

- What is needed
- How much is needed
- When is it needed

An MRP system has three major sources of information---

- A master schedule
- A bill of materials
- An inventory record




Master Schedule also called master production schedule states—

- which end items are to be produced
- when they are needed
- in what quantities

A Bill of Materials contains---

- a listing of all the assemblies, subassemblies, parts & raw materials that are needed to produce one unit of an end items

EACH TYPE of FINISHED PRODUCT has its own Bill of materials

Inventory Records refer to---

- stored information on the status of each item by time periods i.e.
    - Information on quantities on hand
    - Information on quantities ordered
    - Information on supplier, lead time and lot size policy etc.

MRP Objectives:

- Inventory reduction
- Reduction in the manufacturing and delivery lead times
- Realistic delivery commitments
- Increased efficiency

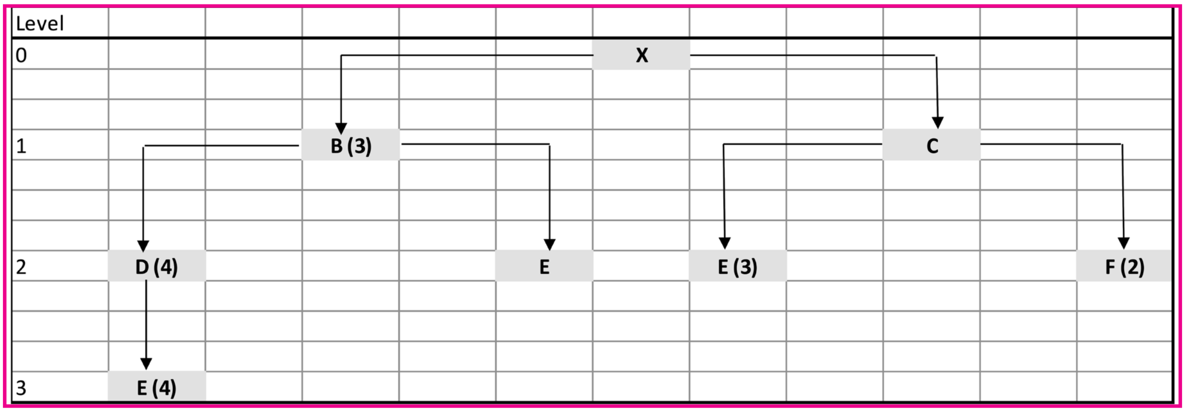
Advantages:

- Reduced inventory,
- Reduced idle time,
- Reduced set up time,
- Ability to change the master production schedule,
- Ability to price more competitively,
- Better customer service,
- Better response to market demands,
- Reduced sales price.

Disadvantages:

- Lack of top management commitment. MRP must be accepted by top management as a planning tool with specific reference to profit results.
- MRP was presented and perceived as a complete and stand-alone system to run a firm, rather than as part of the total system.
- The issue of how MRP can be made to function with just-in-time production system.
- MRP also needs a high degree of accuracy for operation

**Example 1: Refer the following figure:**




(a) Determine the quantities of B, C, D, E and F needed to assemble one unit of X

(b) Determine the quantities of these components that will be required to assemble 10 units of X taking into account the quantities on hand (i.e. in inventory) of various components as

| Component | On Hand |
|---|---|
| B | 4 |
| C | 10 |
| D | 8 |
| E | 60 |
| F | 30 |

Answer: The figure given above is called Product Structure Tree.

To initiate an MRP we know that input information comes from Master Schedule followed by Bills of Materials and Inventory record.

Now the listing in the bill of materials is hierarchical—it shows the quantity of each item needed to complete one unit of its parent item. This aspect of bill of materials is clear when we construct a Product Structure Tree as above which provides a visual depiction of the subassemblies and components needed to assemble a product.

From Master Schedule we gathered the information that we require one unit of end item X. From Bill of materials we collected following information:

- End item X is composed of three Bs and one C
- Each B requires four Ds and one E
- Each D requires four Es
- Each C requires three Es and two Fs

These requirements are listed by level beginning with 0 (available from Master Schedule) for the end item, then 1 for the next level and so on. The items at each level are components of the next level up. The quantities of each item in the product structure tree refer only to the amounts needed to complete the assembly at the next higher level---4 units of E required to complete one unit of D or 4 units of D required for one unit of B etc. So following this knowledge through product structure tree of our problem the total requirement of components for producing one unit of end item X are given below:

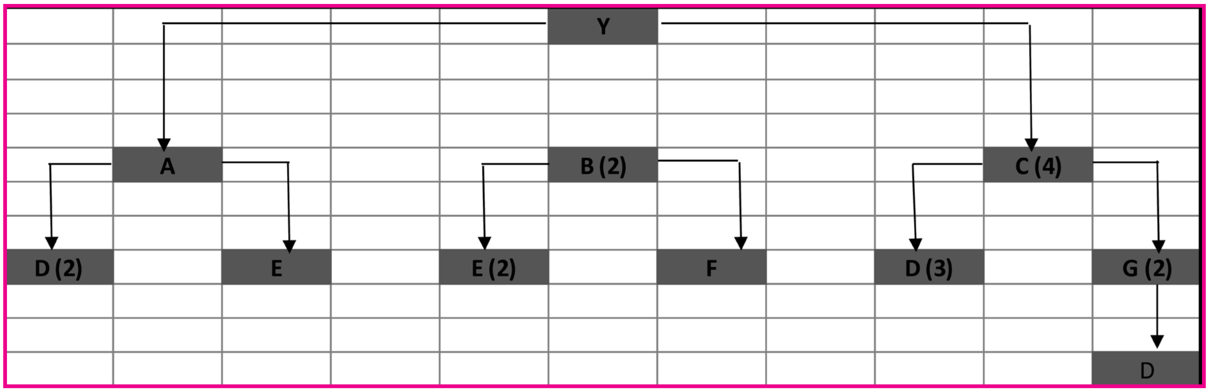
| | B | C | D | E | F |
|---|---|---|---|---|---|
| 1 unit of X requires | 3 | 1 | | | |
| 3 units of B requires | | | 3*4=12 | 3*1=3 | |
| 12 units of D requires | | | | 12*4=48 | |
| 1 unit of C requires | | | | 1*3=3 | 1*2=2 |
| Total Requirement | 3 | 1 | 12 | 54 | 2 |

These are the requirement for producing one unit of X. Now inventory records as given in 2nd table of the question is considered and actual requirement for producing 10 units of X will be as follows:

| | B | C | D | E | F |
|---|---|---|---|---|---|
| Total requirement for 1 unit of X | 3 | 1 | 12 | 54 | 2 |
| Total requirement for 10 units of X | 30 | 10 | 120 | 540 | 20 |
| Less inventory on hand | 4 | 10 | 8 | 60 | 30 |
| Actual requirement now | 26 | 0 | 112 | 480 | 0 |

At present No F is required as in hand stock (30) is more than the requirement for producing 10 units of X (20)

**Example 2:** The following product structure tree indicates the components needed to assemble one unit of Product Y. Determine the quantities of each component needed to assemble 100 units of W considering the inventory records.




Inventory records are

| Component | On Hand |
|---|---|
| A | 5 |
| B | 15 |
| C | 7 |
| D | 75 |
| E | 40 |
| F | 20 |
| G | 12 |

Answer: Assuming the items at each level of product structure tree are components of the next level up & the quantities of each item in the product structure tree refer only to the amounts needed to complete the assembly at the next higher level, the basic requirement of components for producing 1 unit of Y are as follows:

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| 1 unit of Y requires | 1 | 2 | 4 | | | | |
| 3 units of A requires | | | | 1*2=2 | 1 | | |
| 2 units of B requires | | | | | 2*2=4 | 2*1=2 | |
| 4 unit of C requires | | | | 4*3=12 | | | 4*2=8 |
| 8 unit of G requires | | | | 8*1=8 | | | |
| Total Requirement | 1 | 2 | 4 | 22 | 5 | 2 | 8 |

After considering the inventory records the actual requirement for producing 100 units of Y are:

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Total requirement for 1 unit of Y | 1 | 2 | 4 | 22 | 5 | 2 | 8 |
| Total requirement for 10 units of Y | 100 | 200 | 400 | 2200 | 500 | 200 | 800 |
| Less inventory on hand | 5 | 15 | 7 | 75 | 40 | 20 | 12 |
| Actual requirement now | 95 | 185 | 393 | 2125 | 460 | 180 | 788 |

Determining total requirements is usually more complicated than illustrated above. Because---

- Many products have considerably more components and have a complicated Bills of Material
- Issue of timing i.e. when must the components be ordered or made is essential and must be included in analysis

Before application of MRP it is to be fully ensured that the bill of materials accurately reflect the composition of a product as errors at one level become magnified by the multiplication process used to determine quantity requirements.

Like the bill of materials inventory records must also be accurate as erroneous information on requirements can have detrimental impact.

MRP is useful for dependent demand items. The demand for component parts does not have to be forecasted. It can be derived from the demand for the finished product. e.g. suppose demand for a car, consisting of four doors and one engine, is 500/week. Then demand for door-component will be 4*500 =2000/week and demand for engine-component will be 1*500 =500. The demand for door and engine are called derived demand for determining of which we use MRP as discussed in our simple illustrations.

Advantages:

- Reduced inventory,
- Reduced idle time,
- Reduced set up time,
- Ability to change the master production schedule,
- Ability to price more competitively,
- Better customer service,
- Better response to market demands,
- Reduced sales price.

Disadvantages:

- Lack of top management commitment. MRP must be accepted by top management as a planning tool with specific reference to profit results.
- MRP was presented and perceived as a complete and stand-alone system to run a firm, rather than as part of the total system.
- The issue of how MRP can be made to function with just-in-time production system.
- MRP also needs a high degree of accuracy for operation

# Manufacturing Resource Planning 2.6

Manufacturing Resource Planning (MRP II) has been developed to facilitate manufacturing managers address the planning and controlling of a manufacturing process and all of its related support functions. It encompasses logically correct planning and control activities related to materials, capacity, finance, engineering, sales and marketing. MRP II is universally applicable to any manufacturing organisation regardless of its size, location, product or process.

**MRP II** is a management process for taking the business plan and breaking it down into specific, detailed tasks that people evaluate, agree upon and are held accountable for. It involves all departments viz., materials department, engineering department that must maintain bill of materials, sales/marketing department that must keep sales plan upto date, purchasing and manufacturing departments that must meet due dates for bought out items and in-house manufactured items respectively.

**From MRP I to MRP II :** Manufacturing resource planning (MRP II) is a natural outgrowth of Materials Requirement Planning (MRP I) Whereas MRP I focuses upon priorities of materials, CRP is concerned with time. Both material and time requirement are integrated within the MRP system *[i.e.,* MRP I). Beyond this, MRP II has been coined to 'close the loop' by integrating financial, accounting, personnel, engineering and marketing information along with the production planning and control activities of basic MRP systems. MRP II is the heart of corporate management information system for many manufacturing firms.

**Evolution of MRP II**

The earlier resource requirement planning systems were quite simple and unsophisticated. The MRP technique was used for its most limited capability to determine what materials and components are needed, how many are needed and when they are needed and when they should be ordered so that they are likely to be available when needed. In other words, MRP simply exploded the MPS into the required materials and was conceived as an inventory control tool or a requirements calculator. Later the logic of MRP technique was extended to serve as the key component in an information system for planning and controlling production operation and purchasing. It was helpful to production and operations managers to determine the relative priorities of shop orders and purchase orders. As a manufacturing planning and controlsystem, MRP laid the basic foundation for production activity control or shop-floor control.

# Economic Batch Quantity

# 2.7

Production managers often have to decide what quantity of output must be produced in a batch (known as lot size or batch size). The products are manufactured in lot sizes against the anticipated demand for the products. Often the quantity produced may exceed the quantity which can be sold. (i.e., production rates exceed demand rates). The optimum lot size which is known as economic lot size or Economic Order Quantity or economic batch quantity or economic manufacturing quantity is that quantity of output produced in one batch, which is most economical to produce, i.e., which results in lowest average cost of production.

**Determination of Economic Lot Size for Manufacturing:**

The factors to be considered in arriving at the economic lot size are:

(i) **Usage rate:** The rate of production of parts should match with the rate of usage of these parts in the assembly line.

(ii) **Manufacturing cost:** Higher the lot size, lower will be the cost per unit produced because of distribution of set up costs for setting up production or machines and preparing paper work (production orders). But the carrying cost (handling and storing costs) will increase with increase in lot size.

(iii) **Cost of deterioration and obsolescence:** Higher the lot size, higher will be the possibility of loss due to deterioration (items deteriorating after shelf life) or obsolescence (due to change in technology or change in product design).

Before deciding on production using economic lot sizes, the availability of production capacity to produce the product in economic lot size must be verified. The economic lot size balances the two opposing costs related to batch size i.e., setup cost for production and the inventory carrying costs resulting from inventory of products produced when production rate exceeds usage rate or when the items produced are not immediately consumed in the next stage of production. The set up cost per unit decreases with increase in lot size whereas the inventory carrying cost increases with increase in lot size. Diagram below illustrates the concept of economic batch quantity or economic lot size or Economic Order Quantity.

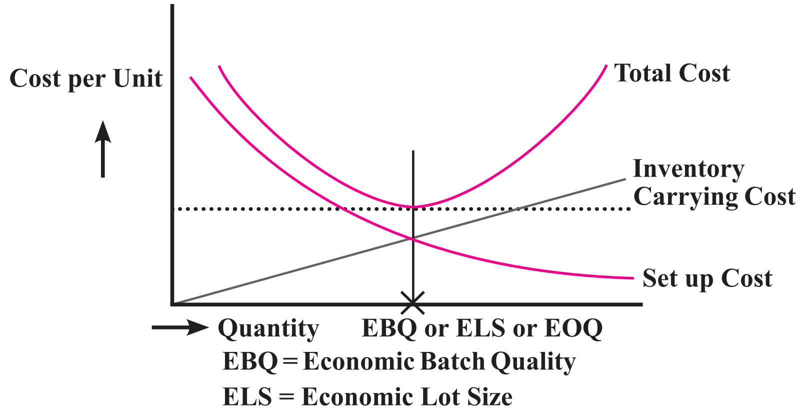



**Figure 2.6: Economic Lot Size**

If S is the set up cost per set up also known as Ordering Cost, 'C' is the production cost per unit produced and I is the inventory carrying or holding changes (%) and A is the annual demand for the item in units, then,

Economic Batch Quantity (EBQ) or Economic Order Quantity (EOQ)

or Economic Lot Size (ELS)

or Economic Manufacturing Quantity (EMQ)

$$= \sqrt{\frac{2AS}{C}} = \sqrt{\frac{2 \times (\text{Annual demand in unit}) \times (\text{Setup cost per setup})}{[\text{Production Cost per unit}] \times [\text{Inventory carrying charges (\%)}]}}$$

**Economic Run Length:** When a firm is producing an item and keeping it in inventory for later use, instead of buying it, the formula used to calculate economic order quantity (EOQ) can be used to calculate the economic production quantity referred to as Economic Run Length (ERL).

If 'p' is the production rate and 'd' is the demand rate (or consumption rate), A is the annual demand for the item in units, I is the inventory carrying charges (percentage), C is the production cost per unit, then,

$$\text{Economic Run Length (ERL)} = \sqrt{\frac{2AS}{C1\left(1-\frac{d}{p}\right)}}$$

$$= \sqrt{\frac{2 \times [\text{Annual demand (in unit)}] \times (\text{Setup cost per setup})}{[\text{Production Cost per unit}] \times [\text{Inventory carrying charges (\%)}] \left(1-\frac{\text{Demand Rate}}{\text{Production Rate}}\right)}}$$

### Illustration 16

The monthly requirement of raw material for a company is 3000 units. The carrying cost is estimated to be 20% of the purchase price per unit, in addition to ₹ 2 per unit. The purchase price of raw material is ₹ 20 per unit. The ordering cost is ₹ 25 per order. (i) You are required to find EOQ.(ii) What is the total cost when the company gets a concession of 5% on the purchase price if it orders 3000 units or more but less than 6000 units per month. (iii) What happens when the company gets a concession of 10% on the purchase price when it orders 6,000 units or more? (iv) Which of the above three ways of orders the company should adopt?

**Solution:**

We are given that,

A = Annual demand = 3,000 × 12 = 36,000 units per annum ; S = Ordering Cost = ₹ 25;

C = Inventory carrying cost = 2 + 20% of ₹ 20 = 2 + 4 = ₹ 6

(i) $EOQ = \sqrt{\frac{2AS}{C}} = \sqrt{\frac{2 \times 36000 \times 25}{6}} = \sqrt{3,00,000} = 548$ units (approx.)

Total cost = Ordering Cost + Cost of purchasing the material + Storage cost

= (36,000 / 548) × 25 + (36,000 × 20) + (548/2) × 6 [ ∵ Storage cost = Average Inventory × Inventory carrying cost

= ₹ 1642.33 + 7,20,000+ 1,644 = ₹ 7,23,286. = $\frac{EOQ}{2} \times 6$]

(ii)When the company has an option to order between 3000 and 6000 units, the EOQ should be calculated with a reduction in price by 5% (due to concession); The purchase price = 95% of ₹ 20 = ₹ 19.

A = 36,000 units per annum; S = ₹ 25; C = 2 + 20% of 19 = 2 + 3.80 = ₹ 5.80

$EOQ = \sqrt{\frac{2 \times 36000 \times 25}{5.80}} = \sqrt{\frac{18,00,000}{5.80}} = 557$ units app.

Total cost = (36,000/557) × 25 + (36,000 × 19) + (557/2) × 5.80

= ₹ (1,615.79 + 6,84,000 + 1,615.30) = ₹ 6,87,231.09

**For monthly order quantity being 3000 units or more but less than 6000 units**

EOQ = 557 units

No. of orders per year = $\frac{\text{Yearly demand}}{\text{EOQ}} = \frac{36000}{557}$ = N (let)

No. of orders per month = $\frac{N}{2} = \frac{36000 / 557}{12}$ = 5.385 = 6 (say) = N*

Quantity to be orderd per month = N* × EOQ = 6 ×557 = 3342 units

This quantity lies in the range of 3000 to 6000 units

Hence the EOQ (557 units) can be considered to be a feasible quantity for availing 5% discount on Purchase Price.

(iii) When the company orders more than 6,000 units purchase price = 90% of ₹ 20 (because 10% concession)

= ₹ 18; A = 36,000 units per annum; S = ₹ 25; C = 2 + 20% of ₹ 18

= 2 + 3.60 = 5.60

$EOQ = \sqrt{\frac{2AS}{C}} = \sqrt{\frac{2 \times 36000 \times 25}{5.60}} = 567$ units app.

**For monthly order quantity more than or equal to 6000 units**

EOQ = 567 units

No of orders per month = $\frac{36000 / 567}{12}$ = 5.29 = 6 (say) = N*

Qty. to be ordered per month = N* ×EOQ = 6×567 = 3402 units

This quantity does not lie in the range of 6000 or more units.

Hence the EOQ (567 units) can not be considered as feasible quantity for availing 10% discount on Purchase Price.

To understand the effect of 10% on Total Cost, we consider the minimum value of price break quantity of this range i.e. 6000 units to be the optimum order quantity and calculate.

Total Cost as follows —

TC = Ordering Cost + Cost of Purchasing the material + Storage Cost

$= \frac{36000}{6000} \times 25 + 36000 \times 18 + \frac{6000}{2} \times 5.60$

= 150 + 648000 + 16800 = ₹ 6,64,950

Hence the total cost will be minimum (₹ 6,64,950) if orders are placed in lot size of 6000 units.

### Illustration 17

M/s. Tubes Ltd. are the manufacturers of picture tubes of T.V. The following are the details of their operation during 2001:

| | |
|---|---|
| Average monthly market demand | 2,000 tubes |
| Ordering cost | ₹ 100 per order |
| Inventory carrying cost | 2% per annum |
| Cost of tubes | ₹ 500 per tube |
| Normal usage | 100 tubes per week |
| Minimum usage | 50 tubes per week |
| Maximum usage | 200 tubes per week |
| Lead time to supply | 2 – 6 weeks |

**Compute from the above:**

(1) Economic order quantity. If the supplier is willing to supply quarterly 1,500 units at a discount of 5%, is it worth accepting?

(2) Maximum level of stock.

(3) Minimum level of stock.

(4) Re-order level of stock.

**Solution:**

(1) Economic Order Quantity:

| | |
|---|---|
| Annual usage of tubes (A) | = Normal usage per week × 52 weeks |
| | = 100 tubes × 52 weeks |
| | = 5,200 tubes. |
| Ordering cost per order (S) | = ₹ 100. |
| Inventory carrying cost per unit per annum (C) | = 2% of ₹ 500 = ₹ 10. |

$\text{EOQ} = \sqrt{\frac{2AS}{C}} = \sqrt{\frac{2 \times 5{,}200 \text{ units} \times 100}{10}} = 322 \text{ units (approx.)}.$

**(A) Evaluation of order size of 1,500 units at 5% discount**

No. of orders $= \frac{5{,}200 \text{ units}}{1{,}500 \text{ units}}$ = 3.46 or 4 (in case of a fraction, the next whole number is considered).

| | ₹ |
|---|---|
| Ordering cost (No. of order per year at ₹ 100 per order) | 400 |
| Carrying cost of average inventory: | |
| $\frac{1{,}500 \text{ units}}{2} \times$ ₹ (500 less 5%) $\times \frac{20}{100}$ | 71,250 |
| Total annual cost (excluding item cost) | 71,650 |
| **(B) Annual cost if EOQ (102 units) is adopted :** | ₹ |
| Ordering cost: 5,200 ÷ 102 or 51 orders per year at ₹100 per order | 5,100 |
| Carrying cost of average inventory $\frac{102 \text{ units}}{2} \times$ ₹ 500 $\times \frac{20}{100}$ | 5,100 |
| Total annual cost (excluding item cost) | 10,200 |

Increase in annual cost by adopting (A) above : ₹ (71,650 – 10,200) = ₹ 61,450.

Amount of quantity discount: 5% × ₹ 500 × 5,200, units = ₹ 1,30,000.

Since the amount of quantity discount (₹ 1,30,000) is more than the increase in total annual cost (₹ 61,450), it is advisable to accept the offer. This will result in a saving of ₹ (1,30,000 - 61,450) or ₹ 68,550 p.a. in inventory cost.

(2) Maximum Level of Stock:

= Re-order level + Re-order quantity – (Minimum usage × Minimum delivery period) = 1,200 units + 322 units – (50 units × 2 weeks) = 1,422 units.

[Assume that the Reorder quantity is supplied as soon as the Reorder level is reached]

(3) Minimum Level of Stock:

= Re-order level – (Normal usage × Normal delivery period) [see Note] = 1,200 units – (100 units × 4 weeks) = 800 units. Note: Normal delivery period is taken to be the average delivery period.

(4) Re-order Level of Stock:

= Maximum usage × Maximum delivery period = 200 units × 6 weeks = 1,200 units.

### Illustration 18

M/s Kobo Bearings Ltd., is committed to supply 24,000 bearings per annum to M/s Deluxe Fans on a steady daily basis. It is estimated that it costs 10 paisa as inventory holding cost per bearing per month and that the setup cost per run of bearing manufacture is ₹ 324.

(a) What is the optimum run size for bearing manufacture?

(b) What should be the interval between the consecutive optimum runs?

(c) Find out the minimum inventory holding cost.

**Solution:**

(a) Optimum run size or Economic Batch Quantity (EBQ)

$$= \sqrt{\frac{2 \times \text{Annual output} \times \text{Setup cost}}{\text{Annual cost of carrying one unit}}} = \sqrt{\frac{2 \times 24000 \times 324}{0.10 \times 12}} = 3600 \text{ units}$$

(b) Interval between two consecutive optimum runs $= \frac{\text{FBQ}}{\text{Monthly output}} \times 30$

$$= \frac{3600}{24{,}000 \div 12} \times 30 = 54 \text{ Calendar days}$$

(c) Minimum inventory holding cost = Average inventory × Annual carry-ing cost of one unit of inventory

= (3600 ÷ 2) × 0.10×12 = ₹ 2,160.

**Illustration 19**

A company planning to manufacture a household cooking range has to decide on the location of the plant. Three locations are being considered viz., Patna, Ranchi, and Dhanbad. The fixed costs of the three location are estimated to be ₹30 lakh, ₹50 lakh, and ₹25 lakh per annum respectively. The variable costs are ₹300, ₹200 and ₹350 per unit respectively.

The expected sales price of the cooking range is ₹700 per unit Find out:

(i) The range of annual production/sales volume for which each location is most suitable and

(ii) Which one of the three locations is the best location at a production/sales volume of 18,000 units?

**Solution:**

The total cost of the three locations are:

At Total cost = Fixed cost + Variable cost for a volume "X"

Patna => Total cost = 30,00,000 + 300 × X

Ranchi => Total cost = 50,00,000 + 200 × X

Dhanbad => Total cost = 25,00,000 + 350 × X

We can compute and plot the total costs per annum at the three different locations for the various cases of production volume of 5,000, 10,000, 15,000, 20,000 25,000 units.

**(i) Patna**

| Volume (x Units) | 5,000 | 10,000 | 15,000 | 20,000 | 25,000 |
|---|---|---|---|---|---|
| Fixed Cost (₹) | 30,00,000 | 30,00,000 | 30,00,000 | 30,00,000 | 30,00,000 |
| Variable Cost (₹ 300 x) | 300 (5,000) | 300 (10,000) | 300 (15,000) | 300 (20,000) | 300 (25,000) |
| Total Cost (₹)* | = ₹45 lakhs | = ₹60 lakhs | = ₹75 lakhs | = ₹90 lakhs | = ₹105 lakhs |

**(ii) Ranchi**

| Volume (x Units) | 5,000 | 10,000 | 15,000 | 20,000 | 25,000 |
|---|---|---|---|---|---|
| Fixed Cost (₹) | 50,00,000 | 50,00,000 | 50,00,000 | 50,00,000 | 50,00,000 |
| Variable Cost (₹ 200 x) | 200 (5,000) | 200 (10,000) | 200 (15,000) | 200 (20,000) | 200 (25,000) |
| Total Cost (₹)* | = ₹60 lakhs | = ₹70 lakhs | = ₹80 lakhs | = ₹90 lakhs | = ₹100 lakhs |

**(iii) Dhanbad**

| Volume (x Units) | 5,000 | 10,000 | 15,000 | 20,000 | 25,000 |
|---|---|---|---|---|---|
| Fixed Cost (₹) | 25,00,000 | 25,00,000 | 25,00,000 | 25,00,000 | 25,00,000 |
| Variable Cost (₹ 300x) | 350 (5,000) | 350 (10,000) | 350 (15,000) | 350 (20,000) | 350 (25,000) |
| Total Cost (₹)* | = ₹42.5 lakhs | = ₹60 lakhs | = ₹77.5 lakhs | = ₹95 lakhs | = ₹112.5 lakhs |

* In all the above tables, Total Cost = Fixed Cost + Variable Cost

If the volume distribution be as follows:

| | Up to 10,000 units | Between 10,000 units to 20,000 units | Above 20,000 units |
|---|---|---|---|
| Favourable Location | Dhanbad | Patna | Ranchi |

For a volume of 18000 units favourable location is Patna which can be substantiated by the followings calculations of Total Cost :-

Patna => 30,00,000 + 300 × 18,000 = ₹84 lakhs

Ranchi => 50,00,000 + 200 × 18,000 = ₹86 lakhs

Dhanbad => 25,00,000 + 350 × 18,000 = ₹88 lakhs.

### Illustration 20

Monthly demand for a component is 1000 units. Setting-up cost per batch is ₹ 120. Cost of manufacture per unit is ₹ 20. Rate of interest may be considered at 10% p.a. Calculate the EBQ.

**Solution:**

Calculation of EBQ:

$$\text{EBQ} = \sqrt{\frac{2 \times \text{Annual demand} \times \text{Setup cost}}{\text{Unit Cost} \times \text{Inventory carrying cost per unit per year}}} = \sqrt{\frac{2 \times 12 \times 1000 \times 120}{0.10 \times 20}} = 1200 \text{ units.}$$

### Illustration 21

Based on the following data on the exports of an item by a company during the various years fit a straight line, (for the time being, assume that a straight line gives a good fit). Give a forecast for the years 2023 and 2024.

| Year | No. of items ('000) |
|---|---|
| 2014 | 13 |
| 2015 | 20 |
| 2016 | 20 |
| 2017 | 28 |
| 2018 | 30 |
| 2019 | 32 |
| 2020 | 33 |
| 2021 | 38 |
| 2022 | 43 |

**Solution:**

We can call the years as 'X' and exports as 'Y. In order to use the normal equations for the least square line, we need ΣX, ΣY, ΣXY and ΣX2. If we arrange X in such a way that ΣX = 0, it will simplify our calculations. Therefore, we call the year 2018 as 0, 2017 as -1 and 2019 as + 1 and likewise for the other years in the data.

The rearrangement is shown in the table as follows:

| X | Y | $X^2$ | XY |
|---|---|---|---|
| -4 | 13 | 16 | -52 |
| -3 | 20 | 9 | -60 |
| -2 | 20 | 4 | -40 |
| -1 | 28 | 1 | -28 |
| 0 | 30 | 0 | 0 |
| 1 | 32 | 1 | 32 |
| 2 | 33 | 4 | 66 |
| 3 | 38 | 9 | 114 |
| 4 | 43 | 16 | 172 |
| ΣX = 0 | ΣY = 257 | $\Sigma x^2 = 60$ | ΣXY - 204 |

Let the equation of the best fit straight line to the given data be $Y = a_0 + a_1x$

So the normal equations are

$\Sigma Y = a_oN + a_1\Sigma X$ ............ (1)

$\Sigma XY = a_o\Sigma X + a_1\Sigma X^2$ ............ (2)

As ΣX = 0, from (1) $\Sigma Y = a_oN$ from (2) $\Sigma XY = a_1\Sigma X^2$

Therefore, $a_o = \Sigma Y / N = 257 / 9 = 28.56$ [N = No. of years]

$a_1 = \Sigma XY / \Sigma X^2 = 204 / 60 = 3.4$

The equation of a straight line fitting the data is:

Y = 28.56 + 3.4 X

(a) Forecast for 2023, (i.e., X = 5): Y = 28.56 + 3.4 (5) = 45.56 ('000) nos.

(b) Forecast for 2024, (i.e., X = 6): Y = 28.56 + 3.4 (6) = 48.96 ('000) nos.

### Illustration 22

Find the economic order quantity and the reorder point, given

Annual demand (D) = 1000 units

Average daily demand (d) = 1000/365

Ordering Cost (S) = ₹5 per order

Holding cost(H) = ₹1.25 per unit per year.

Lead time (L) = 5 days

Cost per unit (C) = ₹ 12.50

What quantity should be ordered?

**Solution:**

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2 \times 1000 \times 5}{1.25}} = \sqrt{8,000} = 89.44 \text{ units}$$

$$\text{Re-order unit} = dL = \frac{1000}{365} \times 5 = 13.7 \text{ units}$$

$$\text{Total Cost} = DC + \frac{D}{Q} \times S + \frac{Q}{2} \times H = 1000\times12.5 + (1000/89.44)\times5 + (89.44/2)\times1.25 = ₹2611.81$$

## Illustration 23

Consider an economic order quantity case where annual demand D=1000 units, economic order quantity Q= 200 units , the desired probability of not stocking out P=0.95 , the standard deviation of demand during lead time 6L =25units and lead time = L=15 days. Determine the reorder point. Assume the demand is over a 250 week day year.

**Solution:**

d = D/no. week days = 1000/250 = 4

Re-order level(R) = dL + z L = 4×15 + 1.64 × 25 = 101

## Illustration 24

Daily demand for a certain product is normally distributed with a mean of 60 and standard deviation of 7. The source of supply is reliable and maintain a constant lead time of six days. The cost of placing the order is ₹ 10 and annual holding costs are ₹ 0.50 per unit. There are no stock out costs, and unfilled orders are filled as soon as the order arrives. Assume sales occur over the entire 365 days of the year. Find the order quantity and reorder point to satisfy a 95 percent probability of not stocking out during the lead time.

**Solution:**

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2\times(60\times365)\times10}{0.5}} = \sqrt{876000} = 936 \text{ units}$$

$$\sigma_1 = \sqrt{\sum_{i=1}^{L} \sigma_d^2} = \sqrt{6 \times 7^2} = 17.15$$

Re-order leve (R) = dL + z6L = 60×6 + 1.64 × 17.15 = 388

## Illustration 25

**Fixed -Time period Model with safety stock**

Daily demand for a product is 10 units with a standard deviation of 3 units. The review period is 30 days, and lead time is 14 days. Management has set a policy of satisfying 98% of demand from items in stock. At the beginning of this review period, there are 150 units in inventory.

**Solution:**

$$Q = d(T+L) + z\sigma_{T+L} - I = 10(30+14) + \tau\, \sigma_{T+L} - 150$$

$$\sigma_{T+L} = \sqrt{\sum_{i=1}^{TL} \sigma_d^2} = \sqrt{(T+L)\sigma^2_T} = \sqrt{(30+40)\times3^2} = 19.90$$

T for P = 0.98 is 2.05

Q = 10 (30+14)+ 2.05×19.9 - 150 = 331 units.

## Illustration 26

**Average Inventory calculation – Fixed order quantity model**

Suppose the following item is being managed using a fixed order quantity model with safety stock

Annual Demand (D) = 1000 units

Order quantity (Q) = 300 units

Safety stock (SS) = 40 units

What are the average inventory level and inventory turn for the item?

**Solution:**

Avg. Inventory = Q/2 + SS = 150 + 40 =190

$$\text{Inventory Turn} = \frac{D}{\frac{Q}{2}+SS} = \frac{1000}{190} = 5.263 \text{ tern per year}$$

## Illustration 27

**Average Inventory calculation – Fixed Time period model**

Consider the following item that is being managed using a fixed time period model with safety stock

Weekly demand (d) = 50 units

Review cycle (T) = 3 weeks

Safety stock (SS) = 30 units

What are the average inventory level and inventory turn for the item?

**Solution:**

Avg. Inventory = dT/2 + SS = (50 × 3)/2 + 30 = 105 units

$$\text{Inventory Turn} = \frac{52d}{\text{Avg Inventory}} = \frac{52\times 50}{105} = 24.8 \text{ turns per year}$$

## Illustration 28

**Price Break Problem**

Consider the following case, where

D = 10000 units (annual demand)

S = ₹ 20 to place order

I = 20 percent of cost (annual carrying cost, storage, interest, obsolescence, etc)

C = Cost per unit (according to the order size: order of 0 to 499 units, ₹5.00 per unit; 500 to 999 units, ₹4.50 per unit; 1000 and up, ₹3.90 per unit )

What quantity should be ordered?

**Solution:**

$$EOQ1 = \sqrt{\frac{2DS}{iC}} = \sqrt{\frac{2\times 10000\times 20}{20 \times 5}} = 63.24$$

$$EOQ2 = \sqrt{\frac{2\times 10000\times 20}{20 \times 4.5}} = 66.67$$

$$EOQ3 = \sqrt{\frac{2\times 10000\times 20}{20 \times 3.9}} = 71.6$$

$$\text{Total Cost1} = DC + \frac{D}{Q} \times S + \frac{Q}{2} \times iC = 56323$$

TC2 = 51000

TC3 = 44585.69

1000 units should be ordered.

## Illustration 29

A product is priced to sell at ₹100 per unit, and its cost is constant at ₹70 per unit. Each unsold unit has a salvage value of ₹20. Demand is expected to range between 35 and 40 units for the period. 35 definitely can be sold and no units over 40 will be sold. The demand probabilities and the associated cumulative probability distribution (P) for this situation follow.

| Number of Units Demanded | Probability of this Demand | Cumulative Probability |
|---|---|---|
| 35 | 0.10 | 0.10 |
| 36 | 0.15 | 0.25 |
| 37 | 0.25 | 0.50 |
| 38 | 0.25 | 0.75 |
| 39 | 0.15 | 0.90 |
| 40 | 0.10 | 1.00 |

How many units should be ordered?

**Solution:**

The cost of underestimating the demand is loss of profit (Cu) or 100-70=30/unit.The cost of overestimating demand is the loss inoccured when the unit must be sold at salvage value(Co)=70-20=50

The optimal prob. Of not being sold

P<= Cu/Co + Cu = 30/30 + 50 = 0.375

From the data, this corrosponds to 37th value.

No. of unit sold

| Unit demand | Prob. | 35 | 36 | 37 | 38 | 39 | 40 |
|---|---|---|---|---|---|---|---|
| 35 | 0.1 | 0 | 50 | 100 | 150 | 200 | 250 |
| 36 | 0.15 | 30 | 0 | 50 | 100 | 150 | 200 |
| 37 | 0.25 | 60 | 30 | 0 | 50 | 100 | 150 |
| 38 | 0.25 | 90 | 60 | 30 | 0 | 50 | 100 |
| 39 | 0.15 | 120 | 90 | 60 | 30 | 0 | 50 |
| 40 | 0.1 | 150 | 120 | 90 | 60 | 30 | 0 |
| Total | 1 | 75 | 53 | 43 | 53 | 83 | 125 |

**Illustration 30**

9. A company currently has 200 units of a product on hand that it orders every two weeks when the salesperson visits the premises. Demand for the product averages 20 units per day with a standard deviation of 5 units. Lead time for the product to arrive is seven days. Management has a goal of 95 percent probability of not stocking out for this product. The salesperson is due to come in late this afternoon when 180 units are left in stock (assuming that 20 are sold today). How many units should be ordered?

**Solution:**

$S.D = \sqrt{21(5)\times(5)} = 23$

$Z = 1.64$

$q = d\times(T + L) + Z\times S.D\text{-}I$

$= 20(14 + 7) + 1.64\times 23\text{-}180$

$= 278$ units

**Illustration 31**

10. Solve the ABC analysis of the following table and show graphically taking Percentage of total list of different stock items as x axis and Percentage of total inventory value along y axis

Annual Usage if Inventory by Value

| Item Number | Annual Rupee Usage (₹) | Percentage of total value (%) |
|---|---|---|
| 22 | 95000 | 40.69 |
| 68 | 75000 | 32.13 |
| 27 | 25000 | 10.71 |
| 03 | 15000 | 6.43 |
| 82 | 13000 | 5.57 |
| 54 | 7500 | 3.21 |
| 36 | 1500 | 0.64 |
| 19 | 800 | 0.34 |
| 23 | 425 | 0.18 |
| 41 | 225 | 0.10 |
| TOTAL | ₹ 233450 | 100% |

**Solution:**

| Classification | Item no. | Annual Rupee Usage | % of total |
|---|---|---|---|
| A | 22,68 | 1,70,000 | 72.9% |
| B | 27,03,82 | 53,000 | 22.7% |
| C | 54,36,19,23,41 | 10,450 | 4.5% |