CONTENTS

Study Note 1 : Operation Management – Introduction

Study Note 2 : Operations Planning

Study Note 3 : Designing Of Operational System and Control

Study Note 4 : Production Planning and Control

Study Note 5 : Productivity Management and Quality Management

Study Note 6 : Project Management

Study Note 7 : Economics of Maintenance and spares Management

STUDY NOTE -1

OPERATION MANAGEMENT -INTRODUCTION

1.1 Operation Management - introduction

Operations management is the management of that part of an organization that is responsible for producing goods and/or services.

There are examples of these goods and services all around you.

Every book you read, every video you watch, every e-mail you send, every telephone conversation you have, and every medical treatment you receive involves the operations function of one or more organizations. So does everything you wear, eat, travel in, sit on, and access the internet with.

However, in order to have a clear idea of operations management, one must have an idea of 'operating systems'.

An **Operating System** is defined as a configuration of resources combined for the provision of goods or services. Retail organizations, hospitals, bus and taxi services, tailors, hotels and dentists are all examples of operating systems. Any operating system converts inputs, using physical resources, to create outputs, the function of which is to satisfy customers wants.

The creation of goods or services involves transforming or converting inputs into outputs. Various inputs such as capital, labour, and information are used to create goods or services using one or more transformation processes (e.g., storing, transporting, and cutting).

To ensure that the desired output are obtained, an organization takes measurements at various points in the transformation process (feedback) and then compares with them with previously established standards to determine whether corrective action is needed (control).

It is important to note that goods and services often occur jointly. **For example**, having the oil changed in your car is a service, but the oil that is delivered is a good. similarly, house painting is a service, but the paint is a good. The goods-service combination is a continuum.

It can range from primarily goods, with little service, to primarily service, with few goods. Because there are relatively few pure goods or pure services, companies usually sell product packages, which are a combination of goods and services. There are elements of both goods production and service delivery in these product packages. This makes managing operations more interesting, and also more challenging.

Objectives of operations management

Objectives of operations management can be categorized into (1) Customer service and (2) Resource Utilization.

1- **Customer service** - The first objective is the customer service for the satisfaction of customer wants. Customer service is therefore a key objective of operations management. The Operations Management must provide something to a specification which can satisfy the customer in terms cost and timing. Thus, primary objective can be satisfied by providing the 'right thing at the right price at the right time'.

These **three aspects** of customer service - **specification, cost and timing** - are described in a little more detail for the four functions in Table 1.

Table- 1 Aspects of Customer Service

Principal function	Primary consideration	Other consideration
Manufacture	Goods of a given, requested or acceptable specification	Cost i.e. purchase price or cost of obtaining goods Timing, i.e. delivery delay from order or request to receipt of goods
Transport	Movement of a given, requested or acceptable specification	Cost, i.e. cost of movement Timing ,i.e. (i) duration or time to move (ii) wait, or delay from requesting to its Commencement
Supply	Goods of a given, requested or acceptable specification	Cost, that is purchase price or cost obtaining goods Timing, i.e. delivery delay from order or request to supply, to receipt of goods
Service	Treatment of a given, requested or acceptable specification	Cost, i.e. cost of treatment Timing, i.e. (i) Duration or timing required for treatment (ii) wait, or delay from requesting to its commencement

2- **Resource Utilization** - Another major objective is to utilize resources for the satisfaction of customer wants effectively, i.e., customer service must be provided with the achievement of effective operations through efficient use of resources. Inefficient use of resources or inadequate customer service leads to commercial failure of an operating system.
Operations management is concerned essentially with the utilization of resources, i.e., obtaining maximum effect from resources or minimizing their loss, under utilization or waste. The extent of the utilization of the resources' potential might be expressed in terms of the proportion of available time used or occupied, space utilization, levels of activity, etc. each measure indicates the extent to which the potential or capacity of such resources is utilized. This is referred as the objective of resource utilization.

Operations management is also concerned with the achievement of both satisfactory customer service and resource utilization. An improvement in one will often give rise to deterioration in the other. often both cannot be maximized, and hence a satisfactory performance must be achieved on both objectives. All the activities of operations management must be tackled with these two objectives in mind, and many of the problems will be faced by operations managers because of this conflict. Hence, operations managers must attempt to balance these basic objectives.

Below Table 2 summarizes the twin objectives of operations management. The type of balance established both between and within these basic objectives will be influenced by market considerations, competitions, the strengths and weaknesses of the organization, etc. Hence, the operations managers should make a contribution when these objectives are set.

Table 2 : The twin objectives of operations management

The customer service objective	The resource utilization objective
To provide agreed/adequate levels of customer service (and hence customer satisfaction) by providing goods or services with the right specification, at the right cost and at the right time.	To achieve adequate levels of resource utilization (or productivity) e.g., to achieve agreed levels of utilization of materials, machines and labour.

SCOPE OF OPERATION MANAGEMENT

Operations Management concern with the conversion of inputs into outputs, using physical resources, so as to provide the desired utilities to the customer while meeting the other organizational objectives of effectiveness, efficiency and adoptability. It distinguishes itself from other functions such as personnel, marketing, finance, etc. by its primary concern for 'conversion by using physical resources'. Following are the activities, which are listed under production and Operations Management functions:

1. **Location of facilities.**
2. **Plant layouts and Material Handling.**
3. **Product Design.**
4. **Process Design.**
5. **Production and Planning Control.**
6. **Quality Control.**
7. **Materials Management.**
8. **Maintenance management.**

1.2 PRODUCTIONS MANAGEMENT vs OPERATIONS MANAGEMENT

There are two points of distinction between production management and operations management. First, the term production management is more used for a system where tangible goods are produced. Whereas, operations management is more frequently used where various inputs are transformed into intangible services. Viewed from this perspective, operations management will cover such service organisations as banks, airlines, utilities, pollution control agencies, super bazaars, educational institutions, libraries, consultancy firms and police departments, in addition, of course, to manufacturing enterprises. the second distinction relates to the evolution of the subject. Operations management is the term that is used nowadays. Production management precedes operations management in the historical growth of the subject

1.3 CHARACTERISTIC OF MODERN OPERATIONS FUNCTION

The production management of today presents certain characteristics which make it look totally different from what it was during the past. Specifically, today's production system is characterized by at least four features.

1. **Manufacturing as Competitive Advantage**

In the past production was considered to be like any other function in the organization. When demand was high and production capacities were inadequate, the concern was to somehow muster all inputs and use them to produce goods which would be grabbed by -narket. But today's scenario is contrasting. plants have excess capacities, competition is mounting and firms look and gain competitive advantage to survive and succeed. Interestingly, production system offers vast scope to gain competitive edge and firms intend to exploit the potential. Total Quality management (TQM), time-Based competition, Business process re-engineering (BPRE), Just-in-time (JIt), Focused Factory, Flexible manufacturing systems (FMS), computer integrated manufacturing (CIM), and the Virtual corporation are but only some techniques which the companies are employing to gain competitive advantage.

2. Services Orientation

As was stated earlier, service sector is gaining greater relevance these days. The production system, therefore, needs to be organized keeping in mind the peculiar requirements of the service component. The entire manufacturing needs to be geared to serve (i) Intangible and perishable nature of the services, (ii) Constant interaction with clients or customers, (iii) Small volumes of production to serve local markets, and (iv) Need to locate facilities to serve local markets. There is increased presence of professionals on the production, instead of technicians and engineers.\

3. Disappearance of Smokestacks

Protective labour legislation, environmental movement and gradual emergence of knowledge based organizations have brought total transformation in the production system. Today's factories are aesthetically designed and built, environment friendly - in fact, they are homes away from homes. Going to factory everyday is no more excruciating experience, it is like holidaying at a scenic spot.

4. Small has Become Beautiful

It was E.F. Schumacher who, in his famous book Small is Beautiful, opposed giant organizations and increased specialization. He advocated, instead, intermediate technology based on smaller working units, community ownership, and regional workplaces utilizing local labour and resources. For him, small was beautiful. Businessmen, all over the world, did not believe in Schumacher's philosophy. inspired by economies of scale, industrialists went in for huge organizations and mass production systems.

1.4 RECENT TRENDS IN PRODUCTION/OPERATIONS MANAGEMENT

Recent trends in production/operations management relate to global competition and the impact it has on manufacturing firms. Some of the recent trends are :

1- **Global Market Place :** Globalization of business has compelled many manufacturing firms to have operations in many countries where they have certain economic advantage. This has resulted in a steep increase in the level of competition among manufacturing firms throughout the world.
2- **Production/Operations Strategy :** More and more firms are recognizing the importance of production/ operations strategy for the overall success of their business and the necessity for relating it to their overall business strategy.
3- **Total Quality Management (TQM) :** TQM approach has been adopted by many firms to achieve customer satisfaction by a never-ending quest for improving the quality of goods and services.

4- **Flexibility :** The ability to adapt quickly to changes in volume of demand, in the product mix demanded, and in product design or in delivery schedules, has become a major competitive strategy and a competitive advantage to the firms. This is sometimes called as agile manufacturing.

5- **Time Reduction :** Reduction of manufacturing cycle time and speed to market for a new product provide competitive edge to a firm over other firms. When companies can provide products at the same price and quality, quicker delivery (short lead times) provide one firm competitive edge over the other.

6- **Technology :** Advances in technology have led to a vast array of new products, new processes and new materials and components. Automation, computerization, information and communication technologies have revolutionised the way companies operate. Technological changes in products and processes can have great impact on competitiveness and quality, if the advanced technology is carefully integrated into the existing system.

7- **Worker Involvement** : The recent trend is to assign responsibility for decision making and problem solving to the lower levels in the organisation. This is known as employee involvement and empowerment. Examples of worker involvement are quality circles and use of work teams or quality improvement teams.

8- **Re-engineering :** This involves drastic measures or break-through improvements to improve the performance of a firm. It involves the concept of clean-slate approach or starting from scratch in redesigning the business processes.

9- **Environmental Issues :** Today's production managers are concerned more and more with pollution control and waste disposal which are key issues in protection of environment and social responsibility. There is increasing emphasis on reducing waste, recycling waste, using less-toxic chemicals and using biodegradable materials for packaging.

10- **Corporate downsizing (or Right Sizing) :** Downsizing or right sizing has been forced on firms to shed their obesity. This has become necessary due to competition, lowering productivity, need for improved profit and for higher dividend payment to shareholders.

11- **Supply-Chain Management :** Management of supply-chain, from suppliers to final customers reduces the cost of transportation, warehousing and distribution throughout the supply chain.

12- **Lean Production :** Production systems have become lean production systems which use minimal amounts of resources to produce a high volume of high quality goods with some variety.

STUDY NOTE -2

OPERATIONS PLANNING

2.1 DEMAND FORECASTING

Forecasting: Forecasting means peeping into the future. As future is unknown and is anybody's guess but the business leaders in the past have evolved certain systematic and scientific methods to know the future by scientific analysis based on facts and possible consequences. Thus, this systematic method of probing the future is called forecasting.

In this way forecasting of sales refers to an act of making prediction about future sales followed by a detailed analysis of facts related to future situations and forces which may affect the business as a whole.

Foresight is not the whole of management, but at least it is an essential part of management and accordingly, to foresee in this context means both to assess the future and make provisions for it, that is forecasting is itself action already. Forecasting as a kind of future picture wherein proximate events are outlined with some distinctness, while remote events appear progressively less distinct and it entails the running of the business as foresee and provide means to run the business over a definite period.

The period of forecasting, that is the time range selected for forecasting depends on the purpose for which the forecast is made. 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' and '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 of more useful in production planning. The manager who does short range forecast must see that they are very nearer to the accuracy.

In long range forecast, 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:**

(i) To work out expected capital expenditure for future developments or to acquire new facilities,
(ii) To determine expected cash flow from sales,
(iii) To plan for future manpower requirements,
(iv) To plan for material requirement,
(v) To plan for research and Development.

Here much importance is given to long range growth factor.

In case of **medium range forecasting** the period may **extend over to one or two years**. The **purpose of this type of forecasting is**:

(i) To determine budgetary control over expenses,
(ii) To determine dividend policy,
(iii) To find and control maintenance expenses,
(iv) To determine schedule of operations,
(v) To plan for capacity adjustments.

In case of **short-term forecast**, which extends from **few weeks to three or six months** and the following **purposes are generally** served:

(i) To estimate the inventory requirement,
(ii) To provide transport facilities for finished goods,
(iii) To decide work loads for men and machines,
(iv) To find the working capital needed,
(v) To set-up of production run for the products,
(vi) To fix sales quota,
(vii) To find the required overtime to meet the delivery promises.

Steps in forecasting

Whatever may be the method used for forecasting, the following steps are followed in forecasting.

(a) Determine the objective of forecast: What for you are making forecast? is it for predicting the demand? is it to know the consumer's preferences? is it to study the trend? You have to spell out clearly the use of forecast.

(b) Select the period over which the forecast will be made? is it long-term forecast or medium-term forecast or short-term forecast? What are your information needs over that period?

(c) Select the method you want to use for making the forecast. this method depends on the period selected for the forecast and the information or data available on hand. it also depends on what you expect from the information you get from the forecast. select appropriate method for making forecast.

(d) Gather information to be used in the forecast. The data you use for making forecasting to produce the result, which is of great use to you. the data may be collected by:

(i) Primary source: This data we will get from the records of the firm itself.

(ii) Secondary source: This is available from outside means, such as published data, magazines, educational institutions etc.

(e) Make the forecast: Using the data collected in the selected method of forecasting, the forecast is made.

Forecasting Methods:

Methods or techniques of sales forecasting: Different authorities on marketing and production have devised several methods or techniques of sales or demand forecasting. The sales forecasts may be result of what market people or buyers say about the product or they may be the result of statistical and quantitative techniques. **The most common methods of sales forecasting are:**

1. Survey of buyer's inventions or the user's expectation method
2. Collective opinion or sales force composite method
3. Group executive judgement or executive judgement method.
4. Experts' opinions
5. Market test method
6. Trend projection method
7. Moving average method

Criteria of a good forecasting method: it cannot be said which method of sales forecasting is the best because everyone has merits and demerits of its own. the suitability of a method depends on various factors such as nature of theproduct, available time and past records, wealth and energy, degree of accuracy and the forecaster etc. of an enterprise. However, in general, a good forecasting method must possess the following qualifications.

(i) **Accuracy:** Accuracy of the forecasting figures is the life blood of the business because many important plans and programmes, policies andstrategies are prepared and followed on the basis of such estimates. If sales forecasts are wrong, the businessman suffer a big loss. Hence, the method of forecasting to be applied must amount to maximum accuracy.

(ii) **Simplicity:** The method for forecasting should be very simple. If the method is difficult or technical, then there is every possibility of mistake. Some information are collected from outside and that will remain unanswered or inaccurate replies will be received, if the method is difficult. Management must also be able to understand and have confidence in the method.

(iii) **Economy:** The method to be used should be economical taking into account the importance of the accuracy of forecast. costs must be

(iv) **Availability:** The method should be such for which the relevant information may be available immediately with reasonable accuracy. moreover, the technique must give quick results and useful information to the management.

(v) **Stability**: The data of forecasting should be such wherein the future changes are expected to be minimum and are reliable for future planning for sometime.

(vi) **Utility**: The forecasting technique must be easily understandable and suitable to the management.

Forecast Error

Normally there is a gap between forecasted demand and actual demand. If the forecasted demand is less than the actual demand, the company would find difficulty in meeting the customer's demands and in some cases might even lose some of its customers, as they could go to other suppliers when their requirements are not met in time. On the contrary, if the forecasted demand is greater than the actual demand, there would be excessive stock of finished goods. Forecast error is the numeric difference between the forecasted and actual demand. It is desirable that the difference between forecasted and actual demand is low as possible. there are two measures of error as stated below.

- **Mean absolute Deviation (MAD)**
- **Bias**

Mean Absolute Deviation (MAD): MAD is the ratio of sum of absolute deviations for all periods to the total number of periods studied.

Bias: Bias is worked out by using algebraic difference between forecasted and actual demands for all the periods. the algebraic differences are summed up and divided by the total number

Tracking Signals (TS)

The difference in forecasted demand and the actual demand has always been of concern to the management. The difference should be as low as possible. Tracking signals are often used to monitor the forecasts especially when the overall forecast is suspect. If the TS is around zero, the forecasting model is performing well. A forecast is considered out of control, if the value of tracking signal exceeds plus or minus4.

Exponential Smoothing

This method is more popular. The pattern of weight is exponential in form. In this method, the demand for the most recent period is weighted most heavily and the weights of just preceding periods are lowered exponentially. As we go back in time, the weight is decreased exponentially. This method cannot be used for an item, which has trend or seasonal pattern. This is best suited for independent demand with no trend and seasonality. A new forecast is presented as under:

NF = OF+ α (AD-OF)

Here NF = New Forecast

OF = Old Forecast

α = Weight Factor, normally called smoothing coefficient

AD = Actual Demand.

QUESTIONS

Q 1. From the following time series data of sale project the sales for the next three years.

Year	2001	2002	2003	2004	2005	2006	2007
Sales(000 units)	80	90	92	83	94	99	92

Ans. **(STUDY NOTE)Ans. 98, 100, 102 (000 , units)**

Q 2. With the help of following data project the trend of sales for the next five years:

Year	2002	2003	2004	2005	2006	2007
Sales(in lakhs)	100	110	115	120	135	140

Ans. 148, 156, 164, 172, 180, (in lakhs) (STUDY NOTE) Dec. 2013 5 Marks

Q 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 000)	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. **(STUDY NOTE)**

Ans. 14.44, 24.84 (000, TV set)

Q 4. An investigation into the use of scooters in 5 towns has resulted in the following data:

Population in town (in lakhs	X	4	6	7	10	13
No of Scooters	Y	4400	6600	5700	8000	10300

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.**(STUDY NOTE)** **Ans. 11960**

Q 5. The following is the demand for Product A in 5 towns.

Population (in lacs)	X	9	5	8	5	3
Demand	Y	12	20	15	10	5

Estimated the demand for product A for a town with a population of 10 lacs.

Ans. b= .875, a= 7.15 , Y = 15.9 **Dec. 2008 4 Marks**

Q 6. The annual sales of TV sets by a dealer in Delhi are as under:

Year	2004	2005	2006	2007	2008
Sales(000 units)	3	14	36	4	33

Fit a linear trend equation to the sales figure and estimated the sales for the year 2009.

Ans. 33 (000, units) **June 2009 4 Marks**

Q 7. From the following time series data of sale of refrigerators, project the sales for the year 2010:

Year	2002	2003	2004	2005	2006	2007	2008
Sales(000 units)	90	100	102	93	104	109	102

Ans. 110 (000, units) **Dec. 2009 6 Marks**

Q 8. There exists a relationship between expenditure on research and its annual profit. The details of theexpenditure for the last six years is given below. Estimate the profit when the expenditure is 6 units

Year	Expenditure for research X	Annual Profit Y
2001	2	20
2002	3	25
2003	5	34
2004	4	30
2005	11	40
2006	5	31
2007	6	?

(One unit corresponds to 1 Crore Rs.)

Ans. 32

Q 9. There exists a relationship between expenditure on advertising and its annual sales. The details of the expenditure for the last six years is given below.

Year	Expenditure on advertising (Rs crore)	Annual sales (Rs crore)
2004	1	18
2005	2	23
2006	4	32
2007	3	28
2008	10	38
2009	4	29

Estimate the annual sales when expenditure on advertising is Rs 5 crore.

Ans. 30 **6 Marks (June 2010)**

Q 10. 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 2013 and 2014.

Year	No. of items ('000)
2004	13
2005	20
2006	20
2007	28
2008	30
2009	32
2010	33
2011	38
2012	43

Ans. 45.56, 48.96 (000) **6 Marks June 2014**

Q 11. The demand for sewing machine was estimated as 1000 per month for 5 months. Later on the actual demand was found as 900, 1050, 1000, 1100 and 950, respectively. Workout MAD and Bias. Analyze whether the forecast made was accurate.

Solution:

MAD $= \frac{|1000-900| + |1000-1050| + |1000-1000| + |1000-1100| + |1000-950|}{5}$

$\frac{100+50+0+100+50}{5}$

= 60 units of sewing machines.

Bias$= \frac{(1000-900)+(1000-1050)+(1000-1000)+(1000-1100)+(1000-950)}{5}$

$\frac{100-50+0-100+50}{5}$

= o units of sewing machines.

In this case, MAD is 60 units whereas Bias has no deviation. Since MAD measures the overall accuracy of the forecasting method, it is found that the forecast is not based on accurate model and the error is 6% (60/1000 x 100).

Q 12. Calculate the value of Tracking Signal for the demand overcast of sewing machine based on the actual demand data given in **Problem 11**. State if the forecast for the demand of the sewing machines is under control.

Solution:

Bias (Algebraic sum of deviations) in Problem 1

$= \frac{(1000-900)+(1000-1050)+(1000-1000)+(1000-1100)+(1000-950)}{5}$

$= \frac{100-50+0-100+50}{5} = o$

Mean Absolute Deviation (MAD) = 60 (As calculated in Problem 1)

Tracking Signal (TS)= Algebraic sum of deviations/Mean Absolute Deviations (MAD)

= 0/60 = 0 (Zero)

Since the value of Tracking Signal is zero and falls within 4, the forecast made for the demand for sewing machines is in control.

Q 13. The demand for 100 Watt bulbs in the months of January, February, March and April was 500, 600, 800 and 700. Forecast the monthly demand for the bulbs.

Solution:

Simple Average (SA) = $\frac{D1+D2+D3+D4}{N}$

= $\frac{500+600+800+700}{4}$

=$\frac{2600}{4}$

=650

The average demand for 100 Watt bulbs is 650 per month.

Q 14. The demand for 100 Watt bulbs in the past 8 months is given as below:

Month	**Demand**
January	500
February	600
March	800
April	700
May	700
June	800
July	600
August	500

Calculate the moving average for a period of 5 months.

Solution:

MA1 = $\frac{500+600+800+700+700}{5}$ = 660

MA2 = $\frac{600+800+700+700+800}{5}$ = 720

MA3 = $\frac{800+700+700+800+600}{5}$ = 720

MA4 = $\frac{700+700+800+600+500}{5}$ = 660

Q 15. The demand for three months for 100 Watt bulbs is give below:

Period	January	February	March
Demand	500	600	800

If the weight assigned to the period of January, February and March are 0.25, 0.35 and 0.4 respectively, forecast the demand for the months of April by using Weighted Moving Average Method

Solution:

D1=500 Nos. W1=0.25

D2=600 Nos. W2=0.35

D3=800 Nos. W3=0.4

There for Weighted Moving Average = W1 x D1 + W2 x D2+ W3 x D3
= 0.25x500+0.35x600+0.4x800
= 125+210+320
= 655
The demand for the month of April is 655 Nos. of 100 Watt bulbs.

Q 16. A restaurant had a demand of 500 sweet dishes in January and 600 sweet dishes in February. So far the restaurant manager had used average monthly demand to forecast for each month of the next year. Average monthly demand for the sweet dish last year was 250. Using 250 sweet dishes as the January forecast and a smoothing coefficient of 0.8 weight the recent demand and calculate the forecast for the month of March this year.

Ans . Feb 450 units , March 570 units

Q 17. (a)The actual demand for five periods are 1100, 1000, 1120, 1400, and 1250 and the opening forecast for the period 1 was 1000. Smoothing coefficient is 0.2. Calculate the new forecasts for the five periods.

(b) If the smoothing coefficient is changed to 0.3 before the end of period 3, what would be the new forecast for period ?

Solution: **NF = OF + α(AD-OF)**

(a) When α = 0.2

Period	OF	AD	AD-OF	α(AD-OF)	NF
1	1000	1100	+100	+20	1020
2	1020	1000	-20	-4	1016
3	1016	1120	+104	+20.8	1036.8
4	1036.8	1400	+363.2	+72.64	1109.44
5	1109.44	1250	+140.56	+28.11	1137.55

(b) When α = 0.3

3	1016	1120	+104	+31.2	1047.2

Q 18. The past data about the load on a stamping centre are as follows:

Month	Load, Machine Hours
May 2012	584
June 2012	610
July 2012	655
Aug. 2012	747
Sept. 2012	862
Oct. 2012	913
Nov. 2012	963

(a) If a five month moving average is used to forecast the next month's of the load on the centre in the month of December (2012).

(b)Compute a weighted three month moving average for December 2012, where the weights are 0.5 for the latest month, 0.3 and 0.2 for the other months, respectively.

Solution:

(a) Five month moving average forecast for December 2012

$$\frac{D_{Nov} + D_{Oct} + D_{Sep} + D_{Aug} + D_{Jul}}{5}$$

$$\frac{963 + 913 + 862 + 747 + 655}{5}$$

$$= \frac{4140}{5} = 828 \text{ machine hours}$$

(b) A three month weighted moving average forecast for December 2012

$(W_{Nov}D_{Nov}) + (W_{Oct}D_{OCt}) + (W_{Sep}D_{Sep})$

$= (0.5 \times 963) + (0.\ 3 \times 913) + (0.2 \times 862)$

= 927.8 machine hour

Q 19. With the help of following data, project the trend of sales for the next 5 years:

Year	2002	2003	2004	2005	2006	2007
Sales(in lakhs)	120	130	135	140	150	165

Ans. **Dec. 2018 10 Marks**

2.2 CAPACITY PLANNING

Capacity Planning:

The effective management of capacity is the most important responsibility of production and operations management. The objective of capacity management i.e., planning and control of capacity is to match the level of operations to the level of demand.

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

(i) What kind of capacity is needed?
(ii) How much capacity is needed?
(iii) When this capacity is needed?

Capacity planning is to be carried out keeping in mind future growth and expansion plans, market trends, sales forecasting, etc. Capacity is the rate of productive capability of a facility. Capacity is usually expressed as volume of output per period of time.

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,
- Capacity planning is the first step when an organization decides to produce more or new products.

Capacity planning is mainly of two types:

(i) Long-term capacity plans which are concerned with investments in new facilities and equipment. These plans cover a time horizon of more than two years.

(ii) Short-term capacity plans which takes into account work-force size, overtime budgets, inventories etc.

Effective Capacity can be determined by the following factors:

Facilities - design, location, layout and environment.

Product - product design and product-mix.

Process - Quantity and quality capabilities.

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.

Factors affecting determination of plant capacity

(i) Capital investment required,
(ii) Changes in product design, process design, market conditions and product life cycles,
(iii) Flexibility for capacity additions,
(iv) Level of automation desired,
(v) Market demand for the product,
(vi) Product obsolescence and technology obsolescence and
(vii) Type of technology selected.

2.3 CAPACITY REQUIREMENT

Capacity Requirement Planning : Capacity requirement planning (CRP) is a technique which determines what equipment and labour/personnel capacities are required to meet the production objectives (i.e., volume of products) as per the master production schedule and material requirement planning (MRP-I).

Efficiency = Standard time/Actual time
Utilization = Actual hours/Scheduled available hours
Planned capacity = Designed capacity × Efficiency × Utilization factor

QUESTIONS

Q 1. 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)	(Standard time in hours)
X	300	4.0
Y	400	6.0
Z	500	3.0

Determine the number of machines required.

Ans. 2.55 machine = 3 machine

Q 2. 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 utilization.

Ans. 90%, 72%(June 2014) 2 Marks

Q 3. An item is produced in a plant having a fixed cost of Rs. 6,000 per month, variable cost of rupees 2 per unit and a selling price of Rs. 7 per unit. Determine

(a) The break-even volume.
(b) If 1000 units are produced and sold in a month, what would be the profit?
(c) How many units should be produced to earn a profit of Rs. 4000 per month?

Ans. (a) 1200 units/month (b) Loss of Rs. 1000 (c) 2000 units.

Q 4. 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	Rs. 12,000	0 to 300
Two	Rs. 15,000	301 to 600
Three	Rs. 21,000	601 to 900

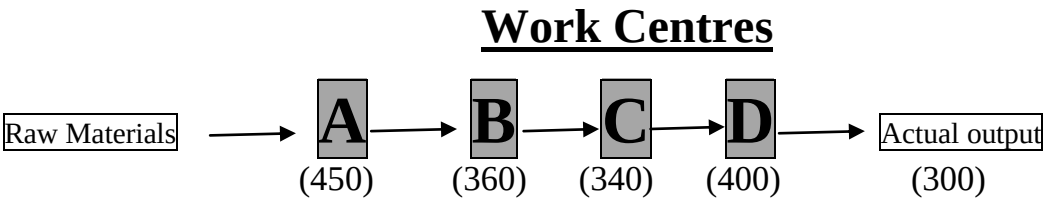
Variable cost is Rs. 20 per unit and revenue is Rs. 50 per unit

(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?

Ans. (a) 400, 500, 700,(units) (b) Two machine

Note- 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.

Q 5. 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?

Ans. (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) 88.23%

Q 6. A firm operates 6 days a week on single shift of 8 hours per day basis. There are 10 machines of the same capacity in the firm. If the machines are utilized for 75 percent of the time at a system efficiency of 80 percent, what is the rated output in terms of standard hours per week?
Ans. 288 Hours

Q 7. A manufacturing company has a product line consisting of five work stations in series. The individual workstation capacities are given. The actual output of the line is 540 units per shift.

Workstation No	1	2	3	4	5
Capacity/Shift	700	650	700	650	600

Calculate (i) System capacity

(ii) Efficiency of the production line.

Ans. (i) 600, (ii) 90% (June 2011) 1+ 2 = 3 Marks

Q 8. The order position (i.e., requirements of dispatch) for the next twelve months in respect of a particular product is as under:

Month	Required units	Month	Required units
1	13,000	7	11,000
2	12,000	8	7,000
3	10,000	9	15,000
4	9,000	10	13,000
5	11,000	11	12,000
6	13,000	12	10,000

The production capacity of the shop is 10,000 units per month on regular basis and 3,000 units per month on overtime basis. Sub-contracting can be relied upon up to a capacity of 3,000 units per month after giving a lead time of 3 months. Cost data reveal as under: Rs. 5.00 per piece on regular basis Rs. 9.00 per piece on overtime basis Rs. 7.00 per piece on sub-contract basis Cost of carrying Inventory is Rs. 1.00 per unit per month. Assuming an initial inventory of 1,000 units and that no backlogging of orders is permissible, suggest an optimal production schedule. Also work out the total cost on the basis of the suggested schedule.

Ans. Rs. 7,17,000

Q 9. A manufacturing company has a product line consisting of five work stations in series. The individual workstation capacities are given. The actual output of the line is 500 units per shift. Calculate: (i) System capacity (ii) Efficiency of the production line

Workstation No	. A	B	C	D	E
Capacity/Shift	600	650	650	550	600

Ans.(i) System capacity is decided by the work station, with minimum capacity/shift. i.e., the bottleneck. In the given question , the work station D has minimum capacity 550 units / shift . **Hence, the system capacity = 550 units/shift. (ii) 90.91%**

Q 10. A company intends to buy a machine having a capacity to produce 1,70,000 goods parts per annum. The machine constitutes a part of the total product line. The system efficiency of the product line is 85%

(i) Find the system capacity.

(ii) If the time required to produce each part is 100 seconds and the machine work for 2000 hours per year. If the utilization of the machine is 60% and the efficiency of the machine is 90%, compute the output of the machine.

(iii) Calculate the number of machines required?

Ans. (i) 2,00,000units/annum, (ii) 19.44 units/hour (iii) 5.14 machin

Q 11. The following activities constitute a work cycle.

(i) Find the total time, theoretical output obtained from the machine.

(ii) Calculate the number of machines required to produce the three components from the information given below.

Sr. No.	Activity	Time (min)
1.	Unloading	0.25
2	Inspection	0.35
3.	Loading job on machine table	0.40
4.	Machine operation time	0.90

Components	A	B	C
1. Setup time per batch	25 min	55 min	45 min
2. Operation time (min/piece)	1.75	3.0	2.1
3. Batch size	350	550	575
4. Production per month	2450	4400	2875

Ans. (i) 1.9 min. (ii) 31.5 units (iii) 2.03 = 2 Machine

Q 12. A company intends to buy a machine having a capacity to produce 1,50,000 goods parts per annum. The machine constitutes a part of the total product line. The system efficiency of the product line is 75%

(iv) Find the system capacity.

(v) If the time required to produce each part is 120 seconds and the machine work for 2200 hours per year. If the utilization of the machine is 65% and the efficiency of the machine is 95%, compute the output of the machine.

(vi) Calculate the number of machines required?

Ans. (i) 2,00,000units/annum, (ii) 40755 units/year (iii) 4.91, (June 2017) 3 X 3 = 9 Marks

Q 13. A worker works for 8 hours in each shift, but during that time he had clocked for 7 hours on the job. Calculate his utilization.

Ans. 87.5%

Q 14. A manager has to decide about the number of machines to be purchase. He has three option i.e. purchasing one, or two, or three machines . The data are given below.

No. of machines	Annual fixed cost (Rs)	Corresponding range of output (unit)
1	10000	0 to 400
2	12000	401 to 700
3	20000	701 to 1000

Variable cost is Rs. 20 and revenue is Rs.40 per unit.

(i) Determine the break- even point for each range.

(ii) If projected demand is between 600 and 750 units, how many machines should the manager purchase?

Ans. (i) 500, 600, 1000, (ii) No.of machine 2 (June, 2010) 3 + 2 Marks

Q 15. A company is considering the expansion of a manufacturing process by adding more 1-Ton capacity furnaces. Each batch (1 ton) must undergo 30 minutes of furnace time, including load and unload operations. However the furnace is used only 80% of the time due to power restriction in other parts of the system. The required output for the new layout is to be 16 tons/shift (8 hours). Plant (system) efficiency is estimated at 50% of system capacity.

(a) Determine system capacity and the number of furnaces required (b) Estimate the percentage of time, the furnaces will be idle.

Ans. (a) 2.5 (say) = 3 furnace June 2015 (Old) 6 Marks
(b) Percentage of idle time:
Total hours available / shift = 3 furnaces × 8 hours = 24 furnace-hour
Total hours of actual use/shift = (24 -8) = 16 ton × 0.5 hour/ton = 8 furnace-hour Idle time = 16 furnace hour % of idle time = 16/24 = 67%

Q 16. Annual demand for a manufacturing company is expected to be as follows

Units demanded	8,000	10,000	15,000	20,000
Probability	0.50	0.20	0.20	0.10

Selling price is Rs. 35 per unit. The **existing manufacturing facility** has annual fixed operating cost of Rs. 2,00,000. Variable manufacturing costs are Rs. 7.75 per unit at the 8000 unit output level, Rs. 5 at the 10,000 unit level, Rs. 5.33 at the 15000 unit level and Rs. 7.42 at the 20,000 unit output level.
An **expanded facility** under consideration would require Rs. 2,50,000 fixed operating costs annually. Variable costs would average Rs. 9.40 at the 8000 unit level, Rs. 5.20 at 10,000 unit level, Rs. 3.80 at the 15000 unit level, and Rs. 4.90 at the 20000 level.
To maximise net earnings, which size facility should be selected?

Ans. Existing facility

Q 17. A manufacturer has the following information on its major product

Regular - time production capacity = 2600 units/period.
Over time production costs = Rs. 12 per unit.
Inventory costs = Rs. 2 per unit per period (based on closing inventory)
Backlog costs = Rs. 5 per unit per period. Opening inventory 400 units.
Demand (in units) for periods 1, 2, 3, 4, is 4000, 3200, 2000 and 2800 respectively.
Develop a level output plan that yields zero inventory at the end of period 4.
What costs result from this plan?

Ans. 16800,

Q 18. A workshop operates on 2 shifts of 8 hours per day. It has 10 machines. It works for 5 days in a week. Machine utilization is 90% and the efficiency of the machines is 85%.
Calculate the designed/ rated capacity of the workshop in standard hours.

Ans. 612 hours

Q 19. The Fixed cost for the production of a particular item is Rs 200 per month. Its variable cost being Rs 3 per unit and its sale price beings 7 per Unit., determine its break-even volume. What would be the profit if 2000 such unit ware sold in a month? How many such units should be sold to earn a profit of Rs 3000 per month .

Ans. 50 units, Rs. 7800 , 800 units (Dec 2008) 5 Marks

Q 20. Standard time for a task is 8 hours. Calculate the efficiency of a workman in the following cases:
(a) Worker completes the job in 10 hours.
(b) Worker completes the job in 6 hours.

Ans. 80% 133.33%

Q 21. A manufacturing company has a product line consisting of five work stations in series. The individual workstation capacities are given. The actual output of the line is 440 units per shift.

Workstation No	1	2	3	4	5
Capacity/Shift	550	650	700	650	600

Calculate (i) System capacity (ii) Efficiency of the production line.

Ans . (i) 550 (ii) 80 % (Dec- 2012) 1+ 2 = 3 Marks

Q 22. A worker is employed for 11 hours. During this period he takes 7 hours to complete a job with the standard time of 6 hours. Calculate the productivity of the workers as a percentage.

Ans. 54.55% (Dec. 2014) 2 Marks

Q 23. Manufacture of a gunmetal bush requires operations on Lathe, Milling and Drilling machine tools. The operator efficiencies, standard times, and machine tool availabilities are as follows :

Type of Machine Tool	Operator Efficiency	Std. Man-Hrs / bush	Machine Tool availability
Lathe	75%	0.15	95%
Milling	80%	0.20	75%
Drilling	80%	0.10	75%

(i) If the factory operates one shift of 8 hours for 6 days in a week, how many Lathe, Milling and Drilling machines will be required to produce 2000 bushes / week?

(ii) What will be the percentage of spare capacity available in each type of the machine tool?

Ans. (i) 8.77, 13.88, 6.94 (ii) 2.55%, .79% .79% 3+3+3= 9 Marks (June 2011)

Q 24. A worker is employed for 12 hours. During this period he takes 8 hours to complete a job with the standard time of 7 hours. Calculate the productivity of the workers as a percentage.

Ans. 58.33%

Q 25. An assembly line of an item A has the following output in a 10 week period:

Week No	Standard hours produced
1	350
2	375
3	380
4	400
5	300
6	325
7	340
8	370
9	390
10	350

Calculate the **demonstrated capacity** of the assembly line per week.

Ans. 358 per week

Q 26. A department works on 8 hours shift, 288 days a year and has the usage data of a machine, as given below:

Product	Annual demand (units)	(standard time in hours)
A	325	5.0
B	450	4.0
C	550	6.0

Calculate (a) Processing time needed in hours to produce products A, B, C, (b) Annual production capacity of one machine in standard hours, and (c) Number of machine required.

Ans. (a) 6725 Hours (b) 2304 hours / year (c) 2.92 machine =3 Machine

(June 2015) 3+2+2 = 7 Marks

Q 27. 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)	(standard time in hours)
X	200	4.0
Y	300	6.0
Z	400	3.0

Determine the number of machines required.

Ans. 1.9 Machine = 2 Machine (June 2016) 6 Marks

Q 28. A department works on 8 hours shift, 285 days a year and has the usage data of a machine, as given below:

Product	Annual Demand (units)	Processing time (Standard time in hours)
A	360	7.0
B	435	5.0
C	570	6.0

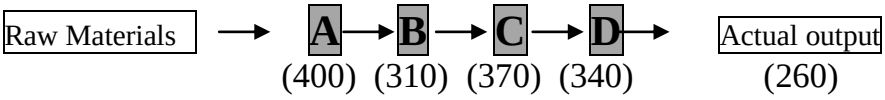
Calculate:

(i) Processing time needed in hours to produce products A, B, and C,
(ii) Annual production capacity of one machine in standard hours, and
(iii) Number of machines required.

Ans. **(Dec. 2017) 2x3 = 6 Marks**

Q 29. A firm has four work centres, A, B, C & D, in series with individual capacities in units per day shown in the figure below.

Work Centres



(iv) Identify the bottle neck centre.

(v) What is the system capacity?

(vi) What is the system efficiency? **(Dec. 2017) 9 Marks**

Ans.(i) (ii) (iii)

2.4 FACILITY LOCATION

Plant location may be understood as the function of determining where the plant should be roeaied for maximum operating economy and effectiveness. The selection of a place for locating a plant is one of the problems, perhaps the most important, which is faced by an entrepreneur while launching a new enterprise. A selection on pure economic considerations will ensure an easy and regular supply of raw materials, labour force, efficient plant layout, proper utilisation of production capacity and reduced cost of production. An ideal location may not, by itself, guarantee success; but it certainly contributes to the smooth and efficient working of an organisation. A bad location, on the other hand, is a severe handicap for any enterprise and it finally bankrupts it. It is, therefore, very essential that utmost care should be exercised in the initial stages to select a proper place. Once a mistake is made in locating a plant it becomes extremely difficult and costly to correct it.

Steps in Location Selection

To be systematic, in choosing a plant location, the entrepreneur would do well to proceed step by step,

1. Within the country or outside;

2. Selection of the region;

3. Selection of the locality or community;

4. selection of the exact site.

1. Deciding on Domestic or international Location

The first step in plant location is to decide whether the facility should be located domestically or internationally. A few years ago, this factor would have received little consideration. But with increasing internationalisation of business, the issue of home or foreign country' is gaining greater relevance. If the management decides on foreign location, the next logical step would be to decide upon a particular country for location. This is necessary because, countries across the world are vying with each other to attract foreign investments. The choice of a particular country depends on such factors as political stability, export and import auotas, currency and exchange rates, cultural and economic peculiarities, and natural or physical conditions.

2. Selection of Region

The selection of a particular region out of the many natural regions of a country is the second step in plant location.

The following factors influence such selection:

(i) Availability of Raw Materials As a manufacturing unit is engaged in the conversion of raw materials into finished products, it is very essential that it should be located in a place where the supply of raw materials is assured at minimum transport cost. the sugar industry, the paper industry, the iron and steel industry, the industries engaged in the solvent extraction of oil from rice bran, the china clay washery, factories manufacturing low tension porcelain insulators, and the like should be located near

the sources of their raw materials. The heavy concentration of the sugar industry in Bihar and Uttar Pradesh is due to the fact that these two states are the leading producers of sugarcane in the country.

Nearness to raw materials offers such advantages as:

(a) Reduced cost of transportation;

(b) Regular and proper supply of materials uninterrupted by transportation breakdowns; and

(c) Savings in the cost of storage of materials.

(ii) Nearness to the Market

Since goods are produced for sale, it is very essential that the factory should be located near their market. A reduction in the cost of transporting finished goods to the market; the ability to adjust the production programme to suit the likes and dislikes of consumers; the ability to render prompt service to the consumers, provide after-sale services, and execute replacement orders without delay - these are some of the advantages that accrue to the entrepreneur if he/she establishes his/her factory near his market.

(iii) Availability of Power

Power is essential to move the wheels of an industry. Coal, electricity, oil and natural gas are the sources of power. Where coal is the source of power, as in the case of the iron and steel industry, the factory has to be located near the coal fields. Examples of such industries are: the iron and steel industry in Germany, in Pennsylvania in the U.S.A. and in Jamshedpur in india.

(iv) Transport Facilities

While making a study of a location, an entrepreneur considers the question of the availability of transport facilities. Transport facilities are essential for bringing raw materials and men to the factory and for carrying the finished products from the factory to the market. a place which is well connected rail, road and water transport is ideal for a plant location. It may be said that industry follows transportation. In other words, places with well-developed means of transport attract industries^In extreme cases, transport may follow industries. For instance, if a public sector unit is started in a remote place, the government will naturally provide transport facilities to cater to the requirements of the unit. But, generally speaking a place with existing transport facilities is perfect for locating a plant.

(v) Suitability of Climate

The climate has its own importance in the location of a plant because of two reasons. First, there are certain industries which, because of the nature of their production, require particular climatic conditions; for example, humid climate for cotton textiles and jute. Such industries have to be located in places where humid climatic conditions are available. This explains why the cotton textile industry is concentrated in mumbai and the jute textile industry in Kolkota.

(Vi) Government Policy

The influence of Government policies and programmes on plant location is apparent in every country, particularly in planned economies like ours. In the name of balanced regional development, many

backward regions in india have been selected for the location of new industries, which would generate the regions economy and on a larger canvas, the national economy.

The Government of India has been influencing plant location in a number of ways. Some of these are: Licensing policy; Freight rate policy; Establishing a unit in the public sector in a remote area and developing it to attract other industries; Institutional finance and government subsidies.

3. Selection of Community

Selecting a particular locality or community in a region is the third step in plant location. the selection of a locality in a particular region is influenced by the following factors:

(i) Availability of Labour

Despite the talk of mechanisation and automation, the importance of labour on the industrial side has not been completely lost. Labour is an important factor in the production of goods. An adequacy of labour supply at reasonable wages is very essential for the smooth and successful working of an organisation.

(ii) Civic Amenities for Workers

Besides good working conditions inside the factory, the employees require certain facilities outside it. Recreation facilities, such as clubs, theatres and parks, must be provided for the employees. They require schools for their children. A place which abounds in all these facilities will naturally be preferred to another place which lacks them.

(iii) Existence of Complementary and Competing Industries

The existence of complementary industries is favourable to the location of industries because an industrial unit, in association with other units, can get the following benefits:

• An industrial unit, in collaboration with other similar units, can secure materials on better terms than it can do it by itself. the concentration of such similar establishments helps to increase the variety of materials that can be offered by suppliers.

(vi) Availability of Water and Fire-fighting Facilities

Some industries require a plentiful supply of water for their working. some of these are: fertilizer units, rayon manufacturing units, absorbent cotton manufacturing units, leather tanneries, bleaching, dyeing and screen printing units. these factories must be located in places where water is available in abundance. Water may be obtained from the local authority, from the canal, from a river or a lake, or by sinking a boreweli. in any case, the supply of water should be considered with respect to its regularity, cost and purity.

4.Selection of the Site

The selection of an exact site in a chosen locality is the fourth step in plant location. The selection of the site is influenced by the following considerations:

Soil, Size and Topography

For factories producing engineering goods, the fertility or otherwise of the soil may not be a factor influencing plant location. But for agro-based industries, a fertile soil is necessary for ensuring a strategic plant location.

The area of the land should be such as to accommodate not only the existing manufacturing facilities, but offer scope for future expansion programmes as well.

2.5 FACILITY LAYOUT

Meaning, Definition and Scope

A plant layout refers to the arrangement of machinery, equipment and other industrial facilities – such as receiving and shipping departments, tools rooms, maintenance rooms, employee amenities, etc., - for the purpose of achieving the quickest and smoothest production at the least cost. The subject of plant layout not only covers the initial layout of machines and other facilities but encompasses improvement in,
or revisions of, the existing layout in the light of subsequent developments in the methods of production.

In other words, a plant layout is a floor plan for determining and arranging the desired machinery and equipment of a plant, whether established or contemplated, in the best place to permit the quickest flow of material at the lowest cost and with the least amount of handling in processing the product from the receipt of the raw materials to the shipment of the finished products.

A more simple, clear and comprehensive definition is given by Knowles and Thompson. They say that a plant layout involves:

(i) Planning and arranging manufacturing machinery, equipment, and services for the first time in completely new plants;

(ii) The improvements in layouts already in use in order to introduce new methods and improvements in manufacturing procedures.

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,
• Reduced material handling costs,
• 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.

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. This principle should receive top consideration in towns and cities where, land is costly.

• ***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;

(ii) Product layout;

(iii) Fixed position layout;

(iv) Cellular Manufacturing (CM) layout;

(v) A combination of the above.

Process Layout

Also called the functional layout, layout for job lot manufacture on batch production layout, the process layout involves grouping together of like machines in one department. For example, machines performing drilling operations are fixed in the drilling department machines performing casting operations are grouped in the casting department; and so on.

In this way, there would be a heating department, a painting department, a machining departments etc., where similar machines 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, engine lathes will be arranged in one department, turret lathes in a second department, and milling machines in a third department.

Advantages

1. R educed investment of machines as they are general purpose machines.
2. Greater flexibility in the production.

3. Better and more efficient supervision is possible through specialisation.
4. There is greater scope for expansion as the capacities of different lines can be easily increased.
5. This type of layout results in better utilisation of men and machines.
6. It is easier to handle breakdown of equipment by transferring work to another machine or station.
7. There is full utilisation of equipment.
8. The investment of equipment would be comparatively lower.
9. There is greater incentive to individual worker to increase his performance.

Disadvantages

1. There is difficulty in the movement of materials. Mechanical devices for handling materials cannot be conveniently used.
2. This type of layout requires more floor space.
3. There is difficulty in production control.
4. Production time is more as work-in-progress has to travel from place to place in search of machines.
5. There is accumulation of work-in-progress at different places.

Product Layout

Also called the straight-line layout or layout for serialized manufacture (the term straight-line, as applied to production, refers to the movements which do not involve

backtracking of crossing of the line of movement of the product), the product layout involves the arrangement of machines in one line , depending upon the sequence of operations. Materials are fed into the first machine and finished goods travel automatically, from machine to machine, the output of one machine becoming the input of the next.

It is a feast for the eyes to watch the way sugarcane, fed at one end of the plant, comes out as sugar at the other end. Similarly, in a paper mill, bamboos are fed into the machine at one end and paper comes out at the other end.A product layout is , therefore, defined in the following words: 'In the product layout, the equipment used to fabricate a given product is lined up in order of appearance. The raw material arrives at one end of the line and goes from one operation to the next quite rapidly,
with a minimum of work-in-progress storage and materials handling.

Advantages

1. There is mechanisation of materials handling and consequently reduction in materials handling cost.
2. This type of layout avoids production bottlenecks.
3. There is economy in manufacturing time.
4. This type of facilities better production control.
5. This type of layout requires less floor area per unit of production.
6. Work-in-progress is reduced and investment thereon is minimised.
7. Early detection of mistakes or badly produced item is possible.
8. There is greater incentive to a group of workers to raise their level of performance.

Disadvantages

1. Product layout is known for its inflex ibility
2. This type of layout is also expensive.
3. There is difficulty of supervision.
4. Expansion is also diffcult.
5. Any breakdown of equipment along a production line can disrupt the whole system.

Load-Distance Analysis Method

Load-distance analysis is useful in comparing alternative layouts to identify the one with the least product or material travel time per period. This method helps to minimise transportation costs by evaluating alternate layouts on the basis of the total of the product of actual distance moved and the load (the units moved) for each layout alternative. Alternatively, the material handling costs can be computed directly by multiplying the number of loads by the material-handling cost per load. The layout with the lowest total (load x distance) or total (load x cost) is the best choice.
The following illustration helps in understanding the load-distance analysis method to determine the best layout alternative which minimises the total (load x distance moved).

QUESTIONS

Q 1. 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	-	-	-	-	-	-

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. **(STUDY NOTES)**

Ans.1640, 1820

Q 2. 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.
Ans. 67 (Dec. 2012) 5 Marks (STUDY NOTES)

Q 3. Mr. X, the factory Manager of S.K.Industries, is considering an interchange of departments 3 and 6 in the present layout. The present layout and the interdepartmental materials handling frequencies are furnished below [All the departments are of the same size and configuration in the following matrix, respectively.

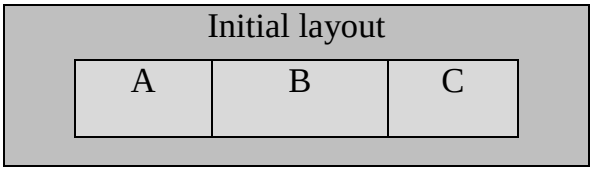
1	**3**	**5**
2	**4**	**6**

Present Layout Weekly frequencies of interdepartmental Material handling

From/ To	1	2	3	4	5	6
1	-	0	90	160	50	0
2	-	-	70	0	100	130
3	-	-	-	20	0	0
4	-	-	-	-	180	10
5	-	-	-	-	-	40

The per unit length inter departmental cost of materials of materials handling are equal. What is the effect of the interchange of the departments 3 and 6 in the layout?
Ans.1640, 1820

Q 4. Find an improved layout for the initial layout given in figure by using CRAFT pair wise exchange technique. The interdepartmental flows are also furnished along with the interdepartmental cost matrix.



Cost Matrix

From / To	A	B	C
A		1	1
B	1		1
C	1	1	

Flow Matrix

From / To	A	B	C
A		1	2
B	1		3
C	3	3	

Distance Matrix

From / To	A	B	C
A		1	2
B	1		1
C	2	1	

Ans. 15

Q 5. Mr; X is considering an interchange of department B and C in the present layout. The present layout and the handling frequencies between the departments are given. What would be the effect of interchange assuming that the department are of the same size ? also assume that the material handling cost per unit length travel between departments is same.

A	**C**	**E**
B	**D**	**F**

From/ To	A	B	C	D	E	F
A	-	20	70	0	40	0
B	-	-	50	200	0	10
C	-	-	-	30	120	40
D	-	-	-	-	50	220
E	-	-	-	-	-	30
F	-	-	-	-	-	-

Ans.1070, 1310, 5 Mark (Dec-2008)

Q 6. Give below is the exiting process layout of a factory manufacturing toys.

C	**B**	**D**
E	**A**	**F**

The following table gives the trip matrix for the unit. Arrive at an improved layout using the load Distance matrix that E and F should remain at their current position.

From/ To	A	B	C	D	E	F
A	-	-	2	2	1	-
B	-	-	1	-	6	5
C	-	-	-	1	4	-
D	-	-	-	-	-	5
E	-	-	-	-	-	1
F	-	-	-	-	-	-

Ans. 45, 32 **6 Marks (Dec, 2010)**

Q 7. Two layout alternatives are shown below. The facility's products, their travel between departments and the distances between departments for each layout alternative are also shown below. The layout alternative that minimises the monthly product travel through the facility has to be determined.

Layout A

8	4	10	2	5
3	7	1	9	6

Layout B

7	1	9	6	3
4	10	2	5	8

Department Movement Combination	Distance between Department (feet)		Department Movement Combination	Distance between Department (feet)	
	Layout A	Layout B		Layout A	Layout B
1-5	30	30	3-9	30	20
1-7	10	10	4-5	30	30
1-9	10	10	4-7	10	10
1-10	10	10	4-10	10	10
2-5	10	10	5-6	10	10
2-6	20	20	6-9	10	10
2-10	10	10	7-8	20	50
3-6	40	10	8-10	20	30

Products	Department Processing Sequence	Number of Products Processed per month	Product	Department Processing sequence	Number of Products Processed per month
A	1-5-4-10	1000	D	1-7-8-10	1000
B	2-6-3-9	2000	E	2-5-6-9	2000
C	2-10-1-9	3000	F	1-7-4-10	4000

Ans. 5,70,000, 5,30,000

Q 8 . A company is planning to undertake the production of medical testing equipments has to decide on the location of the plant. Three locations are being considered, namely, A, B and C. The fixed costs of three locations are estimated to be Rs. 300 Lakhs, 500 Lakhs and 250 Lakhs respectively. The variable costs are Rs. 3,000, Rs. 2,000 and Rs. 3,500 per unit respectively. The average sales price of the equipment is Rs. 7,000 per unit. Find

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

(ii) Select the best location, if the sales volume is of 18,000 units.

Answer : 4 Marks (Dec. 2011)

(1) Up to 10,000 units - C

(2) 10,000 to 20,000 units – A

(3) Above 20,000 units - B

Q 9. 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 locations are estimated to be Rs. 30 lakh, 50 lakh, and 25 lakh per annum respectively. The variable costs are Rs.300, Rs.200 and Rs.350 per unit respectively. The expected sales price of the cooking range is Rs.700 per unit find out.

(a) The range of annual production/sales volume for which each location is the most suitable and
(b) Which one of the three locations is the best location at a production/sales volume of 18,000 units?
(c) Calculation of BEP for each Location

Q 10. Location A would result in annual fixed cost of Rs. 3,00,000 variable costs of Rs. 63 per unit and revenue Rs. 68 per unit. Annual fixed cost at Location B are Rs. 8,00,000 variable costs are Rs. 32 per unit and revenues are Rs. 68 per unit. Sales volume is estimated to be 25000 units / year, which location is attractive?

Answer: Location B is most attractive. 5 Marks (June- 12) 3 Marks (June-13)

Q 11 . A manufacturer is considering four locations for a new plant. It has attempted to study all costs at the various locations and find that the costs of the following items vary from one location to another. The firm will finance the new plant from deposits bearing 10 percent interest

Particular	A	B	C	D
Labour(Rs. Per unit)	0.75	1.10	0.80	0.90
Plant(Rs. Crores)	0.46	0.39	0.40	0.48
Material & equipment*(Rs. Per unit)	0.43	0.60	0.40	0.55
Electricity(per year)	30,000	26,000	30,000	28,000
Water(per year)	7,000	6,000	7,000	7,000
Transportation(per unit)	0.02	0.10	0.10	0.05
Taxes(per year)	33,000	28,000	63,000	35,000

* This cost includes a projected depreciation, but no interest.
Determine the most suitable location (economically) for output volumes in the range of 50,000 to 1,30,000 units per year.

Answer: (a) 50,000 to 1,00,000 units B
(b) 1,00,000 to 1,30,000 units C

Q 12. A company is planning to undertake the production of medical testing equipment and has to decided on the location of the plant. Two location are being considered, namely, A and B. The fixed cost of two location are estimated to be Rs.25 lakhs and Rs.30 lakhs respectively. The variable cost are Rs.300 and rs.250 per unit respectively. The average sale price of the equipment is Rs.550 **4 Marks (June 2009)**

Ans. Up to 10000 Unit Location A
Above to 10000 Units Location B

Q 13. A company planning to start a an assembly unit of television sets has to decide on the location of its plant at any of the three cities viz. Kolkata, Delhi, or Mumbai. The extent of fixed and variable costs for each of these locations are estimated to be as under:

Location	Kolkata	Delhi	Mumbai
Fixed cost per annum Rs. Lakhs	30	50	25
Variable cost per unit	300	200	350

The expected selling price is Rs. 700 per unit.

Calculate :

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

ii) Which one to the three locations is most suitable for a roduction / sales volume of 18000 units?

iii) BEP for each location? **4+3+3=10 Marks (Dec. 2009)**

Q 14. A manufacture's study of various locations has found that the following costs very from one location to another. The firm will finance the new plant from deposits bearing 5% interest. Determine the most suitable location for a sales volume of 20,000 unit /year.

Location	A	B	C
Labour(Rs. Per unit)	0.50	1.00	0.80
Plant(Rs. Crores)	0.25	0.35	0.45
Material & equipment*(Rs. Per unit)	0.20	0.50	0.25
Electricity(per year)	25,000	28,000	30,000
Water	7,000	5,000	4,000
Transportation(per unit)	0.01	0.05	0.10
Taxes(per year)	22,000	15,000	30,000
Revenue (Rs. Per unit)	16.00	25.00	12.00

*This cost includes a projected depreciation, but no interest**.** **6 Marks (June,2010)**

Ans. Profit 126800, 246000, (72000),

Q 15 . A company is planning to undertake the production of medical testing equipments has to decide on the location of the plant. Three locations are being considered, namely, A, B and C. The fixed costs of three locations are estimated to be Rs. 30 Lakhs, 50 Lakhs and 25 Lakhs respectively. The variable costs are Rs. 300 Rs. 200 and Rs. 350 per unit respectively. The average sales price of the equipment is Rs. 700 per unit. Find

(i)The range of annual production/sales volume for which each location is most suitable.
(ii)Select the best location, if the sales volume is of 18,000 units.

Answer : **3+2= 5 Marks (Dec. 2013)**

Up to 10,000 units - C

10,000 to 20,000 units – A

Above 20,000 units – B

Q 16. A firm is considering for alternative locations for a new plant. It has attempted to study all costs at the various locations and find that the production costs of the following items vary from one location to another. The firm will finance the new plant from deposits fetching 10 percent interest

Particular	A	B	C	D
Labour(Rs. Per unit)	7.50	11.00	8.00	9.00
Plant construction cost(Rs. Crores)	4.60	3.90	4.00	4.80
Material &equipment*(Rs. Per unit)	4.30	6.00	4.00	5.50
Electricity(per year) (Rs. lakhs)	3.00	2.60	3.00	2.80
Water(per year) (Rs. lakhs)	0.70	0.60	0.70	0.70
Transportation(per unit)	0.20	1.00	1.00	0.50
Taxes(per year) (Rs. lakhs)	3.30	2.80	6.30	3.50

The material and equipment includes a projected deprecation, but no interest. If the plant is designed to have an effective system capacity of 10,000 units per year and is expected to operate at 80% efficiency, what is the most economic location on the basis of actual output?

Ans. Total cost

A. 53,96,000
B. 46,44,000
C. 51,04,000
D. 56,20,000

Q 17. A Media Company proposes to build a new office in one of the three locations. Using the data below determine the best location. Please assume the following values.
Excellent-10, V.Good-8, Good- 6, Fair-4 and Poor-2

Rating factor	Location	Location	Location	Weight
A. Living standard	Excellent	Good	Fair	30
B. Labour Relations	Good	Fair	Excellent	10
C. Govt. Aid	V. Good	Good	Poor	5
D. Schooling System	Fair	Excellent	Good	15
E. Distance to Customers	V. Good	Poor	Excellent	10
F. Distance to Suppliers	Poor	Good	V. Good	10
G. Revenue Contribution	V. Good	Excellent	Good	20

Ans. 720, 680, 620, Location No.1 is best choic

Q 18. XYZ manufacturing company planning to start its production activities has to decide on the location of the plant. Three locations are being considered. Location A, B and C. The following data are available:

Location	A	B	C
Fixed cost per annum Rs. Lakhs	35	55	30
Variable cost per unit	350	250	400

The expected selling price of the products is Rs. 750 per unit.

Calculate :

iv) The range of annual production / sales volume for which each location is most suitable;

v) Which one to the three locations is most suitable for a production / sales volume of 22,000 units?

Ans. **Dec. 2014 8 Marks**

2.6 RESOURCES AGGREGATE PLANNING

Aggregate Planning:
Aggregate planning is an intermediate term planning decision. It is the process of planning the quantity and timing of output over the intermediate time horizon (3 months to one year). Within this range, the physical facilities are assumed to be fixed for the planning period. Therefore, fluctuations in demand must be met by varying labour and inventory schedule. aggregate planning seeks the best combination to minimise costs.

Production planning in the intermediate range of time is termed as 'aggregate planning'. it is thus called because the demand on facilities and available capacities is specified in aggregate quantities. For example aggregate quantities of number of automobile vehicles, aggregate number of soaps etc. Here the total expected demand is specified without regard to the product mix that makes up the specified figure.

While dealing with production problems, the planning process is normally divided in three categories.

(i) Long range planning which deals with strategic decisions such as purchase of facilities, introduction of new products, processes etc.

(ii) Short term planning which deals with day-to-day work, scheduling and sometimes inventory problems.

(iii) Intermediate planning or aggregate planning, which is in between long range and short term planning which is concerned in generally acceptable planning taking the load on hand and the facilities available into considerations. In aggregate planning the management formulates a general strategy by which capacity can be made to satisfy demand in a most economical way during a specific moderate time period, say for one year. The aggregate planning is made operational through a master schedule that gives the manufacturing schedule (products and dates of manufacture). Generally, day-to-day schedules are prepared from master schedule. Facility planning and scheduling has got very close relationship with aggregate planning.

Aggregate Planning Strategies:
The variables of the production system are labour, materials and capital. More labour effort is required to generate higher volume of output. Hence, the employment and use of overtime (OT) are the two relevant variables. Materials help to regulate output. The alternatives available to the company are inventories, back ordering or subcontracting of items.

These controllable variables constitute pure strategies by which fluctuations in demand and uncertainties in production activities can be accommodated.
Vary the size of the workforce: Output is controlled by hiring or laying off workers in proportion to changes in demand.
Vary the hours worked: Maintain the stable workforce, but permit idle time when there is a 'slack' and permit overtime (OT) when demand is 'peak'.

Vary inventory levels: Demand fluctuations can be met by large amount of inventory.

Subcontract: Upward shift in demand from low level. constant production rates can be met by using

Aggregate planning guidelines:
1. Determine corporate policy regarding controllable variables.
2. Use a good forecast as a basis for planning.
3. plan in proper units of capacity.
4. maintain the stable workforce.
5. maintain needed control over inventories.
6. Maintain flexibility to change.
7. respond to demand in a controlled manner.
8. evaluate planning on a regular basis.

Properties of Aggregate Planning:
To facilitate the production manager the aggregate planning must have the following characteristics:

(i) Both out put and sales should be expressed in a logical overall unit of measuring. For example, an automobile manufacturing can say 1000 vehicles per year, without giving the number of each verity of vehicle. Similarly a paint industry can say 10,000 litres of paint and does not mention the quantities of each colour.

(ii) Acceptable forecast for some reasonable planning period, say one year.

(iii) A method of identification and fixing the relevant costs associated with the plant. Availability of alternatives for meeting the objective of the organization. Ability to construct a model that will permit to take optimal or near optimal decisions for the sequence of planning periods in the planning horizon.

(iv) Facilities that are considered fixed to carry out the objective.

QUESTIONS

Q 1. 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	3920

The firm estimates that it costs Rs. 150 per unit to increase production rate Rs. 200 per unit to decrease the production rate, Rs 50 per unit per quarter to carry the items in inventory and Rs. 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 hire 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 X 200 = 10000	10000
3	470	250 X 150 = 37500		37500
4	670	200 X 150 = 30000		30000
5	450		220 X 200 = 44000	44000
6	270		180 X 200 = 36000	36000
7	200		70 X 200 = 14000	14000
8	370	170 X 150 = 25500		25500
				197000

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 computer in the table. The plan incurs a maximum shortage of 255 units during 5 periods. 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.

Quarter	Demand forecast	Cumulative demand	Production level	Cumu. Prod. level	Inventory	Adjusted Inventory with 255 at beginning of period 1	Cost of holding inventory
1	270	270	365	365	95	350	17500
2	220	490	365	730	240	495	24750
3	470	960	365	1095	135	390	19500
4	670	1630	365	1460	-170	85	4250
5	450	2080	365	1825	-255	0	0
6	270	2350	365	2190	-160	95	4750
7	200	2550	365	2555	5	260	13000
8	370	2920	365	2920	0	255	12750
							96500

Plan III

The additional demand other than the normal capacity is met by subcontracting. the cost of the plan III amounts to Rs. 1,32,000 as shown in table below.

Quarter	Demand forecast	Production units	Subcontract units	Incremental cost @ 100/ units
1	270	200	70	70 X 100 = 7000
2	220	200	20	20 X 100 = 2000
3	470	200	270	270 X 100 = 27000
4	670	200	470	470 X 100 = 47000
5	450	200	250	250 X 100 = 25000
6	270	200	70	70 X 100 = 7000
7	200	200	0	0
8	370	200	170	170 X 100 = 17000
				132000

The total cost of pure strategies is given above. On observation plan II (changing inventory levels) has the least cost.

2.7 MATERIAL REQUIREMENTS PLANNING

Material requirement planning (MRP) refers to the basic calculations used to determine component requirements from end item requirements. It also refers to a broader information system that uses the dependence relationship to plan and control manufacturing operations.

MRP is a technique of working backward from the scheduled quantities and needs dates for end items specified in a master production schedule to determine the requirements for components needed to meet the master production schedule. The technique determines what components are needed, how many are needed, when they are needed and when they should be ordered so that they are likely to be available as needed. The MRP logic serves as the key component in an information system for planning and controlling production operations and purchasing. The information provided by MRP is highly useful in scheduling because it indicates the relative priorities of shop orders and purchase orders.

"Materials requirement planning (MRP) is a technique for determining the quantity and timing for the acquisition of dependent demand items needed to satisfy master production schedule requirements."

MRP is one of the powerful tools that, when applied properly, helps the managers in achieving effective manufacturing control.

MRP Objectives:

1. Inventory reduction: MRP determines how many components are required, when they are required in order to meet the master schedule. It helps to procure the materials/components as and when needed and thus avoid excessive build up of inventory.

2. Reduction in the manufacturing and delivery lead times: MRP identifies materials and component quantities, timings when they are needed, availabilities and procurements and actions required to meet delivery deadlines. MRP helps to avoid delays in production and priorities production activities by putting due dates on customer job orders.

3. Realistic delivery commitments: By using MRP, production can give marketing timely information about likely delivery times to prospective customers.

4. Increased efficiency: MRP provides a close coordination among various work centres and hence helps to achieve uninterrupted flow of materials through the production line. This increases the efficiency of production system.

Functions served by MRP

1. Order planning and control: When to release orders and for what quantities of materials.
2. Priority planning and control: How the expected date of availability is compared to the need date for each component.
3. provision of a basis for planning capacity requirements and developing a broad business plans.

Advantages and Disadvantages of MRP

Advantages :

(i) Reduced inventory,
(ii) Reduced idle time,
(iii) Reduced set up time,
(iv) Ability to change the master production schedule,
(v) Ability to price more competitively,
(vi) Better customer service,
(vii) Better response to market demands,
(viii) Reduced sales price.

In addition the MRP system enables the following:

(i) Aids capacity planning,
(ii) Helps managers to use the planned schedule before actual release orders,
(iii) Tells when to expedite or deexpedite,
(iv) Delays or cancels orders,
(v) Changes order quantities,
(vi) Advances or delays order due dates.

Disadvantages :

Even though MRP system has many advantages, there are some problems with MRP systems which make them fail in many firms. Three major **causes for failures of an MRP system are:**

(i) Lack of top management commitment. MRP must be accepted by top management as a planning tool with specific reference to profit results. All executives concerned with the implementation of the MRP system must be educated emphasizing the importance of MRP as a closed-loop, integrated strategic planning tool.
(ii) MRP was presented and perceived as a complete and stand-alone system to run a firm, rather than as part of the total system.
(iii) 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, **which often requires**

(i) Changing how the firm operates and
(ii) Updating files.

The major complaint by users of MRP is that MRP is too rigid because when MRP develops a schedule, it is quite difficult to deviate from the schedule if need arises.

2.8 MANUFACTURING RESOURCES PLANNING

Manufacturing Resource Planning (MRP II) has been developed by manufacturing mar^gerrto 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 organization 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 control system, MRP laid the basic foundation for production activity control or shop-floor control.

2.9 ENTERPRISE RESOURCES PLANNING

Enterprise resource planning, popularly known as ERP, is today's buzz-word in the corporate world. Companies world-wide use ERP to integrate business processes and thereby reduce costs and increase productivity. It has established its base as a global phenomena.

Traditionally, companies developed isolated computer applications to suit and satisfy each of their functional segments such as sales, purchase, production, inventory, personnel and accounts. Materials requirement planning (MRP I) and manufacturing resource planning re (MRP II) were developed basically to address the requirements of the manufacturing set-up.

But the information available in various functional segments was so scattered that it was almost impossible to consolidate the information and provide the same to the people in the j top management to enable them to take vital business decisions. Hence, the companies, whether in the manufacturing or the service sector have been searching for the 'total solution' on an integrated system which could provide for the information needs of the entire enterprise. ERP software was developed to provide such a 'total solution' to the business enterprise.

To be highly successful in today's global competitive market, it is necessary that business enterprises continuously strive for developing a high level of interaction and co-ordination along the supply chain and improve in the area of quality, time to reach the market, customer satisfaction, performance and profitability. The ERP software fulfils this need.

What is ERP?

ERP is a software package developed for optimum use of resources of an enterprise in a planned manner. ERP integrates the entire enterprise starting from the supplier to the customer, covering logistics, financial and human resources. This will enable the enterprise to increase productivity by reducing costs. ERP is a package for cost saving. Once the ERP is implemented, a single solution addresses the information needs of the whole organisation.

2.10 ECONOMIC BATCH QUANTITY

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 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.

If **S** is the set up cost per set up, **'C'** is the production cost per unit produced and **I** is the inventory carrying changes (%) and **A** is the annual demand for the item in units, then,

Economic Batch Quantity (EBQ)

or Economic Lot size (ELS)

or Economic Manufacturing Quantity (EMQ)

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,

QUESTIONS

Q 1. Monthly demand for a component is 1000 units. Setting - up cost per batch Rs 120. Cost of manufacture per unit Rs 20. Rate of interest may be considered at 10% p.a. Calculate EBQ.

Ans. 1200 Units (STUDY NOTE)

Q 2. Calculate EBQ from the details: Monthly demand 2000 units, setup cost per batch Rs 100 cost of manufacture per unit Rs 30 rate of interest 10% p.a.

Ans. 1265 Units Dec. 2013 (New) 2 Marks

Q 3. Calculate EBQ from the details: Monthly demand 1000 units, setup cost per batch Rs 100 cost of manufacture per unit Rs 20 rate of interest 10% p.a.

Ans. 1095 Units June . 2014 (New) 2 Marks

Q 4. A production manager of a plant must determine the lot size for a particular component that has a steady demand of 50 units per day. The production rate is 200 units per day, Annual demand is 10,000 units, set-up cost is Rs. 200, annual holding cost is Rs 0.20 per unit and the plant operates 350 days per year. Determine (a) The economic production lot size, (b) The total annual set up and inventory holding cost for the component, (c) The time between production orders or cycle length for the economic lot size, (d) The production time per lot.

(STUDY NOTE)

Ans. (a) 5164 (b) 775 (c) 181 Days (d) 26 Days

Q 5. C Ltd. produces a product which has a monthly demand of 4,000 units. The product requires a component X which is purchased at Rs. 20. For every finished product, one unit of component is required. The ordering cost is Rs. 120 per order and the holding cost is 10% p.a. You are required to calculate:

(i) Economic order quantity.
(ii) If the minimum lot size to be supplied is 4,000 units, what is the extra cost the company has to incur?
(iii) What is the minimum carrying cost, the company has to incur.

Ans. (i) 2400 units (ii)Rs. 640 (iii) Rs. 2400

Q 6. 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 Rs. 324.

(a) What is the optimum run size for bearing manufacture?
(b) What should be the interval between the consecutive optimum run.
(c) Find out the minimum inventory holding cost.

Ans. (a) 3600 units (b) 54 Days (iii) Rs. 2160

Q 7. The demand of a certain item is random. It has been estimated that the monthly demand of the item has a normal distribution with a mean of 680 and a standard deviation of 130 units. The unit price of the item is Rs. 10 per unit; the ordering cost is Rs. 20. The inventory carrying cost is estimated to be 25 per cent per year respectively. The procurement lead time is constant and is one week.
Find the most economic ordering policy and the expected total cost of controlling inventory, given that the service level is 97.5%.

Ans. (i) 361 units (ii) Rs. 1228

Q 8. A manufacturer requires 10,00,000 components for use during the next year which is assumed to consist of 250 working days. The cost of storing one component for one year is Rs. 4 and the cost of placing order is Rs. 32.
There must always be a safety stock equal to two working days usage and the lead time from the supplier, which has been guaranteed, will be five working days throughout the year. Assuming that usage takes place steadily throughout the working days, delivery takes place at the end of the day and orders are placed at the end of working day, you are required to
(a) Calculate the EOQ
(b) Calculate the Re-order point.

Ans. (i) 4000 Units (ii) 28000 Units

Q 9. 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 Rs. 2 per unit. The purchase price of raw material is Rs. 20 per unit. The ordering cost is Rs. 25 per order.

(a) You are required to find EOQ.
(b) 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?
(c) What happens when the company gets a concession of 10% on the purchase price when it orders 6,000 units or more?
(d) Which of the above three ways of orders the company should adopt?

Ans.

Q 10. Requirement of raw materials for a company is 250 units per month. The carrying cost for the same is 10% of its purchase price which is Rs.10 per unit. The ordering cost is Rs .15 per order. Compute EOQ and related total cost.

Ans. 300 Units , Rs. 30300 (June 2009) 4 Marks

Q 11. 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	Rs. 100 per order

Inventory carrying cost	20% per annum
Cost of tubes	Rs. 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	6 – 8 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.

Ans. (1) 102 units, Accept the offer. (2) 1402 units (iii) 900 units (iv) 1600 units

Q 12. A manufacturer requires 10,000 components for use during the next year which is assumed to consist of 250 working days. The cost of storing one component for one year is Rs.40 and the cost of placing order is Rs.320.

There must always be a safety stock of two working days usage and the lead time from the supplier will be 5 working days. Assume that usage takes place steadily throughout the working days, delivery takes place at the end of the day and the order are placed at the end of the working day. Compute

(i) EOQ and
(ii) Re- order point.

Ans. (i) 400 Units , (ii) 280 Units (Dec.2009) 2 + 2 = 4 Marks

Q 13 . M/s HMT Bearings Ltd. is committed to supply 24,000 bearing per annum M/s Lokesh Machines on a steady daily basis. It is estimated that it costs Re. 1.00 as inventory holding cost bearing per month and that the setup cost per run of bearing manufacture is Rs.3240.

(i) What is the optimal run size for bearing manufacturer?
(ii) What should be the interval between the consecutive optimum runs?
(iii) What is the minimum inventory holding cost?

Ans. (i) 3600 units (ii) 54 Days (iii) 21600 2 + 1 + 2 = 5 Marks (Dec. 2010)

Q 14 . M/s. Kambu Ltd. are the manufacturers of Lamps. The following are the details of their operation during 2011:

Average monthly market demand	2,000 lamps
Ordering cost	Rs. 200 per order
Inventory carrying cost	20% per annum
Cost of tubes	Rs. 1000 per tube
Normal usage	100 tubes per week
Minimum usage	50 tubes per week
Maximum usage	200 tubes per week

Lead time to supply 4 – 6 weeks

Compute from the above:

(1) Economic order quantity.

(2) If the supplier is willing to supply quarterly 1,500 units at a discount of 10%, is it worth accepting?

(3) Maximum level of stock.

(4) Minimum level of stock.

(5) Re-order level of stock.

Ans. (1) 102 units (2) Accepting (3) 1102 units (4) 700 units

(5) 1200 units 10 Marks (june 2012)

Q 15. The monthly requirement of raw material for a company is 3200 units. The carrying cost is estimated to be 25% of the purchase price per unit, in addition to Rs. 2.5 per unit. The purchase price of raw material is Rs. 24 per unit.

The ordering cost is Rs. 28 per order.

(i) You are required to find EOQ and Total Cost.

(ii) What is the total cost when the company gets a concession of 6% on the purchase price if it orders 3200 units or more but less than 6200 units per month?

(iii) What happens when the company gets a concession of 15% on the purchase price when it orders 6,200 units or more?

(iv) Which of the above three ways of orders the company should adopt?

Ans. 4+2+2+2=10 Marks (June 2018)

STUDY NOTE -3

DESIGNING OF OPERATIONAL SYSTEM AND CONTROL

3.1 PRODUCTION DESIGN

Importance of Product Design

Production or operations strategy is directly influenced by product design for the following reasons:

(i) As products are designed, all the detailed characteristics of each product are established.
(ii) Each product characteristic directly affects how the product can be made or produced (i.e., process technology and process design) and
(iii) How the product is made determines the design of the production system (production design) which is the heart of production and operations strategy.

Further, product design directly affects product quality, production costs and customer satisfaction. Hence, the design of product is crucial to success in today's global competition.

A good product design can improve the marketability of a product by making it easier to operate or use, upgrading its quality, improving its appearance, and/or reducing manufacturing costs.

A distinctive design may be the only feature that significantly differentiates a product. An excellent design includes usability, aesthetics, reliability, functionality, innovation and appropriateness. An excellent design provides competitive advantage to the manufacturer, by ensuring appropriate quality, reasonable cost and the expected product features. Firms of tomorrow will definitely compete not on price and quality, but on product design.

What Does Product Design Do?

The activities and responsibilities of product design include the following:

(i) Translating customer needs and wants into product and service requirements (marketing).
(ii) Refining existing products (marketing).
(iii) Developing new products (marketing, product design and production).
(iv) Formulating quality goals (quality assurance, production).
(v) Formulating cost targets (accounting).
(vi) Constructing and testing prototype (marketing, production).
(vii) Documenting specifications (product design).

Reasons for Product Design or Redesign

The most obvious reason for product design is to offer new products to remain competitive in the market. The second most important reason is to make the business grow and increase profits. Also, when productivity gains result in reduction of workforce, developing new products can mean adding jobs and retaining surplus workforce instead of downsizing by layoffs/ retrenchment.

Sometimes product design is actually redesign or modification of existing design instead of an entirely new design. The reasons for this include customer complaints, accidents or injuries during product use, excessive warranty claims or low demand. Sometimes product redesign is initiated to achieve cost reductions in labour and material costs.

Objectives of Product Design

(i) The overall objective is profit generation in the long run.
(ii) To achieve the desired product quality.
(iii) To reduce the development time and cost to the minimum.
(iv) To reduce the cost of the product.
(v) To ensure productivity or manufacturability (design for manufacturing and assembly).

Factors Influencing Product Design

(i) **Customer requirements**: The designers must find out the exact requirements of the customers to ensure that the products suit the convenience of customers for use. The products must be designed to be used in all kinds of conditions.

(ii) **Convenience of the operator or user:** The industrial products such as machines and tools should be so designed that they are convenient and comfortable to operate or use.

(iii) **Trade off between function and form:** The design should combine both performance and aesthetics or appearance with a proper balance between the two.

(iv) **Types of materials used:** Discovery of new and better materials can improve the product design. Designers keep in touch with the latest developments taking place in the field of materials and components and make use of improved materials and components in their product designs.

(v) **Work methods and equipments:** Designers must keep abreast of improvements in work methods, processes and equipments and design the products to make use of the latest technology and manufacturing processes to achieve reduction in costs.

(vi) **Cost/Price ratio:** In a competitive market, there is lot of pressure on designers to design products which are cost effective because cost and quality are inbuilt in the design. With a constraint on the upper limit on cost of producing products, the designer must ensure cost effective designs.

(vii) **Product quality:** The product quality partly depends on quality of design and partly on quality of conformance. The quality policy of the firm provides the necessary guidelines for the designers regarding the extent to which quality should be built in the design stage itself by deciding the appropriate design specifications and tolerances.

(viii) **Process capability:** The product design should take into consideration the quality of conformance, i.e., the degree to which quality of design is achieved in manufacturing. This depends on the process capability of the machines and equipments. However, the designer should have the knowledge of the capability of the manufacturing facilities and specify tolerances which can be achieved by the available machines and equipments.

(ix) **Effect on existing products:** New product designs while replacing existing product designs, must take into consideration the use of standard parts and components, existing manufacturing and distribution strategies and blending of new manufacturing technology with the existing one so that the costs of implementing the changes are kept to, the minimum.

(x) **Packaging:** Packaging is an essential part of a product and packaging design and product design go hand in hand with equal importance. Packaging design must take into account the objectives of packaging such as protection and promotion of the product. Attractive packaging enhances the sales appeal of products in case of consumer products (nondurable)

Characteristics of good Product Design

A good product design must ensure the following:

(i) **function or performance:** The function or performance is what the customer expects the product to do to solve his/her problem or offer certain benefits leading to satisfaction. **For example**, a customer for a motor bike expects the bike to start with a few kicks on the kick peddle and also expects some other functional aspects such as pick-up, maximum speed, engine power and fuel consumption etc.

(ii) **Appearance or aesthetics:** This includes the style, colour, look, feel, etc. which appeals to the human sense and adds value to the product.

(iii) **Reliability:** This refers to the length of time a product can be used before it fails. In other words, reliability is the probability that a product will function for a specific time period without failure.

(iv) **Maintainability:** Refers to the restoration of a product once it has failed. High degree of maintainability is desired so that the product can be restored (repaired) to be used within a short time after it breaks down. This is also known as serviceability.

(v) **Availability:** This refers to the continuity of service to the customer. A product is available for use when it is in an operational state. Availability is a combination of reliability and maintainability. High reliability and maintainability ensures high availability.

(vi) **Productibility**: This refers to the ease of manufacture with minimum cost (economic production). This is ensured in product design by proper specification of tolerances, use of materials that can be easily processed and also use of economical processes and equipments to produce the product quickly and at a cheaper cost.

(vii) **Simplification:** This refers to the elimination of the complex features so that the intended function is performed with reduced costs, higher quality or more customer satisfaction. A simplified design has fewer parts which can be manufactured and assembled with less time and cost.

(viii) **Standardisation:** Refers to the design activity that reduces variety among a group of products or parts. For example, group technology items have standardised design which calls for similar manufacturing process steps to be followed. Standard designs lead to variety reduction and results in economies of scale due to high volume of production of standard products. However, standardised designs may lead to reduced choices for customers.

(ix) **Specification:** A specification is a detailed description of a material, part or product, including physical measures such as dimensions, volume, weight, surface finish etc. These

specifications indicate tolerances on physical measures which provide production department with precise information about the characteristics of products to be produced and the processes and production equipments to be used to achieve the specified tolerances (acceptable variations).

Interchangeability of parts in products produced in large volumes (mass production and flow-line production) is provided by appropriate specification of tolerances to facilitate the desired fit between parts which are assembled together.

(x) **Safety:** The product must be safe to the user and should not cause any accident while using or should not cause any health hazard to the user. Safety in storage, handling and usage must be ensured by the designer and a proper package has to be provided to avoid damage during transportation and storage of the product. For example, a pharmaceutical product while used by the patient, should not cause some other side effect threatening the user.

3.2 PROCESS DESIGN & SELECTION

Process Design is concerned with the overall sequences of operations required to achieve the product specifications. It specifies the type of work stations to be used, the machines and equipments necessary to carry out the operations. The sequence of operations are determined by (a) The nature of the product, (b) The materials used, (c) The quantities to be produced and (d) The existing physical layout of the plant.

The process design is concerned with the following:

(i) Characteristics of the product or service offered to the customers.
(ii) Expected volume of output.
(iii) Kinds of equipments and machines available in the firm.
(iv) Whether equipments and machines should be of special purpose or general purpose.
(v) Cost of equipments and machines needed.
(vi) Kind of labour skills available, amount of labour available and their wage rates.
(vii) Expenditure to be incurred for manufacturing processes.
(viii) Whether the process should be capital-intensive or labour-intensive.
(ix) Make or buy decision.
(x) Method of handling materials economically.

3.3 PROCESS PLANNING

Process Planning

Process planning refers to the way production of goods or services is organised. It is the basis for decisions regarding capacity planning, facilities (or plant) layout, equipments and design of work systems. Process selection is necessary when a firm takes up production of new products or services to be offered to the customers.

Three primary questions to be addressed before deciding on process selection are:

(i) How much variety of products or services will the system need to handle?
(ii) What degree of equipment flexibility will be needed?
(iii) What is the expected volume of output?

Process Strategy

A **process strategy** is an organisation's approach to process selection for the purpose of transforming resource inputs into goods and services (outputs). The objective of a process strategy is to find a way to produce goods and services that meet customer requirement and product specification (i.e., design specifications) within the constraints of cost and other managerial limitations. The process selected will have a long-term effect on efficiency and production as well as flexibility, cost, and quality of the goods produced. Hence it is necessary that a firm has a sound process strategy at the time of selecting the process.

Key aspects in process strategy include:

(i) Make or buy decisions
(ii) Capital intensity and
(iii) Process flexibility

Make or buy decisions refer to the extent to which a firm will produce goods or provide services in-house or go for outsourcing (buying or subcontracting).

Capital intensity refers to the mix of equipment and labour which will be used by the firm.

Process flexibility refers to the degree to which the system can be adjusted to changes in processing requirements due to such factors as changes in product or service design, changes in volume of products produced and changes in technology.

Three process strategies: Virtually every good or service is made by using some variation of one of three process strategies. They are: **(i) Process Focus (ii) Repetitive Focus and (iii) Product Focus.**

Exhibit 1 illustrates the relationship between the three process strategies and volume and variety of products produced.

Each of these three strategies are discussed below:

(i) **Process focus:** Majority (about 75 per cent) of global production is devoted to low volume, high variety products in manufacturing facilities called job shops. Such facilities are organised around performing processes. For example, the processes might be welding, grinding or painting carried out in departments devoted to these processes. Such facilities are process focussed in terms of equipment, machines, layout and supervision. They provide a high degree of product flexibility as products move intermittently between processes. Each process is designed to perform a wide variety of activities and handle frequent changes. Such processes are called intermittent processes. These facilities have high variable costs and low utilisation of facilities.

(ii) **Repetitive focus:** A repetitive process is a product oriented production process that uses modules. It falls between product focus and process focus. It uses modules which are parts or components prepared often in a continuous or mass production process. A good example of repetitive process is the assembly line which is used for assembling automobiles and household appliances and is less flexible than process-focused facility. Personal computer is an example of a repetitive process using modules in which the modules are assembled to get a custom product with the desired configuration.

(iii) **Product focus:** It is a facility organised around products, a product oriented, high-volume low-variety process. It is also referred to as continuous process because it has very long continuous production run. Examples of product focussed processes are steel, glass, paper, electric bulbs, chemicals and pharmaceutical products, bolts and nuts etc. Product-focussed facilities need standardisation and effective quality control. The specialised nature of the facility requires high fixed cost, but low variable costs reward high facility utilisation.

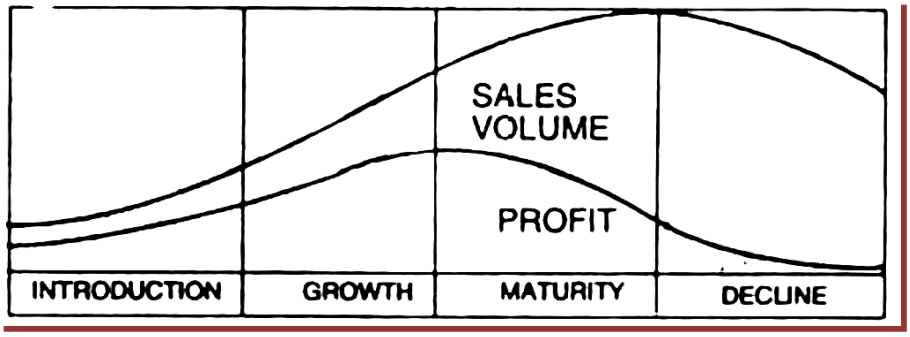
3.4 PRODUCT LIFE CYCLE

Products, like men, are mortal. They flourish for a time, then decline and die. The life cycle of a product has many points of similarity with the human life cycle. A product is born, grows lustily, attains a dynamic maturity, then enters its declining years. Like a human being a product that has not built up its potential during its formative years is likely to be relatively unsuccessful on its maturity. But, there are critical differences between the product and the human life cycle. For instance, every person has an average life expectancy. But the life expected of a product varies widely.

The concept of product failure is applicable both to new products and the existing ones. There may, however, be varying periods of life spans for each product: some failing immediately, other living for a longer period. The product, thus, has "life cycles" just as human beings have. From its birth, a product passes through various stages, until it is finally abandoned, i. e.. discontinued from the market. These stages taken together are referred, to as "the product life cycle". This life cycle of the product comprises four stages: Introduction, Growth, Maturity and Decline. It should be noted that it is purely a theoretical concept.

This may graphically be represented fig. in below:

The **introduction stage** is preceded by 'production planning and development' This period requires greater investment. This investment should be gradually recouped as the sales pick up. The concept of life cycle would give the management an idea as to the time within which the original investment could be recouped.



After testing, a product enters the introduction stage and the product will then become available in the national market. Sales would begin gradually as potential buyers learn of the product through advertising and other selling techniques. But the profits will be low as part of the investment is to be recouped besides heavy expenditure on selling.

In the **growth stage**, both sales and profits will begin to increase. It is here that similar other new products begin to appear in the market as substitutes and offer competition. The management, therefore, should try to change its approach by changing its strategy from "buy my product" to "try my product". At the end of this stage, the distribution arrangement is likely to get completed and the prices, if necessary, are reduced a little.

The third stage is the **maturity stage**. During this stage the manufacturers introduce new models or adopt methods such as trading-in, etc., to promote the sale of their brands with a view to retaining their position in the market. The number of buyers will continue to grow, but more slowly. In economic terms this is the stage where supply exceeds demand. Some of the promotional efforts may lengthen the span of this stage but they will not offer a permanent solution.

At the final stage of **decline**, profit margins touch a low level, competition becomes severe and customers start using newer and better products. It is here that the story of a product ends-a natrural but hard end. The above discussion concentrates only on the life cycle of a product, beginning with its introduction into the market (i.e., post-marketing). But a series of processes are to be undertaken by the management prior to the introduction of a product. The diagram given above is presented in an enlarged form to incorporate the preintroduction (or pre-marketing) stages also.

Product Iife cycle concept may be used as a managerial tool. Marketing strategies must change as the product goes through the life cycle. If managers understand the cycle concept they are in a better position to forecast the future sales activities and plan marketing strategies. The following points, however, may be kept in mind in using this concept.

3.5 PROCESS SELECTION

Process choice determines whether resources are organised around products or processes in order to implement the flow strategy. It depends on the volumes and degree of customisation to be provided.

These major process decisions are discussed in detail in the following paragraphs:

1. **Process Choice:** The production manager has to choose from **five** basic process types —

(i) Job shop

(ii) Batch

(iii) Repetitive or assembly line

(iv) Continuous and

(v) Project.

(i) Job shop process: It is used in job shops when a low volume of high-variety goods are needed. Processing is intermittent, each job requires somewhat different processing requirements. A job shop is characterised by high customisation (made to order), high flexibility of equipment and skilled labour and low volume. A tool and die shop is an example of job shop, where job process is carried out to produce one-of-a kind of tools. Firms having job shops often carry out job works for other firms. A job shop uses a flexible flow strategy, with resources organised around the process.

(ii) Batch process: Batch processing is used when a moderate volume of goods or services is required and also a moderate variety in products or services. A batch process differs from the job process with respect to volume and variety. In batch processing,volumes are higher because same or similar products or services are repeatedly provided, examples of products produced in batches include paint, ice cream, soft drinks, books and magazines.

(iii) Repetitive process: This is used when higher volumes of more standardised goods or services are needed. This type of process is characterised by slight flexibility of equipment (as products are standardised) and generally low labour skills. Products produced include automobiles, home appliances, television sets, computers, toys etc. Repetitive process is also referred to as line process as it include production lines and assembly lines in mass production. Resources are organised around a product or service and materials move in a line flow from one operation to the next according to a fixed sequence with little work-in-progress inventory. This kind of process is suitable to “manufacture-to-stock” strategy with standard products held in finished goods inventory. However, “assemble-to-order” strategy and “mass customisation” are also possible in repetitive process.

(iv) Continuous process: This is used when a very highly standardised product is desired in high volumes. These systems have almost no variety in output and hence there is no need for equipment flexibility. A continuous process is the extreme end of high volume, standardised production with rigid line flows. The process often is capital intensive and operate round the clock to maximise equipment utilisation and to avoid expensive shut downs and shut ups. Examples of products made in continuous process systems include petroleum products, steel, sugar, flour, paper, cement, fertilisers etc.

(v) Project process: It is characterised by high degree of job customisation, the large scope for each project and need for substantial resources to complete the project. Examples of projects are building a shopping centre, a dam, a bridge, construction of a factory, hospital, developing a new product, publishing a new book etc. Projects tend to be complex, take a long time and consist of a large number of complex activities. Equipment flexibility and labour skills can range from low to high depending on the type of projects.

STUDY NOTE -4

4.1 PRODUCTION PLANNING AND CONTROL INTRODUCTION

Introduction

Production planning control can be viewed as the nervous system of a production operation. The primary concern of production planning and control is the delivery of products to customers or to inventory stocks according to some predetermined schedule. All the activities in the manufacturing or production cycle must be planned, coordinated, organised, and controlled to achieve this objective. From a long-term point of view (usually from seven to ten years or more) production planning largely deals with plant construction and location and with product-line, design and development. short-range planning (from several months to a year) focuses on such areas as inventory goals and wage budgets. In plans projected over a two-to-five year period, capital-equipment budgeting and plant capacity and layout are the major concern. Production planning and control normally reflects the short range activities and focuses on the issues and problems that arise in the planned utilisation of the labour force, materials, and physical facilities that are required for manufacturing the products in accordance with the primary objectives of the firm.

Production systems are usually designed to produce a variety of products and are, therefore, complex. in such complex systems, anything can happen and usually it is so. therefore, it is vital to exercise some kind of control over the production activities. control is possible only when everything is planned. production planning and control is thus a very important aspect of production management.

Objectives of production planning and control

The ultimate objective of production planning and control is to contribute to the profits of the enterprise. This is accomplished by keeping the customers satisfied through the meeting of delivery schedules. Further, the specific objectives of production planning and control are to establish the routes and schedules for work that will ensure the optimum utilisation of raw materials, labourers, and machines to provide the means for ensuring the operation of the plant in accordance with these plans. production planning and control is essentially concerned with the control of work-in-process. To control work-in-process effectively it becomes necessary to control not only the flow of material but also the utilisation of people and machines.

Production planning and control fulfils these objectives by focusing on the following points:

(i) Analysing the orders to determine the raw materials and parts that will be required for their completion,
(ii) Answering questions from customers and salesmen concerning the status of their orders,
(iii) Assisting the costing department in making cost estimates of orders,
(iv) Assisting the human resource departments in the manpower planning and assignment of men to particular jobs,

(v) Controlling the stock of finished parts and products,
(vi) Determining the necessary tools required for manufacturing,
(vii) Direction and control of the movement of materials through production process,
(viii) Initiating changes in orders as requested by customers while orders are in process,
(ix) Issuing requisitions for the purchase of necessary materials,
(x) Issuing requisitions for the purchase or manufacture of necessary tools and parts,
(xi) Keeping the up-to-date records scheduled and in process,
(xii) Maintaining stocks of materials and parts,
(xiii) Notifying sales and accounting of the acceptance of orders in terms of production feasibility,
(xiv) Preparing the route sheets and schedules showing the sequence of operation required to produce particular products,
(xv) Production of work orders to initiate production activities,
(xvi) Receiving and evaluating reports of progress on particular orders and initiating corrective action, if necessary,
(xvii) Receiving orders from customers,
(xviii) Revising plans when production activities cannot conform to original plans and when revisions in scheduled production are necessary because of rush orders.

Production control involves the following functions:

(i) **Planning** the production operations in detail,
(ii) **Routing,** i.e., laying down the path for the work to follow and the order in which the various operations will be carried out,
(iii) **Scheduling,** i.e., establishing the quantity of work to be done, and fixing the time table for performing the operations,
(iv) **Dispatching,** i.e., issuing the necessary orders, and taking necessary steps to ensure that the time targets set in the schedules are effectively achieved,
(v) **Follow-up**, taking necessary steps to check up whether work proceeds according to predetermined plans and how far there are variances from the standards set earlier,
(vi) **Inspection,** i.e., conducting occasional check-ups of the products manufactured or assembled to ensure high quality of the production.

Basic types of production control:

Production control can be of six types:

(i) Block control

This type of control is most prominent in textiles and book and magazine printing. In these industries it is necessary to keep things separated and this is the fundamental reason why industries resort to block control.

(ii) Flow control

This type of control is commonly applied in industries like chemicals, petroleum, glass, and some areas of food manufacturing and processing. once the production system is thoroughly designed, the production planning and control department controls the rate of flow of work into the system and checks it as it comes out of the system. But, under this method, routing and scheduling are done when the plant is laid out. that is to say, the

production line which is established is well balanced and sequenced before production operations begin; this type of control is more prevalent in continuous production systems.

(iii) Load control

Load control is typically found wherever a particular bottleneck machine exists in the process of manufacturing.

(iv) Order control

The most, common type of production control is called order control. this type of control is commonly employed in companies with intermittent production systems, the so-called job-lot shops. Under this method, orders come into the shop for different quantities for different products. Therefore, production planning and control must be based, on the individual orders

(v) Special project control

Special production control is necessary in certain projects like the construction of bridges, office buildings, schools, colleges, universities, hospitals and any other construction industries. Under this type of control, instead of having sets of elaborate forms for tooling and scheduling, a man or a group of men keeps in close contact with the work.

(v) Batch control

Batch control is another important, type of production control which is frequently found in the food processing industries. thus, production control in batch-system of control operates with a set of

Production planning and control in continuous-production systems.

Production systems may be continuous or intermittent. The continuous production systems are characterised by:

(i) Fixed-path material handling equipment,
(ii) High volume of production,
(iii) Product layouts,
(iv) Production of standardised products,
(v) Production to stock or long-range orders,
(vi) The use of special-purpose machines or automation.

Production planning and control in continuous-production systems involve two activities:

(i) Assuring that supply of raw materials and supplies are on hand to keep the production system supplied and assuring that finished products are moved from the production-system,
(ii) Maintaining a constant rate of flow of the production, so that the system can operate near capacity in some case or can meet the quantity requirements of the production.

Production planning in intermittent production systems:

The intermittent production systems are characterized by the following:

(i) General purpose production machines are normally utilised and process layout is favoured.
(ii) Materials handling equipment is typically of the varied path type such as hand trucks and forklift trucks.
(iii) Relatively high cost, skilled labour is needed to turn out the various quantities and types of products.
(iv) The company generally manufactures a wide variety of products; for the majority of items, sales volumes and consequently production order sizes are small in relation to the total production.

QUESTIONS

Q 1. Machines K and L, both capable of manufacturing an industrial product, compare as follows:

Particular	Machine K	Machine L
Investment	Rs.60,000	Rs.1,00,000
Interest on borrowed capital	15%	15%
Operating cost(wages , power, etc.) per hour	Rs. 12	Rs. 10
Production Per Hour	6 pieces	10 pieces

The factory whose overhead costs are Rs. 1,20,000 works effectively for 4,000 hours in 2 shifts during the year.

(i) Justify with appropriate calculations which of the two machines you would choose for regular production.

(ii) If only 4000 pieces are to be produced in a year, which machine would give the lower cost per piece.

(iii) For how many pieces of production per year would the cost of production be same on either machine?

Ans. (i) 2.375, 1.375 (ii) 4.25, 4.75 (iii) 6000 Units.

Q 2. A department of a company has to process a large number of components/month. The process equipment time required is 36 minutes/component, whereas the requirement of an imported process chemical is 1.2 liters /component. The manual skilled manpower required is 12 minutes/component for polishing and cleaning. The following additional data is available:

Particular	Availability/month	*Efficiency of utilization*
Equipment hour	500	*85%*
Imported chemicals	1000	*95%*
Skilled manpower – hours	250	*65%*

(i) What is the maximum possible production under the current conditions?

(ii) If skilled manpower availability is increased by overtime by 20%, what will be the impact on production increase**?**

Ans. (i) 708 Components (ii) There will be no impact. 4 + 1 = 5 Marks (Dec.2011)

Q 3. A manufacturing enterprise has introduced a bonus system of wage payment on a slab-rate based on cost of production towards labour and overheads.
The slab-rate being

1% - 10%	saving in production cost	5% of saving
Between 11%-20%	saving in production cost	15%
Between 21%-40%	saving in production cost	30%
Between 41%-70%	saving in production cost	40%
Above 70%	saving in production cost	50%

The rate per hour for three workers A, B, C are Rs. 5, Rs. 5.50 and Rs. 5.25 respectively. The overhead recovery rate is 500% of production wages and the material cost is Rs. 40 per unit. The standard cost of production per unit is determined at Rs. 160 per unit.

If the time taken by A, B, C to finish 10 units is 26 hours, 30 hours and 16 hours respectively, what is the amount of bonus earned by the individual workers and actual cost of production per unit?

Ans. Cost/unit 130.60, 142.15, 118.24

Q 4. Calculate the break-even point for the following:
Production Manager of a unit wants to know from what quantity he can use automatic machine against semi-automatic machine.

Data	Automatic	Semi-automatic
Time for the job	2 minutes	5 minutes
Set up time	2 hours	1.5 hours
Cost per hour	Rs. 20	Rs. 12

Ans. BEP 66 Units **7 Marks** **Dec. 2016**

Q 5. Two alternative set-ups, A and B are available for the manufacture of a component on a particular machine, where the operating cost per hour is Rs. 20/-.

Particular	Set-up A	Set-up B
Components/set-up	4,000 pieces	3,000 pieces
Set up cost	Rs. 3,00/-	Rs. 1,500/-
Production rate/hour	10 pieces	15 pieces

Which of these set-ups should be used for long range and economic production?

Ans. 2.075, 1.833 **6 Marks** **June 2014**

Q 6. A and M are two fierce competitors. N a leading manufacturer of mobile phones approaches them separately to share what they can offer for outsourcing the manufacture of mobile phone components on a standardised machine whose operating cost is Rs. 40/- per hour. N requests you to evaluate and advice based on following offers made by A and M as to which of the should be chosen?

Particular	Company A	Company B
Mobile Components /set-up	8,000 pieces	6,000 pieces
Set up cost	Rs. 600/-	Rs. 3,000/-
Production rate/hour	20 pieces	30 pieces

Ans. 2.075, 1.833 **4 Marks (Dec,2008)**

Q 7. Two alternative set-ups, A and B are available for the manufacture of a component on a particular machine, where the operating cost per hour is Rs. 25/-.

	Set-up A	Set-up B
Components/set-up	20,000 pieces	30,000 pieces
Set up cost	Rs. 500	Rs. 600
Production rate/hour	20 pieces	40 pieces

Find out the manufacturing cost / piece under each setup. Which of these set-ups should be used for long range and economic production, assuming 3000 hours of working in a year?

Ans. 1.275, 0.645 **3 + 5 = 8 Marks (June 2011)**

Q 8. Empire Glass company can produce a certain insulator on any three machine which have the following charges shown below. The firm an opportunity to accept an order for either

(i) 50 units at Rs. 20/units or (ii) 150units at Rs. 12/units.

Machine	Fixed cost (Rs.)	Variable cost(Rs.)
A	50	4/units
B	200	2/units
C	400	1/units

(i) Which machine should be used if 50 units order is accepted and how much profit will result?

(ii) Which machine should be used if 150 units order is accepted and how much profit will result?

(iii) What is the break-even volume for machine B when the price is Rs 12/unit

(iv) Suppose the fixed cost for machine A is a stepped function with Rs. 50 upto 40units and Rs. 100 thereafter, will the answere to (i)and(ii) above ? If so, what will be the revised answer?

Ans. (i) Machine A Profit 750 (ii) Machine B Profit 1300 (iii) BEP 20units

(iv) Hence the answer in this case will not vary. **8 Marks (June- 13)**

Q 9. A manufacturing organization operate in incentive scheme on slab rate based on cost of production as shown below:

Saving in production cost (labour+ material+overheads)	Incentive Amount (as% of saving)
1 to10%	5%
11% to 20%	15%
21% to 40%	30%
41% to 70%	40%
Above 70%	50%

Three workers X, Y, and Z take 25 hour, 30 hour and 15 hour respectively to produce 10 unit of the product and their respective wage rates are Rs 6.00, Rs.6.50 and rs.7.00 per hour .The material cost is Rs. 50/- per unit and the overhead recovery rate is @500% of cost of wages. The standard cost of production per unit is determined at RS. 175 per unit. What is the amount of incentive earn by each of these workers and what is the actual cost production per unit in each case

10 Marks (Dec. 2010)

Ans. Cost /units 145.25 167.40 131.60

Q 10. Machines A and B are both capable of manufacturing a product. They compare as follows:

Particulars	Machine A	Machine B
Investment	Rs 50,000	Rs 80,000
Interest on capital invested	15% per annum	15% per annum
Hourly charges (wages +power)	Rs 10	Rs 8
No. of pieces produced per hour	5	8
Annual operating hours	2000	2000

(i) Which machine will have the lower cost per unit of output, if run for the whole year?

(ii) If only 4000 pieces are to be produced in a year, which machine would have the lower cost per piece?

(iii) Will your answer to (i) above query if you are informed that 12.5% of the output of machine B-gets rejected at the inspection stage. If so, what would be the new solution?

Ans. (i) 2.75 1.75 (ii) 3.875 4 (iii) 2

Q 11. Calculate the number of components that can be produced in a month when available equipment hours are 480 per month, efficiency of utilization is 85%, and it takes 36 minutes of processing time in the equipment for each component.

Ans. 2 Marks June 2015(New)

Q 12. Methods P and Q are both capable of manufacturing a product. They compare as follows

Data	Method P	Method Q
Fixture – cost	Rs. 24,000/–	Rs. 16,000/–
– life	6 months	4 months
Tooling – cost	Rs. 2,560/–	Rs. 4,800/–
– life	300 pieces	500 pieces
Processing time per piece	6mts	4 mts

The annual requirement is 1500 nos. Operating cost per hour of the process is Rs. 128 for both processes. Material cost is same in case. Which method would you choose for production during a period of one year?

Ans. Method Q

Q 13. XYZ company is trying to determine how best to produce a new product. The new product could be produced in-house using either process A or process B or purchased from a supplier. Cost data is given below:

Process	Fixed cost	Variable cost/unit
Make (process A)	Rs 8000	Rs 10
Make (process B)	Rs 20000	Rs 4
Purchase	Nil	Rs 20

For what levels of demand should each alternative (i.e., make with process A, make with process B or purchase from supplier) be chosen?

Ans.

Q 14. A department of a company has to process a large number of components per month. The process equipment time required is 30 minutes/component and manual skilled manpower required is 10 minutes/component. The following additional data is available:

Particular	Availability/month	*Efficiency of utilization*
Equipment hour	400	*80%*
Skilled manpower – hours	250	*65%*

What is the maximum possible production under the current conditions?

Ans. **Dec. 2013 (New)**

Q 15. A department of a company has to process a large number of components/month. The process equipment time required is 42 minutes/component, whereas the requirement of an imported process chemical is 1.8 liters /component. The manual skilled manpower required is 18 minutes/component for polishing and cleaning. The following additional data is available:

Particular	Availability/month	*Efficiency of utilization*
Equipment hour	600	*90%*
Imported chemicals Litres	1200	*98%*
Skilled manpower – hours	300	*70%*

(i) What is the maximum possible production under the current conditions?

(ii) If skilled manpower availability is increased by overtime by 25%, what will be the impact on production increase**?**

Ans. **6 + 2 = 8 Marks (June 2017)**

4.2 TIME STUDY, WORK STUDY, METHOD STUDY, JOB EVALUATION

TIME STUDY

Time study is concerned with the determination of the amount of time required to perform a unit of work. It consists of the process of observing and recording the time required to perform each element of an operation so as to determine the reasonable time in which the work should be completed. Time study is defined by ILO as below "Time study is a work measurement technique for recording the times and rates of working for the elements of a specified job carried out under specified conditions and for analysing the data so as to obtain the time necessary for carrying out the job at a defined level of performance".

Objective of time study: The main objective is "to determine by direct observation, the quantity of human work in a specified task and hence to establish the standard time, within which an average worker working at a normal pace should complete the task using a specified method".

The other objectives are:

(a) To furnish a basis of comparison for determining operating effectiveness.
(b) To set labour standard for satisfactory performance.
(c) To compare alternative methods in method study in order to select the best method.
(d) To determine standard costs.
(e) To determine equipment and labour requirements.
(f) To determine basic times/normal times.
(g) To determine the number of machines an operator can handle.
(h) To balance the work of operatdrs in production or assembly lines.
(i) To provide a basis for setting piece rate or incentive wages.
(j) To set the completion schedules for individual operations or jobs.
(k) To determine the cycle time for completion of a job. Time study by stop watch: The steps involved are

Work Study

It is a general term for the techniques: methods study and work measurement which are used in the examination; of human work in all its contexts and systematically investigate all factors leading to improvement of efficiency. Work study aims at finding the best and most efficient way of using the available resources—men, materials, money and machinery. once the method study has developed an improved procedure for doing a work the work measurement or time study will study the time to complete a job.

Method Study

It is the systematic investigation of the existing method of doing a job in order to develop and install an easy, rapid, efficient, effective and less fatiguing procedure for doing the same job and at minimum cost. This is achieved by eliminating unnecessary motions involved in a certain operation or by changing the sequence of operation or the process itself.

Benefits of Work Study

1. Increased productivity and operational efficiency.
2. R educed manufacturing costs.
3. Improved work place layout.
4. Better manpower planning and capacity planning.
5. Fair wages to employees.
6. Better working conditions to employees.
7. Improved work flow.
8. Reduced material handling costs.
9. Provides a standard of performance to measure labour efficiency.
10. Better industrial relations and employee morale.
11. Basis for sound incentive scheme.
12. Provides better job satisfaction to employees.

Objectives of Method Study

1. To study the existing proposed method of doing any job, operation or activity.
2. To develop an improved method to improve productivity and to reduce operating costs.
3. To reduce excessive material handling or movement and thereby reduce fatigue to workmen.
4. To improve utilization of resources.
5. To eliminate wasteful and inefficient motions.
6. To standardise work methods or processes, working conditions, machinery, equipments and tools.

Advantages of Method Study

1. Work simplification

2. Improved working method (cheaper method)
3. Better product quality
4. Improved workplace layout
5. Improved equipment design
6. Better working conditions/environment
7. Better material handling and lesser material handling cost
8. Improved work flow
9. Less fatigue to operator
10. Optimum utilization of all resources
11. Higher safety to workmen
12. Shorter production cycle time
13. Higher job satisfaction for workmen
14. R educed material consumption and wastages
15. R educed manufacturing cost and higher productivity

Determine the relevant allowances:

Once the basic time per cycle required by the qualified worker to perform each element at standard rate of working is determined, the next step is to determine the time allowance to be given to the operator for relaxation, fatigue, contingency etc. Usually these allowances are taken as a percentage of basic or normal time.

The various type of allowances are:

(i) Relaxation allowance (RA): This is also known as personal, fatigue on delay allowance (PFD allowance), This allowance in given to the work to overcome the fatigue due to physical exertion, posture,

concentration, working condition and personal needs such as going to toilet, drinking water, attending phone calls etc., it usually varies from 10% to 20% of normal or basic time.

(ii) Contingency allowance (CA): This allowance is given for infrequent or non-repetitive activities such as obtaining special materials from stores, sharpening of tools, getting a special tool from the tool stores, and consultation with the supervisor. It is usually about 5% of normal or basic time.

(iii) Process allowance: Allowance given to the worker to compensate himself for enforced idleness due to the nature of a process or operation; for e.g.,. working on automatic machine, electroplating etc., during which the worker is forced to be idle during a part of the work cycle.

(iv) Special allowances:

(a) Interference allowance given to a worker when he/she is looking after 2 or 3 machines. One machine may idle when the worker works on another machine for a short period and allowance has to be given to the worker for this loss of production. Design of Work Systems

(b) Periodic activity allowance - for activities carried out periodically during a work cycle e.g., setting up a tool on the machine.

(c) Determine the standard time by adding the relevant allowance to the normal or basic time. Standard time = Normal time + all relevant allowances

QUESTIONS

Q 1. Continuous stopwatch study observations for a job are given. Compute the standard time for the job, if the total allowances are 15%.

Element no.	Description	Cycle time (min)										P.R.
		1	2	3	4	5	6	7	8	9	10	
A	Loosen vice	0.09	0.49	0.89	1.31	1.70	2.09	2.50	2.88	3.29	3.71	90
B	Set bar length	0.16	0.56	0.95	1.38	1.76	2.16	2.57	2.95	3.36	3.78	110
C	Switch m/c	0.28	0.67	1.07	1.49	1.88	2.28	2.68	3.07	3.50	3.90	120
D	Unlock arm &set saw	0.41	0.80	1.21	1.61	2.00	2.41	2.80	3.20	3.62	4.03	100

Ans. Standard time 0.500 minutes

Q 2. Stopwatch time study figure for a job which is continuous in nature are given below. Calculate the Standard Time for the job assuming that the sample size is adequate, and total allowances are 15 percent.

E.NO.	Description	Cycle time (min)										P.R.
		1	2	3	4	5	6	7	8	9	10	
1	A	0.10	0.50	0.90	1.32	1.71	2.10	2.51	2.89	3.30	3.72	90
2	B	0.17	0.57	0.96	1.39	1.77	2.17	2.58	2.96	3.37	3.79	110
3	C	0.29	0.68	1.08	1.50	1.89	2.29	2.69	3.08	3.51	3.91	120
4	D	0.42	0.81	1.22	1.62	2.01	2.42	2.81	3.21	3.63	4.04	100

Ans. Standard time 0.501 minutes

Q 3. An analyst has observed a job long enough to become familiar with it and has divided it into five elements. The element times for the first four cycles and a performance rating for each element are given in the following table,

Element	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Performance Rating (%)
1	1.246	1.328	1.298	1.306	90
2	0.972	0.895	0.798	0.919	100
3	0.914	1.875	1.964	1.972	100
4	2.121	2.198	2.146	2.421	110
5	1.253	1.175	1.413	2.218	100

(a) Do any of the times look like outliners, i.e. probable errors in reading or recording data that should not be included in the analysis?

(b) Compute an estimated normal time for the job based on the data available at this stage of the study.

(c) On the basis of the data available, what sample size should be taken to estimate the time for element 2 within 5% of the true mean time with 95% confidence? **6 Marks (Dec.2012)**

Ans (a) The time for element 3 in cycle 1 and for element 5 in cycle 4 are outliners.
(b) Normal time 7.723 minutes. (c) n = 10.14

Q 4. The work - study engineer carries out the work sampling study. The following observations were made for a machine shop.

Total number of observations	7000
No. Working activities	1200
Ratio between manual to machine elements	2:1
Average rating factor	120%
Total number of jobs produced during study	800 units
Rest and personal allowances	17%

Compute the standard time for the job.

Ans. 9.89 minutes

Q 5. The time study of a machinery operation recorded cycle times of 8.0, 7.0, 8.0 and 9.0 minutes. The analyst rated the observed worker as 90%. The firm uses a 0.15 allowance fraction. Compute the standard time.

2 Marks (June-2013)

Ans. Standard time 8.47 minutes.

Q 6. An analyst wants to obtain a cycle time estimate that is within ± 5% of the true value. A preliminary run of 20 cycles took 40 minutes to complete and had a calculated standard deviation of 0.3 minutes. What is the coefficient of variation to be used for computing the sample size for the forthcoming time study?

Ans. 0.15 Minutes **2 Marks Dec. 2015**

Q 7. A job has been time standard for 20 observations. The mean actual time was 5.83 minutes and the standard deviation of the time is estimated to be 2.04 minutes. How many total observations should be taken for 95% confidence that the mean actual time has been determined within 10%?

Ans. 47, Therefore a total of observations should be made. Since 20 observations have already been made, only 27 more are necessary.

Q 8. You as a work study engineer carry out a work sampling study . The following observation were made for a machine shop.

Total number of observations	2000
No. Working activities	500
Ratio between manual to machine elements	3:1
Average rating factor	110%
Total number of jobs produced during study	500 units
Rest and personal allowances	10%

Calculate the standard time for the job.

Ans. 11.72 minutes **6 Marks (Dec.2008)**

Q 9. **A**shok works an 8 hours day as a machine operator. He works an with an average P.I. of 105% . A work sampling stdy determines that he is idle 20% of the day. Product record shows that he turned out 400 pieces of acceptable quality during the day. What is the standard time for the operation, if the job is given total Relaxation allowance of 10%?.

Ans. Standard time per piece 1.11 minutes (RTP)

Q 10. An analyst has observed a job long enough to become familiar with it and has divided it into five elements. The element times for the first four cycles and a performance rating for each element are given in the following table.

Element	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Performance Rating (%)
1	1.246	1.328	1.298	1.306	90
2	0.972	0.895	0.798	0.919	100
3	0.914	1.875	1.964	1.972	100
4	2.121	2.198	2.146	2.421	110
5	1.253	1.175	1.413	2.218	100

(a) Do any of the times look like outliners, i.e. probable errors in reading or recording data that should not be included in the analysis?

(b) Compute the basic time for the job and standard time. If a relaxation allowance of 12% a contingency allowance of 3% and an incentive allowance of 20% are applicable for the job.

Ans. Basic time 7.722minutes and standard time 8.88 minutes

Q 11. The work-study engineer carries out the work sampling study in a machine shop for a duration of 120 hours. The following observations were made.

Total number of observations	7000
No Working activities	1200
Ratio between manual to machine elements	2:1
Average rating factor	120%
Total number of jobs produced during study	800 units
Rest and personal allowances	17%

Compute the standard time for the job.

Ans. 9.89 minutes **5 MARKS (Dec 2013)**

Q 12. In a work sampling study, a mechanic was found to idle for 20% of the time. Find out the number of observation needed to conform to the above figures with a confidence level of 95% and a relative error level by ± 5%.
Ans. 6400

Q 13. A work sampling study is to be made of a typist pool. It is felt that typists are idle 30 percent of the item. How many observations should be made in order to have 95.5% confidence that accuracy is within ±4%.

Ans. 525

Q 14. Pilot study showed percentage of occurrence of an activity as 50%. Determine the number of observation required for a work sampling study for 95% confidence level and a relative error of ±2%.

Ans. 10000 nos.

Q 15. Compute the production cost per piece from the following data,
(i) Direct material per piece –Rs 2
(ii) Wage rate Rs 2000 per month consisting of 25 working days and 8 hours per day.
(iii) Overheads expressed as a percentage of direct labour cost - 200%.
(iv) The time for manufacture of 4 pieces of the item was observed during time study. The manufacture of the item consists of 4 elements a, b, c and d. The data collected during the time study are as under. Time observed (in minutes) during the various cycles are as below:

Element	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Element rating on B.S. Scale (0-1 00)
A	1.2	1.3	1.3	1.4	85
B	0.7	0.6	0.65	0.75	120
C	1.4	1.3	1.3	1.2	90
D	0.5	0.5	0.6	0.4	70

The personal, fatigue and delay allowance may be taken as 25%.

Ans.

Q 16. Calculate the standard time per article produced from the following data obtained by a work sampling study.
Total no. of observations = 2500
No. of working observations = 2100
No. of units produced in 100 hours duration = 6000 numbers
Proportion of manual labour = 2/3
Proportion of machine time = 1/3
Observed rating factor = 115%
Total allowances = 12% of normal time

Ans.

Q 17. A work study practitioner who conducted a work sampling study assesses the activity level of a worker to be 70%. During the space of 8 hours working, this worker turns out 320 components. If the company policy is to inflate the normal time arrived at by work sampling study by 20%, what should be the allowed time per unit?

Ans. 1.26 minutes

Q 18. Calculate the standard production per shift of 8 hours duration, with the following data. Observed time per unit = 5 minutes, Rating factor - 120% Total allowances = 100/3 % of normal time

Ans. 60 units

Q 19. An 8 hours work measurement study in a plant reveals the following: Units produced = 320 nos. Idle time = 15%. Performance rating = 120%. Allowances =12% of normal time. Determine the standard time per unit produced.

Ans. **1.714 minutes**

Q 20. For a certain element of work, the basic time is established to be 20 seconds. If for three observations, a time study observer records ratings of 100, 125 and 80 respectively, on a "100-normal scale", what are the observed timings?

Ans. 20 second, 16 second, 25 second

Q 21. An analyst wants to obtain a cycle time estimate that is within ± 5% of the true value. A preliminary run of 10 cycles took 50 minutes to complete and had a calculated standard deviation of 0.4 minutes. What is the coefficient of variation to be used for computing the sample size for the forthcoming time study?
Ans. Dec. 2013 (New)

Q 22. Premabai undertakes knitting of sweaters for various shops. She has several helping hands who, besides knitting also carry out cleaning, disentangling woollen thread, measuring and cutting, sewing and customer contact activities. Hema, an enthusiastic industrial engineer, did an activities sampling (work sampling) study and came up with the following data:

Activity	**No. of Observations**
Knitting	120
Cleaning	40
Disentangling	75
Measuring and Cutting	20
Sewing	20
Speaking to Customers	25
Total No. of Observations	**300**

Hema rated the help she had observed at 95 for the disentangling activity and 100 for the knitting activity. If at the end of the four-day (36 work hours) study, Hema found that the helping hand had disentangled 2.3 kg of woollen thread and knitted a two meter-length equivalent, what are the standard times for these activities?
Take total allowances at 25 per cent.

If Premabai gives the work of disentangling woollen thread to a helper for four hours, how much wool should be disentangled?

Ans.

Q 23. Sonar Gold Fields miners at 10th level have an accepted production standard of **two trolley-loads** an hour in an eight-hour working day. In addition to the mining of the gold-bearing soil, the miners have to do a few routine jobs such as cleaning, sharpening and maintaining the tools, for which they are paid a wage of Rs. 9 per hour upto a maximum of two hours per day. The base wage rate of the miners engaged in production/mining job is Rs 6.60 per hour.

If Subrato, a miner, produced 18 trolley-loads in addition to performing his routine tasks, what wages should he get at the end of the day?

Solution:
Subrato worked for 18 / 2 = 9 standard hours on the 'incentive job'.

This is equivalent to a productivity rate of:
9 std. hrs for 6 hrs. worked = 150%

The 'incentive wages' earned by Subrato are:
150 /100 x (6.60) x (6 hours) = Rs 59.40

The 'non-incentive' wages earned by Subrato are:
(9.00) x (2 hours) = Rs 18.00

The total wages to be paid to him are
Rs 59.40 + Rs 18.00 = Rs 77.40

Q 24. A work sampling study was performed on the activities of the nurses in a large private hospital. The observations are as under:

Activity	**No. of Observations**
Attending to patient	200
Consulting with doctors	50
Working in the wards	90
Doing paper work	170
Reading charts	40
Talking to other nurses	40
Changing linen on beds	60
Lunch/Tea/Rest	50
Total No. of Observations	**700**

The management of the hospital plans to eliminate paper-work by acquiring an EDP system. This, it is felt, will enable the nurses' time to be better utilised. While the nurses' salary on an average is Rs 3,000 per month (25 working days), the value of her time utilised (i.e. for more patient-care) is put at three times what their salary reflects.
There are 150 nurses in the hospital and the EDP system is going to cost Rs 50,000 a month covering the initial investment as well as operation expenses. Should the hospital go in for the EDP system?

Solution:

As per the work sampling data,

170 out of a total of 700 observations are made for the activity
'Doing Paper-work' — i.e., the latter activity occupies 170/700 fraction of a nurse's time.
This means ` 170/700 x (Rs 3,000) is being spent monthly per nurse on doing paperwork. For 150 nurses,
This amount works out to = 170/700 x (Rs 3000) x(150) = Rs 1,09,286.

Notably this expenditure exceeds the amount that would be spent on the EDP system.
Thus, if the number of nurses could be reduced proportionate to the elimination of paperwork done by them, the EDP system can be installed. This approach considers the employment of nurses as 'necessary expenditure'.

Another approach would be to look at the nurses' contribution to patient-care.
If 170/700 fraction of the time is released for additional patient-care, the contribution in this area would be equivalent to: 170/700 x 3 x Rs 3000 x (150) = Rs 3,27,758

This, again, argues in favour of installing the EDP system

Q 25. R.S. Sharma, an Industrial Engineer made random 'snap' observations of the work of four clerk-cumtypists (CT, for short) in his branch office over a period often days. The four typists were present for all the days of this observation. Clerk-cum-typists engage in various activities, one of which is typing. The observations are given in the table below.

Day	No. of Observations				No. of Typing Observations			
	CT-1	CT-2	CT-3	CT-4	CT-1	CT-2	CT-3	CT-4
1	10	10	10	10	3	2	4	1
2	15	15	15	15	8	7	3	8
3	8	8	8	8	2	4	1	4
4	18	18	18	18	5	6	9	4
5	11	11	11	11	3	4	3	3
6	9	9	9	9	4	2	3	1
7	14	14	14	14	2	5	3	6
8	13	13	13	13	3	2	5	4
9	10	10	10	10	3	5	2	4
10	9	9	9	9	4	3	3	2

(Note Overall ratings of the CTs in the 'typing' activity, as estimated by Sharma, were 80, 90, 120, 100 respectively. If Sharma found 306 pages of material typed during the ten days, what might be the standard time per page if the observations are assumed to be adequate and allowances are given as 15 per cent. (The total working time per day is 6½ hours).

Ans.

Q 26. The time study of a machinery operation recorded average cycle time of 9.0 minutes. The analyst rated the observed worker as 90% . The firm uses a 0.15 allowances fraction. Compute the standard time.

Ans. **2 Marks June 2015**

Q 27. A work sampling study was performed on the activities of the customer care executives in a service organization are as undere:

Activity	No. of observations
A1	250
A2	60
A3	100
A4	160
A5	50
A6	60
A7	50
A8	70
Total	**800**

The management of the organization plans to eliminate activity "A4" by acquiring an EDP system. This, it is felt, will enable the executives' time to be better utilized. While the executives' salary on an average is Rs 4000 per month (25 working days), the volume of their time utilized (i.e.for more customer-care) is put at three what their salary reflects. There are 200 executives in the organization and the EDP system is going to cost Rs 75000 a month covering the initial investment as wel as operation expenses. Should the organization go in for the EDP system.

Ans. **6 Marks June 2015**

Q 28. An Industrial Engineer, appointed to conduct a time- study for a job, has after observation , divided the job into 5 elements. He had noted the timing for four cycles of the job as below:

Element	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Performance Rating (%)
1	1.327	1.254	1.351	1.269	85%
2	0.983	1.854	0.882	0.956	95%
3	1.894	1.821	1.928	1.963	100%
4	2.569	2.173	2.132	2.285	120%
5	1.358	1.139	2.561	1.438	100%

(A) Are there any outliners in the data i.e. probable errors in reading or recording data which should **not be included in the analysis?**

(B) Compute the basic time for the job. Also compute the standard time. If a relaxation allowance of 13% a contingency allowance of 4% and an incentive allowance of 25% are applicable for the job. **1 + 6 = 7 Marks Dec. 2014**

Ans. Normal time 7.96 minutes, Standard time 9.313 minutes,
If 25% incentive allowance is given ,total time allowed under incentive scheme 11.641

Q 29. The work-study engineer carries out the work sampling study in a machine shop for a duration of 120 hours. The following observations were made.

Total number of observations	7000
No Working activities	1200
Ratio between manual to machine elements	3:1
Average rating factor	120%
Total number of jobs produced during study	800 units
Rest and personal allowances	17%

Compute the standard time for the job.

Ans. 10.04 minutes **6 MARKS (Dec 2015)**

Q 30 . The time study of a machinery operation recorded cycle times of 7.5, 8.5, 7.0 and 8.0 minutes. The analyst rated the observed worker as 80%. The firm uses a 0.25 allowance fraction. Compute the Average Cycle time, Nprmal time and standard time.

Ans. Standard time 8.47 minutes. 3 X 3 = 9 Marks (June-2017)

Q 31. Calculate the standard time per article produced from the following data obtained by a work sampling study.
Total no. of observations = 2597
No. of working observations = 2000
No. of units produced in 100 hours duration = 5000 numbers
Proportion of manual labour = 3/4
Proportion of machine time = 1/4
Observed rating factor = 120%
Total allowances = 15% of normal time

Ans. 1.187 Minutes **7 Marks** **Dec. 2015**

Q 32. Calculate the standard production per shift of 8 hours duration, with the following data. Observed time per unit = 5 minutes, Rating factor - 120% Total allowances = 30 % of normal time

Ans. 61.538 Minutes **6 Marks** **June 2016**

Q 33. Calculate the standard time per article produced from the following data obtained by a work sampling study.
Total no. of observations = 2600
No. of working observations = 2000
No. of units produced in 100 hours duration = 5000 numbers
Proportion of manual labour = 3/4
Proportion of machine time = 1/4
Observed rating factor = 120%
Total allowances = 15% of normal time

Ans. **10 Marks** **June 2017**

Q 34. An 8 hours work measurement study in a plant reveals the following:
Units produced = 340 nos. Idle time = 17.5%. Performance rating = 130%.
Allowances =13% of normal time. Determine the standard time per unit produced.

Ans. **8 Marks** **Dec. 2017**

4.3 JOB ALLOCATION – ASSIGNMENT TECHNIQUE

HUMAN RESOURCE PLANNING

ASSIGNMENT

Assignment is a special linear programming problem. There are many situations where the assignment of people or machines etc. May be called for. Assignment of workers to machines, clerks to various check-out counters, salesmen to different sales areas are typical examples of these. The assignment is a problem because people possess varying abilities for performing different jobs and therefore the costs of performing jobs by different people are different. Thus, in an assignment problem, the question is how the assignments should be made in order that the total cost involved is minimized.

There are four methods of solving an assignment problem and they are:

1. Complete enumeration method
2. Simplex method
3. Transportation method and
4. Hungarian method

Hungarian Method:

The following are the steps involved in the minimization of an assignment problem under this method:

Step 1: Row Operation

Locate the smallest cost element in each row of the cost table. Now subtract this smallest element from each element in that row. As a result, there shall be at least one zero in each row of this new table, called the reduced cost table.

Step 2: Column Operation

In the reduced cost table obtained, consider each column and locate the smallest element in it. Subtract the smallest value from every other entry in the column. As a consequence of this action, there would be at least one zero in each of the rows and columns of the second reduced cost table.

Step 3: Optimality

Draw the minimum no. Of horizontal and vertical lines (not the diagonal ones) that are required to cover all the zero elements. If the no. Of lines drawn is equal to 'n' (the no. Of rows/columns) the solution is optimal and proceeds to step 6. If the no. Of lines drawn is smaller than 'n' go toStep 4.

Step 4: Improved Matrix

Select the smallest uncovered (by the lines) cost element. Subtract this element from all uncovered elements including itself and add this element to each value located at the intersection of any two lines. The cost elements through which only one line passes remain unaltered.

Step 5: repeat step 3 and 4 until an optimal solution is obtained.

Step 6:

Given the optimal solution, make the job assignments as indicated by the 'zero' elements. This is done as follows:

(a) Locate a row which contains only one zero element. Assign the job corresponding

to this element to its corresponding person. Cross out the zero's if any in the column corresponding to the element, which is indicative of the fact that the particular job and person are no more available.

(b) repeat (a) for each of such rows which contain only one zero. Similarly, perform the same operation in respect of each column containing only one 'zero' element, crossing out the zero(s), if any, in the row in which the elements lies.

(c) If there is no row or column with only a single 'zero' element left, then select a row/column arbitrarily and choose one of the jobs (or persons) and make the assignment. Thus in such a case, alternative solutions exists.

Example 1

A production supervisor is considering how he should assign the four jobs that are to be performed, to four of the workers working under him. He wants to assign the jobs to. The workers such that the aggregate time to perform the jobs is the least. Based on previous experience, he has the information on the time taken by the four workers in performing these jobs, as given in table

Time Taken by Workers on Various Jobs (in minutes)

Worker	Job			
	A	B	C	D
1	45	40	51	67
2	57	42	63	55
3	49	52	48	64
4	41	45	60	55

There are four methods of solving an assignment problem:

(a) Complete enumeration method;

(b) Transportation method;

(c) Simplex method; and

(d) Hungarian assignment method.

(A)Complete Enumeration Method:

In this method, all possible assignments are listed out and the assignment involving the minimum cost (or maximum profit if the problem, is of the maximisation type) is selected.

It represents the optimal solution. in case there are more than one index assignment patterns involving the same least cost, then they all shall represent optimal solutions—the problem has multiple optima then.

S.No.	Assignment	Time	S.No.	Assignment	Time
1.	1a, 2B, 3C, 4D	190	13.	3a, 1B, 2C, 4D	207
2.	1a, 2B, 4C, 3D	211	14.	3a, 1B, 4C, 2D	204
3.	1a, 3B, 2C 4D	215	15.	3a, 2B, 4C, 1D	218
4.	1a, 3B, 4C, 2D	212	16.	3a, 2B, 1C, 4D	197

5.	1a, 4B, 2C, 3D	217	17.	3a, 4B, 1C, 2D	200
6.	1a, 4B, 3C, 2D	193	18.	3a, 4B, 2C, 1D	224
7.	2a, 1B, 3C, 4D	200	19.	4a, 1B, 2C, 3D	208
8.	2a, 1B, 4C, 3D	221	20.	4a, 1B, 3C, 2D	184*
9.	2a, 3B, 1C, 4D	215	21.	4a, 2B, 1C, 3D	198
10.	2a, 3B, 4C, 1D	236	22.	4a, 2B, 3C, 1D	198
11.	2a, 4B, 3C, 1D	207	23.	4a, 3B, 1C, 2D	199
12.	2a, 4B, 1C, 3D	217	24.	4a, 3B, 2C, 2D	223

Example 2:

Solve the assignment problem given in example 1 for optimal solution using HAM. The information is reproduced in table

Time Taken (in minutes) by 4 Workers

Worker	Job			
	A	B	C	D
1	45	40	51	67
2	57	42	63	55
3	49	52	48	64
4	41	45	60	55

The solution to this problem is given here in a step-wise manner.

Step 1

The minimum value of each row is subtracted from all elements in the row. it is shown in the reduced cost table , also called opportunity cost table, given in table

Reduced cost Table 1

Worker	Job			
	A	B	C	D
1	5	0	11	27
2	15	0	21	13
3	1	4	0	16
4	0	4	19	14

Step 2 for each column of this table, the minimum value is subtracted from all the other values.

Obviously, the columns that contain a zero would remain unaffected by this operation. Here only the fourth column values would change. **Table** shows this.

Reduced Cost Table 2

Worker	Job			
	A	B	C	D
1	5	0	11	14
2	15	0	21	0
3	1	4	0	3
4	0	4	19	1

Step 3

Draw the minimum number of lines covering all zeros. As a general rule, we should first cover those rows/columns which contain larger number of zeros. **Table 1** is required in **Table 2** and the lines are draw

Reduced Cost Table 3

Worker	Job			
	A	B	C	D
1	5	0	11	14
2	15	0	21	0
3	1	4	0	3
4	0	4	19	1

Step-4

Since the number of lines drawn is equal to (=n) , the optimal solution is obtained. The assignment are made after scanning the rows and columns for unit zeros. Assignment made are shown with squares. As shown in table 4

Reduced Cost Table 4

Worker	Job			
	A	B	C	D
1	5	0	11	14
2	15	0	21	0
3	1	4	0	3
4	0	4	19	1

Assignment are made in the following order, Rows 1,3,and 4 contain one zero each . So assign 1-B, 3-C, 4-A . Since worker 1 has been assigned job B, we cross the zero in the second column of the second rpw. After making thes assignment, only worker 2 and job B left for assignment. The final pattern of assignment is 1-B, 2-D, 3-C, and 4-A, involving a total time of 40 + 55 + 48 + 41 =184 minutes.

This is the optimal solution to the problem – the same as obtained by enumeration and transportation methods.

QUESTIONS

Q 1. Using the following cost matrix, determine (a) Optimal job assignment, and (b) The cost of assignments.

Machinist	Job				
	1	**2**	**3**	**4**	**5**
A	10	3	3	2	8
B	9	7	8	2	7
C	7	5	6	2	4
D	3	5	8	2	4
E	9	10	9	6	10

Ans.

Q 2. You are given the information about the cost of performing different jobs by different persons. The job-person marking x indicate that the individual involved cannot perform the particular job. Using this information, state (i) The optimal assignment of jobs, and (ii) The cost of such assignment.

Person	Job				
	J_1	J_2	J_3	J_4	J_5
P_1	27	18	×	20	21
P_2	31	24	21	12	17
P_3	20	17	20	×	16
P_4	22	28	20	16	27

Ans.

Q 3. Solve the following assignment problem and obtain the minimum cost at which all the jobs can be performed.

Machinist	Job (Cost in '00)				
	1	2	3	4	5
A	25	18	32	20	21
B	34	25	21	12	17
C	20	17	20	32	16
D	20	28	20	16	27

Ans .

To conclude, the problem has two optimal solutions as given below.

Solution 1		('00) Cost	Solution 2		('00) Cost
Worker	Job		Worker	Job	
A	2	18	A	2	18
B	4	12	B	4	12
C	5	16	C	5	16
D	1	20	D	3	20
Job left	3		Job left	1	
	Total	66		Total	66

Q 4. A company plans to assign 5 salesmen to 5 districts in which it operates. Estimates of sales revenue in thousands of rupees for each salesman in different districts are given the following table. In your opinion, what should be the placement of the salesmen if the objective is to maximise the expected sales revenue?

Expected Sales Data

Salesman	District				
	D_1	D_2	D_3	D_4	D_5
S_1	40	46	48	36	48
S_2	48	32	36	29	44
S_3	49	35	41	38	45
S_4	30	46	49	44	44
S_5	37	41	48	43	47

Solution: Hint

Since it is a maximisation problem, we would first subtract each of the entries in the table from the largest one, which equals 49 here. The resultant data are given in Table

Table Opportunity Loss Matrix

Salesman	District				
	D_1	D_2	D_3	D_4	D_5
S_1	9	3	1	13	1
S_2	1	17	13	20	5
S_3	0	14	8	11	4
S_4	19	3	0	5	5
S_5	12	8	1	6	2

Ans

S1-D2, S2-D5, S3-D1, S4-D3, S5-D4;

or S1-D2, S2-D1, S3-D5, S4-D3, S5-D4;

or S1-D2, S2-D5, S3-D1, S4-D4, S5-D3;

or S1-D2, S2-D1, S3-D5, S4-D4, S5-D3.

Each of these assignment patterns would lead to an expected aggregated sales equal to 231 thousand rupees.

Q 5. To stimulate interest and provide an atmosphere for intellectual discussion, the finance faculty in a management school decides to hold special seminars on four contemporary topics—leasing, portfolio management, private mutual funds, swaps and options. Such seminars should be held once per week in the afternoons.

However, scheduling these seminars (one for each topic, and not more than one seminar per afternoon) has to be done carefully so that the number of students unable to attend is kept to a minimum. A careful study indicates that the number of students who cannot attend a particular seminar on a specific day is as follows:

Days	Leasing	Portfolio Management	Private Mutual Funds	Swaps and Options
Monday	50	40	60	20
Tuesday	40	30	40	30
Wednesday	60	20	30	20
Thursday	30	30	20	30
Friday	10	20	10	30

Find an optimal schedule of the seminars. Also find out the total number of students who will be missing at least one seminar.

Ans. No. of Students Missing = 20 + 0 + 20 + 20 + 10 = 70

Row 5, Column 1;

Row 3, Column 2;

Row 4, Column 3;

Row 3, Column 4; and

Row 2, Column 5.

Accordingly, the optimal schedule is:

Monday : Swaps and Options

Tuesday : No Seminar

Wednesday: Portfolio Management

Thursday : Private Mutual Finds

Friday: Leasing

Q 6. A solicitor's firm employs typists on hourly piece-rate basis for their daily work. There are five typists and their charges and speed are different. According to an earlier understanding, only one job is given to one typist and the typist is paid for a full hour even when he works for a fraction of an hour. Find the least cost allocation for the following data:

Typist	Rate/hour (Rs.)	Number of Pages type per	Job	No. of Pages
A	5	12	P	199
B	6	14	Q	175
C	3	8	R	145
D	4	10	S	298
E	4	11	T	178

solution: Using the given information, we first obtain the cost matrix, when different jobs are performed by different typists. This is shown in Table .The elements of the matrix are obtained as follows. To illustrate, if typist A is given job P, he would require 199/12 =16hours and, hence, be paid for 17 hours @ ` 5 per hour. This results in a cost of ` 85 for this combination

Table 1 Total Cost Matrix

Typist	Job				
	P	Q	R	S	T
A	85	75	65	125	75
B	90	78	66	132	78
C	75	66	57	114	69
D	80	72	60	120	72
E	76	64	56	112	68

Ans. 399

Q 7. WELLDONE Company has taken the third floor of a multi-storeyed building for rent with a view to locate one of their zonal offices. There are five main rooms in this to be assigned to five managers. Each room has its own advantages and disadvantages.

Some have windows, some are closer to the wash rooms or to the canteen or secretarial pool. The rooms are of all different sizes and shapes. Each of the five managers were asked to rank their room preferences amongst the rooms 301, 302, 303, 304 and 305. Their preferences were recorded in a table as indicated below:

MANAGER				
M_1	M_2	M_3	M_4	M_5
302	302	303	302	301
303	304	301	305	302
304	305	304	304	304
	301	305	303	
		302		

Most of the managers did not list all the five rooms since they were not satisfied with some of these rooms and they have left these from the list. Assuming that their preferences can be quantified by numbers, find out as to which manager should be assigned to which room so that their total preference ranking is a minimum.

Ans. Thus, the optimal assignment pattern is:

Room	Manager	Ranking
301	M_5	1
302	M_1	1
303	M_3	1
304	M_2	2
305	M_4	2

Q 8. A company has four sales representatives who are to be assigned to four different sales territories. The monthly sales increase estimated for each sales representative for different sales territories (in lakhs of rupees), are shown in the following table:

Sales Representatives	Sales Territories			
	I	II	III	IV
A	200	150	170	220
B	160	120	150	140
C	190	195	190	200
D	180	175	160	190

Suggest optimal assignment and the total maximum sales increase per month.

If for certain reasons, sales representative B cannot be assigned to sales territory III, will the optimal assignment schedule be different? If so, find that schedule and the effect on total sales.

Ans.

Alternative 1			Alternative 2		
Salesman	Territory	Sales	Salesman	Territory	Sales
A	IV	220	A	IV	220
B	I	160	B	III	150
C	III	190	C	II	195
D	II	175	D	I	180
	Total	745		Total	745

Q 9. A solicitor's firm employs typists on hourly piece-rate basis for their daily work. There are four typists and their charges and speed are different. According to an earlier understanding, only one job is given to one typist and the typist is paid for a full hour even when he works for a fraction of an hour. Find the least cost allocation for the following data:

Typist	Rate/hour (Rs.)	Number of Pages type per	Job	No. of Pages
A	4	8	P	102
B	3	10	Q	135
C	5	11	R	110
D	3	9	S	85

Dec. 2013 10 Marks

Ans.

Typist	Job	Cost
A	**P**	**52**
B	**Q**	**33**
C	**R**	**40**
D	**S**	**45**
	Total	**170**

Q 10. Six men are available for different jobs. From past records the time in hours taken by different persons for different jobs are given below

Men / Job	1	2	3	4	5	6
1	2	9	2	7	9	1
2	6	8	7	6	14	1
3	4	6	5	3	8	1
4	4	2	7	3	10	1
5	5	3	9	5	12	1
6	9	8	12	13	9	1

Find out an allocation of men to different jobs which will lead to minimum operation time.

Ans. 22 Hours

Q 11. A captain of a cricket team has to allot five middle batting positions to five batsmen. The average runs scored by each batsman at these positions are as follows:

Batsmen / Batting Position	III	IV	V	VI	VII
A	40	40	35	25	50
B	42	30	16	25	27
C	50	48	40	60	50
D	20	19	20	18	25
E	58	60	59	55	53

make the assignment so that the expected total average runs scored by these batsmen are maximum.

Ans. 232

Q 12. Average time taken by an operator on a specific machine is tabulated below. The management is considering replacing one of the old machines by a new one and the estimated time for operation by each operator on the new machine is also indicated.

Operator / Machines	M_1	M_2	M_3	M_4	M_5	M_6	New
01	2	3	2	1	4	5	6
02	4	4	6	3	2	5	1
03	6	10	8	4	7	6	1
04	8	7	6	5	3	9	4
05	7	3	4	5	4	3	12
06	5	5	6	7	8	1	6

(a) Find out an allocation of operators to the old machines to achieve a minimum operation time.

(b) Reset the problem with the new machine and find out the allocation of the operators to each machine and comment on whether it is advantageous to replace an old machine to achieve a reduction in operating time only.

(c) How will the operators be reallocated to the machines after replacement?

Ans. (a) 17 Hours (b) 13 Hours (c)

Q 13. Six salesmen are to be allocated to six sales regions so that the cost of allocation of the job will be minimum. Each salesman is capable of doing the job at different cost in each region. The cost matrix is given below:

Salesmen / Region	I	II	III	IV	V	VI
A	15	35	0	25	10	45
B	40	5	45	20	15	20
C	25	60	10	65	25	10
D	25	20	35	10	25	60
E	30	70	40	5	40	50
F	10	25	30	40	50	15

(a) Find the allocation to give minimum cost what is the cost?

(b) Now suppose the above table gives earning of each salesman at each region. How can you find an allocation so that the earning will be maximum? Determine the solution with optimum earning.

(c) There are restrictions for commercial reasons that a cannot be posted to region V and E cannot be posted to region ii. Write down the cost matrix suitably after imposing the restrictions.

Ans. (a) 55 (b) 305 (c)

Q 14. Four jobs can be processed on four different machines, one job on one machine. Resulting profits vary with assignments. They are given below:

Jobs / Machines	M_1	M_2	M_3	M_4
I	42	35	28	21
II	30	25	20	15
III	30	25	20	15
IV	24	20	16	12

Find the optimum assignment of jobs to machines and the corresponding profit.

Ans. 99

Q 15. A blacksmith supervisor in his workshop is considering how he should assign the four jobs that are to be performed, to four of the workers working under him. He wants to assign the jobs to the workers such that the aggregate time to perform the jobs is the least. Based on previous experience, he has the information on the time taken by the four workers in performing these jobs, as given in table

Time Taken (in minutes) by 4 Workers

Worker	Job			
	A	B	C	D
1	46	40	51	68
2	57	42	63	55
3	49	53	48	64
4	41	45	61	55

Solve the assignment problem for optimal solution using Hungarian Method.

Ans. **8 Marks June 2018**

4.4 SCHEDULING

Scheduling: 'Scheduling' is the next important function of production planning and control after 'Routing'. It determines the starting and the completion timings for each of the operations with a view to engage every machine and operator of the system for the maximum possible time and; without imposing unnecessary burden over them. Scheduling is the determination of the time that should be inquired to perform each operation and also the time that should be required to perform the entire series as routed. Scheduling involves establishing the amount of work to be done and the time when each element of the work will start or the order of the work.

Scheduling technique is an important technique of determining the starting and the completion timings of each operation and that of the total manufacturing process so that the man and machines can be utilised to the maximum.

Scheduling depends upon a number of factors, e.g., routing, the method of production, quantity of production, transportation of raw materials, production capacity, the probable data of delivery specified by customers in their orders and the past records.

Relationship between routing and Scheduling: Both are interconnected as scheduling is difficult without routing and routing is also not effective without scheduling. Routing is a prerequisite for scheduling while time to be taken 'may form the basis of routing and that is fixed by scheduling.

Principles of Scheduling: The principles of scheduling are:

(a) The principle of optimum task size: Scheduling tends to achieve its maximum efficiency when the task sizes are small and all tasks are of the same order of magnitude.

(b) The principle of the optimum Production plan: Scheduling tends to achieve its maximum efficiency when the work is planned, so that it imposes an equal/even load on all the plant.

(c) The principle of the optimum operation sequence: Scheduling tends to achieve its maximum efficiency when the work is planned so that the work centers are normally used in the same sequence.

Project Scheduling: generally, a project consists of number of activities managed by defferent apartments or individual supervisors. it can also be said as a complex output made up of many interdependent jobs. examples are: Railway coach building, Shipbuilding etc. The scheduling methods used are:

(i) Project Evaluation and Review Technique (PERT),
(ii) Critical path method (CPM),
(iii) Graphical Evaluation and Review Technique (GERT).

We can also use Bar charts, gantt charts, milestone chart, but these are less superior to the above.

Sequencing rules for single facility: When we have a single facility, and the orders are in queue, then they are processed depending on the rules mentioned below:

(a) First in first served or first in first out (FIFS/FIFO): Here the jobs are processed as they come in. this is commonly observed queue discipline.

(b) Shortest processing time (SPT): The jobs having shortest processing time are processed first. This is just to avoid formation of queue. For example, when you go for Xeroxing a document, and other person comes for Xeroxing a book, then document is Xeroxed and then the book is taken for Xeroxing.

(c) Minimum due date (MDD): Here jobs are processed in ascending order of their available time before delivery date. By doing so, we can keep up the delivery promises. to meet the delivery promises, if necessary, overtime, sub contracting etc., may be used.

(d) Last come first served or last in first out (LCFS/LIFO): this generally happens in case of inventory stocking and using. When material piles up, the material at the top i.e., material last arrived is used first.

(e) Static slack for remaining operations (SSRO): Static slack is given by: (Due date - Remaining processing time/ number of remaining operations). Here jobs are processed in ascending order of the operations.

(f) Dynamic slack for remaining operations (DSRO): Dynamic slack is given by: (Due date - expected time of remaining operations / number of remaining operations). Here the jobs are done in ascending order of the ratio dynamic slack.

QUESTIONS

Q 1. The processing times (Tj) in hrs for the five jobs of a single machine scheduling is given.

(a) Find the optimal sequence which will minimise the mean flow time and find the mean flow time.

(b) Determine the sequence which will minimise the weighted mean flow time and also find the mean flow time

Job	1	2	3	4	5
Processing Time	30	8	10	28	16

Weight are 1, 2, 1, 2, 3

Ans. (a) Job sequence 2-3-5-4-1 and Mean flow time = 42.8 Hours,

(b) Job sequence 2-5-3-4-1 and Weight mean flow time = 37.55 Hours

4.5 QUEUING MODELS

We shall discuss in more details the various elements of a queuing system and then present mathematical results for some specific systems. The elements of a system are:

1. Arrival process:

The arrivals from the input population may be classified on different bases as follows:

(a) According to source: The source of customers for a queuing system can be infinite or finite. For example, all people of a city or state (and others) could be the potential customers at a superbazar. the number of people being very large, it can be taken to be infinite. On the other hand, there are many situations in business and industrial conditions where we cannot consider the population to be infinite — it is finite. Thus, the ten machines in a factory requiring repairs and maintenance by the maintenance crew would exemplify finite population. Removing one machine from a small, finite, population like this will have a noticeable effect on the calls expected to be made (for repairing) by the remaining machines than if there were a large number of machines, say 500.

(b) According to numbers: The customers may arrive for service individually or in groups. single arrivals are illustrated by customers visiting a beautician, students reaching at a library counter, and so on. on the other hand, families visiting restaurants, ships discharging cargo at a dock are examples of bulk, or batch, arrivals.

(c) According to line: Customers may arrive in the system at known (regular or otherwise) times, or they might arrive in a random way. The queuing models wherein customers' arrival times are known with certainty are categorized as deterministic models (insofar as this characteristic is concerned) and are easier to handle. on the other hand, a substantial majority of the queuing models are based on the premise that the customers enter the system stochastically, at random points in time.

With random arrivals, the number of customers reaching the system per unit time might be described by a probability distribution. Although the arrivals might follow any pattern, the frequently employed assumption, which adequately supports many real world situations, is that the arrivals are poisson distributed.

2. Service system:

There are two aspects of a service system—

(a) structure of the service system, and

(b) the speed of service.

(a) Structure of the service system: By structure of the service system we mean how the service facilities exist. there are several possibilities. For example, there may be

(i) A single service facility: A library counter is an example of this. the models that involve a single service facility are called single server models.

(ii) Multiple, parallel facilities with single queue:

That is, there is more than one server. the term parallel implies that each server provides the same type of facility. Booking at a service station that has several mechanics, each handling one vehicle.

(iii) Multiple, parallel facilities with multiple queues:

This type of model is different from the earlier one only in that each of the servers has a different queue. Different cash counters in an electricity office where the customers can make payment in respect of their electricity bills provide

(iv) Service facilities in a series:

In this, a customer enters the first station and gets a portion of service and then moves on to the next station, gets some service and then again moves on to the next station . . . and so on, and finally leaves the system, having received the complete service.

(b) Speed of service: In a queuing system, the speed with which service is provided can be expressed in either of two ways—as service rate and as service time. The service rate describes the number of customers serviced during a particular time period. The service time indicates the amount of time needed to service a customer. Service rates and times are reciprocals of each other and either of them is sufficient to indicate the capacity of the facility. thus, if a cashier can attend, on the average, to 10 customers in an hour, the service rate would be expressed as 10 customers/hour and service time would be equal to 6 minutes/customer, Generally, however, we consider the service time only,

If these service times are known exactly, the problem can be handled easily. But, as generally happens, if these are different and not known with certainty, we have to consider the distribution of the service times in order to analyse the queuing system. Generally, the queuing models are based on the assumption that service times are exponentially distributed about some average service time.

3. Queue structure: Another element of a queuing system is the queue structure. In the queue structure, the important thing to know is the queue discipline which means the order by which customers are picked up from the waiting line for service. There are a number of possibilities. They are:

(a) First-come-first-served: When the order of service of customers is in the order of their arrival, the queue discipline is of the first-come-first-served type. For example, with a queue at the bus stop, the people who came first will board the bus first.

(b) Last-come-first-served: Sometimes, the customers are serviced in an order reverse of the order in which they enter so that the ones who join the last are served first. For example, assume that letters to be typed, or order forms to be processed accumulate in a pile, each new addition being put on the top of them. The typist or the clerk might process these letters or orders by taking each new task from the top of the pile. thus, a just arriving task would be the next to be serviced provided that no fresh task arrives before it is picked up. similarly, the people who join an elevator last are the first ones to leave it.

(c) Service-in-random-order (SIRO): Random order of service is defined as: whenever a customer is chosen for service, the selection is made in a way that every customer in the queue is equally likely to be selected. The time of arrival of the customers is, therefore, of no consequence in such a case.

(d) Priority service: The customers in a queue might be rendered service on a priority basis. Thus, customers may be called according to some identifiable characteristic (length of job, for example) for service. Treatment of VIPs in preference to other patients in a hospital is an example in point.

Operating Characteristics of Queuing System

An analysis of a given queuing system involves a study of its different operating characteristics. This is done using queuing models. Some of the more commonly considered characteristics are discussed below:

1. Queue length—the average number of customers in the queue waiting to get service. Large queues may indicate poor server performance while small queues may imply too much server capacity.

2. System length—the average number of customers in the system, those waiting to be and those being serviced. Large values of this statistic imply congestion and possible customer dissatisfaction and a potential need for greater service capacity,

3. Waiting time in the queue—the average time that a customer has to wait in the queue to get service. Long waiting times are directly related to customer dissatisfaction and potential loss of future revenues, while very small waiting times may indicate too much service capacity.

4. Total time in the system—the average time that a customer spends in the system, from entry in the queue to completion of service. Large values of this statistic are indicative of the need to make adjustment in the capacity.

5. Server idle time—the relative frequency with which the service system is idle, Idle time is directly related to cost. However, reducing idle time may have adverse effects on the other characteristics mentioned above.

Infinite source symbols

Symbol	Represents
λ	Customer arrival rate
μ	Service rate per server
L_a	The average number of customers waiting for service
L_s	The average number of customers in the system (waiting and/or being served)
R	The average number of customers being served
P	The system utilization
W_q	The average time customers wait in line
W_s	The average time customer's spend in the system (waiting in line and service time)
1/μ	Service time
P_o	The probability of zero units in the system
P_n	The probability of n units in the system
M	The number of servers (channels)
L_{max}	The maximum expected number waiting in line

Basic relationships

There are certain basic relationships that hold for all infinite-source models. Knowledge of these can be very helpful in deriving desired performance measures, given a few key values. Here are the basic relationships:

Note: The arrival and service rates, represented by λ and μ , must be in the same units (e.g., customers per hour, customers per minute).

QUESTIONS

Q 1. Customers arrive at a bakery at an average rate of 16 per hour on weekday mornings. The arrival distribution can be described by a poisson distribution with a mean of 16. Each clerk can serve a customer in an average of three minutes; this time can be described by an exponential distribution with a mean of 3.0 minutes.

a. What are the arrival and service rates?

b. Compute the average number of customers being served at any time.

c. Suppose it has been determined that the average number of customers waiting in line is 3.2 compute the average number of customers in the system (i.e., waiting in line or being served), the average time customers wait in line, and the average time in the system.

d. Determine the system utilization for M = 1, 2, and 3 servers.

Ans.

Q 2. An airline is planning to open a satellite ticket desk in a new shopping plaza, staffed by one ticket agent. It is estimated that requests for tickets and information will average 15 per hour, and requests will have a Poisson distribution. Service time is assumed to be exponentially distributed. previous experience with similar satellite operations suggests that mean service time should average about three minutes per request.

Determine each of the following:

a. system utilization.

b. percentage of time the server (agent) will be idle.

c. The expected number of customers waiting to be served.

d. the average time customers will spend in the system.

The probability of zero customers in the system and the probability of four customers in the system.

Ans.

Q 3. Wanda's Car Wash & Cry is an automatic, five-minute operation with a single bay. One a typical Saturday morning, cars arrive at a mean rate of eight per hour, with arrivals tending to follow a poisson distribution. Find
a. the average number of cars in line.
b. the average time cars spend in line and service.

ANS.

Q 4. A departmental store has one cashier. During the rush hours, customer arrive at a rate of 20 customer per hour. The average number of customer that can be handled by the cashier is 24 per hour. Assume the conditions for use of the single channel queuing model. Find out average time a customer spends in the system.

Ans.

Q 5. As a tool service centre the arrival rate is two per hour and the service potential is three per hour. Simple queue conditions exist.

The hourly wages paid to the attendant at the service centre is Rs 1.50 per hour and the hourly cost of a machinist away from his work is Rs 4.

Calculate:

(i) The average number of machinist being served or waiting to be served at any given time.
(ii) The anerage time a machinist spends waiting for service.
(iii) The total cost of operating the system for an eight- hour day.
(iv) The cost of the system if there were two attendants working together as a team, each paid Rs 1.50 per hour and each able to service on average 2 per hour.

Ans.

Q 6. Worker come to tool store room to enquire about special tool (required by them) for accomplishing a particular project assigned to them. The average time between arrivals is 60 seconds and the arrivals are assumed to be in poisson distribution. The average service time (of the tool room attendant) is 40 seconds.

Determine:

(i) Average queue length
(ii) Average length of non empty queues,
(iii) Average number of workers in system including the worker being attended.
(iv) Mean waiting time of an arrival
(v) Average waiting time of an arrival who waits.

Ans.

Q 7: Workers come to a tool store room to enquire about special tools (required by them) for accomplishing a particular project assigned to them. The average time between the two arrivals is 60 seconds and the arrivals are assumed to be in Poisson distribution. The average service time (of the tool room attendant) is 48 seconds.

Determine:

(i) Average Queue Length
(ii) Average Length of non-empty queues
(iii) Average number of workers in system including the worker being attended

Ans. **3 X 3 = 9 Marks** **Dec. 2017**

Q 8: As a tool service centre the arrival rate is 3 per hour and the service potential is 4 per hour. Simple queue conditions exist. The hourly wages paid to the attendant at the service centre is Rs 2 per hour and the hourly cost of a machinist away from his work is Rs 5.

Calculate:

(i) The average number of machinist being served or waiting to be served at any given time.
(ii) The anerage time a machinist spends waiting for service.
(iii) The total cost of operating the system for an eight- hour day.
(iv) The cost of the system if there were two attendants working together as a team, each paid Rs 2 per hour and each able to service on average 3 per hour.

Ans. **2 X 4 = 8 Marks** **June 2018**

4.6 SIMULATION

In general terms, simulation involves developing a model of some real phenomenon and then performing experiments on the model evolved. It is a descriptive, and not optimizing technique. To simulate is to initiate. In simulation, a given system is copied and the constants associated with it are manipulated in that artificial environment to examine the behavior of the system.

Process of Simulation

Broadly there are four phases of the simulation process :
(i) Definition of the problem and statement of objectives
(ii) Construction of an appropriate model
(iii) Experimentations with the model constructed
(iv) Evaluations of the results of simulations.

The first step in problem solving of any situation is to identify and clearly define the problem and list the objective(s) that the solution is intended to achieve. This is true of simulation as well. A clear statement not only facilitates the development of an appropriate model but also provides a basis for evaluation of the simulation results. In general, simulation aims to determine how the system under consideration would behave under certain conditions. Naturally, the more specific the analyst is about what he is looking for, the greater the chances that the simulation model will be designed to accomplish that. Thus, the scope and the level of detail of the simulation should be decided upon carefully.

Monte Carlo Simulation

Although simulation can be of many types, our discussion will focus on the probabilistic simulation using the Monte Carlo method. Also called computer simulation, it can be described as a numerical technique that involves modelling a stochastic system with the objective of predicting the system's behaviour. The chance element is a very significant feature of Monte Carlo simulation and this approach can be used when the given process has a random, or chance, component.

In using the Monte Carlo method, a given problem is solved, by simulating the original data with random number generators. Basically, its use requires two things. First, as mentioned earlier, we must have a model that represents an image of the reality, of the situation. Here the model refers to the probability distribution of the variable in question. What is significant here is that the variable may not be known to explicitly follow any of the theoretical distributions like Poisson, Normal, and so on. The distribution may be obtained by direct observation or from past records.

Example , suppose that a bakery keeps a record of the sale of the number of cakes of a certain type. Information relating to 200 days' sales is,

Demand (No. of cakes)	:	5	6	7	8	9	10	11	12	Total
(No. of days)	:	4	10	16	50	62	38	12	8	200

Assuming that this is an adequate representation of the distribution of demand for the cake, we can derive the probability distribution of demand by expressing each of the frequencies in terms of proportions. This is done by dividing each one of the values by 200—the total frequency. The resultant distribution follows:

Demand (No. of cakes)	:	5	6	7	8	9	10	11	12
Probability	:	0.02	0.05	0.08	0.25	0.31	0.19	0.06	0.04

Thus, there is 0.02 or 2 per cent chance that 5 cakes would be demanded on a day, a 0.05 or 5 per cent chance that the demand would be for 6 cakes . . . and so on. This distribution would serve as the model of the situation under consideration.

Step 1 - An assignment has to be worked out so that the intervals of random numbers will correspond to the probability distribution. Here, since the probabilities have been calculated to two decimal places, which add up to 1.00, we need 100 numbers of two digits to represent each point of probability. Thus we take random numbers 00 through 99 to represent them. Now, as the probability of 5 cakes is equal to 0.02, we assign two random numbers 00-01 to this demand level; the probability of 6 cakes being equal to 0.05, the next five numbers, 02-06 would be assigned to this level. In a similar manner, each of the demand levels would be assigned appropriate intervals as given here. It may be mentioned that cumulative probabilities shown are calculated to ease the determination of the random number intervals. The cumulative probabilities column allows the assigned numbers to correspond to the same probability range for each event.

Demand (No. of cakes)	Probability	Cumulative Probability	Random Number Interval
5	0.02	0.02	00-01
6	0.05	0.07	02-06
7	0.08	0.15	07-14
8	0.25	0.40	15-39
9	0.31	0.71	40-70
10	0.19	0.90	71-89
11	0.06	0.96	90-95
12	0.04	1.00	96-99

Instead, if probabilities are calculated to three decimal places, then 3-digit random numbers would be required . . . and so on.

Step 2 - Once the random number intervals are determined, we select a tracking pattern for drawing random numbers from the random number table. We may start with any column and row of the table and read the values in any set manner—horizontally, vertically, or diagonally. Using the pattern,-we draw the random numbers and match them with the assigned events. We may decide, for example, to read every third value horizontally, starting with the fifth column and fourth row of the table of random numbers. **The random numbers, according to this pattern are 61, 74, 24, 03, 59, 16, 84, 92, 52, 07 and so on.** We draw as many random numbers as the number of days' demand is required to be simulated.

The first of the list of the numbers, 61, lies in the interval 40-70 corresponding to the demand level of 9 units. Thus, the simulated demand for the first day is 9 cakes. In a similar manner, we can obtain the demand for each of the days. For the 10-day period, we have the following demand:

Day	1	2	3	4	5	6	7	8	9	10
Random Number	61	74	24	03	59	16	84	92	52	07
Demand (cakes)	9	10	8	6	9	8	10	11	9	7

QUESTIONS

Q 1. The Tit-Fit scientific Laboratories is engaged in producing different types of high class equipment for use in science laboratories. The company has two different assembly lines to produce its most popular product 'Pressurex'. The processing time for each of the assembly lines is regarded as a random variable and is described by the following distributions.

Process Time (minutes)	Assembly A_1	Assembly A_2
10	0.10	0.20
11	0.15	0.40
12	0.40	0.20
13	0.25	0.15
14	0.10	0.05

Using the following random numbers, generate data on the process times for 15 units of the item and compute the expected process time for the product.
For the purpose, read the numbers **vertically** taking the **first two digits for the processing time on assembly A1 and the last two digits for processing time on assembly A2.**

4134	8343	3602	7505	7428
7476	1483	9445	0089	3424
4943	1915	5415	0880	9309

Solution: In the first stage, we assign random number intervals to the processing times on each of the assemblies.

TABLE 1 Random Number Coding for Process Times

Time (mts.)	Assembly A_1			Assembly A_2		
	Prob.	Cum. Prob.	RN Interval	Prob.	Cum. Prob.	RN Interval
10	0.10	0.10	00-09	0.20	0.20	00-19
11	0.15	0.25	10-24	0.40	0.60	20-59
12	0.40	0.65	25-64	0.20	0.80	60-79
13	0.25	0.90	65-89	0.15	0.95	80-94
14	0.10	1.00	90-99	0.05	1.00	95-99

TABLE 2 Simulation Worksheet

Unit	Assembly A_1		Assembly A_2		Total Time
	R. Number	Time	R. Number	Time	(mts.)
1	41	12	34	11	23
2	74	13	76	12	25
3	49	12	43	11	23
4	83	13	43	11	24
5	11	11	83	13	24
6	19	11	15	10	21
7	36	12	02	10	22
8	94	14	45	11	25
9	54	12	15	10	22
10	75	13	05	10	23
11	00	10	89	13	23
12	08	10	80	13	23
13	74	13	28	11	24
14	34	12	24	11	23
15	93	14	09	10	24

Expected Time = 349/ 15

= 23.27

Q 2. A company manufactures around 150 mopeds. The daily production varies from 146 to 154 depending upon the availability of raw materials and other working conditions.

Production per Day	Probability
146	0.04
147	0.09
148	0.12
149	0.14
150	0.11
151	0.10
152	0.20
153	0.12
154	0.08

The finished mopeds are transported in a specially arranged lorry accommodating only 150 mopeds. Using following random numbers 80, 81, 76, 75, 64, 43, 18, 26, 10, 12, 65, 68, 69, 61, 57, simulate the process to find out:

1. what will be the average number of mopeds waiting in the factory?
2. what will be the average number of empty spaces on the lorry?

Solution: **TABLE 1 Allocation of Random Numbers**

Production per Day	Probability	Cumulative Probability	Random Number Interval
146	0.04	0.04	00-03
147	0.09	0.13	04-12
148	0.12	0.25	13-24
149	0.14	0.39	25-38
150	0.11	0.50	39-49
151	0.10	0.60	50-59
152	0.20	0.80	60-79
153	0.12	0.92	80-91
154	0.08	1.00	92-99

TABLE 2 Simulation Worksheet

S. No.	Random Number	Production	No. of Scooters Waiting for Space	No. of Empty Spaces in Lorry
1	80	153	3	0
2	81	153	3	0
3	76	152	2	0
4	75	152	2	0
5	64	152	2	0
6	43	150	0	0
7	18	148	0	2
8	26	149	0	1
9	10	147	0	3
10	12	147	0	3
11	65	152	2	0
12	68	152	2	0
13	69	152	2	0
14	61	152	2	0
15	57	151	1	0
		Total	21	9

(i)Average number or scooters waiting for space in the lorry

= Total no. of scooters waiting for Space/Total number of days = 21/15 = 1.4

(ii) Average number of empty spaces in the lorry = 9/15 = 0.6

Q 3. A company manufactures 30 units per day. The sale of these items depends upon demand which has the following distribution:

Sales (Units)	Probability
27	0.10
28	0.15
29	0.20
30	0.35
31	0.15
32	0.05

The production cost and sale price of each unit are Rs. 40 and Rs. 50, respectively. Any unsold product is to be disposed off at a loss of Rs. 15 per unit. There is a penalty of Rs. 5 per unit if the demand is not met. Using the following random numbers,
Estimate the total profit/loss for the company for the next ten days:
10, 99, 65, 99, 95, 01, 79, 11, 16, 20
If the company decides to produce 29 units per day, what is the advantage or disadvantage to the company?

Solution:
As a first step, random numbers 00-99 are allocated to various possible sale values in proportion to the probabilities associated with them. **This is shown in Table 1**

Sales (Units)	Probability	Cumulative Probability	Random Number Interval
27	0.10	0.10	00-09
28	0.15	0.25	10-24
29	0.20	0.45	25-44
30	0.35	0.80	45-79
31	0.15	0.95	80-94
32	0.05	1.00	95-99

TABLE 2 Simulation Worksheet: Calculation of Profit/Loss

Q 4. Dr. strong is a dentist who schedules all her patients for 30-minutes appointments. some of the patients take more or less than 30 minutes depending on the type of dental work to be done. The following summary shows the various categories of work, their probabilities and the time actually needed to complete the work.

Category	Time Required	Probability of Category
Filling	45 Minutes	0.40
Crown	60 Minutes	0.15
Cleaning	15 Minutes	0.15
Extraction	45 Minutes	0.10
Check-up	15 Minutes	0.20

simulate the dentist's clinic for four hours and determine average waiting time for the patients as well as the idleness of the doctor. Assume that all the patients show up at the clinic at exactly their scheduled arrival time starting at 8 a.m. Use the following random numbers for handling the above problem: 40, 82, 11, 34, 25, 66, 17, 79.

Solution:
As a first step, we determine random number intervals. This is done below:

Category	Time Required	Prob.	Cum. Prob.	Random Number Interval
Filling	45 m	0.40	0.40	00-39
Crown	60 m	0.15	0.55	40-54
Cleaning	15 m	0.15	0.70	55-69
Extraction	45 m	0.10	0.80	70-79
Check-up	15 m	0.20	1.00	80-99

TABLE 1 Simulation Worksheet: Dentist's Clinic

Patient	Arrival Time	Random Number	Service Time Needed	Service		Waiting Time (Minutes)	Idle Time (Minutes)
				Begins	Ends		
1	8.00 AM	40	60	8.00 AM	9.00 AM	0	0
2	8.30 AM	82	15	9.00 AM	9.15 AM	30	0
3	9.00 AM	11	45	9.15 AM	10.00 AM	15	0
4	9.30 AM	34	45	10.00 AM	10.45 AM	30	0
5	10.00 AM	25	45	10.45 AM	11.30 AM	45	0
6	10.30 AM	66	15	11.30 AM	11.45 AM	60	0
7	11.00 AM	17	45	11.45 AM	12.30 PM	45	0
8	11.30 AM	79	45	12.30 PM	1.15 PM	60	0
					Total	285	0

From the table, we get

Doctor's idle time = nil

Average waiting time of patients = 285/8= 35.6 minutes

Q 5. The occurrence of rain in a city on a day is dependent upon whether it rained on the previous day**. If it rained on the previous day**, the rain distribution is given by:

Event	Probabilit
No rain	0.50
1 cm rain	0.25
2 cm rain	0.15
3 cm rain	0.05
4 cm rain	0.03
5 cm rain	0.02

If it did not rain the previous day, the rain distribution is given by:

Event	Probabilit
No rain	0.75
1 cm rain	0.15
2 cm rain	0.06
3 cm rain	0.04

Simulate the city's weather for 10 days and determine by simulation the total days without rain as well as the total rainfall during the period. Use the following random numbers:
67 63 39 55 29 78 70 06 78 76
for simulation. **Assume that for the first day of the simulation it had not rained the day before.**

Solution:
The random number intervals are determined in the first place as shown in Tables 1 and 2

TABLE 1 Random Number Intervals (Rained Previously)

Event	Prob.	Cum. Prob.	Random Number Interval
No rain	0.50	0.50	00-49
I cm rain	0.25	0.75	50-74
2 cm rain	0.15	0.90	75-89
3 cm rain	0.05	0.95	90-94
4 cm rain	0.03	0.98	95-97
5 cm rain	0.02	1.00	98-99

TABLE 2 Random Number Intervals (No Rain Previously)

Event	Prob.	Cum. Prob.	Random Number Interval
No rain	0.75	0.75	00-74
I cm rain	0.15	0.90	75-89
2 cm rain	0.06	0.96	90-95
3 cm rain	0.04	1.00	96-99

TABLE 3 Simulation Worksheet: Weather

Day	Random Number	Rainfall	Table Reference
1	67	No rain	Table 2
2	63	No rain	Table 2
3	39	No rain	Table 2
4	55	No rain	Table 2
5	29	No rain	Table 2
6	78	1 cm	Table 2
7	70	1 cm	Table 1
8	06	No rain	Table 1
9	78	1 cm	Table 2
10	76	2 cm	Table 1
Total		**5 cm**	

Accordingly, total days without rain = 6, and total rainfall during the period = 5 cm.

Q 6. A confectioner sells confectionery items. Past data of demand per week in hundred kilograms with frequency is given below:

Demand/Week	0	5	10	15	20	25
Frequency	2	11	8	21	5	3

Using the following sequence of random numbers, generate the demand for the next 10 weeks. Also find out the average demand per week.

Random numbers 35, 52, 13, 90, 23, 73, 34, 57, 35, 83, 94, 56, 67, 66, 60,

Ans . average weekly demand = 12

Q 7. The manager of a book store has to decide the number of copies of a particular tax law book to order. A book costs Rs 60 and is sold for Rs 80. Since some of the tax laws change year after year, any copies unsold while the edition is current must be sold for Rs 30. From past records, the distribution of demand for this book has been obtained as follows:

Demand (no of copies)	15	16	17	18	19	20	21	22
Proportion	0.05	0.08	0.20	0.45	0.10	0.07	0.03	0.02

Using the following sequence of random numbers, generate the demand for 20 time periods(years). Calculate the average profit obtainable under each of the courses of action open to the manager. What is the optimal policy? 14, 02, 93, 99, 18, 71, 37, 30, 12, 10, 88, 13, 00, 57, 69, 32, 18, 08, 92, 73

Ans.

Q 8. A small retailer has studied the weekly receipts and payments over the past 200 weeks and has developed the following set of information:

Weekly receipts (Rs)	Probability	Weekly payments (Rs)	Probability
3000	0.20	4000	0.30
5000	0.30	6000	0.40
7000	0.40	8000	0.20
12000	0.10	10000	0.10

Using the following set of random numbers, simulate the weekly pattern of receipts and payments for the 12 weeks of the next quarter, assuming further that the beginning bank balance is Rs 8000. What is the estimated balance at the end of the 12 weekly period?

What is the highest weekly balance during the quarter? What is the average weekly balance for the quarter?

Random Numbers

For Receipts 03, 91, 38, 55, 17, 46, 32, 43, 69, 72, 24, 22,

For Payments 61, 96, 30, 32, 03, 88, 48, 28, 88, 18, 71, 99,

According to the given information, the random number interval is assigned to both the receipts and the payments.

Ans.

Q 9. An automobile production line turns out about 100 cars a day, but deviations occur owing to many causes.Tthe production is more accurately described by the probability distribution given below:

Production/Day	Probability	Production/Day	Probability
95	0.03	101	0.15
96	0.05	102	0.10
97	0.07	103	0.07
98	0.10	104	0.05
99	0.15	105	0.03
100	0.20		

Finished cars are transported across the bay, at the end of each day, by ferry. If the ferry has space for only 101 cars, what will be the average number of cars waiting to be shipped, and what will be the average number of empty space on the boat?

Random No.in 15 days are 20, 63, 46, 16, 45, 41, 44, 66, 87, 26, 78, 40, 29, 92, 21,

Ans. 0.40 , 1.2

Q 10. A book store wishes to carry 'Ramayana' in stock. Demand is probabilistic and replenishment of stock takes 2 days (i.e. if an order is placed on march 1, it will be delivered at the end of the day on march 3). The probabilities of demand are given below:

Demand (daily)	0	1	2	3	4
Probability	0.05	0.10	0.30	0.45	0.10

Each time an order is placed, the store incurs an ordering cost of Rs 10 per order. The store also incurs a carrying cost of Rs 0.50 per book per day. The inventory carrying cost in calculated on the basis of stock at the end of each day.

The manager of the bookstore wishes to compare two options for his inventory decision.

A. Order 5 books when the inventory at the beginning of the day plus order outstanding is less than 8 books.

B. Order 8 books when the inventory at the beginning of the day plus order outstanding is less than 8.

Currently (beginning 1st day) the store has a stock of 8 books plus 6 books ordered two days ago and expected to arrive next day. Using Monte-Carlo simulation for 10 cycles, recommend, which option the manager, should choose.

The two digit random numbers are given 89, 34, 70, 63, 61, 81, 39, 16, 13, 73,

Ans. Option 'B' is better because it has low Inventory costs.

Q 11. After observing heavy congestion of customers over a period of time in a petrol station, Mr. Petro has decided to set up a petrol pump facility on his own in a nearby site. He has compiled statistics relating to the potential customer arrival pattern an service pattern as given below. He has also decided to evaluate the operations by using the simulation technique.

Arrivals		Service	
Inter-arrival time (minutes)	Probability	inter-arrival time (minutes)	Probability
2	0.22	4	0.28
4	0.30	6	0.40
6	0.24	8	0.22
8	0.14	10	0.10
10	0.10		

Assume:

(i) The clock starts at 8:00 hours
(ii) Only one pump is set up.
(iii) The following12 Random Numbers are to be used to depict the customer arrival pattern: 78, 26, 94, 08, 46, 63, 18, 35, 59, 12, 97 and 82.
(iv) The following 12 Random Numbers are to be used to depict the service pattern: 44, 21, 73, 96, 63, 35, 57, 31, 84, 24, 05, 37

You are required to find out the

(i) Probability of the pump being idle, and
(ii) Average time spent by a customer waiting in queue.

Ans,

Q 12. A Bakery shop sells bakery items. Past data of demand per week in hundred kilograms with frequency is given below:

Demand/Week	0	6	12	18	24	30
Frequency	1	12	19	8	6	4

Using the following sequence of random numbers, generate the demand for the next 10 weeks. Also find out the average demand per week.
Random numbers 12, 27, 18, 58, 43, 75, 31, 62, 47, 35, 53, 42, 68, 71,

Ans. **10 marks June 2017**

Q 13. A departmental store is running a snack items selling outlet. Past data of snack items' demand per week in hundred kgs with frequency is given below:

Demand/Week	0	6	12	18	24	30
Frequency	3	10	9	20	6	2

Using the following sequence of random numbers, generate the demand for the next 10 weeks. Also find out the average demand per week.

Random numbers 21, 34, 48, 97, 72, 31, 45, 56, 47, 37, 82, 44, 67, 75, 63,

Ans . average weekly demand **Dec. 2018 (8+2) Marks**

4.7 LINE BALANCING

Line balancing is arranging a production line so that there is an even flow of production from one work station to the next, i.e. so that there are no delays at any work station that will leave the next work station with idle time.

Line balancing is also defined as "the apportionment of sequential work activities into work stations in order to gain a high utilization of labour and equipment and therefore minimize idle time." Balancing may be achieved by rearrangement of the work stations or by adding machines and / or workers at some of the stations so that all operations take about the same amount of time.

Line Balancing Procedure in Assembly Layouts

Step 1 : Determine what tasks must be performed to complete one unit of a finished product and the sequence in which the tasks must be performed. Draw the precedence diagram.

Step 2 : Estimate the task time (amount of time it takes a worker to perform each task).

Step 3; Determine the cycle time (the amount of time that would elapse between products coming off the end of the assembly line if the desired hourly production were being produced.)

Step 4 : Assign each task to a worker and balance the assembly line. This process results in determining the scope of each worker's job or which tasks that he or she will perform.

Steps Involved in Combining of the Tasks into Worker's Jobs

1. starting at the beginning of the precedence diagram, combine tasks into a work station in the order of the sequence of tasks so that the combined task times approach but do not exceed the cycle time or multiples of the cycle time.

2. When tasks are combined into a workstation, the number of multiples of the cycle time is the number of workers required at the work station, all performing the same job.

Terminology used in Line Balancing

(i) Tasks : Element of work or activity
(ii) Task precedence : Indicates the sequence in which tasks must be performed. Except the beginning task, all other tasks have preceding tasks.
(iii) Task times : The amount of time required for an automatic machine or a well trained worker to perform a task.
(iv) Cycle time : The interval of time between two successive products coming off the end of a production line or assembly line.

(v) Productive time per hour : The duration (in minutes) a work station or machine is working in each-hour. The productive time per hour is lesser than the actual available time (one hour) due to lunch break, breakdown, personal time for the worker, start-ups and shutdowns.

(vi) Work station : Physical location where a particular set of tasks is performed. Workstation could be either a machine or equipment operated by a worker or an automatic machine or a machine operated by a robot.

(vii) Work centre : A physical location where two or more identical workstations are located in order to provide the needed production capacity.

(viii) Theoretical minimum number of workstations : The least number of work stations that can provide the required production

(ix) Actual number of workstations: The total number of workstations required on the entire production line, calculated as the next higher integer value of the number of workstations working.

(x) Utilisation : The percentage of time that a production line is working.

The rules of sequencing are explained in detail in the following paragraph.

1. First come-first served (FCFS) rule : Jobs are scheduled for work in the same sequence as they arrive at the facility or work centre. This juie is commonly applied in service centres such as ba'ri'ks, super bazaars and barber shops.

2. Shortest process time job (SPT) first : The job which has the shortest processing/ operation time on the machine or at the work centre is given the highest priority to be loaded as the next job for processing. This rule minimizes the in-process-inventory, however at the expense of keeping the jobs having longer processing time for a longer time in the work centre, thereby increasing the job through-put time (i.e., manufacturing cycle time).

3. Longest processing time (LPT) job first: The job with the longest processing per operation time is scheduled as the first job to be loaded on the machine among the jobs waiting in queue.

4. Least slack (LS) job first: In this rule highest priority is given to the job which has the least slack. Slack is the difference between available time and the duration of processing the job. Slack = Available time - Processing time.

5. Earliest due date (EDD) job first : This rule sequences the jobs waiting in the queue at the work centre or machine according to their due dates and the jobs are processed according to their due dates i.e., job having earliest due date is given highest priority while loading the job on the machine (or work centre). This rule does not ensure that all jobs will be completed on time i.e., within their due dates.

6. Truncated shortest processing time (TSPT) job first : This rule sequences the jobs according to SPT rule, nexcept that the jobs that have been waiting for a time period longer than a specified truncation time are given higher priority than other jobs.

7. Preferred customer order (PCO) rule : Jobs belonging to a preferred customer are given a higher priority than other jobs.

8. Random-selection : This rule is not used normally. It may be used when no other consideration is important.

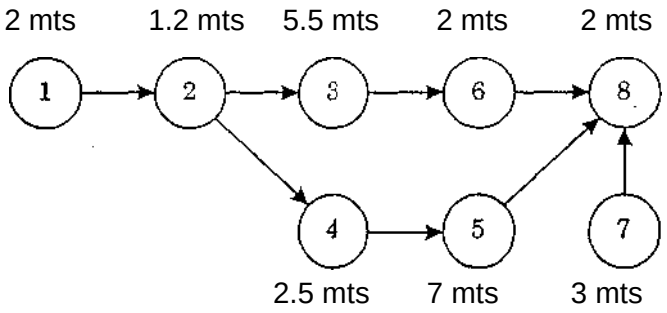
9. COVERT (cost over time) rule : This rule uses the ratio of expected delay cost (C) to the processing time (T). The job with the largest ratio is given the highest priority.

Cost over time ratio = $\frac{\text{Expected delay cost (C)}}{\text{Processing time (T)}}$

10. Least change-over cost : The sequencing of jobs is done by analyzing the total cost of making all of the machine change over between jobs.

QUESTIONS

Q 1. Balance the line for the following:



Only 4 work station are available. Find the idle time and efficiency of balancing.

Ans. 2.8 Minutes, 90%,

Q 2. In a factory, there are six jobs to perform, each of which should go through two machines A and B, in the order AB. The processing timings (in hours) for the jobs are given here. You are required to determine the sequence for performing the jobs that would minimise the total elapsed time, T. What is the value of T?

Job	Machine A	Machine B
1	7	3
2	4	8
3	2	6
4	5	6
5	9	4
6	8	1

Solution:

(a) The least of all the times given in the table is for job 6 on machine B. So, perform job 6 in the end. It is last in the sequence. Now delete this job from the given data.

(b) Of all timings now, the minimum is for job 3 on machine A. So, do the job 3 first.

(c) After deleting job 3 also, the smallest time of 3 hours is for job I on machine B. Thus, perform job 1 in the end (before job 6).

(d) Having assigned job 1, we observe that the smallest value of 4 hours is shared by job 2 on machine A and job 5 on machine B. So, perform job 2 first and job 5 in the end.

(e) Now, the only job remaining is job 4, it shall be assigned the only place left in the sequence. The resultant

sequence of jobs is, therefore, as follows:
3 2 4 5 1 6
This sequence is the optimal one. The total elapsed time, T, is obtained in Table as equal to 36 hours

TABLE Calculation of Total Elapsed Time (T)

Jo	Machine A		Machine B	
	In	Out	In	Out
3	0	2	2	8
2	2	6	8	16
4	6	11	16	22
5	11	20	22	26
1	20	27	27	30
6	27	35	35	36

As shown in this table, the first job, job 3, starts at lime 0 on the machine A and is over by time 2, when it passes to machine B to be worked on till time 8. The job 2 starts on the machine A at time 2 as the machine is free at that lime. It is completed at time 6 and has to wait for 2 hours before it is processed on machine B, starting at time 8 when this machine is free, Similarly, the various jobs are assigned to the two machines and the in and out times are obtained.

Q 3. The maintenance crew of a company is divided in two groups, C1 and C2, which cares for the maintenance of the machines. Crew C1 is responsible for replacement of parts which are worn out while crew C2 oils and resets the machines hack for operation.

The times required by crews C1 and C2 on different machines which need working on them are given as follows:

Machine	Maintenance Time (Hrs.)	
	Crew C_1	Crew C_2
M_1	8	5
M_2	6	3
M_3	10	7
M_4	11	12
M_5	10	8
M_6	14	6
M_7	4	7

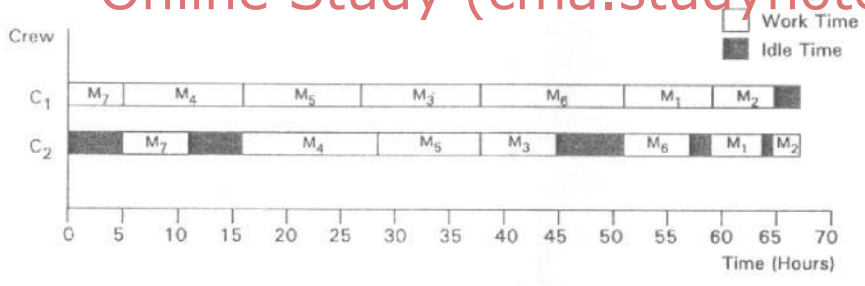
In what order should the machines be handled by crews C1 and C2 so that the total time taken is minimised?

Solution:
In accordance with the rules given earlier, the order in which machines should be handled is as follows:
M7 M4 M5 M3 M6 M1 M2

TABLE 1 Determination of Table Elapsed Time

Machine	Crew C_1		Crew C_2	
	Start	Finish	Start	Finish
M_7	0	4	4	11
M_4	4	15	15	27
M_5	15	25	27	35
M_3	25	35	35	42
M_6	35	49	49	55
M_1	49	57	57	62
M_2	57	63	63	66

The total time required by the maintenance crew to handle the seven machines is 66 hours. The working and the idle hours of the crews C1 and C2 are shown in Figure 2.8.10.



Q 4. A company plans to fill six positions. Since the positions are known to vary considerably with respect to skill and responsibility, different types of aptitude tests and interviews are required for each. While the aptitude tests are conducted by people from the clerical positions, the lob interviews are held by the personnel from the management cadre. The job interviews immediately follow the aptitude test. The time required (in minutes) by each of the positions is given here,

Position	P_1	P_2	P_3	P_4	P_5	P_6
Aptitude Test	140	180	150	200	170	100
Job Interview	70	120	110	80	100	90

If it is desired to minimise the wailing time of the management personnel, in what order the position filling be handled?

Solution:
From the given information, the optimal sequence can he determined using the algorithm. This would be P2, P3. P5, P6. P4 and P 1. The total elapsed time T is equal to 1010 minutes, as shown calculated in Table 2.8.29, while the idle time for the management personnel would he: 180 + 30 + 60 + 110 + 60 = 440 minutes.

TABLE 1 Calculation of Total Elapsed Time *T*

Position	Aptitude Test		Job Interview	
	Start	Finish	Start	Finish
P_2	0	180	180	300
P_3	180	330	330	440
P_5	330	500	500	600
P_6	500	600	600	690
P_4	600	800	800	880
P_1	800	940	940	1010

Q 5. A firm works 40 hours a week and has a capacity of overtime work to the extern of 20 hours in a week. It has received seven orders to be processed on three machines A, B, and C, in the order A, B, C to be delivered in a week's time from now. The process times (in hours) are recorded in the given table:-

Job	:	1	2	3	4	5	6	7
Machine A	:	7	8	6	6	7	8	5
Machine B	:	2	2	1	3	3	2	4
Machine C	:	6	5	4	4	2	1	5

The manager, who, in fairness, insists on performing the jobs in the sequence in which they are received, is refusing to accept an eighth order, which requires 7, 2, and 5 hours respectively on A, B and C machines, because, according to him, the eight jobs would require a total of 61 hours for processing, which exceeds the firm's capacity. Advise him.

Solution:
The processing of 8 jobs according to the manager's plan will indeed take 6t hours. It needs to be examined, however, if this plan is optimal.
To obtain the optimal sequence, first the timings of the processing of all the eight jobs would be tabulated as given in Table 2.8.30.

TABLE 1 Processing Time (Hours)

Job	Machine *A*	Machine *B*	Machine *C*
1	7	2	6
2	8	2	5
3	6	1	4
4	6	3	4
5	7	3	2
6	8	2	1
7	5	4	5
8	7	2	5

From the table,
Min Aj = 5, Max Bi = 4, and Min Ci = 1
Since Min Ai > Max Bi, the first of the conditions laid previously is satisfied. We proceed now to make the consolidation table, as shown in Table 2.8.31.

TABLE 2 Consolidation Table

Job	$G_i = A_i + B_i$	$H_i = B_i + C_i$
1	9	8
2	10	7
3	7	5
4	9	7
5	10	5
6	10	3
7	9	9
8	9	7

According to this, several optimal sequences are possible, of which one is as follows :
7, 1, 8, 4, 2, 5, 3, 6.

The total elapsed time T can be obtained as shown in the Table 2.8.32. It equals 57 hours. Thus, the jobs can be processed within the given capacity level.

TABLE 3 Determination of Total Elapsed Time, *T*

Job	Machine *A*		Machine *B*		Machine *C*	
	Start	Finish	Start	Finish	Start	Finish
7	0	5	5	9	9	14
1	5	12	12	14	14	20
8	12	19	19	21	21	26
4	19	25	25	28	28	32
2	25	33	33	35	35	40
5	33	40	40	43	43	45
3	40	46	46	47	47	51
6	46	54	54	56	56	57

Q 6. Table shows the time remaining (number of days until due date) and the work remaining (number of day's work) for 5 jobs which were assigned the letters A to e as they arrived to the shop. sequence these jobs by priority rules viz., (a) FCFS, (b) EDD, (c) LS, (d) SPT and (e) LPT.

Job	Number days until due date	Number of day's work remaining
A	8	7
B	3	4
C	7	5
D	9	2
E	6	6

Solution :

(a) FCFS (first come first served) : since the jobs are assigned letters A to E as they arrived to the shop,
the sequence according to FCFS priority rule is A B C D E

(b) EDD (early due date job first) rule : Taking into account the number of days until due date, the sequence of jobs as per EDD rules is B E C A D

(3) (6) (7) (8) (9)

(c) L.S. (Least slack) rule

also called as Minimum

slack rule. Calculation of

slack :

slack = (Number of days until due date) - (Number of days work remaining)

Job	Slack	(Days)
A	8-7	= 1
B	3-4	= (-1)
C	7-5	= 2
D	9-2	= 7
E	6-6	= 0

Sequence : B E A C D
(-1) (0) (1) (2) (7)

(d) SPT (shortest Processing Time job first) also referred as SOT (shortest Operation time job first) rule or MINPRT (Minimum Processing time job first) rule.

Sequence :

D	B	C	E	A

2 4 5 6 7

(e) LPT (Longest Processing time job first) also referred to as LOT (Longest operation time job first) rule.

Sequence : A E C B D
7 6 5 4 2

Q 7. The following jobs have to be shipped a week from now (weak has 5 working days)

Job	A	B	C	D	E	F
Number of day's work remaining	2	4	7	6	5	3

sequence the jobs according to priority established by (a) least slack rule (b) critical ratio rule.

7 Marks Dec. 2016

Solution :

(a) Calculation of slack :

Number of days until clue date is 5 days for all jobs

Job	**Slack**	**(days)**
A	5 - 2	= 3
B	5 - 4	= 1
C	5 - 7	= (-2)
D	5 - 6	- (-1)

E	5 - 5	= 0
F	5 - 3	= 2

Sequence :

C	D	E	B	F	A
-2	-1	0	1	2	3

(b)Calculation of Critical ratio = DUE DATE (DAYS)/ operation time

Critical ratio fo job A

= 5/2 = 2.5 Critical

ratio for job B = 5/4

=1.25 Critical ratio for

Job C = 5/7 =0.71

Critical ratio for job D

= 5/6 = 0.83 Critical

ratio for job E = 5/5 =

1.0 **Critical ratio for**

job F = 5/3 =1.67

Job having least critical ratio is given the first priority and so on.

Sequence :	C	D	E	B	F	A
Critical ratio :	(0.71)	(0.83)	(1.0)	(1.25)	(1.67)	(2.5)

Q 8. A company is setting an assembly line to produce 192 units per eight hour shift. The information regarding work elements in terms of times and immediate predecessors are given

Work element	Time (Sec)	Immediate predecessors
A	40	None
B	80	A
C	30	D, E, F
D	25	B
E	20	B
F	15	B
G	120	A
H	145	G
I	130	H
J	115	C, I
Total	720	

(i) What is the desired cycle time?

(ii) What is the theoretical number of stations?

(iii) Use largest work element time rule to workout a solution on a precedence diagram.
(iv) What are the efficiency and balance delay of the solution obtained?

Ans. (i) 150 (ii) 4.8=5 (iv) 96% 4%

Q 9. A company plans to fill Four positions. Since the positions are known to vary considerably with respect to skill and responsibility, different types of aptitude tests and interviews are required for each. While the aptitude tests are conducted by people from the clerical positions, the lob interviews are held by the personnel from the management cadre. The job interviews immediately follow the aptitude test. The time required (in minutes) by each of the positions is given here,

Position	P_1	P_2	P_3	P_4
Aptitude Test	100	110	140	120
Job Interview	70	90	80	110

If it is desired to minimise the wailing time of the management personnel, in what order the position filling be handled?

Ans. 290 Minutes **5 Marks Dec. 2013**

Q 10. The below Table shows the time remaining (number of days until due date) and the work remaining (number of day's work) for 5 jobs which were assigned the letters

A to E as they arrived to the shop. Sequence these jobs by priority rules viz.,

(a) FCFS, (b) EDD, (c) LS, (d) SPT and (e) LPT.

Job	Number days until due date	Number of day's work remaining
A	9	5
B	4	7
C	5	3
D	6	6
E	8	2

Ans. **2X5 = 10 Marks Dec. 2017**

Q 11. The following jobs have to be shipped a week from now (weak has 5 working days)

Job	A	B	C	D	E	F
Number of day's work remaining	4	5	8	7	6	3

sequence the jobs according to priority established by

(a) least slack rule

(b) critical ratio rule.

Ans. **4 X 2 8 Marks June. 2018**

4.8 LEAN OPERATIONS

Lean operation has its roots in the Toyota Automobile Co., of Japan, where waste was to be avoided at all costs:

(i) The waste in time caused by having to repair faulty products
(ii) The waste of investment in keeping high inventories and
(iii) The waste of having idle workers.

The elements of lean production are:

(i) To consider the organisation in terms of supply chain of value streams that extends from suppliers of raw materials, through transformation to the final customer.
(ii) To organise workers in teams and to have every one in the organisation conscious of his or her work.
(iii) To produce products of perfect quality and to have continuous quality improvement as a goal.
(iv) To organise the operation by product or cellular manufacturing, rather than using a functional or process layout.
(v) To operate the facility in a just-in-time mode.

4.9 JUST-IN-TIME (JIT)

Objectives of JIT manufacturing : The specific goal of JIT manufacturing is to provide /the right quality level at the right place. Customer demand always determines what is right. JIT tries to build only what internal and external customers want and when they want it.

The more focussed objectives of JIT are:

(i) Produce only the products (goods or services) that customers want.
(ii) Produce products only as quickly as customers want to use them.
(iii) Produce products with perfect quality.
(iv) Produce in the minimum possible lead times.
(v) Produce products with features that customers want and no others.
(vi) Produce with no waste of labour, materials or equipment, designate a purpose for every movement to leave zero idle inventory.
(vii) Produce with methods that reinforce the occupational development of workers.

Overview of JIT manufacturing

JIT manufacturing includes many activities :

(i) **Inventory reduction :** Jit is a system for reducing inventory levels at all stages of production viz. raw materials, work-in-progress and finished goods.

(ii) **Quality improvement :** JIT provides a protedure for improving quality both within the firm and outside the firm.

(iii) **Lead time reduction** : With JIT, lead time components such as set-up and move times are significantly reduced.

(iv) **Vendor control/Performance improvement** : JIT gives the buying organisation greater power in buyer-supplier relationship. The firm moves from a situation where multiple suppliers are used to a situation where only one or two suppliers are used for supplying most parts. With fewer suppliers, the buying organisation has more power because it is making larger purchases from each vendor. also, the buying organisation can now impose higher requirements on each supplier in terms of delivery and quality.

(v) **Continuous Improvement** : In the JIT system, existing problems are corrected and new problems identified in a never-ending approach to operations management.

(vi) **Total Preventive Maintenance** : JIT emphasises preventive maintenance to reduce the risk of equipment break-downs which may cause production hold ups and increase in manufacturing cycle time due to delays.

(vii) **Strategic gain :** JIT provides the firm's management with a means of developing, implementing and maintaining a sustainable competitive advantage in the market place.

4.10 TRANSPORTATION MODEL

Introduction the basic transportation problem was originally developed by F.L. Hitchcock (1941) in his study entitled "the distribution of a product from several sources to numerous locations". In 1947, t.c. Koopmans independently published a study on "optimum utilization of the transportation system".

Transportation models deals with the transportation of a product manufactured at different plants or factories (supply origins) to a number of different warehouses (demand destinations). The objective is to satisfy the destination requirements within the plants capacity constraints at the minimum transportation cost. Transportation models thus typically arise in situations involving physical movement of goods from plants to warehouses, warehouses to wholesalers, wholesalers to retailers and retailers to customers. Solution of the transportation models requires the determination of how many units should be transported from each supply origin to each demands destination in order to satisfy all the destination demands while minimizing the total associated cost of transportation.

Balanced or unbalanced Transportation Problems: a transportation problem can be balanced or unbalanced. It is said to be balanced if the total demand of all the warehouses equals the amount produced in all the factories. If in reality, capacity is greater than requirement, then a dummy warehouse may be used to create desired equality. If capacity is less than requirement, then a dummy factory may be introduced. The transportation cost in both the dummy cases is assumed to be zero. Where the number of rows and columns are not equal, it is called unbalanced transportation problem.

METHODS OF SOLVING TRANSPORTATION PROBLEM:

The following are the methods of solving transportation problem:

1. The north-west corner rule

2. Lowest cost entry method

3. Vogel's approximation method

1. North West Corner Method (NWCM):

The simplest of the procedures used to generate an initial feasible solution is NWCM. It is so called because we begin with the north west or upper left corner cell of our transportation table. Various steps of this method can be summarized as under:

Step 1:

Select the north west (upper left-hand) corner cell of the transportation table and allocate as many units as possible equal to the minimum between available supply and demand requirement, i.e., min (s1, d1).

Step 2:

Adjust the supply and demand numbers in the respective rows and columns allocation.

Step 3:

(a) If the supply for the first row is exhausted, then move down to the first cell in the second row and first column and go to step 2.

(b) If the demand for the first column is satisfied, then move horizontally to the next cell in the second column and first row and go to step 2.

Step 4:

If for any cell, supply equals demand, then the next allocation can be made in cell either in the next row or column.

Step 5:

Continue the procedure until the total available quantity is fully allocated to the cells required.

2. Least Cost Method (LCM): The allocation according to this method is very useful as it takes into consideration the lowest cost and therefore, reduces the computation as well as the amount of time necessary to arrive at the optimum solution. Various steps of this method can be summarized as under:

Step 1:

(a) select the cell with the lowest transportation cost among all the rows or columns of the transportation table.

(b) If the minimum cost is not unique, then select arbitrarily any cell with this minimum cost.

Step 2:

Allocate as many units as possible to the cell determined in step 1 and eliminate that row (column) in which either supply is exhausted or demand is satisfied.

Step 3:

Repeat steps 1 and 2 for the reduced table until the entire supply at different factories is exhausted to satisfyy the demand at different warehouses.

3. **Vogel's Approximation Method (VAM):** This method is preferred over the other two methods because the initial basic feasible solution obtained is either optimum or very close to the optimum solution. Therefore, the amount of time required to arrive at the optimum solution is greatly reduced. Various steps of this method are summarized as under:

Step 1:

Compute a penalty for each row and column in the transportation table. the penalty for a given row and column is merely the difference between the smallest cost and the next smallest cost in that particular row or column.

Step 2:

Identify the row or column with the largest penalty. In this identified row or column, choose the cell which has the smallest cost and allocate the maximum possible quantity to the lowest cost cell in that

row or column so as to exhaust either the supply at a particular source or satisfy demand at a warehouse. If a tie occurs in the penalties, select that row/column which has minimum cost. If there is a tie in the minimum cost also, select that row/column which will have maximum possible assignments. It will considerably reduce computational work.

Step 3:

Reduce the row supply or the column demand by the amount assigned to the cell.

Step 4:

If the row supply is now zero, eliminate the row, if the column demand is now zero, eliminate the column, if both the row supply and the column demand are zero, eliminate both the row and column.

Step 5:

Recompute the row and column difference for the reduced transportation table, omitting rows or columns crossed out in the preceding step.

Step 6:

Repeat the above procedure until the entire supply at factories are exhausted to satisfy demand at different warehouses.

QUESTIONS

Q 1. A Company has four factories Fl, F2, F3 and F4 manufacturing the same product. Production and raw material costs differ from factory to factory and are given in the following table. The transportation costs from the factories to sales depots S1, S2 and S3 are also given. The sales price and the total requirement at each depot as also the Product capacity at each factory is also stated. Determine the most profitable production and distribution schedule and the corresponding profit. The surplus production should be taken to yield zero profit.

Particulars	Fl	F2	F3	F4	Sales price per unit	Requirements per unit
Production Cost per unit	15	18	14	13		
Raw material Cost per unit	10	9	12	9		
Transportation cost per unit to						
S1	3	9	5	4	34	80
S2	1	7	4	5	32	120
S3	5	8	3	6	31	150
Production capacity (units)	10	150	50	100		

Ans.

Q 2. A company has three factories and four customers. It furnishes the following schedule of profit per unit on transportation of goods to customers in rupees. You are required to solve the transportation problem to maximize the profit. Determine the resultant profit.

Factory / Customer	A	B	C	D	Supply
P	40	25	22	33	100
Q	44	35	30	30	30
R	38	38	28	30	70
Demand	40	20	60	30	

Ans

Q 3. X Company is interested in taking loans from banks for its projects — P, Q, R, S, T. The rates of interest and the lending capacity differ from bank to bank. All these projects are to be completed. The relevant details are provided below. Assuming the role of a consultant, advice the Company as to how it should take the loans so that the total interest payable is least. Find out alternate initial solutions.

Source Bank	Interest rate in % for project					Max credit
	P	Q	R	S	T	(in 000s)
Private Bank	20	18	18	17	17	Any amount
Nationalized Bank	16	16	16	15	16	400
Co-operative Bank	15	15	15	13	14	250
Amount required(in 000s)	200	150	200	125	75	

Ans.

Q 4. A company has 3 factories and 3 customers. The following table gives the transportation cost per unit from the factories to the customers and also the quantities available and required.
Determine the initial transportation solution using Vogel's method

Factory	A	B	C	Availability
F1	10	11	20	10
F2	15	12	10	2
F3	17	9	16	8
Requirement	8	5	7	20

Ans. **6 Marks** **(Dec, 2009)**

Q 5. A company has three plants F1, F2 F3 from which it supplies to 4 markets: ABCE. Determine the initial transportation plan from the following table giving the plant to market shipping costs, quantities available at each plant and quantities required at each market.

Plant	Markets				
	A	B	C	D	Available are plant
F1	13	11	15	20	2
F2	17	14	12	13	6
F3	18	18	15	12	7
Requirement	3	3	4	5	15

Ans.

Q 6. The Raja Company has two factories A and B located at some distance and three regional warehouse R, S, T. The transportation manager must schedule shipments for the coming week according to the following:

Warehouse R requires 70 tones
Warehouse S requires 60 tones
Warehouse T requires 50 tones

Capacity of factory A—100 tones
Capacity of factory B—200 tones

Transportation costs are as follows:
From factory A to warehouse R — Rs. 30 per tone
From factory A to warehouse S — Rs. 10 per tone
From factory A to warehouse T — Rs.50 per tone
From factory B to warehouse R — Rs. 20 per tone
From factory B to warehouse S — Rs. 40 per tone
From factory B to warehouse T — Rs. 60 per tone
Find the least cost shipping schedule.

Ans.

Q 7. Find initial feasible Solution by North-West Corner method.

	W1	**W2**	**W3**	**W4**	**SUPPLIES**
F1	47	59	55	57	**150**
F2	44	54	52	59	**270**
F3	49	64	59	61	**370**
F4	51	63	54	60	**230**
DEMAND	**210**	**330**	**260**	**220**	

W= Warehouse
F= Factory and Cell entries are unit costs.
Ans . **Dec. 2018 6 Marks**

4.11 LINEAR PROGRAMMING TECHNIQUE

Introduction

Linear Programming is an optimization technique. It is "**a technique for specifying how to use limited resources or capacities of a business to obtain a particular objective, such as least cost, highest margin or least time, when those resources have alternate uses**".

A linear programming problem has two basic parts.

• The first part is the objective function, which describes the primary purpose of the formulation – to maximize some return (for example, profit) or to minimize some cost (for example, production cost or investment cost).

• The second part is the constraint set. It is the system of equalities and/or inequalities, which describes the restrictions (conditions or constraints) under which optimization is to be accomplished.

Definition of Linear Programming

According to Kohlar "A method of planning and operation involved in the construction of a model of a real situation containing the following elements:

(a) Variables representing the available choices, and

(b) Mathematical expressions

(i) Relating the variables to the controlling conditions, and

(ii) Reflecting the criteria to be used in measuring the benefits derivable from each of the several possible plans, and

(iii) Establishing the objective. The method may be so devised as to ensure the selection of the best of a large number of alternatives".

Limitations of Linear Programming: Although linear programming is a very useful technique for solving optimization problems, there are certain important limitations in the application of linear programming. Some of these are discussed below:

1. Firstly, the linear programming models can be applied only in those situations where the constraints and the objective function can be stated in terms of linear expressions.

2. In linear programming problems, coefficients in the objective function and the constraint equations must be completely known and they should not change during the period of study.

3. Yet another important limitation of linear programming is that it may give fractional valued answers.

4. Linear programming will fail to give a solution if management have conflicting multiple goals.

5. Linear programming problem requires that the total measure of effectiveness and total resource usage resulting from the joint performance of the activities must equal the respective sums of these quantities resulting from each activity being performed individually.

6. many real-world problems are so complex, in terms of the number of variables and relationships constrained in them, that they tax the capacity of even the largest computer.

7. Other limitations of LP includes:- Does not take into consideration the effect of time and uncertainty. - parameters appearing in the model are assumed to be constants but in real-life situations they are frequently neither known nor constants.

Formulation of an L.P problem: In formulating the linear programming problem, the basic step is to set up some mathematical model. For this purpose, the following considerations should be kept in mind:
(i) unknown variables, (ii) objectives and (iii) constraints. This can be done with the help of the following terms:

1. The objective function: An objective function is some sort of mathematical relationship between variables under consideration. Under linear programming this relationship is always linear. The construction of objective function mainly depends upon abstraction. It is a process whereby the most important features of a system are considered.

The objective function is always positive. The coefficients a1, a2 are certain constants and are known as prices associated to the variables X1, X2.

2. Constraints on the variables of the objective function: In practice, the objective function is to bee optimised under certain restraints imposed on die variables or some combination of few or all the variables occurring in the objective function. These restrictions, in most of the cases, are never exact. Had these been exact, the objective function would have been easily optimised by die use of differential calculus. The restraints should be known and expressed in terms of linear algebraic expression.

3. Feasible solution: One of the essential features of linear programming problem is optimisation of linear objective function Z. It is subject to the linear constraints on the variables of the objective function.

A set of values of X1, X2……which satisfies the constraints and the non- negativity restrictions are called Feasible solution. A feasible solution which optimises the objective function is known as Optimalsolution. Thus, a linear programming problem can be formulated in this way.

There are number of ways of finding the optimal solution for a given linear programming problems. The following three methods are mainly used for this purpose.
(1) Graphic Method
(2) Simplex Method
(3) Transportation Method.

1. Graphic method. This method is generally used for solving the problems having two or three variables. Due to this limitation of handling only two or three variables at a time this method has limited application in industrial problems. In practice, two variable cases are easy to solve by this method because three dimensional geometry becomes too complicated to find accurate results.

2. Simplex Method. This is the most powerful and popular method for solving linear programming problems. Any problem can be solved by this method which satisfies the conditions of linearity and certainty irrespective of the number of variables. It is an iterative procedure which ultimately gives the optimal solution.

3. Transportation Method. This method is used to know the minimum cost of transportation of a product from various origins to different distribution and consumption centres.

QUESTIONS

Q 1. Find the non-negative values of X_1, X_2 and X_3 that maximize the expression $Z=3X_1+5X_2+4X_3$

subject to the following restraints
$2X_1 + 3X_2 \leq 8$
$2X_2 + 5X_3 \leq 10$
$3X_1 + 2X_2 + 4X_3 \leq 15$
Ans.

Q 2. Find the maximum value of $Z = 3X_1 + 5X_2 + 4X_3$. Where $X_1, X_2, X_3 \geq 0$ subject lo the following constraints.
$2X_1 + 3X_2 \leq 18$
$2X_2 + 5X_3 \leq 18$
$3X_1 + 2X_2 + 4X_3 \leq 25$
Ans.

Q 3. Maximize $3X_1 + 2X_2$ under the following restrictions:
$X_1 \geq 0, X_2 \geq 0$

$2X_1 + X_2 \leq 40$
$X_1 + X_2 \leq 24$
$2X_1 + 3X_2 \leq 60$
Ans.

Q 4. A company manufactures two items X_1 and X_2. They are sold at a profit of Rs. 30 per unit of X_1 and Rs. 20 per unit of X_2. X_1 requires 2kgs of materials, 3 man-hours and 1 machine hour per unit. X_2 requires 1 kg of material, 2 man hours and 3 machine hours per unit.
During each production run there are 280 kgs of material available, 500 labour hours and 420 hours of machines used. How much of the two items should the company produce to maximize profits?

Ans.
Q 5. A company manufactures items X_1 and X_2 which are sold at a profit of Rs. 35 per unit of X_1 and Rs. 25 per unit of X_2
X_1 requirs 3kg of materials, 4 man-hours and 2 machine-hours per unit.
X_2 requirs 2kg of materials, 3 man-hours and 2 machine hours per unit.

During each production run, there are 350 kg of materials available, 600 man-hours and 550 machine hours for use.

Formulate under Simplex method of linear programming:

(i) The objective function and the linear constraints, and
(ii) The equations after introducing slack variables,
(iii) What are the various method of solving a linear programming problem?
(June 2009)

Ans.

Q 6. A small manufacturing firm produces two type of gadgets, A and B which are first processed in the foundry, then sent to the machine for finishing . The number of man-hours of labour required in each shop for the production of each unit of A and B and the number of man-hours the firm has available per week are as follows:

	Foundry	Machine Shop
Product A: Man-hours/units	10	5
Product B: Man-hours/units	6	4
Firm's capacity per wee (in hours)	1000	600

Construct the objective function and the corresponding equations for calculating how many units should be produced per week so that the profit is maximum. The profit on the sale of A is Rs. 30 per units as compared to B's Rs. 20 per unit. **(Dec. 2011)**

Ans.

Q 7. A company manufactures two items X_1 and X_2. They are sold at a profit of Rs. 30 per unit of X_1 and Rs. 20 per unit of X_2.
X_1 requires 2kgs of materials, 3 man-hours and 1 machine hour per unit.
X_2 requires 1 kg of material, 2 man hours and 3 machine hours per unit.
During each production run there are 280 kgs of material available, 500 labour hours and 420 hours of machines used. Please introduce the slack variables and write down the equation, including the objective function, that will determine the quantity of production of the two items to maximize profits.
4 Marks (june 2013)

Q 8. What are the three method mainly used for finding the optimal solution for a given linear programming problem ? **3 Marks (Dec- 2012)**

Q 9. A small manufacturing firm produces two type of products, A and B which are first processed in the foundry, then sent to the machine for finishing . The number of labous-hours required in each shop for the production of each unit of A and B and the number of man-hours the firm has available per week are as follows:

	Foundry	Machine Shop
Product A:Labour-hours/units	20	10
Product B: Man-hours/units	6	4
Firm's capacity per wee (in hours)	1500	900

Construct the objective function and the corresponding constraints by introducing Slack variables under Simplex method of linear programming for an optimal solution. The profit on the sale of A is Rs. 40 per units as compared to B's Rs. 30 per unit.

3 Marks Dec. 2013

Q 10. A chemical company produces two compounds a and B. the following table gives the units of ingredients c and D per kg of compounds A and B as well as minimum requirements of C and D and costs/kg of A and B. Using the simplex method, find the quantities of A and B which would give a supply of C and D at a minimum cost.

Ingredient / Compound	A	B	Minimum requirement
C	1	2	80
D	3	1	75
Cost per Kg.	4	6	

Q 11. A pension fund manager is considering investing in two shares A and B. It is estimated that:

(i) Share a will earn a dividend of 12% per annum and share B 4% per annum.

(ii) Growth in the market value in one year of share a will be 10 paise per Rs.1 invested and in B 40 paise per Rs. 1 invested.

He requires investing the minimum total sum which will give:

Dividend income of at least Rs. 600 per annum and growth in one year of at least Rs 1,000 on the initial investment.

You are required to: (i) State the mathematical formulation of the problem

(iii) Compute the minimum sum to be invested to meet the manager's objective by using the simplex method.

Q 12. A company possesses two manufacturing plants each of which can produce three products x, Y and Z from a common raw material. However, the proportions in which the products are produced are different in each plant and so are the plant's operating costs per hour. Data on production per hour costs are given below, together with current orders in hand for each product.

Plant / Product	X	Y	Z	Operating cost/ hour in Rs.
Plant A	2	4	3	9
Plant B	4	3	2	10
Order on hand	50	24	60	

You are required to use the simplex method to find the number of production hours needed to fulfill the orders on hand at minimum cost

Q 13. The products P, Q and R are being produced in a plant having profit margin as Rs 3, Rs 5 and Rs 4 respectively. The raw materials a, B and c are of scarce supply and the availability is limited to 8, 15 and 10 units respectively. Specific consumption is indicated in the table below:

	P	Q	R	Available Units
A	2	3	-	8
B	3	2	4	15
C	-	2	5	10
	3/-	5/-	4/-	

Write down the problem mathematically for maximization of profit margin.

Q 14. A Company produces the products P, Q and R from three raw materials A, B and C. One unit of product P requires 2 units of A and 3 units of B. A unit of product Q requires 2 units of B and 5 units of C and one unit of product R requires 3 units of A, 2 unit of B and 4 units of C. The Company has 8 units of material A, 10 units of B and 15 units of C available to it. Profits/unit of products P, Q and R are Rs.3, Rs.5 and Rs.4 respectively.

(a) Formulate the problem mathematically,

(b) Write the Dual problem.

STUDY NOTE -5

PRODUCTIVITY MANAGEMENT AND QUALITY MANAGEMENT

5.1 MEASUREMENT TECHNIQUES OF PRODUCTIVITY INDEX

Productivity implies development of an attitude of mind and a constant urge to find better, cheaper, quicker, easier and safe ways of doing a job manufacturing an article and providing a service. Since the beginning of the industrial era, the manufacturers or producers have been facing the problem of how to use the available resources and factors of production to the best of their ability and capacity so as to get the maximum output with the minimum cost of production. Industrial revolution, social, technological and scientific developments, changes in economic systems is the various efforts made in this direction and the process of development and changes is still on. New and new machines, methods and technology are being invented and used in the industrial field to minimise the wastage of men, materials and machines. It is all to increase the productivity.

Productivity

The term "productivity" conjures up different images and different interpretations to different people and even segments of society. According to Soloman Fabricant "Productivity" is a subject surrounded by considerable confusion.

The I.L.O. publication, "Higher Productivity in Manufacturing Industries" has defined productivity as the ratio between output of wealth and the input of resources used in the process of production. The Organisation for European Economic Co-operation (OEEC) has defined the concept of productivity as follows :

Definition
The term productivity can be defined in two ways. In simple terms, productivity is defined as a ratio between the output and input – between what is produced and what is required to produce it.

$$\textbf{Productivity} = \frac{\textbf{Output obtained}}{\textbf{inputs consumed}}$$

In a broader sense, productivity is defined as a measure of how well resources are brought together in organizations and utilized for accomplishing a set of results.

$$\textbf{Productivity} = \frac{\textbf{Performance achieved}}{\textbf{Resources consumed}} = \frac{\textbf{Effectiveness}}{\textbf{Efficiency}}$$

Kinds of Productivity

Basically productivity is measured in two ways.

Total Productivity

The ratio of all output to a composite of all inputs. If it rises it signifies a rise in output relative to inputs, greater 'efficiency' in common parlance. It is called 'total' (as distinct from 'partial') productivity because it is not merely output per unit of labour alone, or any one input alone. It is the productivity of all 'factors' (i.e., inputs) taken together.

Total Productivity = $\frac{\text{Total Outputs}}{\text{Total Inputs}}$

Partial Productivity

The ratio of Total output to the partial measure of input is called partial productivity.

Partial Productivity of Labour = $\frac{\text{Total Outputs}}{\text{Labour Hours}}$

Firm uses Rs 50,00,000 in capital and 50,000 labour hours per year produce` Rs 5,00,00,000 in product. What is the Partial Productivity of labour and partial productivity of capital ?

1. Partial Productivity of labour = Rs 5,00,00,000/50,000 = ` 1,000
2. Partial Productivity of capital = Rs 5,00,00,000/ Rs 50,00,000 = 10

QUESTIONS

Q 1. In a particular plant there are 10 workers manufacturing a single product and the output per month consisting of 25 days of that particular product is 200. How much is the monthly productivity?

Ans . 20 units

Q 2. There are two industries A and B manufacturing hose couplings. The standard time per piece is 15 minutes. The output of two small scale industries is 30 and 20 respectively per shift of 8 hours. Find the productivity of each per shift of 8 hours. What is the expected production of each per week consisting of 6 days?

Ans. 93.75% , 62.5%

Q 3. The following data is available for a machine in a manufacturing unit:

Hours worked per day	8
Working days per month	25
Number of operators	1
Standard minutes per unit of production	
Machine time	22
Operator time	8
Total time per unit	30

(i) If plant is operated at 75% efficiency, and the operator is working at 100% efficiency, what is the output per month?

(ii) If machine productivity is increased by 10% over the existing level, what will be the output per month?

(iii) If operator efficiency is reduced by 20% over the existing level, what will be the output per month**?**

Ans. (a) 300 units (b) 321 units (c) 281.25 units

Q 4. An incentive scheme allows proportionate production bonus beyond 100% performance level.

Operation :	Assembling pocket transistor radio set
Work content :	30 standard minutes per assembled set
Attended time :	8 hours
Time spent on unmeasured work :	2 hours
Number of sets assembled during the day :	15
Wage rate :	Rs. 4/- per hour

Calculate the amount of
(i) Incentive bonus and
(ii) Total payment received by an operator on a particular day during, which the following particulars apply
(iii) What is the Net labour productivity achieved by the operator during the day?

Ans. (i) 6 (ii) 38 (iii) 2.5 set per hour.

Q 5. The following data is available for a manufacturing unit:

No. of operators :	15
Daily working hours :	8
No. of days per month :	25
Std. production per month :	300 units
Std. Labour hours per unit :	8

The following information was obtained for November 2010:

Man days lost due to absenteeism :	30
Unit produced :	240
Idle Time :	276 man hours

Find the following:—
(a) Percent absenteeism
(b) Efficiency of utilization of labour
(c) Productive efficiency of labour
(d) Overall productivity of labour in terms of units produced per man per month.

Ans. (a) 8% (ii) 64% (iii) 77.3% (iv) 20 units, 16 units 8 Marks (June 2012)

Q 6. The following data is available for a machine in a manufacturing unit:

Hours worked per day	8
Working days per month	25
Number of operators	1
Standard minutes per unit of production	
Machine time	22
Operator time	8
Total time per unit	30

(iv) If plant is operated at 80% efficiency, and the operator is working at 100% efficiency, what is the output per month?

(v) If machine productivity is increased by 25% over the existing level, what will be the output per month?

(vi) If operator efficiency is reduced by 25% over the existing level, what will be the output per month**?** **2+2+2=6 Marks (June- 2013)**

Ans. (a) 320 units (b) 375 units (c) 294 units

Q 7. Compute the productivity per machine hour with the following data. Also draw your interpretation

Month	No. of machines employed	Working hours	Production Units
January	400	220	99000
February	550	180	100000
March	580	220	125000

4 Marks June 2016

Ans. 1.125, 1.010, 0.980, Interpretation: Though the total production in number of units is increasing, the productivity is declining.

Q 8. Compute the productivity per machine hour with the following data. Also draw your interpretation

Month	No. of machines employed	Working hours	Production Units
July	400	225	99000
August	500	200	100000
September	600	250	135000

5 Marks Dec. 2015

Ans. 1.1, 1, 0.9,

Q 9. Compute the productivity per machine hour with the following data. Also draw your interpretation

Month	No. of machines employed	Working hours	Production Units
March	400	225	99000
April	500	200	100000
May	600	250	135000

2 Marks June 2014

Q 10. Firm uses Rs 20,00,000 in capital and 20,000 labour hours per year produce Rs 2,00,00,000 in product. What is the Partial Productivity of labour and partial productivity of capital ? **1 Marks Dec. 2013**

Ans.

Q 11. Compute the productivity per machine hour with the following data. Also draw your interpretation

Month	No. of machines employed	Working hours	Production Units
July	390	210	95000
August	540	170	100000
September	570	230	130000

7 Marks Dec. 2016

Ans.

Q 12. An incentive scheme allows proportionate production bonus beyond 100% performance level.

Operation :	Assembling pocket transistor radio set
Work content :	40 standard minutes per assembled set
Attended time :	8 hours
Time spent on unmeasured work :	3 hours
Number of sets assembled during the day :	10
Wage rate :	Rs. 5/- per hour

Calculate the amount of

(i) Incentive bonus and

(ii) Total payment received by an operator on a particular day during, which the following particulars apply

(iii) What is the Net labour productivity achieved by the operator during the day?

Ans. **2X3= 6 Marks June 2017**

5.2 TQM BASIC TOOLS AND CERTIFICATION

What is Total Quality Management (TQM)?

A philosophy that involves everyone in an organisation in a continual effort to improve quality and achieve customer satisfaction.

Basic concepts in TQM

1. Top management commitment and support.
2. Focus on both internal and external customers.
3. Employee involvement and empowerment.
4. Continuous improvement (KAIZEN)
5. Partnership with suppliers
6. Establishing performance measures for processes.

Essentials of TQM focus

1. Customer satisfaction

2. Leadership
3. Quality policy
4. Organisation structure
5. Employee involvement
6. Quality costs
7. Supplier selection and development
8. Recognition and reward.

Underlying Principles in TQM

1. Strive for quality in all things (Total Quality)
2. The customer is the creation of quality
3. Improve the process or systems by which products are produced
4. Quality improvement is continuous, never ending activity (continuous improvement-Kaizen)
5. Worker involvement is essential
6. Ground decisions and actions on knowledge

7. Encourage team work and cooperation.

Scope of TQM

1. Are integrated organisational infrastructure

2. A set of management practices

3. A wide variety of tools and techniques.

QM is Japanese approach to quality. The term TQM refers to a quest-for quality in an ganization. TQM is a process that underlines three philosophies. One is never-ending push to improve, which is referred to as continuous improvement; the second is the involvement of every employee in the organization and the third is the goal for customer satisfaction, which means meeting or exceeding customer expectations. It often focuses on benchmarking world-class standards, product and service design and purchasing. In addition, TQM involves a number of other elements such as:

• Team approach,

• Employee empowerment

• Decisions based on facts rather than opinions,

• Knowledge of quality tools [flow charts, check sheets, histograms, pareto analysis, scatter diagrams ets.]

• Quality at the source and

• Inclusive of supplies as a part of quality improvement programme.

5.3 ISO STANDARD BASICS

Quality Certification

Many international businesses recognize the importance of quality certification. The EU, in 1987, established ISO [International Organisation for Standardisation] 9000 certification. Two of the most well known of these are ISO 9000 and ISO 14,000. ISO 9000 pertains to quality management. It concerns what an organization does to ensure that its products or services are suitable to customers expectations. ISO 14,000 concerns minimization of harmful effects to the environment caused by its operations. Both ISO 9000 and ISO 14000 are related to an organization processes rather than its products and services and they stress continual improvement.

ISO 9000 is composed of the national standard bodies of 91 countries. About 90 countries have adopted ISO 9000 as national standards. This certification is intended to promote the idea of quality at every level in the organisation.

ISO certification is an elaborate and expensive process. Any firm seeking this certification needs to document how its workers perform every function that affects quality and install mechanisms to ensure that, they follow on expected lines. ISO 9000 certification entails a complex analysis of management systems and procedures. Rather than judging the quality of a particular product, ISO 9000 evaluates the management of the entire manufacturing process, from purchasing, to design, to training. A firm that seeks this certification must fill out a report and then be certified by a team of independent auditors. With certification comes registration in an ISO directory, that firms seeking suppliers can refer to, for a list of certified companies. They are generally given preference over unregistered companies.

There are essentially five standards associated with the ISO 9000 series. The series, if we place them on a continuum, would range from design and development through procurement, production, installation and servicing. Whereas, ISO 900X3 and 9004 only establish guidelines for operation, ISO 9001, 9002 and 9003 are well-defined standards.

Quality System

9001 Model for Quality Assurance in Design, Production, Installation and Servicing. (To be used when conformance to specified requirements is to be assured by the supplier during several stages that may include design/ development, production, installation and servicing).

9002 Model for Quality Assurance in Production and Installation. (To be used when conformance to specified requirements is to be assured by the supplier during production and installation).

9003 Model for Quality Assurance in Final Inspection Test. (To be used when conformance to specified requirements is to be assured by the supplier solely at final inspection and test).

Guidelines for use

9000 Quality Management and Quality Assurance Standards - Guidelines for Selection and Use. 9004 Quality Management and Quality System Elements - Guidelines.

ISO certification is a must for doing business with any member of the EU. In addition to the benefits of accessing the EU, ISO 9000 certification and registration is particularly helpful for companies that do not currently have a quality management system, as it provides guidelines for establishing the system and making it effective. The latest version of ISO 9000 2000 forms the basis of eight quality management principles.

1. A system approach to management
2. Continual improvement
3. Actual approach to decision making
4. Mutually beneficial supplier relationships
5. Customer focus
6. Leadership
7. People involvement
8. Process approach.

STUDY NOTE -6

6.1 PROJECT MANAGEMENT

Project Definitions: Project can be defined in the following ways:

Project is an organisational unit dedicated to the allotment of a goal, the successful completion of a development product in time, within specified budget, in conformance with the pre-determined performance specifications. It is a set of finite activities that are usually prepared only once and have well designed objectives, using a combination of human and non-human resources within limits of time.

It consists of a series of non-routine, interrelated activities with a goal that must be completed with a set amount of resources and within a set time limit. It is a proposal for investment to create and/or develop certain facilities in order to increase the production of goods and/or services in a community during a certain period of time.

Network-Based Scheduling Techniques

The biggest advance in project scheduling since the development of the *Gantt Chart* in 1917 was made between 1956 and 1958. During this period, two new scheduling techniques were developed that have much in common, although they were developed independently. These techniques are the *Program Evaluation and Review Technique* (**PERT**) and the *Critical Path Method* (**CPM**). Both are based on the use of a network or graphical model to depict the work tasks being scheduled. Both were designed to schedule long-duration projects that were to be performed only once or in low volume. Computer programs are available for both PERT and CPM, which are helpful in developing timely information about large projects, particularly those that are to be updated and revised several times before completion.

Following techniques can be used to solve a problem through a network:

- Programme Evaluation and Review Technique (PERT)
- Critical Path Method (CPM)
- Resource Allocation and Multi-project Scheduling (RAMS)
- Graphical Evaluation and Review Technique (GERT)
- Multi Operation Scheduling System (MOSS)
- Critical Operating Production Allocation Control (COPAC)
- Least Cost Scheduling (LCS)
- Man Power Allocation Procedure (MAP)
- Resource Planning and Scheduling Method (RPSM)

Steps in using Network Techniques

Three major steps are involved in the use of network scheduling:

- **Planning the Project**
  - Analyse the project by determining all the individual activities, and
  - Show the planned sequence of these activities on a network.
- **Scheduling the Project**
  - Estimate how long it will take to perform each activity,
  - Perform computations to locate the critical path. This information will also provide information for scheduling, and
  - Use this information to develop a more economical and efficient schedule.
- **Monitoring the Project**
  - Use the plan and schedule to control and monitor progress, and
  - Revise and update the schedule throughout execution of the project so that the schedule represents the current plans and current status of progress.

Some of the Assumptions in PERT or CPM are Given Below

- Project activities can be identified as entities (there is a clear beginning and ending point for each activity).

- Project activity sequence relationships can be specified and networked.

- Project control should focus on critical path

- The activity times in PERT follow the Beta Distribution with the variance of the project assumed to equal the sum of the variances along the critical path.

Symbols Used in Network

1. Activity by → (arrow)

Arrow can have any size or slope. It starts from tail and ends at the head of arrow, e.g., assembly of parts, mixing of concrete, preparing budget, etc.

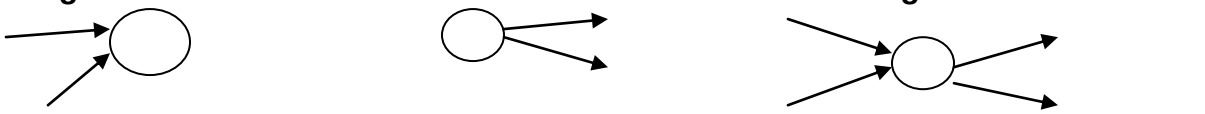
2. Dummy activity ---------> (broken arrow)

These activities consume no time. This is introduced to prevent dangling. This happens when an activity ends without being joined to end event, thus breaking continuity.

3. Event O (circle or node)

Event is represented by node. Event takes no time but it connects two or more activities. Events may be classified into three categories: merge event, burst event, merge and burst event, e.g. design completed, pipe line laid, started issue, tested.

Merge Event **Burst Event** **Merge and Burst Event**



Terminologies used in networks include the following:

Network
It is the graphic representations of projects operations composed of activities and events to achieve objective of project, showing planning sequence.

Event (node)
It is a recognisable as particular instant of time and does not consume time or source. It is generally represented on network by circle, rectangle or hexagon.

Activity
It is a task or item that consumes time, money, effort, etc. It lies between preceding and succeeding events.

Float or Slack
The term slack time refers to an ***event-controlled network*** and ***float*** time refers to the ***activity network***. But, generally float and slack are used interchangeably. ***Float or Slack*** is defined, as amount of time and activity can be delayed without effecting the duration of project. On a critical path, the float is zero. So, float gives an indication criticalness of an activity. An activity with little float, stands a good chance of delaying project and should be carefully monitored.

ES (a) = Early start time of activity 'a'
EF (a) = Early finish time of activity 'a'
LS (a) = Late start time of activity 'a'
LF (a) = Late finish time of activity 'a'
t = duration of the activity considered
TF = total float
FF = Free float
IF = Independent float

Total duration
Total duration of time available for any job is the difference between its earliest start time and latest finish time. If activity 1-2 is considered, then Maximum Time Available = LF (1-2) - ES (1-2)

Earliest start time (ES)
This is the earliest occurrence time for the event from which the activity arrow originates.

Earliest finish time (EF)
This is the earliest occurrence time for the event from which activity arrow originates plus duration for the activity EF (a) = ES (a) +t
Latest start time (LS)
This is the latest occurrence time for the node at which activity arrow terminates minus the duration for the activity LS = LF-t
Latest finish time (LF)
This is the latest occurrence time for the node at which activity arrow terminates.

Precedence Relationships Some activities cannot be performed until other activities have been completed. This type of requirement establishes a technical *precedence relationship*. There may sometimes be options as to the way activities may be performed, but management's prerogatives or differences in costs lead to a particular planned sequence of activities. Other activities may be performed independently. Task independence and precedence relationships should be incorporated into the job plan and indicated on the project network.

Networking Conventions: AON and AOA
A network is a graph using circles and arrows to represent the planned relationships among the activities required to complete a project. Either of the two conventions can be used to develop a network. One uses circles to represent the project activities, with arrows linking them together to show the sequence in which they are to be performed. This is called the *activity-on-node* (AON) convention, or Precedence notation.

An alternative is to show the activities as arrows and use circles to connect predecessor and successor activities. This method is called the *activity-on-arrow* (AOA) *convention*. With this convention, the circles or nodes represent events, which are points in time at which activities begin or end. An event consumes no resources, whereas an activity consumes time and other resources.
Statistical Method Of Deriving: Single Time Estimate
Ability to measure uncertainty in estimating

a = Optimistic Time
b= Pessimistic Time
m = Most Likely Time

Single Time Estimate (Expected Time) te = $\frac{(a+4m+b)}{6}$

Total Float
Amount of time by which the completion of an activity could be delayed beyond the earliest completion time without affecting the overall project duration time. It is measured by the maximum time of the difference between maximum time available to perform activity and activity duration time or the difference between latest start time and earliest start time.

Free Float

Time by which the completion of an event can be delayed beyond the earliest finish time without affecting the earliest start of a subsequent (succeeding) activity is based on the possibility that all events occur at their earliest times, i.e., all activities start as early as possible.

Free float for an activity is the difference between its earliest finish time and the earliest start time for its successor activity. It is that portion of the total float within which an activity can be manipulated without affecting the floats of subsequent activity. So, for all activities, the free float can take the values from 'Total Float' to 'Zero' but cannot exceed Total Float. Free float is useful for rescheduling the activities with minimum disruption of earlier plans.

FF (I-J) = (Earliest time for event 'J'-Earliest time for event 'I') - Activity time for (I-J)

FS (a) = Minimum of ES times of all immediate successors of activity 'a'- EF (a)

FF = ES (Succeeding) - EF (Activity)

FF = Total Float - Slack at Head Event

Free Float (FF) = (EF - ES) - t

Independent Float

The amount of time by which the start of an activity can be delayed without effecting the earliest start time of any immediately following activities, assuming that the preceding activity has finished at its latest finish time.

It is the portion of the total float, which an activity may be delayed for start without affecting floats of preceding activities.

CRITICAL PATH

A critical path is a chain of sequential activities beginning with the project start and ending with its completion. Several or many path may exist through the network. Work may proceed on many independent path concurrently, but, of course, work may proceed on an activity only after all the necessary predecessor activities in its path have been completed. All activities, hence all paths, must be completed before the project is finished.

The path through the network that has the longest expected completion time and is expected to determine the completion date of the project is called the critical path.

Often, activities that are not on the critical path can be delayed without causing a delay in the completion of the project. On the other hand, activities on the critical path, if delayed, cause delay in the entire project. In other words, there is no float along the critical path.

Probability of Completion Time

We assume a normal distribution table (see Appendix) for calculating probability. For this distribution Z-value tables are available. In a normal distribution curve the chances of the project being completed within the mean time is 50 per cent. This is obtained by dividing the area to the left of mean by total areas.

6.2 Gantt chart

Gantt chart is a graphical representation of a series of activities drawn to a time scale. Horizontal axis (X-axis) represents time and vertical axis (Y-axis) shows the activities to be performed. The Gantt chart shows activities to specific jobs at individual/work centers by horizontal bars. Also known as a 'bar chart' because of its graphic presentation of the information, the position and the length of the horizontal bar indicate the start and completion date of the activity.

Strengths of Gantt Charts

Gantt charts are preferred for various reasons, which are as follows:

· Very simple to understand by everyone e.g. foreman, engineers, managers, and top management.

· Provide useful information in a format that is simple to develop and interpret.

· It is a good tool for planning as well as monitoring the progress of the work. It helps schedulers to evaluate the progress of a project at various levels.

· Helps in loading the work center in relation to the available capacity.

· It provides the user with a quick, visual indication of the actual status of each order and its anticipated or planned status.

· The scheduler could easily incorporate changes in timing, machine loads, and current status.

· Some common changes make Gantt charts fairly flexible to apply. It indicates the need for reassessing the resources incase the load at one work station becomes too much. Workforce could be temporarily adjusted to meet the high demand of the heavily loaded workstation by shifting the manpower from a relatively less loaded work center. Even multi-purpose equipments are shifted from less loaded work centers to heavily loaded work centers.

· Gantt charts suit the requirements of a wide range of media from ruled paper to mechanical devices and computer systems.

Limitations

· It does not convey the variability of the task duration, equipment performance (including breakdowns), and
human potential, any one of which could influence the accuracy of loading the work centers.

· It does not clearly indicate the details regarding progress of activities.

· It does not give a clear indication of the interrelationship between separate activities.

· The chart is static and has to be updated periodically to account for new job arrivals and revised time estimates for existing jobs.

6.3 PERT & CPM

Differences between PERT & CPM

PERT	CPM
1. It is a technique for planning scheduling & controlling of projects whose activities are subject to uncertainty in the performance time. Hence it is a probabilistic model.	1. It is a technique for planning scheduling & controlling of projects whose activities not subjected to any uncertainty and the performance times are fixed. Hence it is a deterministic model.
2. It is an Event oriented system	2. It is an Activity oriented system
3. Basically does not differentiate critical and noncritical activities	3. Differentiates clearly the critical activities from the other activities.
4. Used in projects where resources (men, materials, money) are always available when required	4. Used in projects where overall costs is of primarily important. Therefore better utilized resources
5. Suitable for Research and Development projects where times cannot be predicted.	5. Suitable for civil constructions.

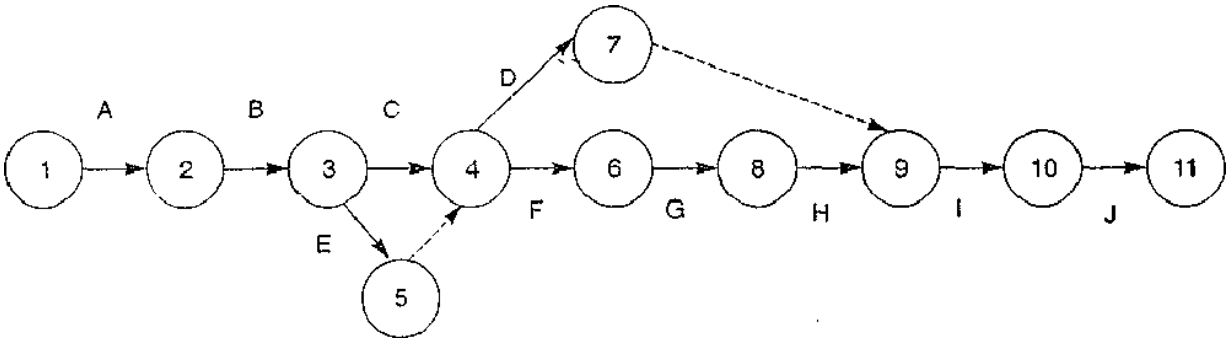
Questions

Q 1. Draw the network diagram for the activities of a maintenance job of a part of refinery

Table: Refinery Date

Activity	***Description of Activity***	***Predecessor Activity***
A	Dismantle the pipe line.	None
B	Disassemble other fittings.	A
C	Remove valves and check them.	B
D	Clean the valves and check them.	C,E
E	Clean the pipe lines and others.	B
F	Replace the defective items.	C, E
G	Layout of the assembly lines.	F
H	Assemble the valves.	G
I	Do the final connections.	H, D
J	Test the fittings.	I

Solution:

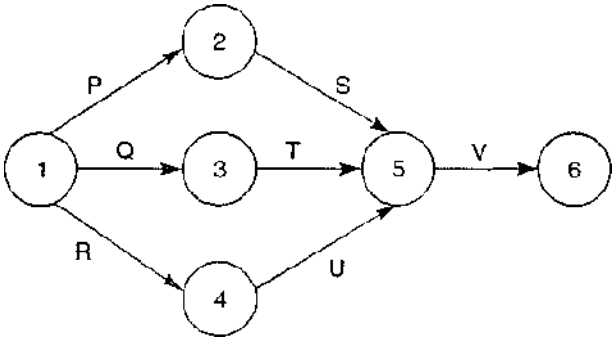


Q 2. A project consists of seven activities. Activities P, Q, R run simultaneously. The relationships among the various activities is as follows:

Activity	Immediate Successor
P	S
Q	T
R	U

Activity "V is the last operation of the project and it is also immediate successor to S,T and U. Draw the network of the project.

Solution:



Q 3. Draw the network of the project with the following situations:

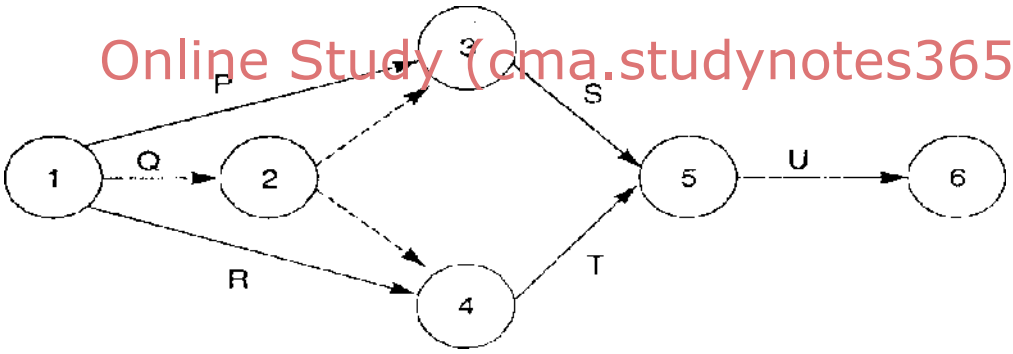
P is the prerequisite for S

Q is the prerequisite for S and T

R is the prerequisite for T

S and T are the prerequisite for U

Solution:



Q 4. A project consists of five activities. Activities P and Q run simultaneously. The relationships among the various activities is as follows:

Activity	Immediate Successor
P	R
Q	S

Activity T is the last operation of the project and it is also immediate successor to R and S. Draw the network of the project.

2 Marks June 2014, 4 Marks June 2016

Q 5. A project consist of seven activities. Draw the network diagram of this project with the following situations:

Q is the prerequisite for T

R is the prerequisite for T and U

S is the prerequisite for U

T and U are the prerequisite for V

Activity W is the last activity and is the immediate successor to activity v.

6 Marks June 2017

Q 6. A project consists of eleven activities A, B, C, D, E, F, G. H, I, J and K.

The relationships among the various activities is as follows:

Activity	Preceding Activity
A	-
B	A
C	A
D	B
E	C
F	D,E
G	F
H	F
I	G
J	I,H
K	J

Draw the network diagram. **6 Marks June 2017**

Q 7. Project with the following data is to be implemented. Draw the network and find the critical path.

Activity	***Predecessor***	***Duration (days)***	***Cost (` Day)***
A	-	2	50
B	-	4	50
C	A,B	1	40
D	B	2	100
E	A,B	3	100
F	E	2	60

(1) What is the minimum duration of the project?
(2) Draw a Gantt chart for early start schedule.
(3) Determine the peak requirement money and day on which it occurs above schedule.

Q 8. Draw the network using AON system and find Critical Path for Computer Design Project. And calculate ES, EF,LS,LF, Total slack or float

Table: Activity Relationship

Activity	***Designation***	***Immediate Predecessors***	***Time in Weeks***
Design	A	—	21
Built Prototype	B	A	5
Evaluate	C	A	7
Test Prototype	D	B	2
Write Equipment Report	E	C,D	5
Write Method Report	F	C,D	8
Write Final Report	G	E,F	2

Q 9. A project has the following time schedule

Activity	1-2	1-3	1-4	2-5	3-6	3-7	4-6	5-8	6-9	7-8	8-9
Time											
(months)	2	2	1	4	8	5	3	1	5	4	3

Construct a PERT network and compute

- Critical path and its duration
- Total float for each activity

Solution:

Steps:

1. Moving forward, find EF times (choosing the Maximum at activity intersection)
2. Maximum EF = LF = Critical Path Time.
3. Return path find LF (Choosing the Minimum at activity intersection)
4. Note LF, EF from network (except activity intersections)

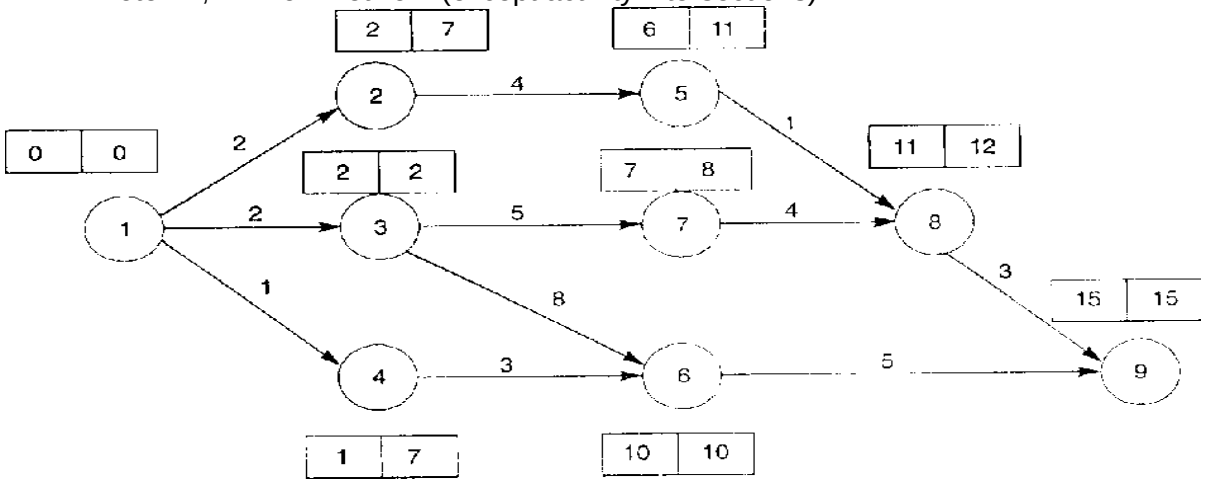


Table: Activity Relationship

Activity	*Duration*	*ES*	*EF*	*LS*	*LF*	*TF*
1 -2	2	0	2	5	7	5
1 -3	2	0	2	0	2	0
1 -4	1	0	1	6	7	6
2-5	4	2	6	7	11	5
3-6	8	2	10	2	10	0
3-7	5	2	7	3	8	1
4-6	3	1	4	5	10	6
5-8	1	6	7	11	12	5
6-9	5	10	15	10	15	0
7-8	4	7	11	8	12	1
8-9	3	11	14	12	15	1

Q 10. Considering a small maintenance project, as given below, plan it with the help of CPM.

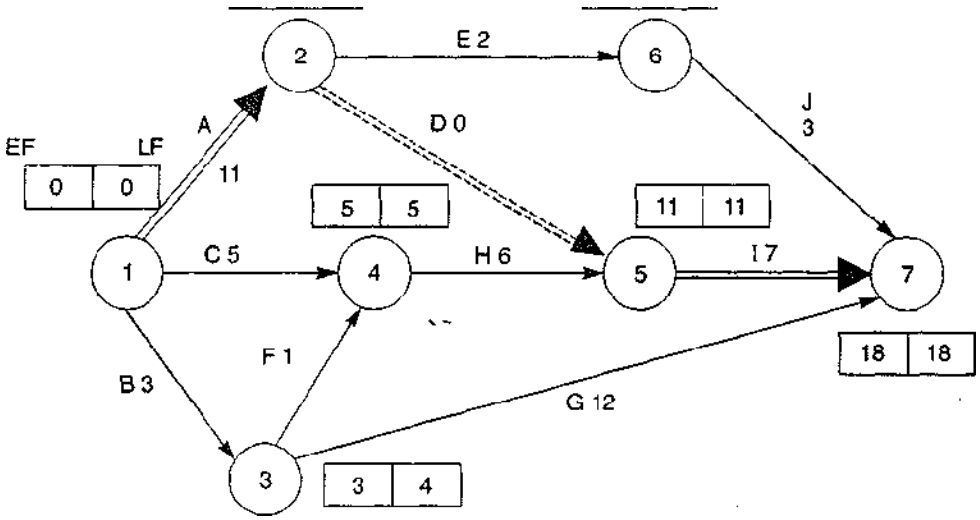
Table: Activity Relationship

Activity	*Duration*	*Predecessor*
A	11	Nil
B	3	Nil
C	5	Nil
D	0	A
E	2	A
F	1	B
G	12	B
H	6	C,F
I	7	D,H
J	3	E

Compute the following for each job:

Early start time (ES), late start time (LS), early finish time (EF), late finish time (LF), Total Float (TF), Free float (FF), minimum total duration of the project,

Solution: Network representing the given project:

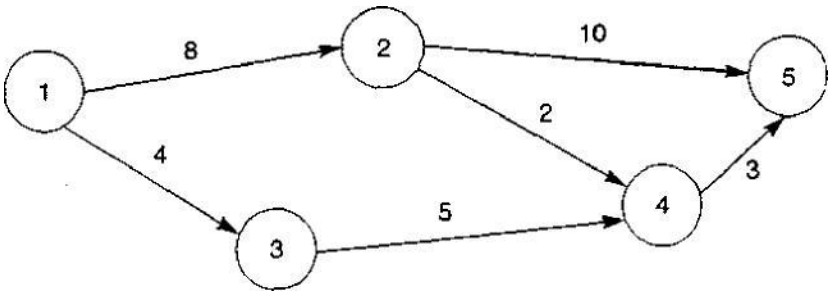


The ES, EF, LS, LF, TS, FS have been computed as discuss earlier and entered in the below.

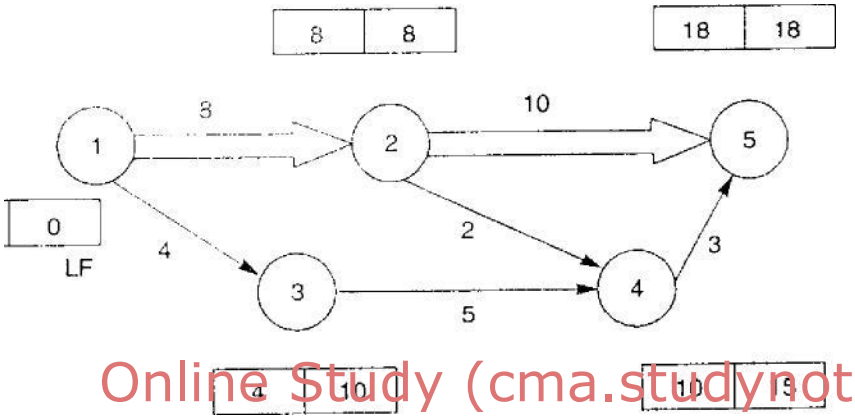
Table: Activity Relationship

Activity	*Duration*	*ES*	*EF*	*LS*	*LF*	*TS*	*Slack at Head*	*FS*
A	11	0	11	0	11	0	0	-
B	3	0	3	1	L 4	1	1	-
C	5	0	5	0	5	0	0	-
D	0	11	11	11	11	0	0	-
E	2	11	13	13	15	2	2	-
F	1	3	4	4	5	1	0	1
G	12	3	15	6	18	3	0	3
H	6	5	11	5	11	0	0	-
I	7	11	18	11	18	0	0	-
J	3	13	16	15	18	2	0	2

Q 11. For given network find Total Float (TF), Free Float (FF) and Independent Float (IF)



Solution:



Activity	*T*	*ES*	*EF (1+2)*	*LS (5-1)*	*LF*	*TF (4-2) (5-3)*	*Slack at head event*	*FF (6-7)*	*Slack at tail event*	*IF (8-9)*
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1 -2	8	0	8	0	8	0	0	0	0	0
1 -3	4	0	4	6	10	6	6	0	0	0
2-4	2	8	10	13	15	5	5	0	0	0
2-5	10	8	18	8	18	0	0	0	0	0
3-4	5	4	9	10	15	6	5	1	6	-5 (taken as 0)
4-5	3	10	13	15	18	5	0	5	5	0

Total Float = 0 on the Critical Path, which is 1 - 2 -5

Q 12. Draw PERT Network

- Find expected time and variance for each activity
- Probability of completing project in 32 days.
- Total project duratio

Table: Activity Relationship

Activity	***Estimated Time***		
	T_O	T_M	Tp
1 -2	6	9	18
1 -3	5	8	17
2-4	4	7	22
3-4	4	7	16
4-5	4	10	22
2-5	4	7	10
3-5	2	5	8

Q 13. Using the three time estimates of the activities draw the AON network for Computer Design Project and find probability of completing project in 35 weeks.

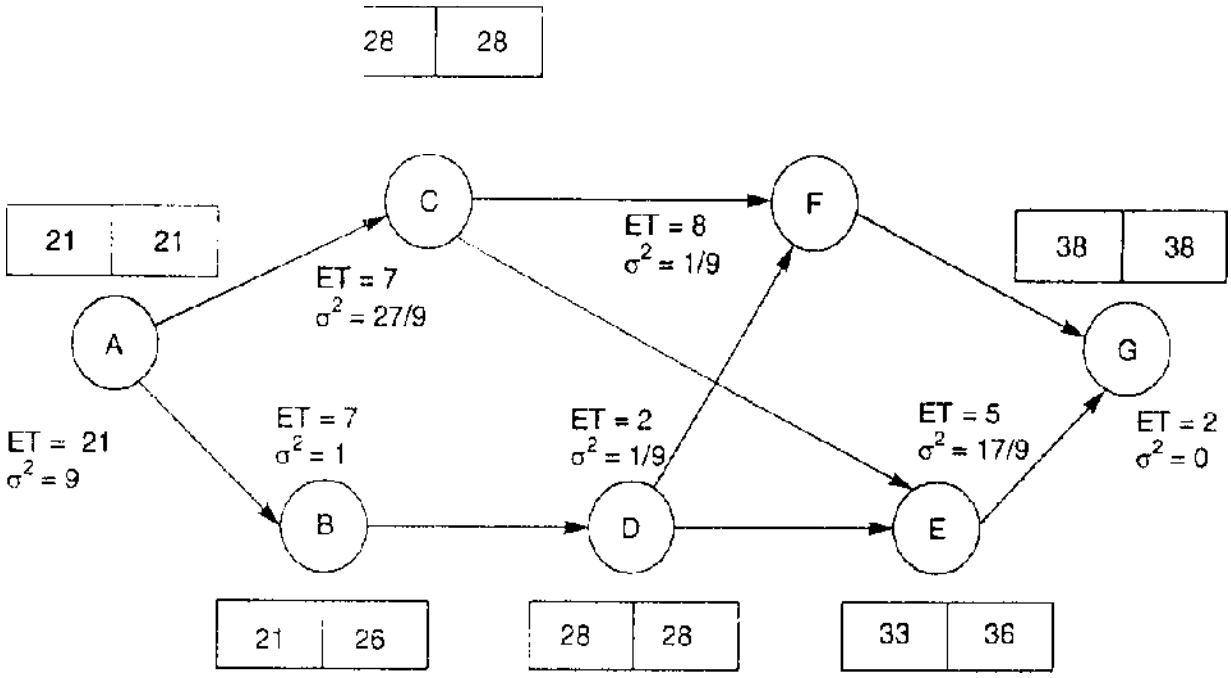
Table: Activity Relationship

Activity	***Designation***	***Immediate Predecessors***	***Time Estimates***		
			a	*b*	*C*
Design	A	—	10	22	28
Built Prototype	B	A	4	4	10
Evaluate Equipment	C	A	4	6	14
Test Prototype	D	B	1	2	3
Write equipment report	E	C,D	1	5	9
Write method report	F	C,D	7	8	9
Write final report	G	E,F	2	2	2

Soluation

Table: Activity Relationship

Designation	***Time Estimates***			***Expected Time***	***Activity Variances***
	A	***M***	***b***	***(a+4m+b)/6***	
A	10	22	28	21	9
B	4	4	10	5	1
C	4	6	14	7	7
D	1	2	3	2	1/9
E	1	5	9	5	7
F	7	8	9	8	1/9
G	2	2	2	2	0



where

a = Optimistic path m = Most likely time

b = Pessimistic time

te = Expected time = (a + 4m + b)/6

Variances = $\sum \sigma^2 = \sum(\frac{b-a}{6})^2$

The project network was created in the same way as done previously with the only difference that the activity times are weighted averages. We determine critical path as before taking these values as if they were single numbers. The difference between single time estimate and three time estimates (optimistic, most likely, pessimistic) is in computing probabilities for completion.

There are two critical paths throughout the network. The first critical path includes activities A, C, F, G, the second path includes A, B, D, F, G. Only activity E is not on critical path. Using conservative approach, we choose the largest total variance which needs maximum attention. So, variance is associated with activities A, C, F, and G.

For Critical Path $\sum \sigma^2$ = 9 + 2 7/9 + 1/9 + 0 = 11.89

Probability of completing the project in 35 weeks.

Expected Completion Time (T_E) = 38 weeks

D = Actual Completion Time = 35 weeks

$\sum \sigma^2$= variance = 11.89

Z = (D - Te)/ $(\sum \sigma^2 \, critical \, path)^{1/2}$ = (35-38)/ $(11.89)^{1/2}$ = —0.87

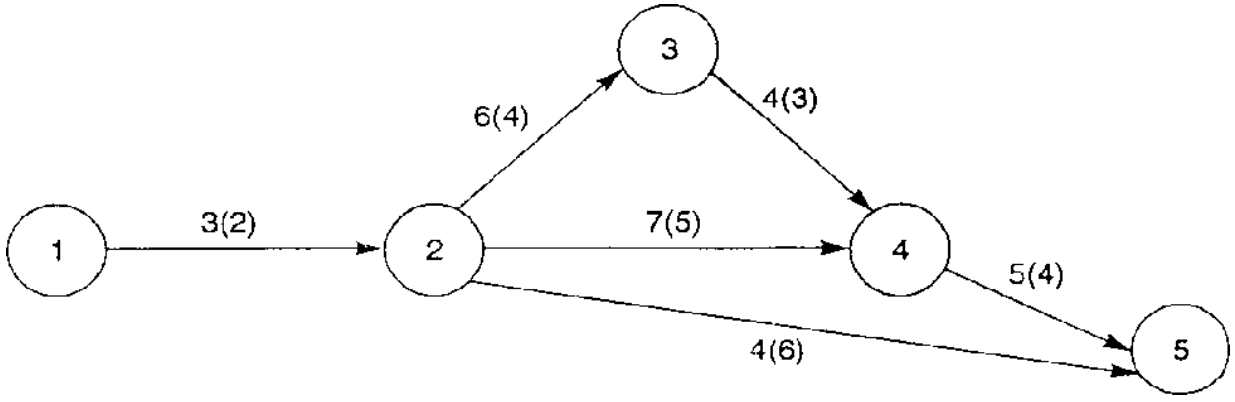
P (D<35) = P (Z < -0.87) = P (Z > - 0.87) since symmetric

= 0.5 – P (0 < Z < - 0.87)

= 0.5 - 0.31

=0.19 From the Normal Distribution Tables we find that at value of Z = - 0.87 gives a probability of 0.19.

Q 14. For a network shown in figure, normal time, crash time, and normal costs are given in the table; construct the network by crashing it to optimum value and calculate the optimum project cost. Indirect cost is given as Rs 100 per day.



Activity	*Normal*		*Crash*	
	Time (days)	*Cost (`)*	*Time (days)*	*Cost (`)*
1-2	3	300	2	400
2-3	6	480	4	520
2-4	7	2100	5	2500
2-5	8	400	6	600
3-4	4	320	3	360
4-5	5	500	4	520

Table : Activity Relationship

10 Marks dec. 2013

Solution:

From the network diagram, critical path is 1-2-3-4-5 and the project duration is 18 days. To construct the network in first stage we must identify those activities on critical path, which have cost slopes less than the indirect cost. The slopes are calculated as under.

Table: Activity Relationship

	Normal		**Crash**		**Crash Cost Nor-mal Cost**	**Normal Time Crash Time**	**Cost Slope**
	Time (days)	**Cost (`Rs)**	**Time (days)**	**Cost (`Rs)**	$C_c - N_c$	$N_t - C_t$	$\frac{C_c - N_c}{N_t - C_t}$
1-2	3	300	2	400	100	1	100
2-3	6	480	4	520	40	2	20
2-4	7	2100	5	2500	400	2	200
2-5	8	400	6	600	200	2	100
3-4	4	320	3	360	40	1	40
4-5	5	500	4	520	20	1	20

Now, for crashing we consider all possible paths in the network and the corresponding durations in tabular form as under.

Path	Sequence	Target Time	Time Crashed at Various Stages		
			2-3	3-4	4-5
P_I	1-2-3-4-5	18	16	14	15
P_2	1-2-4-5	15	15	14	14
P_3	1-2-5	11	11	11	11

Critical path activities, 2-3 and 4-5, have least cost slopes.

Therefore, crashing the activities 2-3 and 4-5 by 2 days and 1 day respectively.

Project duration = 18-3 = 15 days

Cost of project = Normal cost + extra crashing cost + indirect cost

= (300 +480 +2100 +400 +320 +500)+ (2 x 20 + lx 20) + 15 x 100

= ` 5660

In second stage, crashing the least cost slope activity 3-4 on critical path by 1 day.

Project duration = 14 days.

Cost of project = Normal cost + extra crashing cost + indirect cost

= 4100 + (20 x 2 + 1 x 20 + 1 x 40) + 14 x 100 =Rs 5600

The total project cost with normal activities (without crashing) = Normal cost + indirect cost for 18 days = 4100+1800 = Rs 5900 Therefore, **the optimum cost of the project is Rs 5600.**

Q 15. The following table gives data on normal time & cost and crash time & cost for a project.

Activity	Normal Time (Days)	Normal cosr	Crash Time (days	Crash Cost
1-2	6	600	4	1000
1-3	4	600	2	2000
2-4	5	500	3	1500
2-5	3	450	1	650
3-4	6	900	4	2000
4-6	8	800	4	3000
5-6	4	400	2	1000
6-7	3	450	2	800

The indirect cost per day is Rs 100.

(i) Draw the network and identify the critical path.
(ii) What are the normal project duration and associated cost?
(iii) Crash the relevant activities systematically and determine the optimum project completion time and cost.

Q 16. Draw the network for the following activities and critical path and total duration of project.

Activity	Duration (Month)
1-2	2.5
2-3	2.5
2-4	1.5
3-4	1.0
3-5	1.0
4-5	2.0
5-6	3.0
6-7	1.5
5-7	1.5

Q17. A project consists of 8 activities.

Activity	Immediate Successor
Q	**T**
R	**U**
S	**V**
W	**X**

Activity "X" is the last operation of the project, and activity "W" is the immediate successor to T, U, V. Draw the network of the project. **Dec. 2017 8 Marks**

Q 18. Draw the network for the following activities and Find critical path and total duration of project.

Activity	Duration (Month)
1-2	2
2-3	3
2-4	1
3-4	2
4-5	3
5-6	2
5-7	4
6-8	1
7-8	3
8-9	4

Ans. Dec. 2017 2+ 2+ 2= 6 Marks

Q 19. Draw the network for the following activities and critical path and total duration of the project.

Activity	Duration (Month)
1-2	3
2-3	4
2-4	5
2-5	6
3-4	3
3-6	5
4-6	7
5-6	4
6-7	5

Ans. **Dec. 2018 (2X3) Marks**

STUDY NOTE -7

ECONOMICS OF MAINTENANCE AND SPARES MANAGEMENT

7.1 BREAK DOWN MAINTENANCE

Here the production facility is run without much routine maintenance until it breakdown. Once the machine breakdown it is taken for repair and inspected to find out the defects. After identifying the defect, the required repair is planned and the spares are procured to repair the machine. As the breakdowns are random in nature and the machine cannot be used during the repair period, production hours are lost hence the productivity is reduced. Repair maintenance is not a recommended practice, in general, but many a time many organizations prefer this, because they do not want to keep the machine idle for maintenance. But they ignore the fact that the break down repair costs more than the regular maintenance practice. It is however, an economical way of maintaining certain non-critical items whose repair and down time costs are less this way than with any other system of maintenance.

7.2 PREVENTIVE MAINTENANCE

A system of scheduled, planned or preventive maintenance tries to minimize the problems of breakdown maintenance. It locates weak parts in all equipments, provides them regular inspection and minor repairs thereby reducing the danger of unanticipated breakdowns. The underlying principle of preventive maintenance is that prevention is better than cure. It involves periodic inspection of equipment and machinery to uncover conditions that lead to production breakdown and harmful depreciation. The system of preventive maintenance varies from plant to plant depending on the requirement of the plant.

Any company, adopting the preventive maintenance should keep the record of failure of various components and equipment, which help the maintenance department to statistically analyze the failure pattern and replace the item before it fails, so that the breakdown can be eliminated. This reduces the unanticipated breakdowns, increases the availability of the equipment, maintain optimum productive efficiency of equipment and machinery reduces the work content of maintenance job, increases productivity and safety of life of worker.

Production department or maintenance department depending on the size of the plant generally takes up preventive maintenance work. As the preventive maintenance is a costly affair, it is better to maintain records of cost (both labour, materials used and spares used) and a valuation of the work done by the department will show us what benefits are derived from preventive maintenance. The analytical approach to evaluate the work done by preventive maintenance is

(i) (Inspections incomplete) / (Inspections scheduled) × 100 should be less than 10%

(ii) (Hours worked for maintenance) / (Scheduled hours) × 100 = Performance of the department.

(iii) Down time to be given as a ratio of the available hours and to be compared against a standard to be worked out for each company or against a figure of the past. The ratio is given as:
= Down time in hours/ Available hours = working days × hours per day × number of machines. Here down time is the total time of stoppage of the machine for scheduled and unscheduled maintenance work.

(iv) Frequency of break downs = (Number of break downs) / (Available machine hours)

(iv) Effectiveness of planning = (Labour hours on scheduled maintenance) / (Total labour hours spent on maintenance).

Or

(Down time due to scheduled maintenance)/(Down time due to total maintenance work)

Advantages of preventive maintenance:

(i) Reduced breakdowns and downtime,
(ii) Greater safety to workers,
(iii) Fewer large scale repairs,
(iv) Less standby or reserve equipment or spares,
(v) Lower unit cost of the product manufactured,
(vi) Better product quality,
(vii) Increased equipments life and
(viii) Better industrial relations.

7.3 ROUTINE MAINTENANCE

It includes lubrication, cleaning, periodic overhaul; etc. This is done while the equipment is running or during preplanned shut-downs. Running maintenance is the work which can be carried out while the facility is in service.

Maintenance Techniques

It can be discussed as under:

In some cases the loss and inconvenience due to breakdown of equipment is so high that standby equipment is kept. As soon as the original equipment fails, the standby facility is employed to avoid interruption and downtime. Standby machines are often kept to reduce the loss due to the breakdown of a key machine. Breakdown maintenance also requires use of standby machines. The main question here is how many standby machines to keep and for how long. In order to decide this, a cost benefit analysis of standby machines should be made. There are various costs involved in standby machines. First, there is interest cost on capital investment. Secondly, space is needed to keep standby machines. Thirdly, there is depreciation in the value of standby machines. Fourthly, periodic checking and servicing is necessary to keep the standby machines in new condition. The benefits of standby machines consist of protection against a complete shutdown or shut down of operations. It avoids loss of production and,

therefore, it is necessary to estimate loss of future failures a table of expected costs and benefits can be prepared.

Shifting production during breakdown. Under this method spare capacity is maintained not in the form of standby machines but by allowing rest to running machines at intervals and by rotation. If one machine in a production line requires shutdown, the output is maintained by shifting to under uitilised machines in other lines. For such application, the capacities of different machines must be properly matched.

Organizing Maintenance work

In order to facilitate proper control of maintenance work; we must enforce three rules as below.

Maintenance Request

This must be made in writing to a central point in the organization. No work should be carried out without the knowledge and approval of maintenance supervision - if this discipline is not followed by the organization, it leads to wastage of skilled manpower and inability of the maintenance personnel to schedule essential maintenance work.

Maintenance Stores

Non-availability of vital spare parts when required to meet an emergency like breakdown, may lead to excessive shutdown of the plant and equipment. A large number of items or materials are required to be stored and it involves investing valuable funds from the working capital. A proper stores management is essential as a backup service of good maintenance.

Records of Maintenance work Done

Paper work for maintenance is crucial for establishing a good maintenance organization and is often neglected. The records of maintenance work carried out from time to time have to be kept equipment wise. History cards or logbooks of all the plants and equipment must be compiled meticulously giving details of materials used, components replaced and time spent by the workforce.

Creation and maintaining this database is essential for proper planning and control, which alone will lead to effective and efficient maintenance.

To get the full benefits of effective maintenance the following requirement is to be fulfilled:

(i) Good Supervision and administration of maintenance department,
(ii) Good and clear instructions to be given to maintenance crew regarding the repair,
(iii) Proper control of work in coordination with production department,
(iv) Good training should be given to the maintenance personnel,
(v) Good scheduled maintenance program should be chalked out, (vi) Proper maintenance record keeping is a must,
(vi) There should be adequate stock of spare parts, particularly insurance spares.

Maintenance Problem

The main problem in maintenance analysis is to minimise the overall cost of maintenance without sacrificing the objectives. There are two alternatives before management. One is to repair a machine or equipment only when it breaks down. This will save expense of inspection and replacement of a part before its lifetime ends. The other alternative is to replace the equipment before the expiry of its working life. This will involve cost of periodic shutdown for check up and repairs. However, it will avoid the loss due to sudden failure or breakdown.

The two types of cost - cost of premature replacement and cost of breakdown - need to be balanced. The objective is to minimise total maintenance cost and downtime. Economic analysis is helpful in finding a judicious combination of two types of maintenance. The relationship between preventive maintenance time and repair time is also significant. Preventive maintenance policy is justified only when the average downtime and its cost is less than the average time taken to carry out breakdown repairs. If the machine happens to be part of production line, the breakdown of a machine would throw the entire production line out of gear while a preventive maintenance schedule might enable the repair to be performed during a scheduled idle time of the line.

QUESTIONS

Q 1. PQR company has kept records of breakdowns of its machines for a 300 day work year as shown below:

No. of breakdown	Frequency in days
0	40
1	150
2	70
3	30
4	10
	300

The firm estimates that each breakdown costs Rs. 650 and is considering adopting a preventive maintenance program which would cost Rs.200 per day and limit the number of breakdown to an average of one per day. What is the expected annual savings from preventive maintenance program?

Ans.

Q 2. In a stimulated operation, a firm's maintenance crew received requests for service and provided service during an 8 hours period as shown below:

Request arrival (clock) time	Service time (hours)
0.00	1.5
1.00	0.5
3.30	2.0
4.00	0.5
7.00	1.0

The maintenance labour cost is rs.140 per hour and the delay time cost is Rs.450 per hour.

(a) Find the idle time cost for the maintenance crew.
(b) Find the delay time cost for the machinery.

Solution:

Request arrival time (clock time)	Repair One	time for crew	Repair ends time)	begins- (clock	Machine	down	Time
	Hours	Mines.			Waiting time	Repair time	Total time
00.00	1.50	90	00.00	01.30	Nil	1.5	1.5
01.00	0.50	30	01.30	02.00	0.5	0.5	1.0
03.30	2.00	120	03.30	05.30	Nil	2.0	2.0
04.00	0.50	30	05.30	06.00	1.5	0.5	2.0
07.00	1.00	60	07.00	08.00	Nil	1.0	1.0
Total	5.50 hrs.				2.0	5.5	7.5

Idle time for the maintenance crew = 8 - 5.5 = 2.5 hrs.

Idle time cost for maintenance crew = 2.5 x 140 = Rs.350

Delay time or waiting time = 2.0 hours

Delay time cost for the machinery = 2.0 x 450 = Rs.900

Q 3. The number of breakdowns of equipment over the past 2 years is as below:

No. of breakdowns	No. of month this occurred
0	3
1	7
2	9
3	3
4	2
Total	24

Each break down costs an average of Rs.300. Preventive maintenance service can be hired at a cost of Rs.150 per month and it will limit the breakdowns to an average of one per month. Which maintenance arrangement is preferable, the current breakdown maintenance policy or a preventive maintenance service contract?

Ans.

Q 4. Request for maintenance service made upon a centralized maintenance facility have been stimulated for a typical 8 hours shift with arrival and service pattern as shown below:

Request arrival (clock) time	Repair service time
1:30	60 mins.
2:00	20 mins.
4:15	45 mins.
4:30	120 mins.
5:30	30 mins.
7:00	10 mins.

The labour charges of maintenance crew is Rs.40 per hour whether working or idle. The waiting time of operators and machinery that has broken-down is costed at Rs.70 per hour.

(a) Find the idle time cost of the maintenance facility.
(b) Find the waiting time cost of operators and machinery (not including repair time).
(c) Find the total facility idle time and machinery waiting time cost.
(d) Assuming that for an additional cost of Rs.10 per hour the maintenance centre could add another crew and decrease the repair time by one third, would the additional cost be justified?

Solution: Calculation of machine down time:

Request Arrival time	Repair time reqd. with one crew (mins)	Repair time begins (clock time)	Repair time ends (clock time)	M/c down time with one crew Idle time + Repair time = Total time
01:30	60	01:30	02:30	Nil + 1.0 = 1.00
02:00	20	02:30	02:50	0.5+ 0.33 = 0.83
04:15	45	04:15	05:00	Nil + 0.75 = 0.75
04:30	120	05:00	07:00	0.5 + 2.0 = 2.50
05:30	30	07:00	07:30	1.5 + 0.5 = 2.00
07:00	10	07:30	07:40	0.5+0.166= .666
			Total (Hrs.) =	3.00 + 4.746 = 7.746 = 7.75 Hrs.

(a) Calculation of the idle time cost of maintenance facility:
Total repair service time = (60 + 20 +45 +120 +30 + 10) mts.
= 285 mts. = 4.75 hrs.

Total idle time of maintenance facility = 8.00 – 4.75 = 3.25 hrs.
Total idle time cost of maintenance facility = 3.25 x 40 = Rs.130

(b) Calculation of waiting time of operators:
Total waiting time for repair = 3.0 hrs.
Waiting time cost = 3.0 x 70 = Rs.210

(c) Calculation of total facility idle time and machinery waiting time cost:
Total idle time cost of maintenance facility + Machinery waiting time cost = 130 + 210 = Rs.340

(d) **Adding one more maintenance crew** at a cost of Rs.10 per hour decreases repair time by one third. Increase in labour cost/shift of 8 hours = Rs.10 x 8 = Rs.80
Decrease in repair time = 1/3 of repair time with one crew
Idle time cost = 1.582 x 70 = Rs.110.74

Since savings in operator and machinery idle time costs is (i.e., Rs.110.74) more than the increase in repair cost (i.e., Rs.80/-), it is justified to have one more maintenance crew.

Q 5 A workshop has 20 nos. of identical machines. The failure pattern of the machine is given below:-

Elapsed time after Maintenance attention (in month)	Probability of failure
1	0.20
2	0.15
3	0.15
4	0.15
5	0.15
6	0.20

It costs Rs. 150 to attend a failed machine and rectify the same. Compute the yearly cost of servicing the broken down machines.
Ans. 10286

Q 6. A Public transport system is experiencing the following number of breakdowns for months over the past 2 years in their new fleet of vehicles:

Number of breakdowns	0	1	2	3	4
Number of months this occurred	2	8	10	3	1

Each break down costs the firm an average of Rs. 2,800. For a cost of Rs. 1,500 per month, preventive maintenance can be carried out to limit the breakdowns to an average of one per month. Which policy is suitable for the firm?

Ans. 4788, 4300, **3 Marks (June- 2013)**

Q 7. Indian Electronics, manufactures TV sets and carries out the picture tube testing for 2000 hours. A sample of 100 tubes was put through this quality test during which two tubes failed. If the average usage of TV by the customer is 4 hours/day and if 10,000 TV sets were sold, then in one year how many tubes were expected to fail and what is the mean time between failures for these tubes? **5 Marks (Dec 2013)**

Ans. 147.47, tubes 67.8 year tubes per failure

Q 8. Load shedding power Utility Company has been given the task of power supply by the state. The Company has noticed that the system has been experiencing the following number of failure for months over the past 1 year.

Number of failures	0	1	2	3
Number of months this occurred	2	3	3	4

Each breakdown costs an average of Rs 10,000/- Preventive maintenance can be carried out for a cost of Rs3,000/- to limit the failures to an average of one per month. The Company seeks advice on which policy is most suitable for adoption.

(Dec.2008)

Ans. 17490,

Q 9. A company has 50 identical machines in its facilities. The cost of preventive servicing (Cp) is Rs. 20, and the cost of repair after breakdown (CR) is Rs. 100. The company seeks the minimum cost preventive servicing frequency and has collected the data on breakdown probabilities in the following table:

Probabilities of machine breakdown, by month:

Months after servicing that breakdown occurs (i)	Probability that breakdown will occur (Pi)	i.Pi
1	0.10	0.10
2	0.05	0.10
3	0.05	0.15
4	0.10	0.40
5	0.15	0.75
6	0.15	0.90
7	0.20	1.40
8	0.20	1.60
	1.00	5.40

8 Marks (Dec-2012) & June 2015

Ans.

Q 10. Super Electronics, manufactures TV sets and carries out the picture tube testing for 2500 hours. A sample of 200 tubes was put through this quality test during which **4** tubes failed. If the average usage of TV by the customer is 5 hours/day and if 15,000 TV sets were sold, then in one year how many tubes were expected to fail and what is the mean time between failures for these tubes?

(Dec. 2009)

Ans. 221, 67.8 year

Q 11. A solar manufacturing company has observed the following number of breakdowns in its new lantern over the past year.

Number of breakdowns	0	1	2	3
Number of months this occurred	3	6	2	1

It cot the firm Rs 1500 to rectify a lantern .Should the company go in for preventive maintence at Rs 600 per month which will limit the breakdown to one per month? Please advice. **(Dec. 2010)**

Ans. 1624

Q 12. A workshop has 30 nos. of identical machines. From the failure pattern of the machine it is calculated that the expected time before failure is 3 months. It costs Rs. 200 to attend a failed machine and rectify the same. Compute the yearly cost of servicing the broken down machines. **Ans. 24000 (Dec.2008)**

Q 13. Calculate the number of unitd expected to fail in a year and the mean time between failures from the following:
Testing time =100 hours, Samples tested = 50 units
Failures =2 units, Average usage = 2 hours/day
Total sales in the year = 500 units **(June 2009)**

Ans. 149, 3.36 year

Q 14. A public Transport Corporation has gathered the data about the number of breakdowns for months over the past two years in their new fleet of vehicles:

Number of breakdown	0	1	2	3	4
Number of months this occurred	3	7	11	2	1

Each breakdown costs the firm an average of Rs.3000. For a cost of Rs. 1375 per month, preventive maintenance can be carried out to limit the breakdown to an average of one per month. Which policy will be suitable for the firm? **Ans. 4875 (June 2009)**

Q 15. A workshop has 25 nos. of identical machines. The failure pattern of the machine is given below:-

Elapsed time after Maintenance attention (in month)	Probability of failure
1	0.10
2	0.15
3	0.15
4	0.15
5	0.20
6	0.25

It costs Rs. 160 to attend a failed machine and rectify the same. Compute the yearly cost of servicing the broken down machines.

5 Marks (June 2011)

Ans. 12151

Q 16. The porobability of failure P_n of an equipment in the n period after maintenance have been estimated as follows:

N	1	2	3	4
P_n	0.1	0.2	0.4	0.3

Cost of preventive maintenance :Rs. 150

Cost of breakdown maintenance Rs. 1000

Determine the optimum frequency of preventive maintenance. 5 Marks **(Dec. 2011)**

Ans. 230 ,

Q 17. A workshop has 20 nos. of identical machines. The failure pattern of the machine is given below:-

Elapsed time after Maintenance attention (in month)	Probability of failure
1	0.20
2	0.05
3	0.20
4	0.20
5	0.15
6	0.20

It costs Rs. 200 to attend a failed machine and rectify the same. Compute the yearly cost of servicing the broken down machines. **5 Marks (Dec. 2013)**

Q 18. PQR company has kept records of breakdowns of its machines for a 300 day work year as shown below:

No. of breakdown	Frequency in days
0	40
1	150
2	70
3	30
4	10
Total	**300**

The firm estimates that each breakdown costs Rs 600 and is considering adopting a preventive maintenance program which would cost Rs 200 per day and limit the number of breakdown to an average of one per day. What is the expected annual savings from preventive maintenance program? **5 Marks (Dec 2013) new**

Ans. 12000 saving amount in one year

Q 19. A machine X costs Rs.5,000. Its maintenance cost is Rs.1000 in each of the first four years and then it increases by Rs.200 every year. Assuming that the machine has no salvage value and the maintenance cost is incurred in the beginning of each year, determine the optimal replacement time for the machine assuming that the time value of money is 10% p.a.

Ans.

Q 20. The data on the operating costs per year and resale prices of equipment. A whose purchase price is Rs.10,000 are given here:

Year	1	2	3	4	5	6	7
Operating cost (Rs)	1500	1900	2300	2900	3600	4500	5500
Resale value (Rs)	5000	2500	1250	600	400	400	400

(a) What is the optimum period for replacement?

(b) When equipment A is 2 years old, equipment B, which is a new model for the same usage, is available. The optimum period for replacement is 4 years with an average cost of Rs.3600. Should we change equipment A with that of B? If so, when?

Solution:

(a) The determination of the optimal period of replacement of equipment A is given in Table below.

Table: Determination of Optimal Replacement Period

Year	M_t	Cum M_t	C-S	T(n)	A(n)
1	1500	1500	5000	6500	6500.0
2	1900	3400	7500	10900	5450.0
3	2300	5700	8750	144500	4816.7
4	2900	8600	9400	18000	4500.0
5	3600	12200	9600	21800	4360.0*
6	4500	16700	9600	26300	4383.3
7	5500	22200	9600	31800	4542.9

Since the average cost corresponding to the 5-yearly period is the least, the optimal period for replacement = 5 years.

(b) As the minimum average cost for equipment B is smaller than that for equipment A, it is prudent to change the equipment. To decide the time of change, we would determine the cost of keeping the equipment in its 3rd, 4th and 5th year of life and compare each of these values with Rs.3,600 (the average cost for equipment B). The equipment A shall be held as long as the marginal cost of holding it would be smaller than the minimum average cost of equipment B. The calculations are given here:

Year	Operating Cost	Depreciation	Total Cost
3	2300	1250(=2500-1250)	3550
4	2900	650(=1250-600)	3550
5	3600	200(=600-400)	3800

Since the cost incurred in keeping the equipment A in the third and the fourth years is less than the average cost for equipment B, the replacement should be done after 2 years.

Q 21. The Mini Transport Company owns three mini buses, two of which are two years old while the third one is only a year old. Each of these buses was purchased for Rs.80,000, The company contemplates replacing the three buses by two full-sized buses, each such bus containing 50% more seating capacity than a mini buys. Cost of each is Rs.1,20,000. Using the following data on the running costs and the resale value of both the types of buses, state

whether the mini buses be replaced by the full-sized buses. If not, state why? If yes, state when?

Year	For a Mini Bus		For a Full-sized Bus	
	Running Cost	Resale Value	Running Cost	Resale Value
1	3000	70000	3400	100000
2	3600	61000	3900	92000
3	4800	55000	4700	86000
4	5000	49000	5800	81000
5	8000	32000	7200	76000
6	11200	20000	9000	66000
7	15000	10000	12000	54000
8	20000	5000	16000	40000

Solution:

We shall first calculate the minimum average cost for each type of the buses. This is given in Tables below. For Mini Bus

Table: Determination of Average Cost

Year	M_t	Cum M_t	C - S	T(n)	A(n)
1	3000	3000	10000	13000	13000
2	3600	6600	19000	25600	12800
3	4800	11400	25000	36400	12133
4	5000	16400	31000	47400	11850*
5	8000	24400	48000	72400	14480
6	11200	35600	60000	95600	15933
7	15000	50600	70000	120600	17229
8	20000	70600	75000	145600	18200

For Full Sized Bus

Table: Determination of Average Cost

Year	M_t	Cum M_t	C - S	T(n)	A(n)
1	3400	3400	20000	23400	23400
2	3900	7300	28000	35300	17650
3	4700	12000	34000	46000	15333
4	5800	17800	39000	56800	14200
5	7200	25000	44000	69000	13800*
6	9000	34000	54000	88000	14667
7	12000	46000	66000	112000	16000
8	16000	62000	80000	142000	17750

Thus, the minimum average cost for a mini bus is rs.11,850 p.a. and Rs.13,800 p.a. for a full sized bus. However, these two should not be compared directly because three mini buses are equivalent to two full-size buses. Thus,

Average cost for all 3 mini buses = 11850 x 3 = 35,550

Average cost for 2 large buses = 13800 x 2 = 27,600

Clearly, then, it is prodent to replace the mini buses by the full sized buses.

To decide the timing at which the replacement be done, we shall first find the total yearly costs for the new buses. The year in which the average cost of the new buses shall be lower than the total cost of maintaining and running the old ones shall be the year when the replacement should be done. The calculations are given in Table below.

Table: Determination of Yearly Cost of a Mini Bus

Year	Running Cost	Depreciation	Total Cost
1	3000	10000	13000
2	3600	9000	12600
3	4800	6000	10800
4	5000	6000	11000
5	8000	17000	25000
6	11200	12000	23200
7	15000	10000	25000
8	20000	5000	25000

Total cost for next year would be: 2 x 10,800 + 12,600 = Rs.34,200 (since two of the buses would be running in the third year and the third one in the second year). Total cost for the subsequent years shall be:

2 x 11000 + 10800 = Rs.32,800

2 x 25000 + 11000 = Rs.61,000 etc.

Since the total average cost of running the two buses is Rs.27,600 whereas in the years to come the cost of owning and running the old buses would be greater than this, the conclusion is that the buses should be replaced immediately.

Q 22. A firm has a machine whose purchase price is Rs.20,000. Its maintenance cost and resale price at the end of different years are as given here:

Year	1	2	3	4	5	6
Maintenance Cost	1500	1700	2000	2500	3500	5500
Resale Price	17000	15300	14000	12000	8000	3000

(a) Obtain the economic life of the machine and the minimum average cost.
(b) The firm has obtained a contract to supply the goods produced by the machine, for a period of 5 years from now. After this time period, the firm does not intend to use the machine. If the firm has a machine of this type that is one year old, what replacement policy should it adopt if it intends to replace the machine not more than once?

Solution:

(a) The calculation of average cost is shown in Table below.

Table: Determination of Optimal Replacement Interval

Year	M_t	Cum. M_t	C – S	T(n)	A(n)
1	1500	1500	3000	4500	4500
2	1700	3200	4700	7900	3950
3	2000	5200	6000	11200	3733*
4	2500	7700	8000	15700	3925
5	3500	11200	12000	23200	4640
6	5500	16700	17000	33700	5617

Since the minimum average cost, Rs.3,733, corresponds to year 3, the economic life of the machine is 3 years.

(b) To consider the situation regarding the one-year old machine, we shall first obtain the yearly cost of keeping this machine in second, third,… year of its life. This is given in Table below.

Table: Determination of Yearly Costs for Existing Machine

Year	Maint. Cost	Depreciation	Total Cost	Cum. Total Cost
1	1700	1700	3400	3400
2	2000	1300	3300	6700
3	2500	2000	4500	11200
4	3500	4000	7500	18700
5	5500	5000	10500	29200

Alternate policies and the costs associated with each one are as follows:

Policy 1: Keep old machine for the zero year and buy a new one for full 5 years.

Total cost = 0 + 23,200 = Rs.23,200

Policy 2: Keep old machine for one year and buy a new one for 4 years.

Total cost = 3,400 + 15,700 = Rs.19,100

Policy 3: Keep old machine for 2 years and buy a new one for 3 years.

Total cost = 6,700 + 11,200 = Rs.17,900

Policy 4: Keep old machine for 3 years and buy a new one for 2 years.

Total cost = 11,200 + 7,900 = Rs.19,100

Policy 5: Keep old machine for 4 years and buy a new one for 1 year.

Total cost = 18,700 + 4,500 = Rs.23,200

Policy 6: Keep old machine for 5 years and don't buy a new one

Total cost = 29,200 + 0 = Rs.29,200

Therefore policy 3 is the optimal policy.

Q 23. Reddy transport company (RTC) has a fleet of 50 trucks. The past data on the breakdown of the truck show the following probability distribution (for a new truck as well as for one which has been repaired after a breakdown).

Month after maintenance	Probability of breakdown
1	0.10
2	0.20
3	0.30
4	0.40

Each breakdown cost Rs 3000 on an average , which includes cost of time lost and cost of materials and manpower.

The manager of RTC knows the importance of preventive maintenance . He estimated the cost of preventive maintenance to be Rs 500 per such preventive action.

What should be the appropriate maintenance policy in terms of the mix of preventive and breakdown.

Ans. 35750 **10 Marks Dec. 2016**

Q 24. A Company XYZ has kept records of breakdowns of its machines for a 300 day work year as shown below:

No. of breakdown	Frequency in days
0	45
1	140
2	65
3	35
4	15
	300

The firm estimates that each breakdown costs Rs. 620 and is considering adopting a preventive maintenance program which would cost Rs.250 per day and limit the number of breakdown to an average of one per day. What is the expected annual savings from preventive maintenance program?

Ans. **Dec. 2017 9 Marks**

Q 25. A Public transport Company is experiencing the following number of breakdowns for months over the past 2 years in their new fleet of vehicles:

Number of breakdowns	0	1	2	3	4
Number of months this occurred	3	6	9	4	2

Each break down costs the firm an average of Rs. 2,500. For a cost of Rs. 1,700 per month, preventive maintenance can be carried out to limit the breakdowns to an average of one per month. Which policy is suitable for the firm?

Ans. **Dec. 2017 10 Marks**

Q 26. A cab operation Company is experiencing the following number of breakdowns for months over the past 2 years in their new fleet of cabs:

Number of breakdowns	0	1	2	3	4
Number of months this occurred	3	7	9	4	1

Each break down costs the firm an average of Rs. 2,500. For a cost of Rs. 1,600 per month, preventive maintenance can be carried out to limit the breakdowns to an average of one per month. Which policy is suitable for the firm?

Ans. **June 2018 8 Marks**

7.4 Replacement of Machine

Replacement of Machine and other Relevant Concept

Replacement of Machines and Equipment

Machines are purchased and replacement of old machines-are made mainly for two reasons:

1. To increase the productive capacity and
2. To reduce cost of production.

Various other reasons for replacement are the following,

1. To get rid of worn out, broken down or obsolete machines,
2. To accommodate larger sizes of work and increase the machine capacity,
3. To reduce labour cost by introducing semi-automatic machines or machines more than one of which can be operated by a single operator,
4. To simplify operations by using automatic machines which are capable of performing variety of work usually performed by a number of different machines,
5. To minimise repair cost and reduce idle time. An analysis of the above six reasons will lead to either increase in capacity or reduction in cost or both.

Factors on which equipment is replaced: The replacement plan depends on evaluation of present and replacement machines from the point of view of technical suitability and cost saving features.
The points to check for replacement studies vary from industry, to industry on management conditions and management policies. But some factors are common to practically all cases. These are:

Technical Factors:

(i) Inadequacy from the stand paint of range, speed, accuracy, strength, rigidity, output and capacity,
(ii) Obsolescence and equipment worn out condition,
(iii) Special advantage of the new machine as to easiness of set ups convenience of operation, safety, reliability performance, control panels and special features,
(iv) Flexibility and versatility of the machine.

Cost Factors:

(i) High repair cost of existing machine,
(ii) High remodelling cost of existing machine,
(iii) Less chance of spoilage and rejection work causing: saving in cost,
(iv) Faster rate of production causes lower cost,
(v) Replacement of skilled -workers by semi-skilled and: unskilled workers leading to lesser labour cost,
(vi) Compactness of the machine leading to a saving in-space which means saving of overhead costs,
(vii) Machine pay back period i.e. how soon the cost of the equipment is recovered,
(viii)Life of the new machine giving effective service,
(ix) Flexibility and versatility of the machine tending to reduce idle time cost with changes in methods of production-which might occur in future,
(x) Availability of funds for the acquisition of the equipment or possibility of special arrangement like hire-purchase or government loans or other accommodations.

Replacement Programmes:

It is prudent to have phased .policies of machine replacement plans than to wait until breakdowns occur causing production hold ups. There are different forms of the programme.

1. A definite amount of money or a certain percentage of earning of the company is used each year to replace existing machines which are either superseded by improved models or are not in tip top condition or are having insufficient capacity.

2. Replacement is made of the oldest or most inadequate machine each year by upto date machines of greater accuracy or higher capacity. Some times automatic machines are gradually introduced in this way which is capable of doing several operations with lesser number of operators.

3. The economy of working on various machines are studied .and replacement of machines are made only to have a definite cost reduction.

Questions

Q 1. The following table gives the running costs per year and resale values of a certain equipment whose purchase price is Rs. 6,500. At what year is the replacement due optimally.

Year	1	2	3	4	5	6	7	8
Running costs (Rs.)	1400	1500	1700	2000	2400	2800	3300	3900
Resale value (Rs.)	4000	3000	2200	1700	1300	1000	1000	1000

5 Marks (Dec-2012)

Ans. Optimal replacement period at the end of 5th year.

Q 2. A truck-owner finds from his past experience that the maintenance costs are Rs. 200 for the first year and then increase by Rs. 2,000 every year. The cost of the Truck Type A is Rs. 9,000. Determine the best age at which to replace, i.e. truck. If the optimum replacement is followed what will be the average yearly cost of owing and operating the Truck? Truck Type B cost Rs. 10,000. Annual operating costs are Rs.400 for the first year and then increase by Rs. 800 every year. The Truck owner have now the Truck Type A which is one year old. Should it be replaced with B type, and if so, when?

Ans. At the year third, the Truck A can be replaced by Truck B

Q 3. A Plant Manager is considering replacement policy to a new machine. He estimates the following costs:

Year	1	2	3	4	5	6
Replacement cost at the beginning of the year	100	110	125	140	160	190
Salvage value at the end of the year	60	50	40	25	10	0
Operating costs	25	30	40	50	65	80

Find the year when replacement is to be made.

Ans. Replacement end of the 2nd year.

Q 4. A fleet owner finds from his past records that the costs per year of running a vehicle whose purchase price is Rs 50,000 are as under:

Year	1	2	3	4	5	6	7
Running cost (Rs.)	5000	6000	7000	9000	11500	16000	18000
Resale value (Rs.)	30000	15000	7500	3750	2000	2000	2000

Thereafter, running cost increases by Rs. 2,000, but resale value remains constant at Rs. 2,000. At what age is a replacement due?

Ans. Optimal replacement at the end of 6th year.

Q 5. The following mortality rates have been observed for a certain type of light bulbs:

Week	**1**	**2**	**3**	**4**	**5**
Per cent failing by end of week	10	25	50	80	100

There are 1,000 bulbs in sue, and it costs Rs. 2 to replace an individual bulb which has burnt out. If all bulbs were replaced simultaneously it would cost 50 paise per bulb. It is proposed to replace all bulbs at fixed intervals, whether or not they have burnt out, and to continue replacing burnt out bulbs as they fail. At what intervals should all the bulbs be replaced?

Ans. It should be replacement by the end of second week.

Q 6. An electric company which generates and distributes electricity conducted a study on the life of poles. The repatriate life data are given in the following table:

Life data of electric poles

Years after installation	1	2	3	4	5	6	7	8	9	10
Percentage polesfailing	1	2	3	5	7	12	20	30	16	4

(i) If the Company now installs 5,000 poles and follows a policy of replacing poles only when they fail, how many poles are expected to be replaced each year during the next ten years?
To simplify the computation assume that failures occur and replacements are made only at the end of a year.

(ii) If the cost of replacing individually is Rs. 160 per pole and if we have a common group replacement policy it costs Rs. 80 per pole, find out the optimal period for group replacement.

Ans. 1,13.440 Replacement end of the 6th year.

Q 7. A manufacturer is offered two machines A and B. A is priced at Rs. 5,000 and running costs are estimated Rs. 800 for each of the first five years, increasing by Rs. 200 per year in the sixth and subsequent year. Machine B, which has the same capacity as A, costs Rs. 2,500 but will have running costs of Rs.1,200 per year for six years, increasing by Rs.200 per year thereafter.

If money is worth 10% per year, which machine should be purchased? (Assume that the machines will eventually be sold for scrap at a negotiable price).

Ans. 1752, 1680,

Q 8. Suppose that a special purpose type of light bulb never lasts longer than 2 weeks. There is a chance of 0.3 that a bulb will fail at the end of the first week. There are 100 new bulbs initially. The cost per bulb for individual replacement is Re. 1 and the cost per bulb for a group replacement is Re. 0.50. It is cheapest to replace all bulbs:

(i) Individually,
(ii) Every week,
(iii) Every second week,
(iv) Every third week?

Ans.

Q 9. A manufacturing firm is considering a policy of replacing certain key electrical components
belonging to one group of machines on a group replacement basis instead of making repairs as needed.
There are approximately 100 parts of one type that have the mortality distribution shown below. The cost of replacing parts on individual basis is estimated to be Rs. 10 per part whereas that on group basis comes to Rs. 3 per part. Compare the average weekly cost of the two replacement alternatives:

Week	Probability of failure during week
1	0.3
2	0.1
3	0.1
4	0.2
5	0.3

Ans.

Q 10. Replacement policy is being considered for a new machine installed .Find the year when the replacement is to be made based on the following information.

Year	1	2	3	4	5
Replacement cost at beginning of the year of the year	1700	2000	2500	2850	3000
Salvage value at the end of the year	1175	1200	900	400	0
Operating costs	500	700	750	1100	1200

4 Marks (June, 2010)

Ans.

Q 11. A key electric component lasts for a maximum of 3 weeks. The chance of its failing at the end of first week is 0.1 and the chance of its failing at the end of second week is 0.3 . The cost per component for individual replacement is Rs.5 and cost per component for bulk replacement is Rs. 3. What is the optimal replacement period assuming there are 100 component initially?
(Dec.2008)

Q 12. A fleet owner finds from his past records that the costs per year of running a vehicle whose purchase price is Rs 1,00,000 are as under:

Year	**1**	**2**	**3**	**4**	**5**		
Running cost (Rs.)	10,000	12,000	13,500	15,000	18,000		
Resale value (Rs.)	80,000	65,000	55,000	25,000	6,000		

Thereafter, running cost increases by Rs. 3,000, but resale value remains constant at Rs. 6,000. At what age is a replacement due? **5 Marks (June- 2013)**
Ans.

Q 13. A firm is using a machine whose purchase price is Rs 13,000. The installation charges amount to Rs 3,600 and the machine has a scrap value of only Rs 1,600 because the firm has a monopoly of this type of work. The maintenance cost in various years is given in the following table.

Year	1	2	3	4	5	6	7	8	9
Cost(Rs)	250	750	1000	1500	2100	2900	4000	4800	6000

The firm wants to determine after how many years should the machine be replaced on economic considerations, assuming that the machine replacement can be done only at the year ends.
Ans. Replacement end of the 6th year .

Q 14. An engineering firm a machine whose purchase price is Rs.85000. The expected maintenance cost and resale price in different year are given below . At what year is the replacement due optimally.

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
Maint. cost (Rs.)	1200	1400	1800	2600	3200	4100	5200	
Resale value (Rs. 000)	80	76	71	67	63	58	52	

Dec. 2014(new)

Q 15. A firm is using a machine whose purchase price is Rs 15,000. The installation charges amount to Rs 3,500 and the machine has a scrap value of only Rs 1,500 because the firm has a monopoly of this type of work. The maintenance cost in various years is given in the following table.

Year	1	2	3	4	5	6	7	8	9
Main. Cost(Rs)	260	760	1100	1600	2200	3000	4100	4900	6100

The firm wants to determine after how many years should the machine be replaced on economic considerations, assuming that the machine replacement can be done only at the year ends.

Ans. **June 2015**

Q 16. A firm is using a machine whose purchase price is Rs 12,000. The installation charges amount to Rs 3,500 and the machine has a scrap value of only Rs 1,500 because the firm has a monopoly of this type of work. The maintenance cost in various years is given in the following table.

Year	1	2	3	4	5	6	7	8	9
Main. Cost(Rs)	260	760	1200	1800	2500	3200	4100	5000	6100

The firm wants to determine after how many years should the machine be replaced on economic considerations, assuming that the machine replacement can be done only at the year ends.

Ans. **7 Marks June 2017**

Q 17. An automotive firm is using a machine whose purchase price is Rs 18,000. The installation charges amount to Rs 3,800 and the machine has a scrap value of only Rs 1,800 because the firm has a monopoly of this type of work. The maintenance cost in various years is given in the following table.

Year	1	2	3	4	5	6	7	8	9
Main. Cost(Rs)	250	720	1200	1700	2300	3200	4300	4800	6300

The firm wants to determine after how many years should the machine be replaced on economic considerations, assuming that the machine replacement can be done only at the year ends.

Ans. **Dec. 2018 10 Marks**

7.5 Spare Parts Management (FAILURE)

The phenomenon of breakdown or failure is very important in Maintenance Management. A vital information in this regard relates to Failure Statistics. An important statistic is the relative frequency of failure or probability density of failure with respect to the age of the item in question. It has been observed that there are three prominent kinds of failure probability distribution:

(a) Normal Distribution
(b) Negative exponential Distribution
(c) Hyper-exponential Distribution

Most wear-out phenomena show Normal Failure Behaviour, the items failing at some mean operating age, with some failing sooner and some later. Some items fail, not because they wear out, but due to overload or defect in the system external to them; e.g., an electrical fuse. The failure rate, here, is not age-specific; it is constant. The Negative Exponential distribution fits well in this case. For many equipments the probability density of failure is much higher during the initial 'teething' periods than during their subsequent life. Hyper-exponential distribution fits these types of failure behaviours. The above information on failure behaviour will be of much help in planning various maintenance actions.

Q 1. Automobile wheel assembly bearings exhibit times of failure which are normally distributed with a mean of 25,000 km run. The times of failure have a dispersion which has a standard deviation of 3,000 km. If a transport company has 90 automobiles, how many of them could be expected to have the problem of bearing failure

(i) By 20,000 km?
(ii) Between 20,000 and 35,000 km?

Each automobile has 4 such bearings.

Solution :

(i) $Z = \frac{X - \mu}{\sigma}$

Here μ = 25,000 km; σ = 3,000 km and χ = 20,000 km

Therefore $Z = \frac{20{,}000 - 25{,}000}{3{,}000}$ = - 1.667

From the Standard Normal Distribution table, we have:

Area = 0.4522 So, the desired area = 0.5000 – 0.4522 = 0.0478

Therefore, 0.0478 x 90 x 4 = 17.2 bearings may be expected to fail by 20,000 km.

(ii) Between 20,000 and 35,000 km can be translated in Z values as follows.

$Z_1 = \frac{20{,}000 - 25{,}000}{3{,}000}$ = - 1.667

$Z_2 = \frac{35,000-25,000}{3,000}$= + 3.333

Referring to the Standard Normal table: Area between 20,000 and 35,000 km

= (Area between 20,000 and 25,000) + (Area between 25,000 and 35,000)

= (0.4522) + (0.4988) = 0.9510

Therefore, the number of bearings expected to fail in this range = (0.9510) (90 x 4) = 342.36

Q 2. Product A has a Mean Time between Failures (MTBF) of 30 hours and has a Mean Time To Repairs (MTTR) of 5 hours . Product B has a MTBF of 40 hours and has a MTTR od 2 hours.

(i) Which product has the higher reliability ?
(ii) Which product has greater maintainability?
(iii) Which product has greater availiabilty?

Ans. (i) Product **B,** with higher MTBF (40 hours) than Product A (30 hours), is more reliable since it has lesser chance failure during servicing.

(ii)By MTTR we mean the time taken to repair a machine and put it into operation. Thus Product B with lesser MTTR (2 hours) than product A (5 hours) has greater maintainability.

(iii)Availability of a machine/product = MTBF/ MTBF +MTTR

Therefor, Availability of product A = 30/ (30+5) = 85.714%

Availability of product B =40/ (40+2)= 95.238%

Hence, Product B has more availability

Q 3. Product A has a Mean Time between Failures (MTBF) of 35 hours and has a Mean Time To Repairs (MTTR) of 6 hours . Product B has a MTBF of 45 hours and has a MTTR od 3 hours.

(i) Which product has the higher reliability ?
(ii) Which product has greater maintainability?
(iii) Which product has greater availiabilty?

Ans. **3+3+4= 10 Marks June 2017**