ARTICLE 51A

Fundamental Duties - It shall be the duty of every citizen of India—

(a) to abide by the Constitution and respect its ideals and institutions, the National Flag and the National Anthem;

(b) to cherish and follow the noble ideals which inspired our national struggle for freedom;

(c) to uphold and protect the sovereignty, unity and integrity of India;

(d) to defend the country and render national service when called upon to do so;

(e) to promote harmony and the spirit of common brotherhood amongst all the people of India transcending religious, linguistic and regional or sectional diversities, to renounce practices derogatory to the dignity of women;

(f) to value and preserve the rich heritage of our composite culture;

(g) to protect and improve the natural environment including forests, lakes, rivers and wild life and to have compassion for living creatures;

(h) to develop the scientific temper, humanism and the spirit of inquiry and reform;

(i) to safeguard public property and to abjure violence;

(j) to strive towards excellence in all spheres of individual and collective activity so that the nation constantly rises to higher levels of endeavour and achievement;

(k) who is a parent or guardian to provide opportunities for education to his child or, as the case may be, ward between the age of six and fourteen years.
Mathematics and Statistics
(Commerce)
Part - II
STANDARD TWELVE

Maharashtra State Bureau of Textbook Production and Curriculum Research,
Pune - 411 004

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The Constitution of India

Preamble

WE, THE PEOPLE OF INDIA, having solemnly resolved to constitute India into a
SOVEREIGN SOCIALIST SECULAR DEMOCRATIC REPUBLIC and to secure to
all its citizens:

JUSTICE, social, economic and political;

LIBERTY of thought, expression, belief, faith
and worship;

EQUALITY of status and of opportunity;

and to promote among them all

FRATERNITY assuring the dignity of
the individual and the unity and integrity of the
Nation;

IN OUR CONSTITUENT ASSEMBLY this
twenty-sixth day of November, 1949, do HEREBY
ADOPT, ENACT AND GIVE TO OURSELVES
THIS CONSTITUTION.
NATIONAL ANTHEM

Jana-gana-mana-adhināyaka jaya hē
Bhārata-bhāgya-vidhātā,

Panjāba-Sindhu-Gujarāta-Marāthā
Drāvida-Utkala-Banga

Vindhyā-Himāchala-Yamunā-Gangā
uchchala-jaladhi-taranga

Tava subha nāmē jāgē, tava subha āśisa māgē,
gāhē tava jaya-gāthā,

Jana-gana-mangala-dāyaka jaya hē
Bhārata-bhāgya-vidhātā,

Jaya hē, jaya hē, Jaya hē,
Jaya jaya jaya, jaya hē.

PLEDGE

India is my country. All Indians are my brothers and sisters.

I love my country, and I am proud of its rich and varied heritage. I shall always strive to be worthy of it.

I shall give my parents, teachers and all elders respect, and treat everyone with courtesy.

To my country and my people, I pledge my devotion. In their well-being and prosperity alone lies my happiness.
Dear Students,

Welcome to Standard XII, an important milestone in your student life.

Standard XII or Higher Secondary Certificate opens the doors of higher education. After successfully completing the higher secondary education, you can pursue higher education for acquiring knowledge and qualification. Alternatively, you can pursue other career paths like joining the workforce. Either way, you will find that mathematics education helps you every day. Learning mathematics enables you to think logically, consistently, and rationally. The curriculum for Standard XII Commerce Mathematics and Statistics has been designed and developed keeping both of these possibilities in mind.

The curriculum of Mathematics and Statistics for Standard XII Commerce is divided in two parts. Part I deals with more theoretical topics like Mathematical Logic, Differentiation and Integration. Part II deals with application oriented topics in finance and management. Random Variables and Probability Distributions are introduced so that you will understand how uncertainty can be handled with the help of probability distributions.

The new text books have three types of exercises for focused and comprehensive practice. First, there are exercises on every important topic. Second, there are comprehensive exercises at end of all chapters. Third, every chapter includes activities that students must attempt after discussion with classmates and teachers. Textbooks cannot provide all the information that the student can find useful. Additional information has been provided on the E-balbharati website (e-balbharati.in).

We are living in the age of the Internet. You can make use of the modern technology with help of the Q.R. code given on the title page. The Q.R. code will take you to websites that provide additional useful information. Your learning will be fruitful if you balance between reading the text books and solving exercises. Solving more problems will make you more confident and efficient.

The text books are prepared by a subject committee and a study group. The books are reviewed by experienced teachers and eminent scholars. The Bureau would like to thank all of them for their valuable contribution in the form of creative writing, constructive criticism and useful suggestions for making the text books valuable. The Bureau is grateful to the members of the subject committee, study group and review committee for sparing their valuable time while preparing these text books. The Bureau hopes and wishes that the text books are appreciated and well received by students, teachers and parents.

Students, you are now ready to study. All the best wishes for a happy learning experience and a well deserved success. Enjoy learning and you will succeed.

Pune
Date : 21 February 2020
Bharatiya Saur : 2 Phalguna 1941

(Vivek Gosavi)
Director
Maharashtra State Bureau of Textbook Production and Curriculum Research, Pune.
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<th>Sr. No.</th>
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| 1      | Commission, Brokerage, Discount | • understand terms like Agent, Commission Agent, Broker, Auctioneer, Factor, Del credere Agent  
     |                                  | • identify trade discount and cash discount  
     |                                  | • know meaning and formula of present worth, true discount, sum due, date of bill, face value, period, nominal due date, discount, banker’s gain  
     |                                  | • solve problems on commission and brokerage                                                                                                          |
| 2      | Insurance                        | • understand the terms premium, policy value, types of insurance (fire, marine and accident)  
     |                                  | • know rules and formulae for claims                                                                                                                   |
| 3      | Annuity                          | • identify types of annuity  
     |                                  | • know terms related to annuity  
     |                                  | • understand annuity formulae including abbreviations used in them  
     |                                  | • solve annuity problems                                                                                                                               |
| 4      | Linear Regression                | • understand the meaning of regression  
     |                                  | • understand types of regression  
     |                                  | • understand meaning of linear regression  
     |                                  | • find the regression coefficient  
     |                                  | • state the equations of regression lines  
     |                                  | • state interrelations between standard deviations, regression coefficients and correlation coefficient  
     |                                  | • remember the properties of regression coefficients  
     |                                  | • solve problems based on regression                                                                                                                  |
| 5      | Time Series                      | • understand the concept of a time series  
     |                                  | • identify the components of a time series  
     |                                  | • use graphical method to find the trend line for a time series  
     |                                  | • use moving averages to find the trend line for a time series  
     |                                  | • use least squares method to find the trend line for a time series                                                                                   |
| 6      | Index Numbers                    | • understand the concept of index numbers  
     |                                  | • identify types of index numbers  
     |                                  | • understand the terminology of index number  
     |                                  | • construct different index numbers  
<pre><code> |                                  | • solve economic problems involving index numbers                                                                                                       |
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| 6 | • understand the concept of linear programming  
• understand the general form and meaning of LPP  
• formulate a given problems as LPP  
• draw constraint lines and find the region of feasible solutions  
• obtain the optimal solution of LPP | • understand the assignment problem  
• formulate an assignment problem  
• solve an assignment problem by Hungarian method  
• identify the special cases of assignment problem | • understand the concept of job sequencing  
• solve problems of processing n jobs through two machines  
• solve problem of processing n job through three machine | • understand the meaning of random variables and types of random variables  
• understand probability mass function and its properties  
• understand the cumulative distribution function and its properties  
• find the expected value and variance of a discrete random variable  
• understand the probability density function and its properties  
• find the cumulative distribution function, expected value and variance of continous random variables | • understand Bernouli trial, Bernouli distribution, condition for Binomial distribution and their properties  
• use Binomial distribution to calculate required probabilities | • understand the Poission distribution and its properties  
• use Poission distribution to calculate required probabilities |
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Commission, Brokerage and Discount

Let's Study

- Commission, Brokerage
- Discount

Let’s Discuss...

1.1 Commission and Brokerage Agent:
When transactions like sale, purchase, auction etc. are done through some middlemen, such middlemen are called agents.

(The charges paid to an agent for doing the work on behalf of some other person, called principal, is called commission.)

Principal: Principal refers to an individual party or parties participating in a transaction.

Commission: The charges paid to an agent for doing the work on behalf of principal is called commission. The commission or the remuneration paid to an agent is generally fixed as some percentage of the value of the transaction. For example, suppose an agent charges commission at 5% on the sales. Then in the transaction of Rs.15,000/-, the agent will get a commission of Rs.750/- as follows.

\[ \text{Rs. 15,000} \times \frac{5}{100} = \text{Rs. 750/-} \]

Following are different types of agents named according to their specialization.

Commission Agents: A commission agent is a person who buys or sells goods on behalf of his principal and gets commission for his service.

Broker: A broker is an agent who brings together the buyer and the seller for the purpose of purchase or sale. This commission is called brokerage and is charged to both the parties.

Auctioneer: An auctioneer is an agent who sells goods by auction. He sells goods to the highest bidder. Many a time name of the principal is not disclosed in the transaction.

Factor: A factor is an agent who is given the possession of goods and enters a contract for sale in his/her own name.

Del Credere Agent: A del credere agent gives guarantee to his principal that the party to whom he/she sells the goods will pay the sale price of goods. If a buyer is unable to pay after the transaction is completed, a del credere agent is liable for the payment.

Agent gets additional commission other than the usual commission for this. This is known as delcredere commission.

SOLVED EXAMPLES

Ex.1: A merchant gives his agent 5% ordinary commission plus 2% del credere commission on sale of goods, worth Rs.55,000/-. How much does the agent receive? How much does the merchant receive?

Solution:

Agent's Commission at 5% = 55000 \times \frac{5}{100} = Rs.2750

Rate of delcredere = 2%

Amount of delcredere = 55000 \times \frac{2}{100} = Rs.1100

\therefore \text{Agent's Total Commission} = 2750 + 1100 = Rs.3850

Merchant receives = 55000 - 3850 = Rs.51150
Ex.2: The price of a refrigerator is Rs. 47,000. An agent charges commission at 6% and earns Rs. 42,300. Find the number of refrigerators.

Solution: The price of a refrigerator = Rs. 47,000/-
Rate of commission = 6%

Commission for one refrigerator
\[ = \frac{6}{100} \times 47000 \]
\[ = 2820 \]

Total Commission earned = Rs. 42,300 (given)

\[ \therefore \text{Number of total refrigerators sold} = \frac{42300}{2820} \]
\[ = 15 \]

\[ \therefore 15 \text{ refrigerators were sold.} \]

Ex.3: A house was sold through an agent for Rs. 60 lakhs. He charged 1% Commission from both buyer and seller. Calculate agent’s commission. Calculate the net amount received by the seller and amount paid by the buyer.

Solution: Selling price of the house = Rs. 60 lakhs.

Commission on the sale of the house
\[ = 60 \times \frac{1}{100} \]
\[ = Rs. 0.60 \text{ lakh from each party.} \]

\[ \therefore \text{Agents Commission is Rs. 1.20 lakh from both the parties.} \]

\[ \therefore \text{Price of the house paid by the buyer} = Rs. 60 \text{ lakh} + Rs. 0.60 \]
\[ = Rs. 60.60 \text{ lakh} \]

Net amount received by the seller
\[ = 60 - 0.60 \]
\[ = Rs. 59.40,000 \]

Ex.4: A sales representative gets fixed monthly salary plus commission based on the sales. In two successive months he received Rs. 23,250 and Rs. 24,250 on the sale of Rs. 70,000 and Rs. 85,000 respectively. Find his monthly salary and the rate of commission on sales.

Solution: Income of sales representative
\[ = \text{Salary + Commission on the sales} \]
\[ 23500 = \text{Salary + Commission on Rs. 70,000 ...(1)} \]
\[ 24250 = \text{Salary + Commission on Rs. 85,000 ...(2)} \]

Subtracting (1) from (2) we get
\[ 750 = \text{commission on 15,000} \]

Rate of Commission
\[ = \frac{100 \times 750}{15000} \]
\[ = 5 \%

\[ \therefore \text{Rate of Commission} = 5\% \]

\[ \therefore \text{Commission on Rs. 70000} = 70000 \times \frac{5}{100} \]
\[ = 3500 \]

Substituting in equation (1), we get
\[ 23500 = \text{Salary} + 3500 \]

\[ \therefore \text{Salary} = 23500 - 3500 \]
\[ = Rs. 20000 \]

Ex.5: The income of an agent remain unchanged though the rate of commission is increased from 5% to 6.25%. Find the percentage reduction in the value of business.

Solution: Let the initial value of the business be Rs. 100

\[ \therefore \text{Original income of the agent} = Rs. 5 \]

Let the new value of the business be Rs. x

\[ \therefore \text{New income of the agent} = x \times \frac{6.25}{100} \]
\[ = \frac{x \times 625}{100} \]
\[ = \frac{x}{16} \]
Now Original income = new income (given)

\[ : \quad 5 = \frac{x}{16} \]
\[ \therefore \quad x = 80 \]
\[ \therefore \quad \text{New value of the business} = \text{Rs.} 80 \]
\[ \therefore \quad \text{There is 20% reduction in the value of the business.} \]

**Ex.6:** A salesman receives 8% commission on the total sales. If his sales exceeds Rs. 20,000 he receives an additional commission at 2% on the sales over Rs. 20,000/- If he receives Rs. 7,600 as commission, find his total sales.

**Solution:** Let the total sales be Rs. \( x \).

\[ \therefore \quad \text{Commission at 8% on total sales} \]
\[ = x \times \frac{8}{100} = \frac{8x}{100} \]

Sales exceeding Rs.20000 = \( x - 20000 \)

\[ \therefore \quad \text{Commission at 2% on excess sales} \]
\[ = (x-20000) \times \frac{2}{100} \]

But total commission earned = Rs.7,600

\[ \frac{8x}{100} + \frac{2(x-20000)}{100} = 7,600 \]
\[ \therefore \quad 8x + 2x - 40000 = 7600 \times 100 \]
\[ \therefore \quad 10x = 800000 \]
\[ \therefore \quad x = 80000 \]

\[ \therefore \quad \text{His total sales is Rs.} 80,000 \]

**Trade Discount and Cash Discount**

Discount is the reduction in the price of an article, allowed by the seller to the purchaser. It is generally expressed in terms of percentage.

There are two types of Discounts:

1) **Trade discount:** Trade discount is allowed by one trader to another. It is given on the catalogue price, list price or market price of the goods.

2) **Cash discount:** Cash discount is allowed in consideration of ready cash payment.

The buyer may be allowed both of these discounts. In such a case the trade discount is first calculated on the catalogue (list) price. The cash discount is then calculated on the price obtained after deducting the trade discount from the list price.

**Invoice price = List price (Catalogue price) – Trade discount.**

**Selling Price / Net Selling Price = Invoice price – Cash discount**

**Profit = Net selling price – Cost price**

**Loss = Cost price – Net selling price**

**SOLVED EXAMPLES**

**Ex.7:** M/s. Saket Electronics is given 15% trade discount and 5% cash discount on purchase of television sets by the distributor. Find the total discount availed if M/s. Saket Electronics purchases TV sets worth Rs. 12,00,000 from the distributor.

**Solution:** Discount at 15% on Rs 12,00,000

\[ = 1200000 \times \frac{15}{100} = Rs.1,80,000 \]

\[ \therefore \quad \text{Invoice price of T.V. Sets} \]
\[ = 12,00,000 - 1,80,000 \]
\[ = Rs.10,20,000 \]

Now cash discount is given on Rs. 10,20,000

Cash discount at 5% on Rs.10,20,000

\[ = 10,20,000 \times \frac{5}{100} = Rs.51,000 \]

\[ \therefore \quad \text{Total discount availed} = 1,80,000 + 51,000 \]
\[ = Rs.2,31,000 \]

**Ex.8:** Vaishnavi wants to buy an i-phone worth Rs 55,000. A shopkeeper gives 8% trade discount and 8% cash discount. Another shopkeeper gives 10% trade discount and 5% cash discount. Which shopkeeper should be preferable?
Solution: The first shopkeeper gives

8% on Rs.55000 = \( 55000 \times \frac{8}{100} \)
\[ = \text{Rs.} 4400 \]

\[
\therefore \text{Invoice price of the i-phone} = 55000 - 4400 = 50,600
\]

Cash discount at 8% on Rs.50,600
\[ = 50600 \times \frac{8}{100} \]
\[ = \text{Rs.} 4048 \]

Net amount payable to the first shopkeeper
\[ = 50600 - 4048 = \text{Rs.} 46552 \]

Second shopkeeper gives 10% discount on

Rs.55000 = \( 55000 \times \frac{10}{100} \)
\[ = \text{Rs.} 5500 \]

Net price after deducting trade discount
\[ = 55000 - 5500 = \text{Rs.} 49500 \]

Cash discount at 5% on Rs.49,500
\[ = 49500 \times \frac{5}{100} \]
\[ = \text{Rs.} 2475 \]

Net amount payable to the second shopkeeper.
\[ = 49,500 - 2475 = \text{Rs.} 47025 \]

\[ \therefore \text{The first shopkeeper should be preferred.} \]

Ex.9: A motor bike is marked at Rs 50,000. A retailer allows a discount at 16% and still gains 20% on the cost. Find purchase price of the retailer.

Solution: List price of the motor bike
\[ = \text{Rs.} 50,000 \]

Discount at 16% on Rs 50,000.
\[ = 50000 \times \frac{16}{100} \]
\[ = \text{Rs.} 8,000 \]

\[
\therefore \text{Selling price} = 50000 - 8000 = \text{Rs.} 42,000
\]

In case the purchase price is Rs.100, the selling price is Rs.120

\[
\therefore \text{For selling price} = 42,000
\]

the purchase price = \( \frac{100 \times 42000}{120} \)
\[ = \text{Rs.} 35,000 \]

\[
\therefore \text{Purchase Price of the motor bike is Rs.35,000.}
\]

Ex.10: Prakash gets a commission at 10% on cash sales and 8% on credit sales. If he receives Rs 4,400 as commission on the total sales of Rs 50,000. Find the sales made by him in cash and on credit.

Solution: Let the cash sales be Rs. \( x \)

\[
\therefore \text{Credit sales} = \text{Rs.} (50,000 - x)
\]

Total commission =10% on \( x \) + 8% on \( (50,000 - x) \)

\[
4400 = x \times \frac{10}{100} + (50000 - x) \times \frac{8}{100}
\]
\[ = \frac{10x}{100} + \frac{400000 - 8x}{100} \]
\[ = \frac{400000 + 2x}{100} \]
\[ 4400 \times 100 = 400000 + 2x \]

\[
\therefore 2x = 40000
\]
\[ x = 20,000 \]

\[ \therefore \text{Prakash's cash sales is Rs.20,000 and his credit sales is} \]

\[ 50,000 - 20,000 = \text{Rs.} 30,000 \]

Ex.11: Mr. Anand charges 10% commission on cash sales and 8% commission on credit sales. If his overall commission is 8.8%, Find the ratio of cash sales to the credit sales.

Solution: Let the cash sales be Rs. \( x \)

and the credit sales be Rs. \( y \)
Commission on cash sales is 10%
\[= x \times \frac{10}{100} = \frac{10x}{100}\]
Commission on credit sales is 8%
\[= y \times \frac{8}{100} = \frac{8y}{100}\]

Anand's Total Sales = (x + y)
\[\therefore\text{ Commission at 8.8% on the total sales}\]
\[= \frac{(x+y) \times 8.8}{100} = \frac{(x+y) \times 88}{1000}\]
\[\therefore\frac{10x}{100} + \frac{8y}{100} = \frac{88x+88y}{1000}\]
\[\therefore 100x + 80y = 88x + 88y\]
\[\therefore 12x = 8y\]
\[\therefore \frac{x}{y} = \frac{8}{12} = \frac{2}{3}\]
\[\therefore\text{ Ratio of cash sales to the credit sales is 2:3}\]

**EXERCISE 1.1**

1. An agent charges 12% commission on the sales. What does he earn if the total sale amounts to Rs. 48,000? What does the seller get?

2. A salesman receives 3% commission on the sales up to Rs. 50,000 and 4% commission on the sales over Rs. 50,000. Find his total income on the sale of Rs. 2,00,000.

3. Ms. Saraswati was paid Rs. 88,000 as commission on the sale of computers at the rate of 12.5%. If the price of each computer was Rs. 32,000, how many computers did she sell?

4. Anita is allowed 6.5% commission on the total sales made by her, plus a bonus of \(\frac{1}{2}\) % on the sale over Rs. 20,000. If her total commission amount to Rs. 3400. Find the sales made by her.

5. Priya gets salary of Rs. 15,000 per month and commission at 8% on the sales over Rs. 50,000. If she gets Rs. 17,400 in a certain month. Find the sales made by her in that month.

6. The income of a broker remains unchanged though the rate of commission is increased from 4% to 5%. Find the percentage reduction in the value of the business.

7. Mr. Pavan is paid a fixed weekly salary plus commission based on percentage of sales made by him. If on the sale of Rs. 68,000 and Rs. 73,000 in two successive weeks, he received in all Rs. 9,880 and Rs. 10,180. Find his weekly salary and the rate of commission paid to him.

8. Deepak’s salary was increased from Rs. 4,000 to Rs. 5,000. The sales being the same, due to reduction in the rate of commission from 3% to 2%, his income remained unchanged. Find his sales.

9. An agent is paid a commission of 7% on cash sales and 5% on credit sales made by him. If on the sale of Rs. 1,02,000 the agent claims a total commission of Rs. 6,420, find his cash sales and credit sales.

10. Three cars were sold through an agent for Rs. 2,40,000, Rs. 2,22,000 and Rs. 2,25,000 respectively. The rates of commission were 17.5% on the first, 12.5% on the second. If the agent overall received 14% commission on the total sales, find the rate of commission paid on the third car.

11. Swatantra Distributors allows 15% discount on the list price of washing machine. Further 5% discount is given for cash payment. Find the list price of the washing machine if it was sold for the net amount of Rs. 38356.25.
12. A book seller received Rs.1,530 as 15% commission on list price. Find list price of the books.

13. A retailer sold a suit for Rs.8,832 after allowing 8% discount on marked price and further 4% cash discount. If he made 38% profit, find the cost price and the marked price of the suit.

14. An agent charges 10% commission plus 2% delcred. If he sells goods worth Rs.37,200, find his total earnings.

15. A whole seller allows 25% trade discount and 5% cash discount. What will be the net price of an article marked at Rs. 1600.

**Let’s discuss**

1.2 Discount

a) Present worth, sum due, true discount

When businessmen sell goods on credit, the price quoted for goods includes a sufficient margin of interest for the period of credit allowed.

Suppose the goods are worth Rs. 100, if the payment is made on the spot. However if a credit of 4 months is allowed, then the businessmen will quote the price by adding interest for 4 months to Rs.100. If the rate of interest is 12% per annum then the interest for 4 months will be Rs. 4. Therefore the customer has to pay Rs.104 after 4 months.

In other words Rs.104 due after 4 months at 12% p.a. are equivalent to Rs.100 today. Hence Rs.100 are known as present value (P.V.) of Rs.104 due after 4 months. Hence at 12% per annum Rs.104 is known as sum due (S.D) and Rs.4 is known as the true discount (T.D) on the sum due.

The true discount is the interest on the present worth at the given rate of interest for the given period.

We have,

\[ \text{Present worth} + \text{True discount} = \text{Sum due} \]

i.e. \[ P.W. + T.D. = S.D. \]

where \( P.W. \) is the principal or the present worth, \( n \) is period of the bill in years, \( r \) is the rate of interest per annum.

**Drawer and Drawee:**

A person who draws the bill is called the drawer. A person on whom the bill is drawn is called as Drawee.

**Date of bill and Face value:**

The date on which the bill is drawn is called as ‘date of bill’. The amount for which the bill is drawn is called face value (F.V) of the bill. It is the sum due on the present worth.

Period of the bill is the time after completion of which the drawer receives the payment.

**Nominal Due Date and Legal Due Date:**

The date on which the period of bill expires is called the nominal due date. The buyer has to make the payment to the seller on this date.

However, the buyer is allowed to pay the amount even 3 days later. These 3 days are called the days of grace. The date obtained after adding 3 days of grace to the nominal due date is known as the legal due date.

**Discounting a Bill:**

If the drawer of the bill wants money before the legal due date, then there is a facility available at the bank or with an agent who can discount a bill and pay the amount to the drawer (after deducting some amount from face value of the bill). This is called discounting the bill.

**Banker’s Discount, Cash Value, Banker’s Gain:**

When a bill is discounted in a bank, the banker will deduct the amount from the face value of the bill at the given rate of interest for the period from the date of discounting to the legal due date and pay the balance to the drawer. This amount is known as Banker’s Discount (B.D).
The amount paid to the holder of the bill after deducting banker’s discount is known as Cash Value (C.V) of the bill paid on the date of discounting.

The banker’s discount is called commercial discount.

Thus, true discount is calculated on present worth and the banker’s discount is calculated on the face value. Hence the banker’s discount is always higher than the true discount.

The difference between the banker’s discount and the true discount is called Banker’s Gain (B.G). It is equal to the interest on true discount.

**Abbreviations:**
- Present Worth: P.W. or P
- Sum Due/Face Value: S.D. or F.V.
- True Discount: T.D.
- Banker’s Gain: B.G.
- Banker’s Discount: B.D.
- Cash Value: C.V.

**Notation**
- Period (in Years): \( n \)
- Rate of Interest (p.a.): \( r \)

**List of Formula:**

1. S.D. = P.W. + T.D.
2. T.D. = \( \frac{P.W. \times n \times r}{100} \)
3. B.D. = \( \frac{S.D. \times n \times r}{100} \)
4. B.G. = B.D. – T.D.
5. B.G. = \( \frac{T.D. \times n \times r}{100} \)
6. Cash value = S.D. – B.D.

---

**SOLVED EXAMPLES**

**Ex.1:** If the present worth of a bill due six months hence is Rs.23,000 at 8% p.a., What is sum due?

**Solution:**

\[ \text{P.W.} = 23,000, \quad r = 8\% \]

\[ n = 6 \text{ months} = \frac{1}{2} \text{ year} \]

\[ \text{T.D.} = \frac{\text{P.W.} \times n \times r}{100} = \frac{23000 \times \frac{1}{2} \times 8}{100} = \frac{9200}{2} \]

\[ = Rs.920 \]

Now S.D. = P.W. + T.D. \[ = 23,000 + 920 \]

\[ = Rs.23,920 \]

\[ \therefore \text{The sum due is Rs.23,920} \]

**Ex.2:** What is the true discount on a sum of Rs.12,720 due 9 months hence at 8% p.a. simple interest?

**Solution:**

\[ \text{S.D.} = \text{Rs.12,720}, \quad n = \frac{9}{12} \text{ years}, \]

\[ r = 8\% \]

Now S.D. = P.W. + T.D. \[ = \frac{\text{P.W.} \times n \times r}{100} \]

\[ = \text{P.W.} \left[ 1 + \frac{n \times r}{100} \right] \]

\[ = \text{P.W.} \left[ 1 + \frac{\frac{9}{12} \times 8}{100} \right] \]

\[ \therefore 12720 = \text{P.W.} \left[ 1 + \frac{6}{100} \right] \]

\[ = \text{P.W.} \frac{106}{100} \]

\[ = \text{P.W.} \frac{106}{100} \]

\[ \therefore \text{P.W.} = \frac{12720 \times 100}{106} \]
= Rs.12,000

\[ \therefore \text{T.D.} = \text{S.D.} - \text{P.W.} \]
= 12,720 - 12,000

\[ \therefore \text{T.D.} = \text{Rs.720} \]

**Ex.3:** The present worth of sum of Rs.8,268 due 8 months hence is Rs.7,800. Find the rate of interest.

**Solution:**
\[ \text{S.D.} = \text{Rs.8,268}, \text{P.W.} = 7,800, \]
\[ n = \frac{8}{12} \text{ years} \]

Now \[ \text{T.D.} = \text{S.D.} - \text{P.W.} \]
= 8,268 - 7,800
= 468

\[ \text{T.D.} = \frac{\text{P.W.} \times n \times r}{100} \]

\[ 468 = \frac{7800 \times \frac{8}{12} \times r}{100} \]

\[ 468 = 78 \times \frac{2}{3} \times r \]

\[ r = \frac{468 \times 3}{78 \times 2} \]

\[ = 9 \]

\[ \therefore \text{Rate of interest is 9%} \]

**Ex.4:** A bill of Rs.15,000 drawn on 15th February 2015 for 10 months was discounted on 13th May 2015 at \( \frac{3}{4} \) \% p.a. Calculate banker’s discount.

**Solution:**

\[ \text{F.V. of the bill}= \text{Rs 15,000} \]

\[ r = \frac{3}{4} \% = \frac{15}{4} \% \]

Date of drawing = 15th February 2015

Period of bill = 10 months

Nominal due date = 15th December 2015

Legal due date = 18th December 2015

Date of discounting = 13th May 2015

\[ \therefore \text{B.D.} = \text{interest on F.V. for 83 days at} \ r \% \]

\[ 160.75 = 10,100 \times \frac{83}{365} \times \frac{r}{100} \]

\[ \therefore r = \frac{16075 \times 365}{10100 \times 83} \]

\[ = 6.99 \]

\[ \therefore \text{Rate of interest is 6.99\%} \approx 7\% \]
**Ex.6:** A bill of Rs.18,000 was discounted for Rs.17,568 at a bank on 25th October 2017. If the rate of interest was 12% p.a., what is the legal date?

**Solution:**

\[ S.D. = 18,000 \quad C.V. = 17,568 \]
\[ r = 12\% \text{ p.a.} \]

Now, B.D. = S.D. - C.V.
\[ = 18,000 - 17,568 \]
\[ = Rs. 432 \]

Also, B.D. = \( \frac{S.D. \times n \times r}{100} \)
\[ 432 = \frac{18000 \times n \times 12}{100} \]
\[ \therefore n = \frac{432 \times 100}{18000 \times 12} \]
\[ \therefore n = \frac{1}{5} \]
\[ \therefore n = \frac{1}{5} \text{ years} \]
\[ \frac{365}{5} = 73 \text{ days} \]

The period for which the discount is deducted is 73 days, which is counted from the date of discounting i.e. 25th October 2017.

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<td>18</td>
<td>30</td>
<td>12</td>
<td>60</td>
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Date of discounting = (31 – 12) = 19th Oct.
\[ \therefore \text{Date of discounting is 19th October.} \]

**Ex.7:** A bill of Rs.29,200 drawn on 15th June for 6 months, was discounted for Rs.28,960 at 5% p.a. On which day was the bill discounted?

**Solution:**

\[ F.V. = Rs \, 29200, \quad C.V. = Rs \, 28960 \]

Now, B.D. = F.V. - C.V.
\[ = 29200 - 28960 \]
\[ = Rs. \, 240 \]

Date of drawing = 15th June

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<td>06</td>
<td>30</td>
<td>31</td>
<td>6</td>
<td>73</td>
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Hence legal due date is 6th January 2017.

**Ex.8:** Find the true discount, banker’s discount and banker’s gain on a bill of Rs.64,800 due 3 months hence discounted at 5% p.a.

**Solution:**

\[ S.D. = 64,800, \quad n = 3 \text{ months} = \frac{3}{12} = \frac{1}{4} \text{ years} \]
\[ r = 5\% \text{ p.a.} \]

Now
\[ \text{B.D.} = \frac{S.D. \times n \times r}{100} \]
\[ = 64,800 \times \frac{1}{4} \times \frac{5}{100} \]
\[ = Rs. \, 810 \]

Let T.D. = Rs. \, x

\[ \text{B.D.} = \text{T.D.} + \text{Interest on T.D. for } \frac{1}{4} \text{ year at } 5\% \text{ p.a.} \]
\[ 810 = x + \left( x \times \frac{1}{4} \times \frac{5}{100} \right) \]
\[ = x + \frac{x}{80} \]
\[ = \frac{81x}{80} \]
\[ \therefore x = \frac{810 \times 80}{81} = Rs. 800 \]

Banker's gain = banker's discount - true discount

i.e. B.G. = B.D. - T.D.

= 810 - 800

= Rs. 10

\therefore Banker's gain is Rs. 10

**Ex. 9:** The difference between true discount and banker's discount on a bill due 6 months hence at 4% is Rs. 160. Calculate true discount, banker's discount and amount of bill.

**Solution:** Let T.D. = Rs. \( x \), \( n = \frac{6}{12} = \frac{1}{2} \) years

B.G. = B.D. - T.D.

= Interest on T.D for 6 months at 4% p.a.

\[ \therefore 160 = x \times \frac{1}{2} \times \frac{4}{100} = \frac{x}{50} \]

\[ \therefore x = 8,000 \]

B.D. = B.G. + T.D.

= 160 + 8,000

= 8,160

\therefore Banker's Discount = Rs. 8,160

B.D. = interest on F.V. for 6 months at 4% p.a.

Let the face value (F.V.) be \( y \).

\[ \therefore B.D. = y \times \frac{1}{2} \times \frac{4}{100} \]

\[ 8,160 = \frac{y}{50} \]

\[ \therefore y = 4,08,000 \]

\therefore Amount of bill is Rs. 4,08,000

**Ex. 10:** A banker's discount calculated for 1 year is 13.5 times its banker’s gain. Find the rate of interest.

**Solution:** Let the banker’s gain = Rs. \( x \)

\[ \therefore B.D. = 13.5 \times x \]

\[ = 13.5 \times x \]

Now

B.G. = B.D. - T.D.

\[ x = 13.5x - T.D. \]

T.D. = 12.5 \( x \)

But

B.G. = Interest on T.D. for 1 year

\[ = \frac{T.D. \times n \times r}{100} \]

\[ x = \frac{12.5x \times 1 \times r}{100} \]

\[ 100x = 12.5xr \]

\[ r = 8 \]

\therefore Rate of interest is 8% p.a.

**Let's Remember**

- Invoice Price = List Price (catalogue price) - Trade Discount
  
  i.e. I.P. = L.P. - T.D.

- Net Selling Price = Invoice Price - Cash Discount
  
  i.e. N.S.P. = I.P. - C.D.

- Profit = Net Selling price (NSP) - Cost Price (C.P)

- Loss =
  
  Cost Price (C.P) - Net Selling Price (NSP)

- Sum due = Present Worth + True Discount
  
  i.e. S.D. = P.W. + T.D.

- T.D. = \( \frac{P.W. \times n \times r}{100} \)

- B.D. = \( \frac{S.D. \times n \times r}{100} \)

- B.G. = B.D. - T.D.

- B.G. = \( \frac{T.D. \times n \times r}{100} \)

- Cash value = S.D. - B.D.
EXERCISE 1.2

1. What is the present worth of a sum of Rs.10,920 due six months hence at 8% p.a. simple interest?

2. What is sum due of Rs.8,000 due 4 months hence at 12.5% simple interest?

3. True discount on the sum due 8 months hence at 12% p.a. is Rs.560. Find the sum due and present worth of the bill.

4. The true discount on a sum is \(\frac{3}{8}\) of the sum due at 12% p.a. Find the period of the bill.

5. 20 copies of a book can be purchased for a certain sum payable at the end of 6 months and 21 copies for the same sum in ready cash. Find the rate of interest.

6. Find the true discount, Banker’s discount and Banker’s gain on a bill of Rs.4,240 due 6 months hence at 9% p.a.

7. True discount on a bill is Rs.2,200 and bankers discount is Rs.2,310. If the bill is due 10 months, hence, find the rate of interest.

8. A bill of Rs.6,935 drawn on 19th January 2015 for 8 months was discounted on 28th February 2015 at 8% p.a. interest. What is the banker’s discount? What is the cash value of the bill?

9. A bill of Rs.8,000 drawn on 5th January 1998 for 8 months was discounted for Rs.7,680 on a certain date. Find the date on which it was discounted at 10% p.a.

10. A bill drawn on 5th June for 6 months was discounted at the rate of 5% p.a. on 19th October. If the cash value of the bill is Rs 43,500, find face value of the bill.

11. A bill was drawn on 14th April for Rs.7,000 and was discounted on 6th July at 5% p.a. The Banker paid Rs.6,930 for the bill. Find period of the bill.

12. If difference between true discount and banker’s discount on a sum due 4 months hence is Rs 20. Find true discount, banker’s discount and amount of bill, the rate of simple interest charged being 5%p.a.

13. A bill of Rs.51,000 was drawn on 18th February 2010 for 9 months. It was encashed on 28th June 2010 at 5% p.a. Calculate the banker’s gain and true discount.

14. A certain sum due 3 months hence is \(\frac{21}{20}\) of the present worth, what is the rate of interest?

15. A bill of a certain sum drawn on 28th February 2007 for 8 months was encashed on 26th March 2007 for Rs.10,992 at 14% p.a. Find the face value of the bill.

MISCELLANEOUS EXERCISE - 1

I) Choose the correct alternative.

1. An agent who gives guarantee to his principal that the party will pay the sale price of goods is called
   a. Auctioneer  b. Del Credere Agent  c. Factor  d. Broker

2. An agent who is given the possession of goods to be sold is known as
   a. Factor  b. Broker  c. Auctioneer  d. Del Credere Agent

3. The date on which the period of the bill expires is called
   a. Legal Due Date  b. Grace Date  c. Nominal Due Date  d. Date of Drawing

4. The payment date after adding 3 days of grace period is known as
   a. The legal due date  b. The nominal due date  c. Days of grace  d. Date of drawing

5. The sum due is also called as
   a. Face value  b. Present value  c. Cash value  d. True discount
6. P is the abbreviation of
   a. Face value   b. Present worth
c. Cash value   d. True discount

7. Banker’s gain is simple interest on
   a. Banker’s discount
   b. Face Value
c. Cash value
d. True discount

8. The marked price is also called as
   a. Cost price   b. Selling price
c. List price   d. Invoice price

9. When only one discount is given then
   a. List price = Invoice price
   b. Invoice price = Net selling price
c. Invoice price = Cost price
d. Cost price = Net selling price

10. The difference between face value and present worth is called
    a. Banker’s discount
    b. True discount
c. Banker’s gain
d. Cash value

II) Fill in the blanks.
    1. A person who draws the bill is called _____
    2. An _____ is an agent who sells the goods by auction.
    3. Trade discount is allowed on the ____ price.
    4. The banker’s discount is also called _____.
    5. The banker’s discount is always _____ than the true discount.
    6. The difference between the banker’s discount and the true discount is called _____.
    7. The date by which the buyer is legally allowed to pay the amount is known as _____.

8. A _____ is an agent who brings together the buyer and the seller.
9. If buyer is allowed both trade and cash discounts, _____ discount is first calculated on _____ price.
10. _____ = List price (catalogue Price) – Trade Discount.

III) State whether each of the following is True or False.
    1. Broker is an agent who gives a guarantee to seller that the buyer will pay the sale price of goods.
    2. Cash discount is allowed on list price.
    3. Trade discount is allowed on catalogue price.
    4. The buyer is legally allowed 6 days grace period.
    5. The date on which the period of the bill expires is called the nominal due date.
    6. The difference between the banker’s discount and true discount is called sum due.
    7. The banker’s discount is always lower than the true discount.
    8. The bankers discount is also called as commercial discount.
    9. In general cash discount is more than trade discount.
    10. A person can get both, trade discount and cash discount.

IV) Solve the following problems.
    1. A salesman gets a commission of 6.5% on the total sales made by him and bonus of 1% on sales over Rs.50,000. Find his total income on a turnover of Rs.75,000.

    2. A shop is sold at 30% profit, the amount of brokerage at the rate of $\frac{3}{4}$% amounts to Rs.73,125. Find cost of the shop.
3. A merchant gives 5% commission and 1.5% del credere to his agent. If the agent sells goods worth Rs.30,600 how much does he get? How much does the merchant receive?

4. After deducting commission at \( \frac{7 \frac{1}{2}}{2} \) on first Rs.50,000 and 5% on balance of sales made by him, an agent remits Rs.93750 to his principal. Find the value of goods sold by him.

5. The present worth of Rs.11,660 due 9 months hence is Rs.11,000. Find the rate of interest.

6. An article is marked at Rs.800, a trader allows a discount of 2.5% and gains 20% on the cost. Find the cost price of the article.

7. A salesman is paid fixed monthly salary plus commission on the sales. If on sale of Rs.96,000 and Rs.1,08,000 in two successive months he receives in all Rs.17,600 and Rs.18,800 respectively. Find his monthly salary and rate of commission paid to him.

8. A merchant buys some mixers at 15% discount on catalogue price. The catalogue price is Rs.5,500 per piece of mixer. The freight charges amount to \( 2 \frac{1}{2} \) on the catalogue price. The merchant sells each mixer at 5% discount on catalogue price. His net profit is Rs.41,250. Find number of mixers.

9. A bill is drawn for Rs.7000 on 3rd May for 3 months and is discounted on 25th May at 5.5%. Find the cash value.

10. A bill was drawn on 14th April 2005 for Rs.3,500 and was discounted on 6th July 2005 at 5% per annum. The banker paid Rs.3,465 for the bill. Find the period of the bill.

11. The difference between true discount and banker’s discount on 6 months hence at 4% p.a. is Rs.80. Find the true discount, banker’s discount and amount of the bill.

12. A manufacturer makes clear profit of 30% on cost after allowing 35% discount. If the cost of production rises by 20%, by what percentage should he reduce the rate of discount so as to make the same rate of profit keeping his list prices unaltered.

13. A trader offers 25% discount on the catalogue price of a radio and yet makes 20% profit. If he gains Rs.160 per radio, what must be the catalogue price of the radio?

14. A bill of Rs.4,800 was drawn on 9th March 2006 for 6 months and was discounted on 19th April 2006 at 6 \( \frac{1}{2} \) % p.a. How much does the banker charge and how much does the holder receive?

15. A bill of Rs.65,700 drawn on July 10 for 6 months was discounted for Rs.65,160 at 5% p.a. On what day was the bill discounted?

16. An agent sold a car and charged 3% commission on sale value. If the owner of the car received Rs.48,500, find the sale value of the car. If the agent charged 2% from the buyer, find his total remuneration.

17. An agent is paid a commission of 4% on cash sales and 6% on credit sales made by him. If on the sale of Rs.51,000 the agent claims a total commission of Rs.2,700, find the sales made by him for cash and on credit.
1) The value of the goods sold = Rs. $x$

Commission @ 7.5% on first Rs.10,000
= Rs. $\frac{5}{100} \times 10000$

Commission @ 5% on the balance
= Rs. $\frac{(x-10000) \times 5}{100}$

An Agent remits Rs.33950 to his Principal

\[ x - \boxed{10000} - \boxed{33950} = 33950 \]

\[ \frac{95x}{100} = 33950 + \boxed{10000} \]

\[ \frac{19x}{100} = 34200 \]

\[ x = Rs. \boxed{177000} \]

2) Rate of discount = 15% and other charges = 2.5% on list price.

List price of tricycle in Mumbai = Rs. 600

Net Selling price = List Price – Discount + Other charges

\[ = 600 \times \frac{100}{100} + \frac{2.5}{100} \times \boxed{600} = 525 \]

List price of tricycle in Nashik = Rs. 750

Rate of discount = 10%

Net Selling price = List Price – Discount

\[ = \boxed{750} - \boxed{100} \times 750 \]

\[ = Rs.675 \]

A merchant bought tricycles from Mumbai and sold it in Nashik and made a profit of Rs.13,500

\[ \therefore \text{Profit per tricycles} = 675 - \boxed{13500} \]

\[ = Rs.150 \]

No. of tricycles bought = \[ \frac{\text{Total Profit}}{\text{Profit per tricycles}} \]

\[ = \boxed{22} \]

\[ = 13\% \]

3) Cost Price = Rs.100

A manufacturer makes a profit of 30% on cost after allowing 35% discount.

\[ \therefore \text{Selling price} = 100 + \frac{30}{100} \times \boxed{100} \]

\[ = Rs.130 \]

\[ \therefore \text{Selling price} = \text{List price} - \text{Discount} \]

\[ \therefore 130 = \text{List price} - \frac{35}{100} \times \boxed{100} \]

\[ \therefore 130 = \frac{65}{100} \times \boxed{100} \]

\[ \therefore \text{List price} = \boxed{200} \]

Now the cost of production rises by 20%

\[ \therefore \text{New cost price} = 100 + \frac{20}{100} \times 100 \]

\[ = Rs.120 \]

New list price = Rs 200

Rate of discount = $x\%$

\[ \therefore \text{Selling price} = \boxed{200} + \frac{x}{100} \times 200 \]

\[ = Rs.156 \]

\[ \therefore \text{List price} = \text{Selling price} + \text{Discount} \]

\[ \therefore 2x = 200 - \boxed{200} \]

\[ \therefore 2x = 44 \]

\[ \therefore x = \boxed{22} \]

\[ \therefore \text{Reduction in the rate of discount} = \boxed{22} - 22 \]

\[ = 13\% \]
4) Face Value (S) = Rs 4,015 \( r = 8\% \) p.a.
Date of drawing bill = 19th January 2018
Period of the bill = 8 months
Nominal Due date = 
Legal Due date = 22nd September 2018
Date of discounting the bill = 28th February 2018
Number of days from date of discounting to legal due date

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<td>Aug.</td>
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<td>Sept.</td>
<td>30</td>
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<td>Total</td>
<td>206</td>
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\[ \text{B.D.} = \frac{S \times n \times r}{100} = \frac{4015 \times 206 \times 8}{365 \times 100} = \text{Rs.} 181.30 \]

\[ \text{C.V.} = 4015 - \Box = \text{Rs.} 3833.70 \]

5. Face value (S) = Rs 7,300 \( r = 12\% \) p.a.
Cash value (C.V.) = Rs 7,108

\[ \text{B.D.} = S - \Box = \text{Rs.} 192 \]
Date of drawing the bill = 7th June 2017
Date of discounting the bill = 22nd October 2017
Number of days from date of discounting to legal due date = \( x \)

\[ \text{B.D.} = \frac{S.D. \times n \times r}{100} = \frac{\Box \times x \times 12}{100} \]

\[ x = \Box \text{ days} \]

\[ \text{Legal due date is 80 days after the date of discounting the bill.} \]

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<td>80</td>
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\[ \text{Legal due date} = 10\text{th Jan.} \]
Nominal due date = 7th Jan.
period of the bill = \( \Box \) months

🌟🌟🌟
Let's Learn

- Fire, Marine and Accident Insurance
- Annuity
  - Terminology of Annuity
  - Annuity Due
  - Sinking Fund

Introduction

Life is full of risk. Risk is due to uncertainty. It involves a loss or some other undesirable or negative outcome. All of us face some type of risk in every-thing we do and every decision we make. We often look for ways to avoid risk by taking steps to prevent it. However, it is impossible to completely prevent every possible risk. As an alternative, we try to minimize the impact of risk by having insurance or some other type of protection from loss. Insurance is a way of managing the risk in order to protect our life, property, vehicle, or other financial assets against possible loss or damage due to contingencies like burglary, fire, flood, earthquake, etc.

The verb "to insure" means to arrange for compensation in the event of damage or total loss of property or injury or the death of someone, in exchange of regular payments to a company or to the state. The word "insurance" means creation of some security or monetary protection against a possible damage or loss. Insurance is a legal contract between an insurance company (insurer) and a person covered by the insurance (insured). An insurance policy is a legal document of the contract or agreement between the two parties, the insured and the insurer.

Insurance is of two types: Life Insurance and General Insurance.

(1) Life insurance

A person who wishes to be insured for life agrees to pay the insurance company a certain amount of money periodically. This amount is called the premium. The period of the payment can be a month, a quarter, half-year, or a year. In return, the insurance company agrees to pay a definite amount of money in the event of death of the insured or maturity of the policy, that is, at end of the contract period. This amount is called the policy value.

(2) General Insurance

General insurance covers all types of insurance except life insurance. General insurance allows a person to insure properties like buildings, factories, and goodowns containing goods against a possible loss (total or partial) due to fire, flood, earthquake, etc.

Vehicles can be insured to cover the risk of possible damage due to accidents.

In case of loss or damage, the insurance company pays compensation in the same proportion that exists between the policy value and the property value.

All contracts of general insurance are governed by the principle of indemnity, which states that an insured may not be compensated by the insurance company in an amount exceeding the insured's economic loss. As a result, an insured person cannot make profit from an insurance policy.

2.1 Fire, Marine, and Accident Insurance

(1) Fire Insurance

Fire insurance is property insurance that covers damage and losses caused by
fire to property like buildings, godowns containing goods, factories, etc. It is possible to insure the entire property or only its part. The value of the property is called Property Value. The value of the insured part of property is called Policy Value. The amount paid to the insurance company to insure the property is called premium.

\[ \text{Premium} = \text{Rate of Premium} \times \text{Policy Value} \]

The period of a fire insurance policy is one year and the premium is expressed as percentage of the value of the insured property.

In case of damage to the property due to fire, the insurance company agrees to pay compensation in the proportion that exist between policy value and property value. The value of the damage is called “loss” and the amount that the insured can demand under the policy is called claim.

\[ \therefore \text{Claim} = \text{Loss} \times \frac{\text{Policy Value}}{\text{Property Value}} \]

(2) **Accident Insurance**

Personal accident insurance is a policy that can reimburse your medical costs, provide compensation in case of disability or death caused by accidents. Accident insurance allows insuring vehicles like cars, trucks, two wheelers, etc. against a vehicle due to accidents. This policy also covers the liability of the insured person to third parties involved in the accident. The period of such policies is one year.

(3) **Marine Insurance**

Marine Insurance covers goods, freight, cargo, etc. against loss or damage during transit by road, rail, sea or air. Shipments are protected from the time they leave the seller’s warehouse till the time they reach the buyer’s warehouse. Marine insurance offers complete protection during transit goods and compensates in the events of any loss.

The party responsible for insuring the goods is determined by the sales contract. The amount of claim is calculated by the same method that is used in the case of fire insurance.

### SOLVED EXAMPLES

Ex. 1: A building worth Rs. 50,00,000 is insured for \( \left(\frac{4}{5}\right) \) of its value at a premium of 5%. Find the amount of premium. Also, find commission of the agent if the rate of commission is 3%.

**Solution:**

\[
\begin{align*}
\text{Property value} & = \text{Rs. } 5000000 \\
\text{Policy value} & = \frac{4}{5} \times 5000000 \\
& = \text{Rs. } 4000000 \\
\text{Rate of premium} & = 5\% \\
\therefore \text{Amount of premium} & = 4000000 \times \frac{5}{100} \\
& = \text{Rs. } 200000 \\
\therefore \text{Premium amount} & = 200000 \times \frac{3}{100} \\
& = \text{Rs. } 6000 \\
\therefore \text{Agent's commission} & = \text{Rs. } 6000
\end{align*}
\]

Ex. 2: A shopkeeper insures his shop valued Rs. 20 lakh for 80% of its value. He pays a premium of Rs. 80000. Find the rate of premium. If the agent gets commission at 12%, find the agent’s commission.

**Solution:**

\[
\begin{align*}
\text{Property value} & = \text{Rs. } 2000000 \\
\text{Insured value} & = 80\% \text{ of property value} \\
& = 2000000 \times \frac{80}{100} \\
& = \text{Rs. } 1600000
\end{align*}
\]
Now, the premium paid = Rs.80000

\[ \therefore \text{Rate of premium} = \frac{100 \times 80000}{1600000} \]

\[ \therefore \text{Rate of premium} = 5\% \]

Commission paid at 12% of premium

\[ = 80000 \times \frac{12}{100} \]

\[ = Rs. 9600. \]

\[ \therefore \text{Agent's commission is Rs.9600}. \]

**Ex. 3:** A car worth Rs.5,40,000 is insured for Rs.4,50,000. The car is damaged to the extent of Rs.2,40,000 is an accident. Find the amount of compensation that can be claimed under the policy.

**Solution:**

Value of the car = Rs. 540000

Insured value = Rs. 450000

Damage = Rs. 240000

\[ \text{Claim} = \frac{\text{Insured value}}{\text{Property value}} \times \text{loss} \]

\[ = \frac{450000}{540000} \times 240000 \]

\[ = Rs.200000 \]

\[ \therefore \text{A compensation of Rs. 2,00,000 can be claimed under the policy.} \]

**Ex. 4:** 10000 copies of a book, priced Rs. 80 each were insured for \( \frac{3}{5} \)th of their value. Some copies of the book were damaged in transit, and were therefore reduced to 60% of their value. If the amount recovered against the damage was Rs.24000, find the number of damaged copies of the book.

**Solution :**

Total number of copies = Rs. 10000

Cost of one book = Rs.80

Insured value = \( \frac{3}{5} \) \times \text{Property value}

Insurance claim = Rs.24000

Now, claim = \( \frac{\text{Insured value}}{\text{Property value}} \times \text{loss} \)

\[ \therefore 24000 = \frac{3}{5} \times \text{loss} \]

\[ \therefore \text{loss} = 24000 \times \frac{5}{3} \]

\[ = Rs.40000 \]

This amount was equal to 40% of the damage.

\[ \therefore \text{Total damage} = 40000 \times \frac{100}{40} \]

\[ = Rs.100000 \]

Since cost of one book was Rs. 80

The number of books damaged = \( \frac{100000}{80} \)

\[ \therefore 1250 \text{ books were damaged}. \]

**Ex. 5:** A cargo valued at Rs.10,00,000 was insured for Rs.7,00,000 during a voyage. If the rate of premium is 0.4%, find (i) the amount of premium, (ii) The amount that can be claimed if the cargo worth Rs.6,00,000 is destroyed, (iii) the amount that can be claimed, if cargo worth Rs.6,00,000 is destroyed completely and the remaining cargo is so damaged that its value is reduced by 40%.

**Solution:**

Property value = Rs. 10,00,000

Policy value = Rs. 7,00,000

Rate of premium = 0.4%

i) Premium = 0.4% of policy value

\[ = 700000 \times \frac{0.4}{100} \]

\[ = Rs. 2800 \]

\[ \therefore \text{Total Premium} = Rs. 2800 \]

ii) Claim = \( \text{loss} \times \frac{\text{Policy Value}}{\text{Property value}} \)

\[ = 600000 \times \frac{700000}{1000000} \]

\[ = Rs. 420000 \]
iii) Total value of cargo = Rs. 1000000

Value of the cargo completely destroyed = Rs.600000

\[ \therefore \text{Value of remaining cargo} = \text{Rs.400000} \]

Loss on value of remaining cargo = 40% of the value of remaining cargo

\[ = \frac{40}{100} \times 400000 = \text{Rs.160000} \]

\[ \therefore \text{Total loss} = 600000 + 160000 = \text{Rs.760000} \]

\[ \therefore \text{Claim} = \text{loss} \times \frac{\text{Policy Value}}{\text{Property Value}} \]

\[ = 760000 \times \frac{700000}{1000000} = \text{Rs. 532000} \]

**Ex. 6**: A property worth Rs.4,00,000 is insured with three companies X, Y, and Z for amounts Rs.1,20,000, Rs.80,000, and Rs. 1,00,000 respectively. A fire caused a loss of Rs. 2,40,000. Calculate the amounts that can be claimed from the three companies.

**Solution**:

Loss = Rs.2,40,000

\[ \text{Claim} = \text{Loss} \times \frac{\text{Policy Value}}{\text{Property Value}} \]

Claim from company X = 2,40,000 \times \frac{120000}{400000} = Rs. 72,000

Claim from company Y = 2,40,000 \times \frac{80000}{400000} = Rs. 48,000

Claim from company Z = 2,40,000 \times \frac{100000}{400000} = Rs. 60,000

**Ex. 7**: An agent places insurance for Rs. 4,00,000 on life of a person. The premium is to be paid annually at the rate of Rs.35 per thousand per annum. Find the agent’s commission at 15% on the first premium.

**Solution**:

Policy value = Rs. 4,00,000

Rate of premium = Rs.35 per thousand p.a.

\[ \therefore \text{Amount of premium} = \frac{35}{1000} \times 400000 = \text{Rs.14,000} \]

Rate of commission = 15% 

\[ \therefore \text{Amount of commission} = 14000 \times \frac{15}{100} = \text{Rs.2100} \]

**Ex. 8**: A person takes a life policy of Rs. 2,00,000 for 15 years. The rate of premium is Rs. 55 per thousand per annum. If the bonus is paid at the average rate of Rs. 6 per thousand, what is the benefit to the insured?

**Solution**:

Policy value = Rs. 2,00,000

Rate of premium = Rs.55 per thousand p.a.

\[ \therefore \text{Amount of premium} = \frac{55}{1000} \times 200000 = \text{Rs.11,000} \]

The insured pays premium for 15 years.

\[ \therefore \text{Total premium paid} = 11000 \times 15 = \text{Rs.165000} \]

Rate of bonus is Rs.6 per thousand per annum on the policy value. Therefore, on the policy Rs. 2,00,000

bonus for 1 year = 6 \times 200

= Rs.1200

\[ \therefore \text{bonus for 15 year} = 1200 \times 15 = \text{Rs.18000} \]

Hence, when the policy matures, the insured gets

\[ = 200000 + 18000 = \text{Rs.2,18,000} \]

\[ \therefore \text{Benefit} = 218000 - 165000 = \text{Rs.53000} \]
EXERCISE 2.1

1. Find the premium on a property worth Rs. 25,00,000 at 3% if (i) the property is fully insured, (ii) the property is insured for 80% of its value.

2. A shop is valued at Rs. 3,60,000 for 75% of its value. If the rate of premium is 0.9%, find the premium paid by the owner of the shop. Also, find the agent's commission if the agent gets commission at 15% of the premium.

3. A person insures his office valued at Rs. 5,00,000 for 80% of its value. Find the rate of premium if he pays Rs.13,000 as premium. Also, find the agent's commission at 11%.

4. A building is insured for 75% of its value. The annual premium at 0.70 per cent amounts to Rs.2625. If the building is damaged to the extent of 60% due to fire, how much can be claimed under the policy?

5. A stock worth Rs.7,00,000 was insured for Rs.4,50,000. Fire burnt stock worth Rs.3,00,000 completely and damaged the remaining stock to the extent of 75% of its value. What amount can be claimed under the policy?

6. A cargo of rice was insured at 0.625 % to cover 80% of its value. The premium paid was Rs.5250. If the price of rice is Rs.21 per kg, find the quantity of rice (in kg) in the cargo.

7. 60,000 articles costing Rs.200 per dozen were insured against fire for Rs. 2,40,000. If 20% of the articles were burnt and 7200 of the remaining articles were damaged to the extent of 80% of their value, find the amount that can be claimed under the policy.

8. The rate of premium is 2% and other expenses are 0.75%. A cargo worth Rs.3,50,100 is to be insured so that all its value and the cost of insurance will be recovered in the event of total loss.

9. A property worth Rs. 4,00,000 is insured with three companies. A, B, and C. The amounts insured with these companies are Rs.1,60,000, Rs.1,00,000 and Rs.1,40,000 respectively. Find the amount recoverable from each company in the event of a loss to the extent of Rs. 9,000.

10. A car valued at Rs.8,00,000 is insured for Rs.5,00,000. The rate of premium is 5% less 20%. How much will the owner bear including the premium if value of the car is reduced to 60% of its original value.

11. A shop and a godown worth Rs.1,00,000 and Rs.2,00,000 respectively were insured through an agent who was paid 12% of the total premium. If the shop was insured for 80% and the godown for 60% of their respective values, find the agent's commission, given that the rate of premium was 0.80% less 20% .

12. The rate of premium on a policy of Rs. 1,00,000 is Rs.56 per thousand per annum. A rebate of Rs.0.75 per thousand is permitted if the premium is paid annually. Find the net amount of premium payable if the policy holder pays the premium annually.

13. A warehouse valued at Rs.40,000 contains goods worth Rs.240,000. The warehouse is insured against fire for Rs.16,000 and the goods to the extent of 90% of their value. Goods worth Rs.80,000 are completely destroyed, while the remaining goods are destroyed to 80% of their value due to a fire. The damage to the warehouse is to the extent of Rs.8,000. Find the total amount that can be claimed.

14. A person takes a life policy for Rs.2,00,000 for a period of 20 years. He pays premium for 10 years during which bonus was declared at an average rate of Rs.20 per year per thousand. Find the paid up value of the policy if he discontinues paying premium after 10 years.
2.2 Annuity

When you deposit some money in a bank, you are entitled to receive more money (in the form of interest) from the bank than you deposit, after a certain period of time. Similarly, when people borrow money for a certain period of time, they pay back more money (again, in the form of interest). These two examples show how money has a time value. A rupee today is worth more than a rupee after one year. The time value of money explains why interest is paid or earned. Interest, whether it is on a bank deposit or a loan, compensates the depositor or lender for the time value of money. When financial transactions occur at different points of time, they must be brought to a common point in time to make them comparable.

Consider the following situation. Ashok deposits Rs.1000 every year in his bank account for 5 years at a compound interest rate of 10 per cent per annum. What amount will Ashok receive at the end of five years? In other words, we wish to know the future value of the money Ashok deposited annually for five years in his bank account.

Assuming that Rs.1000 are deposited at end of every year, the future value is given by

\[ 1000 \left(1 + \frac{1}{10}\right)^4 + \left(1 + \frac{1}{10}\right)^3 + \left(1 + \frac{1}{10}\right)^2 + \left(1 + \frac{1}{10}\right) + 1 \]

\[ = 6105.1 \]

In the same situation, the present value of the amount that Ashok deposits in his bank account is given by

\[ \frac{1000}{(1.10)^4} + \frac{1000}{(1.10)^3} + \frac{1000}{(1.10)^2} + \frac{1000}{1.10} + 1 \]

\[ = Rs.3790.78 \]

We also come across a situation where a financial company offers to pay Rs.8,000 after 12 years for Rs.1000 deposited today. In such situations, we wish to know the interest rate offered by the company.

Studies of this nature can be carried out by studying Annuity.

An annuity is a sequence of payments of equal amounts with a fixed frequency. The term "annuity" originally referred to annual payments (hence the name), but it is now also used for payments with any frequency. Annuities appear in many situations: for example, interest payments on an investment can be considered as an annuity. An important application is the schedule of payments to pay off a loan. The word "annuity" refers in everyday language usually to a life annuity. A life annuity pays out an income at regular intervals until you die. Thus, the number of payments that a life annuity makes is not known. An annuity with a fixed number of payments is called an annuity certain, while an annuity whose number of payments depend on some other event (such as a life annuity) is a contingent annuity. Valuing contingent annuities requires the use of probabilities.

**Definition**

An annuity is a series of payments at fixed intervals, guaranteed for a fixed number of years or the lifetime of one or more individuals. Similar to a pension, the money is paid out of an investment contract under which the annuitant(s) deposit certain sums (in a lump sum or in installments) with an annuity guarantor (usually a government agency or an insurance company). The amount paid back includes principal and interest.

**1.2.1 Terminology of Annuity**

**Four parties to an annuity**

**Annuitant** - A person who receives an annuity is called the annuitant.
Issuer - A company (usually an insurance company) that issues an annuity.

Owner - An individual or an entity that buys an annuity from the issuer of the annuity and makes contributions to the annuity.

Beneficiary - A person who receives a death benefit from an annuity at the death of the annuitant.

Two phases of an annuity

Accumulation phase - The accumulation (or investment) phase is the time period when money is added to the annuity. An annuity can be purchased in one single lump sum (known as a single premium annuity) or by making investments periodically over time.

Distribution phase - The distribution phase is when the annuitant receiving distributions from the annuity. There are two options for receiving distributions from an annuity. The first option is to withdraw some or all of the money in the annuity in lump sums. The second option (commonly known as guaranteed income or annuitization option) provides a guaranteed income for a specific period of time or the entire lifetime of the annuitant.

Types of Annuities - There are three types of annuities.

(i) Annuity Certain. An annuity certain is an investment that provides a series of payments for a set period of time to a person or to the person's beneficiary. It is an investment in retirement income offered by insurance companies. The annuity may also be taken as a lump sum.

Because it has a set expiration date, an annuity certain generally pays a higher rate of return than lifetime annuity. Typical terms are 10, 15, or 20 years.

Contingent Annuity. Contingent annuity is a form of annuity contract that provides payments at the time when the named contingency occurs. For instance, upon death of one spouse, the surviving spouse will begin to receive monthly payments. In a contingent annuity policy the payment will not be made to the annuitant or the beneficiary until a certain stated event occurs.

Perpetual Annuity or Perpetuity. A perpetual annuity, also called a perpetuity promises to pay a certain amount of money to its owner forever.

Though a perpetuity may promise to pay you forever, its value isn’t infinite. The bulk of the value of a perpetuity comes from the payments that you receive in the near future, rather than those you might receive 100 or even 200 years from now.

Classification of Annuities - Annuities are classified in three categories according to the commencement of income. These three categories are: Immediate Annuity, Annuity Due, and Deferred Annuity.

Immediate Annuity or Ordinary Annuity - The immediate annuity commences immediately after the end of the first income period. For instance, if the annuity is to be paid annually, then the first installment will be paid at the expiry of one year. Similarly in a half-yearly annuity, the payment will begin at the end of six months. The annuity can be paid either yearly, half-yearly, quarterly or monthly.

The purchase money (or consideration) is in a single amount. Evidence of age is always asked for at the time of entry.

Annuity Due - Under this annuity, the payment of installment starts from the time of contract. The first payment is made as soon as the contract is finalized. The premium is generally paid in single amount but can be paid in installments as is discussed in the deferred annuity. The difference between the annuity due and immediate annuity is that the payment for each period is paid in its beginning under the annuity due contract while at the end of the period in the immediate annuity contract.

Deferred Annuity - In this annuity contract the payment of annuity starts after a deferment period or at the attainment by the annuitant of
a specified age. The premium may be paid as a single premium or in instalments.

The premium is paid until the date of commencement of the instalments.

We shall study only immediate annuity and annuity due.

**Present value of an annuity** - The present value of an annuity is the current value of future payments from an annuity, given a specified rate of return or discount rate. The annuity's future cash flows are discounted at the discount rate. Thus the higher the discount rate, the lower the present value of the annuity.

**Future value of an annuity** - The future value of an annuity represents the amount of money that will be accumulated by making consistent investments over a set period, assuming compound interest. Rather than planning for a guaranteed amount of income in the future by calculating how much must be invested now, this formula estimates the growth of savings given a fixed rate of investment for a given amount of time.

The present value of an annuity is the sum that must be invested now to guarantee a desired payment in the future, while the future value of an annuity is the amount to which current investments will grow over time.

**Note:**

1. We consider only uniform and certain annuities.
2. If the type of an annuity is not mentioned, we assume that the annuity is immediate annuity.
3. If there is no mention of the type of interest, then it is assumed that the interest is compounded per annum.

If payments are made half-yearly (that is, twice per year), then \( r \) is replaced by \( \frac{r}{2} \) (the compounding rate) and \( n \) is replaced by \( 2n \) (the number of time periods).

If payments are made quarterly (that is, four times per year), then \( r \) is replaced by \( \frac{r}{4} \) (the compounding rate) and \( n \) is replaced by \( 4n \) (the number of time periods).

If payments are made monthly (that is, 12 times per year), then \( r \) is replaced by \( \frac{r}{12} \) (the compounding rate) and \( n \) is replaced by \( 12n \) (the number of time periods).

**Immediate Annuity** - Payments are made at the end of every time period in immediate annuity.

**Basic formula for an immediate annuity** - The accumulated value \( A \) of an immediate annuity for \( n \) annual payments of an amount \( C \) at an interest rate \( r \) per cent per annum, compounded annually, is given by:

\[
A = \frac{C}{i} \left[ \frac{1}{1 + i} \right] \quad \text{where} \quad i = \frac{r}{100}
\]

Also, the present value \( P \) of such an immediate annuity is given by

\[
P = \frac{C}{i} \left[ 1 - (1 + i)^{-a} \right]
\]

The present value and the future value of an annuity have the following relations.

\[
\frac{1}{P} \quad \frac{1}{A} \quad \frac{i}{C}
\]

**SOLVED EXAMPLES**

**Ex. 1:** Find the accumulated value after 3 years of an immediate annuity of Rs. 5000 p.a. with interest compounded at 4% p.a. \([\text{given} \ (1.04)^3 = 1.12490]\)

**Solution:**

The problem states that \( C = 5000 \), \( r = 4\% \) p.a., and \( n = 3 \) years.

Then, accumulated value is given by

\[
A = \frac{C}{i} \left[ \frac{1}{1 + i} \right] \quad \left\{ \frac{i}{100} 0.04 \right\}
\]
\[
\begin{align*}
5000 &= \frac{0.04}{0.04} \left[(1+0.04)^5 - 1\right] \\
&= \frac{5000}{0.04} \left[(1.04)^5 - 1\right] \\
&= \frac{5000}{0.04} \left[1.1249 - 1\right] \\
\therefore \ A &= \frac{5000}{0.04} \left[1.1249 - 1\right] \\
\therefore \ A &= \frac{5000}{0.04} (0.1249) \\
\therefore \ A &= 5000(3.12250) \\
\therefore \ A &= 15,612.50
\end{align*}
\]

The accumulated value of the annuity is Rs. 15,612.50

**Ex. 2:** A person plans to accumulate a sum of Rs. 5,00,000 in 5 years for higher education of his son. How much should he save every year if he gets interest compounded at 10% p.a.? [Given : \((1.1)^5 = 1.61051\)]

**Solution:** From the problem, we have

\[A = Rs.5,00,000, \ r = 10\%\text{ p.a.}, \text{ and } n = 5 \text{ years}.\]

\[\therefore \ i = \frac{r}{100} = \frac{10}{100} = 0.10\]

We find \(C\) as follows,

\[A = \frac{C}{i} \left[(1 + \frac{i}{n})^n - 1\right]\]

\[5,00,000 = \frac{C}{0.1} \left[(1 + 0.1)^5 - 1\right]\]

\[5,00,000 = \frac{C}{0.1} \left[(1.1)^5 - 1\right]\]

\[5,00,000 = \frac{C}{0.1} \left[1.61051 - 1\right]\]

\[5,00,000 = \frac{C}{0.1} (0.61051)\]

\[\therefore \ C = \frac{500000 \times 0.1}{0.61051}\]

\[\therefore \ C = \frac{500000}{0.61051} = 81898.74\]

That is, the person should save Rs. 81898.74 every year for 5 years to get Rs. 5,00,000 at the end of 5 years.

**Ex. 3:** Mr. X saved Rs. 5000 every year for some years. At the end of this period, he received an accumulated amount of Rs. 23205. Find the number of years if the interest was compounded at 10% p.a. [Given : \((1.1)^4 = 1.4641\)]

**Solution:** From the problem, we have

\[A = Rs.23205, \ C = Rs.5000 \text{ and } r = 10\%\text{ p.a.}\]

\[\therefore \ i = \frac{r}{100} = \frac{10}{100} = 0.10\]

The value of \(n\) is found as follows.

\[A = \frac{C}{i} \left[(1 + \frac{i}{n})^n - 1\right]\]

\[23205 = \frac{5000}{0.1} \left[(1 + 0.1)^n - 1\right]\]

\[23205 \times 0.1 = (1.1)^n - 1\]

\[\frac{2320.5}{5000} = (1.1)^n - 1\]

\[0.4641 = (1.1)^n\]

\[0.4641 + 1 = (1.1)^n\]

\[1.4641 = (1.1)^n\]

since \((1.1)^4 = 1.4641\)

\[\therefore \ n = 4 \text{ years}\]

**Ex. 4:** Find the rate of interest compounded annually if an immediate annuity of Rs. 20,000 per year amounts to Rs. 41,000 in 2 years.

**Solution:** From the problem, we have

\[A = Rs.41,000, \ C = Rs.20,000 \text{ and } n = 2 \text{ years}.\]

The value of \(n\) is then found as follows.

\[A = \frac{C}{i} \left[(1 + \frac{i}{n})^n - 1\right]\]

\[41000 = \frac{20000}{i} \left[(1 + \frac{i}{2})^2 - 1\right]\]

\[\therefore \ 41000 = \frac{1 + 2i + \frac{i^2}{2}}{i} \cdot \frac{1}{i}\]
\[ \therefore 2.05 = \frac{2i + \frac{r}{i}}{i} \]
\[ \therefore 2.05 = 2 + i \]
\[ \therefore i = 2.05 - 2 \]
\[ \therefore i = 0.05 \text{ but } i = \frac{r}{100} \]
\[ \therefore r = i \times 100 \]
\[ \therefore r = 5 \]
\[ \therefore \text{the rate of interest is } 5\% \text{ p.a.} \]

**Ex. 5:** A person deposited Rs.15,000 every six months for 2 years. The rate of interest is 10\% p.a. compounded half-yearly. Find the amount accumulated at the end of 2 years.

[Given : \((1.05)^4 = 1.2155\)]

**Solution:**

Since an amount of Rs.15,000 is deposited every six months, it is a case of immediate annuity. The problem states that \(C = \text{Rs. } 15,000\). Rate of interest is 10\% p.a. Therefore, it is 5\% for six months. That is, \(r = 5\%\).

\[ \therefore i = \frac{r}{100} = \frac{5}{100} = 0.05 \]

The number of half years in 2 years is 4, and therefore \(n = 4\).

Now we use the formula for accumulated value \(A\) and get

\[ A = \frac{C}{i} \left[ (1 + i)^n - 1 \right] \]
\[ \therefore A = \frac{15000}{0.05} \left[ (1 + 0.05)^4 - 1 \right] \]
\[ = 3,00,000 \left[ 1.2155 - 1 \right] \]
\[ = 3,00,000 \left[ 0.2155 \right] \]
\[ = 64650 \]

\[ \therefore \text{The accumulated amount after 2 years is Rs.64650.} \]

**Ex. 6:** A person deposits Rs.3000 in a bank every quarter. The interest is 8\% compounded every quarter. Find the accumulated amount at the end of 1 year. [Given : \((1.02)^4 = 1.0824\)]

**Solution:**

Since the amount is deposited every quarter, it is an immediate annuity. From the given problem, \(C = 3000\). The rate of interest is 8\% p.a. and hence it is 2\% per quarter. That is, \(r = 0.02\) and hence \(i = 0.02\). The number of quarters in a year is 4. That is, \(n = 4\). We use the formula for accumulated amount to obtain

\[ A = \frac{C}{i} \left[ (1 + i)^n - 1 \right] \]
\[ = \frac{3000}{0.02} \left[ (1 + 0.02)^4 - 1 \right] \]
\[ = 1,50,000 \left[ (1.02)^4 - 1 \right] \]
\[ = 1,50,000 \left[ 1.0824 - 1 \right] \]
\[ = 1,50,000 \left[ 0.0824 \right] \]
\[ = 12360. \]

\[ \therefore \text{Accumulated amount after 1 year is Rs.12,360} \]

**Ex. 7:** Find the present value of an immediate annuity of Rs.50,000 per annum for 4 years with interest compounded at 10\% p.a.

[Given : \((1.1)^4 = 0.6830\)]

**Solution:**

From the problem, we get \(C = 50,000\), \(n = 4\) years, \(r = 10\%\) p.a., so that \(i = 0.1\). We use the formula for present value and get

\[ P = \frac{C}{i} \left[ 1 - (1 + i)^n \right] \]
\[ \therefore P = \frac{50000}{0.1} \left[ 1 - (1 + 0.1)^{-4} \right] \]
\[ \therefore P = \frac{50000}{0.1} \left[ 1 - (1.1)^{-4} \right] \]
\[ \therefore P = \frac{50000}{0.1} \left[ 1 - 0.68300 \right] \]
\[ = 500000(0.3170) \]
\[ = 1,58,493. \]

\[ \therefore \text{Present value of the given annuity is Rs.1,58,493.} \]
Ex. 8: The present value of an immediate annuity paid for 4 years with interest accumulated at 10% p.a. is Rs. 20,000. What is its accumulated value after 4 years? \[\text{Given : } (1.1)^4 = 1.4641\]

Solution:

It is given that \(P = 20,000\), \(n = 4\) years, \(r = 10\%\) p.a., so that \(i = 0.1\). Using the formula for the relation between \(A\) and \(P\), we obtain

\[
A = P(1 + i)^n
\]

\[
\therefore \quad A = 20,000(1 + 0.1)^4
\]

\[= 20,000(1.1)^4
\]

\[= 20,000(1.4641)
\]

\[= 29282.
\]

\[\therefore \text{Accumulated value after 4 years is Rs. 29,282.}\]

Ex. 9: The present and accumulated values of an immediate annuity paid for some years at interest compounded at 10% p.a. are Rs. 4,000 and Rs. 8,000 respectively. Find the amount of every annuity paid.

Solution:

It is given that \(P = 4000\), \(A = 8000\), \(r = 10\%\) p.a., so that \(i = 0.1\).

We use the following formula for finding \(C\).

\[
\frac{1}{P} - \frac{1}{A} = \frac{i}{C}
\]

\[
\therefore \quad \frac{1}{4000} - \frac{1}{8000} = \frac{0.1}{C}
\]

\[= 0.00025 - 0.000125 = \frac{0.1}{C}
\]

\[\therefore \quad 0.000125 = \frac{0.1}{C}
\]

\[\therefore \quad C = \frac{0.1}{0.000125}
\]

\[= \frac{100000}{125}
\]

\[= 800.
\]

\[\therefore \text{Every annuity paid is Rs. 800.}\]

Annuity Due

Payments are made at the beginning of every time period in annuity due.

Basic formula for an annuity due

Let \(C\) denote the amount paid at the beginning of each of \(n\) years and let \(r\) denote the rate of interest per cent per annum.

Let \(i = \frac{r}{100}\)

The accumulated value \(A'\) is given by

\[A' = \frac{C(1+i)}{i}[(1 + i)^n - 1]\]

The present value \(P\) is given by

\[P = \frac{C(1+i)}{i}[1 - (1 + i)^n]\]

\(A'\) and \(P\) have the following relations.

\[\frac{1}{P} - \frac{1}{A'} = \frac{i}{C(1+i)}\]

Note:

We can use the formula of immediate annuity for annuity due only by replacing \(C\) by \(C(1 + i)\)

SOLVED EXAMPLES

Ex. 1: Find an accumulated value of an annuity due of Rs. 2,000 per annum for 4 years at 10% p.a. \([\text{Given } (1.1)^4 = 1.4641]\)

Solution: Given \(C = \text{Rs. 2,000}\), \(n = 4\) years,

\(r = 10\%\) p.a. so that \(i = 0.1\).

We use the formula for accumulated value \(A'\) of an annuity due to get

\[A' = \frac{C(1+i)}{i}[(1 + i)^n - 1]\]

\[\therefore \quad A' = \frac{2000(1+0.1)}{0.1}[(1 + 0.1)^4 - 1]\]

\[= \frac{4000}{0.1}[1.4641 - 1]\]

\[= 800.
\]

\[\therefore \text{Every annuity paid is Rs. 800.}\]
\[ A = 10,00,000 - 50,000 \]
\[ A = 9,50,000 \]

**Ex. 2:** Find the present value of an annuity due of Rs. 5,000 to be paid per quarter at 16% p.a. compounded quarterly for 1 year. [Given: \((1.04)^4 = 0.8548\)]

**Solution:**

Given \( C = \text{Rs. 5000}. \) Rate of interest is 16% p.a. and hence it is 4% per quarter. This gives \( i = 0.04. \) Finally, \( n = 4. \)

We use the formula for present value of annuity due to obtain

\[
P = \frac{C(1+i)}{i} [1 - (1+i)^{-n}] \]
\[
= \frac{5000(1+0.04)}{0.04} [1 - (1+0.04)^{-4}] \]
\[
= \frac{5000(1.04)}{0.04} [1 - (0.8548)] \]
\[
= 1,25,000 (1.04)(0.1452) \]
\[
= 18,876 \]

\( \therefore \) Present Value is Rs. 18,876

**Sinking Fund:**

A sinking fund is a fund established by financial organization by setting aside revenue over a period of time compounded annually, to fund a future capital expense, or repayment of a long-term debt.

---

**SOLVED EXAMPLES**

**Ex.** The cost of a machine is Rs. 10 lakh and its effective life is 12 years. The scrap realizes only Rs. 50,000. What amount should be kept aside at the end of every year to accumulate Rs. 9,50,000 at compound interest 5% p.a.?

[Given \((1.05)^{12} = 1.796\)]

**Solution:** Here \( A = \text{Rs. 9.5 lakh}, \) \( r = 5\% , \)

\[
i = \frac{r}{100} = 0.05, \text{ and } n = 12.\]

---

**EXERCISE 2.2**

1. Find the accumulated (future) value of annuity of Rs. 800 for 3 years at interest rate 8% compounded annually.

[Given \((1.08)^3 = 1.2597\)]

2. A person invested Rs. 5,000 every year in finance company that offered him interest compounded at 10% p.a., what is the amount accumulated after 4 years?

[Given \((1.1)^4 = 1.4641\)]

3. Find the amount accumulated after 2 years if a sum of Rs. 24,000 is invested every six months at 12% p.a. compounded half yearly. [Given \((1.06)^2 = 1.2625\)]

4. Find accumulated value after 1 year of an annuity immediate in which Rs. 10,000 are invested every quarter at 16% p.a. compounded quarterly.

[Given \((1.04)^4 = 1.1699\)]

5. Find the present value of an annuity immediate of Rs. 36,000 p.a. for 3 years at 9% p.a. compounded annually.

[Given \((1.09)^3 = 0.7722\)]

6. Find the present value of an ordinary annuity of Rs. 63,000 p.a. for 4 years at 14% p.a. compounded annually.

[Given \((1.14)^{-4} = 0.5921\)]
7. A lady plans to save for her daughter’s marriage. She wishes to accumulate a sum of Rs.4,64,100 at the end of 4 years. What amount should she invest every year if she gets an interest of 10% p.a. compounded annually? [Given \((1.1)^4 = 1.4641\)]

8. A person wants to create a fund of Rs.6,96,150 after 4 years at the time of his retirement. He decides to invest a fixed amount at the end of every year in a bank that offers him interest of 10% p.a. compounded annually. What amount should he invest every year? [Given \((1.1)^4 = 1.4641\)]

9. Find the rate of interest compounded annually if an annuity immediate at Rs.20,000 per year amounts to Rs.2,60,000 in 3 years.

10. Find the number of years for which an annuity of Rs.500 is paid at the end of every year, if the accumulated amount works out to be Rs. 1,655 when interest is compounded annually at 10% p.a.

11. Find the accumulated value of annuity due of Rs.1000 p.a. for 3 years at 10% p.a. compounded annually. [Given \((1.1)^3 = 1.331\)]

12. A person plans to put Rs.400 at the beginning of each year for 2 years in a deposit that gives interest at 2% p.a. compounded annually. Find the amount that will be accumulated at the end of 2 years.

13. Find the present value of an annuity due of Rs.600 to be paid quarterly at 32% p.a. compounded quarterly. [Given \((1.08)^4 = 0.7350\)]

14. An annuity immediate is to be paid for some years at 12% p.a. The present value of the annuity is Rs.10,000 and the accumulated value is Rs.20,000. Find the amount of each annuity payment.

15. For an annuity immediate paid for 3 years with interest compounded at 10% p.a., the present value is Rs.24,000. What will be the accumulated value after 3 years? [Given \((1.1)^3 = 1.331\)]

16. A person sets up a sinking fund in order to have Rs.1,00,000 after 10 years. What amount should be deposited bi-annually in the account that pays him 5% p.a. compounded semi-annually? [Given \((1.025)^{20} = 1.675\)]

---

**Let’s Remember**

- Premium is paid on insured value.
- Agent’s commission is paid on premium.
- Claim = \(\frac{\text{Policy Value}}{\text{Property Value}} \times \text{Loss}\)
- **Immediate Annuity**
  
  \[
  A = \frac{C}{i} \left[1 - (1+i)^{-a}\right]
  \]

  Present value \(P = \frac{C}{i} \left[1 - (1+i)^{-a}\right]\)

  \[
  A = P \left(1 + i\right)^a
  \]

  \[
  \frac{1}{P} - \frac{1}{A} = \frac{i}{C}
  \]

- **Annuity Due**

  \[
  A' = \frac{C(1+i)}{i} \left[(1+i)^{-a}\right]
  \]

  Present value \(P = \frac{C(1+i)}{i} \left[1 - (1+i)^{-a}\right]\)

  \[
  A' = P \left(1 + i\right)^a
  \]

  \[
  \frac{1}{P} - \frac{1}{A'} = \frac{i}{C(1+i)}
  \]
I) Choose the correct alternative.

1. “A contract that pledges payment of an agreed upon amount to the person (or his/her nominee) on the happening of an event covered against” is technically known as
   a. Death coverage  b. Savings for future  
   c. Life insurance  d. Provident fund

2. Insurance companies collect a fixed amount from their customers at a fixed interval of time. This amount is called
   a. EMI  b. Installment  
   c. Contribution  d. Premium

3. Following are different types of insurance.
   I. Life insurance  
   II. Health insurance  
   III. Liability insurance
      (a) Only I  (b) Only II  
      (c) Only III  (d) All the three

4. By taking insurance, an individual
   a. Reduces the risk of an accident  
   b. Reduces the cost of an accident  
   c. Transfers the risk to someone else.  
   d. Converts the possibility of large loss to certainty of a small one.

5. You get payments of Rs.8,000 at the beginning of each year for five years at 6%, what is the value of this annuity?
   a. Rs 34,720  b. Rs 39,320  
   c. Rs 35,720  d. Rs. 40,000

6. In an ordinary annuity, payments or receipts occur at
   a. Beginning of each period  
   b. End of each period  
   c. Mid of each period  
   d. Quarterly basis

7. Amount of money today which is equal to series of payments in future is called
   a. Normal value of annuity  
   b. Sinking value of annuity  
   c. Present value of annuity  
   d. Future value of annuity

8. Rental payment for an apartment is an example of
   a. Annuity due  b. Perpetuity  
   c. Ordinary annuity  d. Installment

9. ______ is a series of constant cashflows over a limited period of time.
   a. Perpetuity  b. Annuity  
   c. Present value  d. Future value

10. A retirement annuity is particularly attractive to someone who has
    a. A severe illness  
    b. Risk of low longevity  
    c. Large family  
    d. Chance of high longevity

II) Fill in the blanks

1. An installment of money paid for insurance is called _______.

2. General insurance covers all risks except _________.

3. The value of property is called _________.

4. The value of insured property is called _________.

5. The person who receives annuity is called _________.

6. The payment of each single annuity is called _________.

7. The intervening time between payment of two successive installments is called as _________.

8. An annuity where payments continue forever is called _________.

9. If payments of an annuity fall due at the beginning of every period, the series is called annuity __________.  
10. If payments of an annuity fall due at the end of every period, the series is called annuity __________.

III) State whether each of the following is True or False.
1. General insurance covers life, fire, and theft.
2. The amount of claim cannot exceed the amount of loss.
3. Accident insurance has a period of five years.
4. Premium is the amount paid to the insurance company every month.
5. Payment of every annuity is called an installment.
6. Annuity certain begins on a fixed date and ends when an event happens.
7. Annuity contingent begins and ends on certain fixed dates.
8. The present value of an annuity is the sum of the present value of all installments.
9. The future value of an annuity is the accumulated values of all installments.
10. Sinking fund is set aside at the beginning of a business.

IV) Solve the following problems.
1. A house valued at Rs. 8,00,000 is insured at 75% of its value. If the rate of premium is 0.80%, find the premium paid by the owner of the house. If agent's commission is 9% of the premium, find agent's commission.
2. A shopkeeper insures his shop and godown valued at Rs.5,00,000 and Rs.10,00,000 respectively for 80% of their values. If the rate of premium is 8%, find the total annual premium.
3. A factory building is insured for \( \left( 5 \right) \) of its value at a rate of premium of 2.50%. If the agent is paid a commission of Rs.2812.50, which is 7.5% of the premium, find the value of the building.
4. A merchant takes fire insurance policy to cover 80% of the value of his stock. Stock worth Rs.80,000 was completely destroyed in a fire, while the rest of stock was reduced to 20% of its value. If the proportional compensation under the policy was Rs.67,200, find the value of the stock.
5. A 35-year old person takes a policy for Rs.1,00,000 for a period of 20 years. The rate of premium is Rs.76 and the average rate of bonus is Rs.7 per thousand p.a. If he dies after paying 10 annual premiums, what amount will his nominee receive?
6. 15,000 articles costing Rs.200 per dozen were insured against fire for Rs.1,00,000. If 20% of the articles were burnt completely and 2400 of other articles were damaged to the extent of 80% of their value, find the amount that can be claimed under the policy.
7. For what amount should a cargo worth Rs.25,350 be insured so that in the event of total loss, its value as well as the cost of insurance may be recovered when the rate of premium is 2.5%.
8. A cargo of grain is insured at \( \left( \frac{3}{4} \right) \) % to cover 70% of its value. Rs.1,008 is the amount of premium paid. If the grain is worth Rs. 12 per kg, how many kg of the grain did the cargo contain?
9. 4000 bedsheets worth Rs. 640,000 were insured for \( \left( \frac{3}{7} \right) \) of their value.

Some of the bedsheets were damaged in the rainy season and were reduced to 40% of their value. If the amount recovered against damage was Rs. 36,000, find the number of damaged bedsheets.

10. A property valued at Rs. 700,000 is insured to the extent of Rs. 560,000 at \( \left( \frac{5}{8} \right) \% \) less 20%. Calculate the saving made in the premium. Find the amount of loss that the owner must bear, including premium, if the property is damaged to the extent of 40% of its value.

11. Stocks in a shop and godown worth Rs. 75,000 and Rs. 1,50,000 respectively were insured through an agent who receive 15% of premium as commission. If the shop was insured for 80% and godown for 60% of the value, find the amount of agent's commission when the premium was 0.80% less 20%. If the entire stock in the shop and 20% stock in the godown is destroyed by fire, find the amount that can be claimed under the policy.

12. A person holding a life policy of Rs. 1,20,000 for a term of 25 years wants to discontinue after paying premium for 8 years at the rate of Rs. 58 per thousand p. a. Find the amount of paid up value he will receive on the policy. Find the amount he will receive if the surrender value granted is 35% of the premiums paid, excluding the first year's premium.

13. A godown valued at Rs. 80,000 contained stock worth Rs. 4,80,000. Both were insured against fire. Godown for Rs. 50,000 and stock for 80% of its value. A part of stock worth Rs. 60,000 was completely destroyed and the rest was reduced to 60% of its value. The amount of damage to the godown is Rs. 40,000. Find the amount that can be claimed under the policy.

14. Find the amount of an ordinary annuity if a payment of Rs. 500 is made at the end of every quarter for 5 years at the rate of 12% per annum compounded quarterly. \((1.03)^{20} = 1.8061\)

15. Find the amount that a company should set aside at the end of every year if it wants to buy a machine expected to cost Rs. 1,00,000 at the end of 4 years and interest rate is 5% p. a. compounded annually. \((1.05)^4 = 1.2155\)

16. Find the least number of years for which an annuity of Rs. 3,000 per annum must run in order that its amount exceeds Rs. 60,000 at 10% compounded annually.
\[(1.1)^{11} = 2.8531, \quad (1.1)^{12} = 3.1384\]

17. Find the rate of interest compounded annually if an ordinary annuity of Rs. 20,000 per year amounts to Rs. 41,000 in 2 years.

18. A person purchases a television by paying Rs. 20,000 in cash and promising to pay Rs. 1000 at the end of every month for the next 2 years. If money is worth 12% p. a., converted monthly. find the cash price of the television. \((1.01)^{24} = 0.7875\)

19. Find the present value of an annuity immediate of Rs. 20,000 per annum for 3 years at 10% p.a. compounded annually. \((1.1)^3 = 0.7513\)

20. A man borrowed some money and paid back in 3 equal installments of Rs. 2160 each. What amount did he borrow if the rate of interest was 20% per annum compounded annually? Also find the total interest charged. \((1.2)^3 = 0.5787\)
21. A company decides to set aside a certain amount at the end of every year to create a sinking fund that should amount to Rs. 9,28,200 in 4 years at 10% p.a. Find the amount to be set aside every year. \[ [(1.1)^4 = 1.4641] \]

22. Find the future value after 2 years if an amount of Rs. 12,000 is invested at the end of every half year at 12% p. a. compounded half yearly.
\[ [(1.06)^4 = 1.2625] \]

23. After how many years would an annuity due of Rs. 3,000 p.a. accumulated Rs.19,324.80 at 20% p. a. compounded yearly?
\[ \text{[Given } (1.2)^4 = 2.0736\text{]} \]

24. Some machinery is expected to cost 25% more over its present cost of Rs. 6,96,000 after 20 years. The scrap value of the machinery will realize Rs.1,50,000. What amount should be set aside at the end of every year at 5% p.a. compound interest for 20 years to replace the machinery?
\[ \text{[Given } (1.05)^20 = 2.653\text{]} \]

Now, the property worth Rs.60,000 is totally destroyed and in addition the remaining property is so damaged as to reduce its value by 40%.

\[ \therefore \text{ Loss} = 60,000 + \frac{40}{100} \times \square \]

\[ = 60,000 + 16,000 \]

\[ = \text{Rs. } \square \]

\[ \therefore \text{ Claim} = \square \times \frac{7}{10} \]

\[ = \text{Rs. } 53,200 \]

2. Policy value = Rs. 70,000

Period of policy = 15 years

Rate of premium = Rs. 56.50 per thousand p.a.

\[ \therefore \text{ Amount of premium} = \frac{56.50}{100} \times \square \]

\[ = \text{Rs.3955} \]

\[ \therefore \text{ Total premium paid} = 3955 \times \square \]

\[ = \text{Rs.59,325} \]

Rate of bonus = Rs. 6 per thousand p.a.

\[ \therefore \text{ Amount of bonus} = 6 \times \square \]

\[ = \text{Rs.420} \]

\[ \therefore \text{ Bonus for 15 years} = 420 \times \square \]

\[ = \text{Rs.6,300} \]

\[ \therefore \text{ The person gets} = \square + 6300 \]

\[ = \text{Rs.76,300} \]

\[ \therefore \text{ Benefit} = \square - 59,325 \]

\[ = \text{Rs.16,975} \]

3. For an immediate annuity,

\[ P= \text{Rs.2000, } A = \text{Rs.4000} \]

\[ r = 10\% \text{ p.a.} \]

\[ \therefore I = \frac{r}{100} = \square = 0.1 \]
\[
\begin{align*}
\therefore \quad \frac{1}{P} - \frac{1}{A} &= \frac{i}{C} \\
\therefore \quad \frac{1}{A} - \frac{1}{C} &= \frac{0.1}{C} \\
\therefore \quad \frac{0.1}{C} &= \frac{1}{4000} \\
\therefore \quad C &= \text{Rs. } \underline{\underline{4000}}
\end{align*}
\]

4. For an annuity due,

\[C = \text{Rs}.2000, \text{rate} = 16\% \text{ p.a. compounded quarterly for 1 year}\]

\[\therefore \quad \text{Rate of interest per quarter} = \frac{r}{4} = \underline{4}\]

\[\therefore \quad r = 4\% \]

\[\therefore \quad i = \frac{r}{100} = \frac{100}{100} = 0.04\]

\[n = \text{Number of quarters} = 4 \times 1 = \underline{4}\]

\[\therefore \quad P = \frac{C(1+i)}{i} \left[1 - (1+i)^{-n}\right]
\]

\[\therefore \quad P = \frac{\underline{\underline{2000}}}{0.04} \left[1 - (1+0.04)^{-4}\right]
\]

\[= \frac{2000}{0.04} \left[1 - (1.04)^{-4}\right]
\]

\[= 50,000 \left[1 - (1.04)^{-4}\right]
\]

\[= 50,000 \times 0.8548
\]

\[= \text{Rs}.7,550.40
\]

5. The cost of machinery = Rs.10,00,000

\[\text{Effective life of machinery} = 12 \text{ years}\]

\[\text{Scrap value of machinery} = \text{Rs}.50,000\]

\[r = 5\% \text{ p.a.}\]

\[\therefore \quad i = \frac{r}{100} = \frac{100}{100} = 0.05\]

\[A = 10,00,000 - 50,000 = \underline{9,50,000}\]

For an immediate annuity

\[A = \frac{C}{i} \left[1 - (1+i)^{-n}\right]
\]

\[\therefore \quad \underline{\underline{9,50,000}} = \frac{C}{0.05} \left[1 - (1.05)^{-1}\right]
\]

\[= \frac{95,000 \times 0.797}{0.05}
\]

\[= \text{Rs}.59,598.40
\]
Let’s Study

- Meaning and Types of Regression
- Fitting Simple Linear Regression
  - Least Square Method
  - Regression of Y on X
  - Regression of X on Y
- Properties of Regression Coefficients

Let’s Recall

- Concept of Correlation
- Coefficient of Correlation
- Interpretation of Correlation

Introduction

We have already learned that correlation is used to measure the strength and direction of association between two variables. In statistics, correlation denotes association between two quantitative variables. It is assumed that this association is linear. That is, one variable increases or decreases by a fixed amount for every unit of increase or decrease in the other variable. Consider the relationship between the two variables in each of the following examples.

1. Advertising and sales of a product. (Positive correlation)
2. Height and weight of a primary school student. (Positive correlation)
3. The amount of fertilizer and the amount of crop yield. (Positive correlation)
4. Duration of exercise and weight loss. (Positive correlation)
5. Demand and price of a commodity. (Positive correlation)
6. Income and consumption. (Positive correlation)
7. Supply and price of a commodity. (Negative correlation)
8. Number of days of absence (in school) and performance in examination. (Negative correlation)
9. The more vitamins one consumes, the less likely one is to have a deficiency. (Negative correlation)

Correlation coefficient measures association between two variables but cannot determine the value of one variable when the value of the other variable is known or given. The technique used for predicting the value of one variable for a given value of the other variable is called regression. Regression is a statistical tool for investigating the relationship between variables. It is frequently used to predict the value and to identify factors that cause an outcome. Karl Pearson defined the coefficient of correlation known as Pearson’s Product Moment correlation coefficient. Carl Friedrich Gauss developed the method known as the Least Squares Method for finding the linear equation that best describes the relationship between two or more variables. R.A. Fisher combined the work of Gauss and Pearson to develop the complete theory of least squares estimation in linear regression. Due to Fisher’s work, linear regression is used for prediction and understanding correlations.

Note: Some statistical methods attempt to determine the value of an unknown quantity, which may be a parameter or a random variable. The method used for this purpose is called estimation if the unknown quantity is a parameter, and prediction if the unknown quantity is a variable.
3.1 Meaning and Types of Regression

Meaning of Regression

Linear regression is a method of predicting the value of one variable when the values of all other variables are known or specified. The variable being predicted is called the response or dependent variable. The variables used for predicting the response or dependent variable are called predictors or independent variables. Linear regression proposes that the relationship between two or more variables is described by a linear equation. The linear equation used for this purpose is called a linear regression model. A linear regression model consists of a linear equation with unknown coefficients. The unknown coefficients in the linear regression model are called parameters of the linear regression model. Observed values of the variables are used to estimate the unknown parameters of the model. The process of developing a linear equation to represent the relationship between two or more variables using the available sample data is known as fitting the linear regression model to observed data. Correlation analysis is used for measuring the strength or degree of the relationship between the predictors or independent variables and the response or dependent variable. The sign of correlation coefficient indicates the direction (positive or negative) of the relationship between the variables, while the absolute value (that is, magnitude) of correlation coefficient is used as a measure of the strength of the relationship. Correlation analysis, however, does not go beyond measuring the direction and strength of the relationship between predictor or independent variables and the response or dependent variable. The linear regression model goes beyond correlation analysis and develops a formula for predicting the value of the response or dependent variable when the values of the predictor or independent variables are known. Correlation analysis is therefore a part of regression analysis and is performed before performing regression analysis. The purpose of correlation analysis is to find whether there is a strong correlation between two variables. Linear regression will be useful for prediction only if there is strong correlation between the two variables.

Types of Linear Regression

The primary objective of a linear regression is to develop a linear equation to express or represent the relationship between two or more variables. Regression equation is the mathematical equation that provides prediction of values of the dependent variable based on the known or given values of the independent variables.

When the linear regression model represents the relationship between the dependent variable \( (Y) \) and only one independent variable \( (X) \), then the corresponding regression model is called a simple linear regression model. When the linear regression model represents the relationship between the dependent variable and two or more independent variables, then the corresponding regression model is called a multiple linear regression model.

Following examples illustrate situations for simple linear regression.

1. A firm may be interested in knowing the relationship between advertising \( (X) \) and sales of its product \( (Y) \), so that it can predict the amount of sales for the allocated advertising budget.

2. A botanist wants to find the relationship between the ages \( (X) \) and heights \( (Y) \) of seedling in his experiment.

3. A physician wants to find the relationship between the time since a drug is administered \( (X) \) and the concentration of the drug in the blood-stream \( (Y) \).

Following examples illustrate situations for multiple linear regression

1. The amount of sales of a product (dependent variable) is associated with
several independent variables such as price of the product, amount of expenditure on its advertisement, quality of the product, and the number of competitors.

2. Annual savings of a family (dependent variable) are associated with several independent variables such as the annual income, family size, health conditions of family members, and number of children in school or college.

3. The blood pressure of a person (dependent variable) is associated with several independent variables such as his or her age, weight, the level of blood cholesterol, and the level of blood sugar.

The linear regression model assumes that the value of the dependent variable changes in direct proportion to changes in the value of an independent variable, regardless of values of other independent variables. Linear regression is the simplest form of regression and there are more general and complicated regression models. We shall restrict our attention only to linear regression model in this chapter.

3.2 Fitting Simple Linear Regression

Consider an example where we wish to predict the amount of crop yield (in kg. per acre) as a linear function of the amount of fertilizer applied (in kg. per acre). In this example, the crop yield is to be predicted. Therefore, it is dependent variable and is denoted by $Y$. The amount of fertilizer applied is the variable used for the purpose of making the prediction. Therefore, it is the independent variable and is denoted by $X$.

<table>
<thead>
<tr>
<th>Amount of fertilizer ($X$) (Kgs. In per acre)</th>
<th>Yield ($Y$) (in '00 kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>43</td>
</tr>
<tr>
<td>40</td>
<td>45</td>
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<tr>
<td>50</td>
<td>54</td>
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<td>60</td>
<td>53</td>
</tr>
<tr>
<td>70</td>
<td>56</td>
</tr>
<tr>
<td>80</td>
<td>63</td>
</tr>
</tbody>
</table>

Table 3.1

Table 3.1 shows the amount of fertilizer and the crop yield for six cases. These pairs of observations are used to obtain the scatter diagram as shown in Fig. 3.1

![Fertilizer ($X$)](image.png)

**Fig. 3.1**: Scatter digram of the yield of grain and amount of fertilizer used.

We want to draw a straight line that is closest to the points in the scatter diagram (Fig. 3.1). If all the points were collinear (that is, on a straight line), there would have been no problem in drawing such a line. There is a problem because all the points are not on a straight line.

Since the points in the scatter diagram do not form a straight line, we want to draw a straight line that is closest to these points. Theoretically, the number of possible line is unlimited. It is therefore necessary to specify some condition in order to ensure that we draw the straight line that is closest to all the data points in the scatter diagram. The method of least squares provide the line of best fit because it is closest to the data points in the scatter diagram according to the least squares principle.

3.2.1 Method of Least Squares

The principle used in obtaining the line of best fit is called the method of least squares. The method of least squares was developed by Adrien-Marie Lagendre and Carl Friedrich Gauss independently of each other. Let us understand the central idea behind the principle of least squares.
Suppose the data consists of \( n \) pairs of values \((x_1, y_1), \ldots, (x_n, y_n)\) and suppose that the line that fits best to the given data is written as follows. 
\[
\hat{Y} = a + bx
\]
(Here, \( \hat{Y} \) is to be read as \( Y \) cap.) This equation is called the prediction equation. That is using the same values of constants \( a \) and \( b \), the predicted value of \( Y \) are given by \( \hat{Y} = a + bx_i \), where \( x_i \) is the value of the independent variable and \( \hat{Y}_i \) is the corresponding predicted value of \( Y \). Note that the observed value \( y_i \) of the independent variable \( Y \) is different from the predicted value \( \hat{Y}_i \).

The observed values (\( y_i \)) and predicted values (\( \hat{Y}_i \)) of \( Y \) do not match perfectly because the observations do not fall on a straight line. The difference between the observed values and the predicted values are called errors or residuals. Mathematically speaking the quantities
\[
y_1 - \hat{Y}_1, \quad y_2 - \hat{Y}_2, \quad \cdots \quad y_n - \hat{Y}_n
\]
or equivalently,
\[
y_1 - (a + bx_1), \quad y_2 - (a + bx_2), \quad \cdots \quad y_n - (a + bx_n)
\]
are deviations of observed values of \( Y \) from the corresponding predicted values and are therefore called errors or residuals. We write \( e_i = y_i - \hat{Y}_i = y_i - (a + bx_i) \), for \( i = 1, 2, \ldots, n \).

Geometrically, the residual \( e_i \), which is given by \( y_i - (a + bx_i) \), denotes the vertical distance (which may be positive or negative) between the observed value \( y_i \) and the predicted value \( \hat{Y}_i \).

The principle of the method of least squares can be stated as follows.

Among all the possible straight lines that can be drawn on the scatter diagram, the line of best fit is defined as the line that minimizes the sum of squares of residuals, that is, the sum of squares of deviations of the predicted \( y \)-values from the observed \( y \)-values. In other words, the line of the best fit is obtained by determining the constant \( a \) and \( b \) so that
\[
\sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (y_i - \hat{Y}_i)^2 = \sum_{i=1}^{n} [y_i - (a + bx_i)]^2
\]
is minimum.

The straight line obtained using this principle is called the least regression line.

Symbolically, we write
\[
S^2 = \sum_{i=1}^{n} (y_i - \hat{Y}_i)^2
\]
as the sum of squared errors. It can also be written as
\[
S^2 = \sum_{i=1}^{n} [(y_i - (a + bx_i))^2]
\]
We want to determine the constants \( a \) and \( b \) in such a way that \( S^2 \) is minimum.

Note that \( S^2 \) is a continuous and differentiable function of both \( a \) and \( b \). We differentiate \( S^2 \) with respect to \( a \) (assuming \( b \) to be constant) and with respect to \( b \) (assuming \( a \) constant). We then equate both these derivatives to zero in order to minimize \( S^2 \). As the result, we get the following two linear equations in two unknowns \( a \) and \( b \).

\[
\sum_{i=1}^{n} y_i = na + b \sum_{i=1}^{n} x_i
\]
\[
\sum_{i=1}^{n} x_i y_i = a \sum_{i=1}^{n} x_i + b \sum_{i=1}^{n} x_i^2
\]

When we solve these two linear equations, the values of \( a \) and \( b \) that minimize \( S^2 \) are given by
\[
a = \frac{\sum_{i=1}^{n} x_i y_i}{\sum_{i=1}^{n} x_i^2}, \quad b = \frac{\text{cov}(X, Y)}{\sigma_X^2},
\]
where
\[
\text{cov}(X, Y) = \frac{1}{n} \sum_{i=1}^{n} x_i y_i - \bar{x} \bar{y}
\]
and
\[
\sigma_X^2 = \frac{1}{n} \sum_{i=1}^{n} x_i^2 - \bar{x}^2
\]

Substituting the values of \( a \) and \( b \) obtained as indicated above in the regression equation
\[
Y = a + bX,
\]
we get the equation
\[
Y - \bar{y} = b (X - \bar{x})
\]
Note: The constant $b$ is called the regression coefficient (or the slope of the regression line) and the constant $a$ is called the $Y$-intercept (that is, the $Y$ value when $X = 0$). Recall that the equation $Y = a + bX$ defining a straight line is called the slope intercept formula of the straight line.

When observations on two variables, $X$ and $Y$, are available, it is possible to fit a linear regression of $Y$ on $X$ as well as a linear regression of $X$ on $Y$. Therefore, we consider both the models in order to understand the difference between the two and also the relationship between the two.

3.2.2 Regression of $Y$ on $X$.

We now introduce notation $b_{yx}$ for $b$ when $Y$ is the dependent variable and $X$ is the independent variable.

Linear regression of $Y$ on $X$ assumes that the variable $X$ is the independent variable and the variable $Y$ is the dependent variable. In order to make this explicit, we express the linear regression model as follows.

\[ Y = b_{yx}(X - \bar{X}), \]

or

\[ Y = b_{yx}X. \]

Here, note that $b$ is replaced by $b_{yx}$.

\[ b_{yx} = \frac{\text{cov}(X, Y)}{\text{var}(X)} = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sum(x_i - \bar{x})^2} = \frac{\sum x_i y_i - n \bar{x} \bar{y}}{\sum x_i^2 - n \bar{x}^2} \]

2.2.3 Regression of $X$ on $Y$

The notation $b_{xy}$ stands for $b$ when $X$ is the dependent variable and $Y$ is the independent variable.

Linear regression of $X$ on $Y$ assumes that the variable $Y$ is the independent variable and the variable $X$ is the dependent variable. In order to make it clear that this model is different from the linear regression of $Y$ on $X$, we express the linear regression model as follows.

\[ X = a' + b'Y. \]

The method of least squares, when applied to this model leads to the following expressions for the constant $a'$ and $b'$.

\[ a' = \bar{x} - b' \bar{y}, \]

and

\[ b' = \frac{\text{cov}(X,Y)}{\text{var}(Y)}. \]

Substituting the values of $a'$ and $b'$ in the linear regression model, we get

\[ X = a' + b'Y \]

\[ X = \bar{x} - b' \bar{y} + b'Y \]

i.e. $(X - \bar{x}) = b'(Y - \bar{y}).$

Note: The constant $b'$ in the above equation is called the regression coefficient of $X$ on $Y$. In order to make this explicit, it will henceforth be written as $b_{xy}$ instead of $b'$. The least squares regression of $X$ on $Y$ will therefore be written as

\[ (X - \bar{x}) = b_{xy}(Y - \bar{y}). \]

Note that the linear regression of $X$ on $Y$ is expressed as

\[ X = a' + b_{xy}Y. \]

Here note that $b$ is replaced by $b_{xy}$. This can be written as

\[ Y = \frac{1}{b_{xy}}(X - a') \]

Showing that the constant $\left( \frac{1}{b_{xy}} \right)$ is the slope of the line of regression of $X$ on $Y$.

Further, note that the regression coefficient $b_{xy}$ involved in the linear regression of $X$ on $Y$ is given by

\[ b_{xy} = \frac{\text{cov}(X,Y)}{\text{var}(Y)} = \frac{\frac{1}{n} \sum(x_i - \bar{x})(y_i - \bar{y})}{\frac{1}{n} \sum(y_i - \bar{y})^2} \]
\[
\bar{xy} = \frac{1}{n} \sum x_i y_i \quad \text{and} \quad \bar{x} \quad \bar{y} = \frac{1}{n} \sum x_i \quad \frac{1}{n} \sum y_i
\]

Also,
\[
b_{xy} = \frac{\sum (x_i \bar{y}) (y_i \bar{x})}{\sum (y_i \bar{y})^2} = \frac{\sum x_i y_i}{n} = \frac{\sum x_i^2}{n} \frac{nxy}{nxy^2}
\]

Observe that the point \((\bar{x}, \bar{y})\) satisfies the equation of both the lines of regression. Therefore, the point \((\bar{x}, \bar{y})\) is the point of intersection of the two lines of regression.

**SOLVED EXAMPLES**

**Ex. 1:** For the data on fertilizer application and yield of grain is given in the table 3.2.

i) Obtain the line of regression of yield of grain on the amount of fertilizer used.

ii) Draw the least squares regression line.

iii) Estimate the yield of grain when 90kgs. of fertilizer is applied.

**Solution:**

<table>
<thead>
<tr>
<th>Amount of fertilizer (X = x_i)</th>
<th>Yield (Y = y_i)</th>
<th>(x_i)</th>
<th>(y_i)</th>
<th>(xy_i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>43</td>
<td>900</td>
<td>1290</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>45</td>
<td>1600</td>
<td>1800</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>54</td>
<td>2500</td>
<td>2700</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>53</td>
<td>3600</td>
<td>3180</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>56</td>
<td>4900</td>
<td>3920</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>63</td>
<td>6400</td>
<td>5040</td>
<td></td>
</tr>
</tbody>
</table>

**Table : 3.2**

Since \(n = 6\), \(\sum x_i = 330\), \(\sum y_i = 314\).

\[
\sum x_i^2 \quad = 19900 \quad \text{and} \quad \sum x_i y_i = 17930
\]

\[
\bar{x} = \frac{\sum x_i}{n} = 55, \quad \bar{y} = \frac{\sum y_i}{n} = 52.3
\]

\[
b_{xy} = \frac{\sum x_i y_i}{n} \frac{nxy}{nxy^2} = \frac{17930 \times 55 \times 52.3}{19900 \times 6 \times 3025}
\]

\[
= \frac{671}{1750} = 0.38
\]

and \(a = \bar{y} - b_{xy} \bar{x} = 31.4\).

Finally, the line of regression of \(Y\) on \(X\) is given by

\[
Y = 31.4 + 0.38 X
\]

**Fig. 3.2 : Scatter diagram and the line of regression of yield on amount of fertilizer**

ii) To draw the least squares regression line, we pick any two convenient values of \(X\) and find the corresponding values of \(Y\).
For \( x = 35 \), \( y = 44.7 \)

\[ x = 45, \quad y = 48.5 \]

Joining the two points (35,44.7) and (45,48.5), we get the line in Fig 3.2.

iii) Putting \( x = 90 \) in the regression equation

\[ \bar{Y} = 31.4 + 0.38 \times 90 = 65.6 \]

Ex. 2: A departmental store gives in service training to the salesmen followed by a test. It is experienced that the performance regarding sales of any salesman is linearly related to the scores secured by him. The following data give test scores and sales made by nine salesmen during fixed period.

<table>
<thead>
<tr>
<th>Test scores (X)</th>
<th>16</th>
<th>22</th>
<th>28</th>
<th>24</th>
<th>29</th>
<th>25</th>
<th>16</th>
<th>23</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales (00Rs.) (Y)</td>
<td>35</td>
<td>42</td>
<td>57</td>
<td>40</td>
<td>54</td>
<td>51</td>
<td>34</td>
<td>47</td>
<td>45</td>
</tr>
</tbody>
</table>

i) Obtain the line of regression of \( Y \) on \( X \).

ii) Estimate \( Y \) when \( X = 17 \).

**Solution**: To show the calculations clearly, it is better to prepare the following table

<table>
<thead>
<tr>
<th>( X = x_i )</th>
<th>( y = y_i )</th>
<th>( x_i - \bar{x} )</th>
<th>( y_i - \bar{y} )</th>
<th>( (x_i - \bar{x})^2 )</th>
<th>( (x_i - \bar{x})(y_i - \bar{y}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>35</td>
<td>-7</td>
<td>-10</td>
<td>49</td>
<td>70</td>
</tr>
<tr>
<td>22</td>
<td>42</td>
<td>-1</td>
<td>-3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>28</td>
<td>57</td>
<td>5</td>
<td>12</td>
<td>25</td>
<td>60</td>
</tr>
<tr>
<td>24</td>
<td>40</td>
<td>1</td>
<td>-5</td>
<td>1</td>
<td>-5</td>
</tr>
<tr>
<td>29</td>
<td>54</td>
<td>6</td>
<td>9</td>
<td>36</td>
<td>54</td>
</tr>
<tr>
<td>25</td>
<td>51</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>16</td>
<td>34</td>
<td>-7</td>
<td>-11</td>
<td>49</td>
<td>77</td>
</tr>
<tr>
<td>23</td>
<td>47</td>
<td>0</td>
<td>2</td>
<td>00</td>
<td>00</td>
</tr>
<tr>
<td>24</td>
<td>45</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>00</td>
</tr>
<tr>
<td>207</td>
<td>405</td>
<td>00</td>
<td>00</td>
<td>166</td>
<td>271</td>
</tr>
</tbody>
</table>

\[ n = 9 \text{ and } \sum_{i=1}^{9} x_i = 207, \sum_{i=1}^{9} y_i = 405. \]

\[ \bar{x} = \frac{\sum x_i}{n} = 23, \quad \bar{y} = \frac{\sum y_i}{n} = 45 \]

Since the means of \( X \) and \( Y \) are whole numbers, it is preferable to use the formula

\[ \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sum (x_i - \bar{x})^2} \]

for the calculation of \( b_{xy} \).

Line of regression of \( Y \) on \( X \) is

\[ Y = a + b_{xy}X \]

where \( b_{xy} = \frac{\text{cov}(X,Y)}{\sigma_X^2} \)

\[ = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{n} \]

\[ = \frac{\sum (x_i - \bar{x})^2}{n} \]

\[ = \frac{271}{166} \]

\[ = 1.6325 \]

and \( a = \bar{y} - b_{xy} \bar{x} \)

\[ = 7.4525 \]

Here, the line of regression of \( Y \) on \( X \) is

\[ Y = 7.4525 + 1.6325X \]

ii) Estimate of \( Y \) when \( X = 17 \) is

\[ Y = 7.4525 + (1.6325) (17) \]

\[ = 35.205 \]

Ex 3: The management of a large furniture store would like to determine sales (in thousands of Rs.) \((X)\) on a given day on the basis of number of people \((Y)\) that visited the store on that day. The necessary records were kept, and a random sample of ten days was selected for the study. The summary results were as follows:
\[ \sum x_i = 370, \sum y_i = 580, \sum x_i^2 = 17200, \]
\[ \sum y_i^2 = 41640, \sum x_i y_i = 11500, n = 10 \]

Obtain the line of regression of \( X \) on \( Y \).

**Solution:**

Line of regression of \( X \) on \( Y \) is

\[ X = a' + b_{xy} Y \]

where

\[ b_{xy} = \frac{\text{cov}(X, Y)}{\sigma_Y^2} \]

\[ = \frac{\sum x_i y_i}{n} \frac{1}{\sum y_i^2} \]

\[ = \frac{11500}{10} \frac{370}{10} \frac{580}{10} \]

\[ = \frac{41640}{10} \frac{580}{10}^2 \]

\[ = \frac{1150}{37 \times 58} \frac{37 \times 58}{4164} \frac{58}{58} \]

\[ = \frac{996}{800} \]

\[ = -1.245 \]

and

\[ a' = \bar{x} - b_{xy} \bar{y} \]

\[ = 37 - (-1.245) (58) \]

\[ = 109.21 \]

\[ : \text{ Line of regression of } X \text{ on } Y \text{ is } X = 109.21 - 1.245 Y \]

**EXERCISE 3.1**

1. The HRD manager of a company wants to find a measure which he can use to fix the monthly income of persons applying for the job in the production department. As an experimental project, he collected data of 7 persons from that department referring to years of service and their monthly incomes.

<table>
<thead>
<tr>
<th>Years of service (( X ))</th>
<th>11</th>
<th>7</th>
<th>9</th>
<th>5</th>
<th>8</th>
<th>6</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monthly Income (Rs.1000's) (( Y ))</td>
<td>10</td>
<td>8</td>
<td>6</td>
<td>5</td>
<td>9</td>
<td>7</td>
<td>11</td>
</tr>
</tbody>
</table>

(i) Find the regression equation of income on years of service.

(ii) What initial start would you recommend for a person applying for the job after having served in similar capacity in another company for 13 years?

2. Calculate the regression equations of \( X \) on \( Y \) and \( Y \) on \( X \) from the following data:

| \( X \) | 10 | 12 | 13 | 17 | 18 |
| \( Y \) | 5  | 6  | 7  | 9  | 13 |

3. For a certain bivariate data on 5 pairs of observations given

\[ \sum x = 20, \sum y = 20, \sum x^2 = 90, \]

\[ \sum y^2 = 90, \sum xy = 76 \]

Calculate (i) \( \text{cov}(x, y) \) (ii) \( b_{xx} \) and \( b_{yx} \) (iii) \( r \)

4. From the following data estimate \( y \) when \( x = 125 \)

| \( X \) | 120 | 115 | 120 | 125 | 126 | 123 |
| \( Y \) | 13  | 15  | 14  | 13  | 12  | 14  |

5. The following table gives the aptitude test scores and productivity indices of 10 workers selected at random.

<table>
<thead>
<tr>
<th>Aptitude score (( X ))</th>
<th>60</th>
<th>62</th>
<th>65</th>
<th>70</th>
<th>72</th>
<th>48</th>
<th>53</th>
<th>73</th>
<th>65</th>
<th>82</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity Index (( Y ))</td>
<td>68</td>
<td>60</td>
<td>62</td>
<td>80</td>
<td>85</td>
<td>40</td>
<td>52</td>
<td>62</td>
<td>60</td>
<td>81</td>
</tr>
</tbody>
</table>
Obtain the two regression equations and estimate:

(i) The productivity index of a worker whose test score is 95.
(ii) The test score when productivity index is 75.

6. Compute the appropriate regression equation for the following data:

<table>
<thead>
<tr>
<th>$X$ [Independent Variable]</th>
<th>2</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>8</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y$ [Dependent Variable]</td>
<td>18</td>
<td>12</td>
<td>10</td>
<td>8</td>
<td>7</td>
<td>5</td>
</tr>
</tbody>
</table>

7. The following are the marks obtained by the students in Economics ($X$) and Mathematics ($Y$)

<table>
<thead>
<tr>
<th>$X$</th>
<th>59</th>
<th>60</th>
<th>61</th>
<th>62</th>
<th>63</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y$</td>
<td>78</td>
<td>82</td>
<td>82</td>
<td>79</td>
<td>81</td>
</tr>
</tbody>
</table>

Find the regression equation of $Y$ on $X$.

8. For the following bivariate data obtain the equations of two regression lines:

<table>
<thead>
<tr>
<th>$X$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y$</td>
<td>5</td>
<td>7</td>
<td>9</td>
<td>11</td>
<td>13</td>
</tr>
</tbody>
</table>

9. From the following data obtain the equation of two regression lines:

<table>
<thead>
<tr>
<th>$X$</th>
<th>6</th>
<th>2</th>
<th>10</th>
<th>4</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y$</td>
<td>9</td>
<td>11</td>
<td>5</td>
<td>8</td>
<td>7</td>
</tr>
</tbody>
</table>

10. For the following data, find the regression line of $Y$ on $X$

<table>
<thead>
<tr>
<th>$X$</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y$</td>
<td>2</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>

Hence find the most likely value of $y$ when $x = 4$.

11. From the following data, find the regression equation of $Y$ on $X$ and estimate $Y$ when $X = 10$.

<table>
<thead>
<tr>
<th>$X$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y$</td>
<td>2</td>
<td>4</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

12. The following sample gives the number of hours of study ($X$) per day for an examination and marks ($Y$) obtained by 12 students.

<table>
<thead>
<tr>
<th>$X$</th>
<th>3</th>
<th>3</th>
<th>3</th>
<th>4</th>
<th>4</th>
<th>5</th>
<th>5</th>
<th>5</th>
<th>6</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y$</td>
<td>45</td>
<td>60</td>
<td>55</td>
<td>75</td>
<td>70</td>
<td>80</td>
<td>75</td>
<td>90</td>
<td>80</td>
<td>75</td>
<td>85</td>
<td>85</td>
</tr>
</tbody>
</table>

Obtain the line of regression of marks on hours of study.

3.3 Properties of Regression Coefficients

The line of regression of $Y$ on $X$ is given by $Y = a + b_{xy}X$ and the line of regression of $X$ on $Y$ is given by $X = a' + b_{yx}Y$.

Here, $b_{yx} = \frac{\text{cov}(X,Y)}{\text{var}(X)}$, the slope of the line of regression of $Y$ on $X$ is called the regression coefficient of $Y$ on $X$. Similiarly, $b_{xy} = \frac{\text{cov}(X,Y)}{\text{var}(Y)}$, the reciprocal of the slope of the line of regression of $X$ on $Y$ is called the regression coefficient of $X$ on $Y$. These two regression coefficients have the following property.

(a) $b_{xy} \cdot b_{yx} = r^2$

where $r$ is the correlation coefficient between $X$ and $Y$.

$b_{xy}$ is the regression coefficient of $X$ on $Y$ and $b_{yx}$ is the regression coefficient of $Y$ on $X$.

**Proof:** Note that

$b_{xy} \cdot b_{yx} = \frac{\text{cov}(X,Y)}{\text{var}(Y)} \cdot \frac{\text{cov}(X,Y)}{\text{var}(X)}$

$= \left[ \frac{\text{cov}(X,Y)}{\sigma_X \cdot \sigma_Y} \right]^2 = r^2.$

Can it be said that the correlation coefficient is the square root of the product of the two regression coefficients?
(b) If \( b_{yx} > 1 \), then \( b_{xy} < 1 \).

**Proof:** Let, if possible, \( b_{xy} > 1 \) and \( b_{yx} > 1 \).

Then, using the above result, \( b_{xy} \cdot b_{yx} > 1 \), implies that \( r^2 > 1 \), which is impossible. (Can you provide the reason?)

This shows that our assumption must be invalid. That is, both the regression coefficients cannot simultaneously exceed unity.

We already know that the two variances \( \sigma_x^2, \sigma_y^2 \), and the correlation coefficient \( r \) satisfy the relation.

\[
\text{cov}(X, Y) = r \cdot \sigma_x \cdot \sigma_y
\]

\[
\therefore r = \frac{\text{cov}(X, Y)}{\sigma_x \cdot \sigma_y}
\]

The regression coefficients can also be written as follows.

\[
b_{yx} = \frac{\text{cov}(X, Y)}{\sigma_y^2}
= \frac{r \cdot \sigma_x \cdot \sigma_y}{\sigma_y^2}
= r \cdot \frac{\sigma_y}{\sigma_y}
\]

and

\[
b_{xy} = \frac{\text{cov}(X, Y)}{\sigma_x^2}
= \frac{r \cdot \sigma_x \cdot \sigma_y}{\sigma_x^2}
= r \cdot \frac{\sigma_x}{\sigma_y}
\]

\[
\left| \frac{b_{yx} + b_{xy}}{2} \right| \geq \left| r \right|
\]

**Proof:** We have already seen that

\[
b_{yx} = r \cdot \frac{\sigma_y}{\sigma_x} \quad \text{and} \quad b_{xy} = r \cdot \frac{\sigma_x}{\sigma_y}
\]

where \( \sigma_x \) and \( \sigma_y \) are the standard deviations of \( X \) and \( Y \), respectively.

Therefore,

\[
b_{yx} + b_{xy} = r \frac{\sigma_y}{\sigma_x} + r \frac{\sigma_x}{\sigma_y}
= r \left[ \frac{\sigma_y^2 + \sigma_x^2}{\sigma_x \cdot \sigma_y} \right]
= r \left[ \frac{\sigma_y^2 + \sigma_x^2}{\sigma_x \cdot \sigma_y} \right]
\]

But \((\sigma_x^2 - \sigma_y^2)^2 > 0\) and therefore

\[
\sigma_x^2 - \sigma_y^2 - 2\sigma_x \sigma_y \geq 0
\]

\[
\sigma_x^2 + \sigma_y^2 \geq 2\sigma_x \sigma_y
\]

\[
\frac{\sigma_y^2 + \sigma_x^2}{\sigma_x \cdot \sigma_y} \geq 2
\]

\[
\therefore r \frac{\sigma_y^2 + \sigma_x^2}{\sigma_x \cdot \sigma_y} \geq 2r
\]

From (1) and (2), we have

\[
b_{yx} + b_{xy} \geq 2r
\]

\[
\therefore \frac{b_{yx} + b_{xy}}{2} \geq r
\]

this result shows that the arithmetic mean of the two regression coefficients, namely \( b_{yx} \) and \( b_{xy} \), is greater than or equal to \( r \). This result, however, holds only when \( b_{yx} \) and \( b_{xy} \) are positive. (Can you find the reason?)

Consider the case where \( b_{yx} = -0.8 \) and \( b_{xy} = -0.45 \). In this case, we have \( r = -0.6 \). (Can you find the reason?)

**Note** that \( b_{yx} + b_{xy} = -1.25 \), and \( 2r = -1.2 \). This shows that \( b_{yx} + b_{xy} \leq 2r \).

It may be interesting to note that

\[
b_{yx} = \frac{\text{cov}(X, Y)}{\sigma_x^2}
\]

\[
b_{xy} = \frac{\text{cov}(X, Y)}{\sigma_y^2}
\]

\[
r = \frac{\text{cov}(X, Y)}{\sigma_x \cdot \sigma_y}
\]
It is evident from the above three equations that all the coefficients have the same numerator and this denominator determines their sign. As the result, all these coefficients have the same sign. In other words, if \( r > 0 \), then \( b_{xy} > 0 \), and \( b_{yx} > 0 \). Similarly, if \( r < 0 \), then \( b_{yx} < 0 \), and \( b_{xy} < 0 \). Finally, if \( r = 0 \), then \( b_{xy} = b_{yx} = 0 \).

\( b_{yx} \) and \( b_{xy} \) are not affected by change of origin, but are affected by change of scale. This property is known as \textit{invariance} property.

The invariance property states that \( b_{yx} \) and \( b_{xy} \) are invariant under change of origin, but are not invariant under change of scale.

**Proof:** Let \( U = \frac{X - a}{h} \) and \( V = \frac{Y - b}{k} \),

where \( a, b, h \) and \( k \) are constants with the condition that \( h, k \neq 0 \)

We have already proved that \( \sigma_X^2 h^2 \sigma_Y^2 \), \( \sigma_Y^2 = k^2 \sigma_Y^2 \), and \( \text{cov}(X, Y) = hk \text{cov}(U, V) \).

Therefore,

\[
\begin{align*}
b_{yx} &= \frac{\text{cov}(X,Y)}{\sigma_X^2} = \frac{hk \text{cov}(U,V)}{h^2 \sigma_Y^2} = \frac{k \text{cov}(U,V)}{h \sigma_Y^2} \\
\end{align*}
\]

that is,

\[
\begin{align*}
b_{yx} &= \frac{k}{h} b_{xy} \\
\end{align*}
\]

Similarly,

\[
\begin{align*}
b_{xy} &= \frac{h}{k} b_{yx} \\
\end{align*}
\]

These two results show that regression coefficients are invariant under change of origin, but are not invariant under change of scale.

### SOLVED EXAMPLES

**Ex. 1:** The table below gives the heights of fathers (\( X \)) and heights of their sons (\( Y \)) respectively.

<table>
<thead>
<tr>
<th>Heights of fathers (inches) ((X))</th>
<th>64</th>
<th>62</th>
<th>66</th>
<th>63</th>
<th>67</th>
<th>61</th>
<th>69</th>
<th>65</th>
<th>67</th>
<th>66</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heights of sons (inches) ((Y))</td>
<td>67</td>
<td>65</td>
<td>67</td>
<td>64</td>
<td>68</td>
<td>65</td>
<td>67</td>
<td>64</td>
<td>70</td>
<td>66</td>
</tr>
</tbody>
</table>

(i) Find the regression line of \( Y \) on \( X \).
(ii) Find the regression line of \( X \) on \( Y \).
(iii) Predict son's height if father's height is 68 inches.
(iv) Predict father's height if son's height is 59 inches.

**Solution:**

Let us use the change of origin for computations of regression coefficients.

<table>
<thead>
<tr>
<th>( x_i )</th>
<th>( y_i )</th>
<th>( u_i )</th>
<th>( v_i )</th>
<th>( u_i^2 )</th>
<th>( v_i^2 )</th>
<th>( u_i v_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>64</td>
<td>67</td>
<td>-1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>62</td>
<td>65</td>
<td>-3</td>
<td>-2</td>
<td>9</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>66</td>
<td>67</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>63</td>
<td>64</td>
<td>-2</td>
<td>-3</td>
<td>4</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>67</td>
<td>68</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>61</td>
<td>65</td>
<td>-4</td>
<td>-2</td>
<td>16</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>69</td>
<td>67</td>
<td>4</td>
<td>0</td>
<td>16</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>65</td>
<td>64</td>
<td>0</td>
<td>-3</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>67</td>
<td>70</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>66</td>
<td>66</td>
<td>1</td>
<td>-1</td>
<td>1</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>0</td>
<td>-7</td>
<td>56</td>
<td>37</td>
<td>27</td>
</tr>
</tbody>
</table>

Here, \( n = 10 \), \( \sum u_i = 0 \), \( \sum v_i = -7 \),

\[
\begin{align*}
\sum u_i^2 &= 56, \quad \sum v_i^2 = 37, \text{ and } \sum u_i v_i = 27 \\
\mu &= \frac{\sum u_i}{n} = \frac{0}{10} = 0,
\end{align*}
\]
\[ \sigma^2 = \frac{\sum u_i^2}{n} - \overline{u}^2 \]
\[ \sigma^2 = \frac{56}{10} - 0^2 = 5.6 \]
\[ \Sigma v_i = \frac{\sum v_i^2}{n} - \overline{v}^2 \]
\[ = \frac{37}{10} - (-0.7)^2 = 3.21 \]
\[ \text{cov} (u, v) = \frac{\sum u_i v_i}{n} - \overline{u} \overline{v} \]
\[ = \frac{27}{10} - 0 \times -0.7 = 2.7 \]

Now, you know that, regression coefficients are independent of change of origin.
\[ \therefore b_{XY} = \frac{\text{cov} (u, v)}{\sigma_y} = \frac{2.7}{3.21} = 0.84 \]
and \[ b_{YX} = \frac{\text{cov} (u, v)}{\sigma_u} = \frac{2.7}{5.6} = 0.48 \]

You are also aware that mean is affected by change of origin.
\[ \therefore \overline{X} = \overline{u} + 65 = 0 + 65 = 65 \]
and \[ \overline{Y} = \overline{v} + 67 = -0.7 + 67 = 66.3 \]

(i) Line of regression of \( Y \) on \( X \) is
\[ (Y - \overline{Y}) = b_{XY} (X - \overline{X}) \]
\[ \therefore (Y - 66.3) = 0.48 (X - 65) \]
\[ \therefore Y = 0.48 \cdot X + 35.1 \]

ii) Regression line of \( X \) on \( Y \) is
\[ (X - \overline{X}) = b_{YX} (Y - \overline{Y}) \]
\[ \therefore (X - 65) = 0.84 (Y - 66.3) \]
\[ \therefore X = 0.84 \cdot Y + 9.31 \]

iii) Estimate of sons height \( Y \) for \( X = 68 \)
\[ Y = 0.48 \times 68 + 35.1 \]
\[ = 67.74 \text{ inches} \]

iv) Estimate of fathers height \( X \) for \( Y = 59 \)
\[ X = 0.84 \times 59 + 9.31 \]
\[ = 58.87 \text{ inches} \]

v) Correlation coefficient
\[ r = \sqrt{b_{XY} \cdot b_{YX}} \]
\[ = \sqrt{0.84 \times 0.48} = 0.635 \]

We choose positive square root! (why?)

Ex. 2: Compute regression coefficient from the following data on the variable weight (\( X \)) and height (\( Y \)) of 8 individuals:
\[ n = 8, \sum (x_i, 45) = 48 \]
\[ \sum (x_i, 45)^2 = 4400, \]
\[ \sum (y_i, 150) = 280, \]
\[ \sum (y_i, 150)^2 = 167432, \]
\[ \sum (x_i, 45) \cdot (y_i, 150) = 21680 \]

Solution: Let \( u_i = x_i - 45 \) and \( v_i = y_i - 150 \)
So \[ \sum u_i = 48, \sum u_i^2 = 4400, \]
\[ \sum v_i = 280, \sum v_i^2 = 167432, \]
\[ \sum u_i v_i = 21680 \]
\[ \therefore \frac{\sum u_i}{n} = \frac{48}{8} = 6 \]
\[ \frac{\sum v_i}{n} = \frac{280}{8} = 35 \]
\[ \sigma_u^2 = \frac{\sum u_i^2}{n} - \overline{u}^2 \]
\[ = 5.6 \]
\[ \sigma^2_v = \frac{\sum v_i^2}{n} - \left( \bar{v} \right)^2 = \frac{167432}{8} - (35)^2 = 19704 \]
\[ \text{cov}(u, v) = \frac{\sum u_i v_i}{n} - u \cdot v = \frac{21680}{8} - (6) (35) = 2500 \]

From the properties of regression coefficients, you know that they are independent of change of origin.

\[ b_{yx} = b_{wy} = \frac{\text{cov}(u, v)}{\sigma_u} = \frac{2500}{514} = 4.86 \]

and

\[ b_{xy} = b_{ux} = \frac{\text{cov}(u, v)}{\sigma_v} = \frac{2500}{19704} = 0.12 \]

(Have you noticed \( b_{yx} > 1 \) and \( b_{xy} < 1 \)?)

**Ex. 3:** The following results were obtained from records of age \((X)\) and systolic blood pressure \((Y)\) of a group of 10 women.

<table>
<thead>
<tr>
<th></th>
<th>(X)</th>
<th>(Y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>53</td>
<td>142</td>
</tr>
<tr>
<td>Variance</td>
<td>130</td>
<td>165</td>
</tr>
</tbody>
</table>

\[ \sum (x_i - \bar{x})(y_i - \bar{y}) = 1170 \]

Find the appropriate regression equation and use it to estimate the blood pressure of a woman with age 47 years.

**Solution:**

Here, we need to find line of regression of \(Y\) on \(X\), which is given as

\[ Y = a + b_{yx} X \]

where,

\[ b_{yx} = \frac{\text{cov}(X, Y)}{\sigma_x^2} \]

\[ \sum (x_i - \bar{x})(y_i - \bar{y}) = \frac{1170}{10} = 130 \]

and \(\sigma_x = 3.5, \ \sigma_y = 28\) and \(r = 0.8\)

Therefore, regression equation of \(Y\) on \(X\) is

\[ Y = 94.3 + 0.9 \times X \]

Now, the estimate of blood pressure of women with age 47 years is

\[ Y = 94.3 + 0.9 \times 47 \]

\[ = 136.6 \]

**Ex. 4:** Given the following data, obtain the linear regression & estimate of \(X\) for \(Y = 10\)

\( \bar{x} = 7.6, \ \bar{y} = 14.8, \ \sigma_x = 3.5, \ \sigma_y = 28 \) and \(r = 0.8\)

**Solution:**

Here, we need to obtain line of regression of \(X\) on \(Y\) which can be expressed as

\[ X = a' - b_{yx} Y \]

where

\[ b_{yx} = \frac{\text{cov}(X, Y)}{\sigma_y^2} \]

\[ = r \frac{\sigma_x}{\sigma_y} \]

\[ = 0.8 \frac{3.5}{28} \]

\[ = 0.1 \]
and \[ a' = \bar{x} - b_{yx} \bar{y} \]
\[ = 7.6 - (0.1)(14.8) \]
\[ = 6.12 \]
\[ \therefore \text{Line of regression of } X \text{ on } Y \text{ is} \]
\[ X = 6.12 + 0.1 \times Y \]

Estimate of \( X \) for \( Y = 10 \) is
\[ X = 6.12 + 0.1 \times 10 \]
\[ X = 7.12 \]

### EXERCISE 3.2

1. For a bivariate data.
   \[ \bar{x} = 53, \quad \bar{y} = 28, \quad b_{yx} = -1.2, \quad b_{xy} = -0.3 \]
   Find
   i) Correlation coefficient between \( X \) and \( Y \).
   ii) Estimate of \( Y \) for \( X = 50 \)
   iii) Estimate of \( X \) for \( Y = 25 \)

2. From the data of 20 pairs of observation on \( X \) and \( Y \), following results are obtained.
   \[ \bar{x} = 199, \quad \bar{y} = 94, \]
   \[ \sum (x_i - \bar{x})^2 = 1200 \]
   \[ \sum (y_i - \bar{y})^2 = 300 \]
   \[ \sum (x_i - \bar{x})(y_i - \bar{y}) = -250 \]
   Find
   i) The line of regression of \( Y \) on \( X \).
   ii) The line of regression of \( X \) on \( Y \).
   iii) Correlation coefficient between \( X \) and \( Y \).

3. From the data of 7 pairs of observations on \( X \) and \( Y \), following results are obtained.
   \[ \sum x_i = 70 \]
   \[ \sum y_i = 60 \]
   \[ \sum x_i^2 = 2989 \]
   \[ \sum y_i^2 = 476 \]
   \[ \sum (x_i - \bar{x})(y_i - \bar{y}) = 1064 \]
   [Given \( \sqrt{0.7884} = 0.8879 \)]

### Obtain
i) The line of regression of \( Y \) on \( X \).
ii) The line of regression of \( X \) on \( Y \).
iii) The correlation coefficient between \( X \) and \( Y \).

4. You are given the following information about advertising expenditure and sales.

<table>
<thead>
<tr>
<th>Advertisement expenditure (Rs. in lakh)</th>
<th>Sales (Rs. in lakh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X )</td>
<td>( Y )</td>
</tr>
<tr>
<td>Arithmetic mean</td>
<td>10</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>3</td>
</tr>
</tbody>
</table>

Correlation coefficient between \( X \) and \( Y \) is 0.8

(i) Obtain the two regression equations.
(ii) What is the likely sales when the advertising budget is Rs 15 lakh?
(iii) What should be the advertising budget if the company wants to attain sales target of Rs.120 lakh?

5. Bring out inconsistency if any, in the following:
   i) \( b_{yx} + b_{xy} = 1.30 \) and \( r = 0.75 \)
   ii) \( b_{yx} = b_{xy} = 1.50 \) and \( r = -0.9 \)
   iii) \( b_{yx} = 1.9 \) and \( b_{xy} = -0.25 \)
   iv) \( b_{yx} = 2.6 \) and \( b_{xy} = \frac{1}{2.6} \)

6. Two samples from bivariate populations have 15 observations each. The sample means \( \bar{X} \) and \( \bar{Y} \) are 25 and 18 respectively. The corresponding sum of squares of deviations from respective means are 136 and 150. The sum of product of deviations from respective means is 123. Obtain the equation of line of regression of \( X \) on \( Y \).
7. For a certain bivariate data

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>S.D.</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

And $r = 0.5$. Estimate $y$ when $x = 10$ and estimate $x$ when $y = 16$.

8. Given the following information about the production and demand of a commodity obtain the two regression lines:

<table>
<thead>
<tr>
<th></th>
<th>Production (X)</th>
<th>Demand (Y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>85</td>
<td>90</td>
</tr>
<tr>
<td>S.D.</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

Coefficient of correlation between $X$ and $Y$ is 0.6. Also estimate the production when demand is 100.

9. Given the following data, obtain linear regression estimate of $X$ for $Y = 10$

$\bar{x} = 7.6$, $\bar{y} = 14.8$, $\sigma_x = 3.2$, $\sigma_y = 16$, and $r = 0.7$

10. An inquiry of 50 families to study the relationship between expenditure on accommodation (Rs. $X$) and expenditure on food and entertainment (Rs. $Y$) gave the following results:

$\sum x = 8500$, $\sum y = 9600$, $\sigma_x = 60$, $\sigma_y = 20$, and $r = 0.6$

Estimate the expenditure on food and entertainment when expenditure on accommodation is Rs 120.

11. The following data about the sales and advertisement expenditure of a firm is given below (in Rs. Crores)

<table>
<thead>
<tr>
<th></th>
<th>Sales</th>
<th>Adv. Exp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>40</td>
<td>6</td>
</tr>
<tr>
<td>S.D.</td>
<td>10</td>
<td>1.5</td>
</tr>
</tbody>
</table>

i) Estimate the likely sales for a proposed advertisement expenditure of Rs.10 crores.

ii) What should be the advertisement expenditure if the firm proposes a sales target Rs.60 crores.

12. For a certain bivariate data the following information are available.

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.M.</td>
<td>13</td>
<td>17</td>
</tr>
<tr>
<td>S.D.</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Correlation coefficient between $x$ and $y$ is 0.6. Estimate $x$ when $y = 15$ and estimate $y$ when $x = 10$.

**SOLVED EXAMPLES**

**Ex.1:** The equations of the two lines of regression are $3x + 2y - 26 = 0$ and $6x + y - 31 = 0$

(i) Find the means of $X$ and $Y$.

(ii) Obtain correlation coefficient between $X$ and $Y$.

**Solution:**

(i) We know that the co-ordinates of the point of intersection of the two lines are $\bar{x}$ and $\bar{y}$, the means of $X$ and $Y$.

The regression equations are

$3x + 2y - 26 = 0$

and $6x + y - 31 = 0$

Solving these equations simultaneously, we get

$6x + 4y - 52 = 0$

$6x + y - 31 = 0$

$(-)(+)$

$3y - 21 = 0$

$\therefore 3y = 21$

i.e. $y = 7$

and $x = 4$
Hence the means of $X$ and $Y$ are $\bar{x} = 4$ and $\bar{y} = 7$

(ii) Now, to find correlation coefficient, we have to find the regression coefficients $b_{xy}$ and $b_{yx}$.

For this, we have to choose one of the lines as that of line of regression of $Y$ on $X$ and other the line of regression of $X$ on $Y$.

Let $3x + 2y - 26 = 0$ be the line of regression on $Y$ on $X$ this gives

$$Y = -\frac{3}{2}X + 13$$

The coefficient of $X$ in this equation is

$b_{yx} = -\frac{3}{2}$

Then the other equation is that of line of regression of $X$ on $Y$ which can be written as

$$X = -\frac{1}{6}Y + \frac{31}{6}$$

Here, the regression coefficient $b_{yx} = -\frac{1}{6}$.

Now, you know that

$$r^2 = b_{xy} \cdot b_{yx}$$

$$= 0.25$$

$$\therefore r = \pm 0.5$$

The correlation coefficient has the sign as that of $b_{yx}$ and $b_{xy}$

$$\therefore r = -0.5$$

Note: We choose arbitrarily the lines as that of regression of $Y$ on $X$ or $X$ on $Y$. if the product $b_{yx} \cdot b_{xy}$ is less than unity, our choice is incorrect. Fortunately, there are only two choices.

Ex 2.: The regression equation of $Y$ on $X$ is

$$y = \frac{4}{3}x$$

and the regression equation $X$ on $Y$ is

$$x = \frac{y}{3} + \frac{5}{3}$$

Find

(i) Correlation coefficient between $X$ and $Y$.

(ii) $\sigma_y^2$ if $\sigma_X^2 = 4$

Solution:

Here, the regression lines are specified.

So $b_{yx} = \frac{4}{3}$ and $b_{xy} = \frac{1}{3}$

(i) $\therefore r^2 = b_{yx} \cdot b_{xy}$

$$= \frac{4}{3} \cdot \frac{1}{3}$$

$$= \frac{4}{9}$$

$$\therefore r = \pm \frac{2}{3}$$ (why $\pm \frac{2}{3}$ only?)

(ii) You know that

$$b_{yx} = r \cdot \frac{\sigma_y}{\sigma_x}$$

$$\therefore \frac{4}{3} = \frac{2}{3} \cdot \frac{\sigma_y}{\sigma_x}$$

$$\therefore \sigma_y = 4$$

$$\therefore \sigma_y^2 = 16$$

EXERCISE 3.3

1. From the two regression equations find $r$, $\bar{x}$ and $\bar{y}$.

$4y = 9x + 15$ and $25x = 4y + 17$

2. In a partially destroyed laboratory record of an analysis of regression data, the following data are legible:

Variance of $X = 9$

Regression equations:

$8x - 10y + 66 = 0$

and $40x - 18y = 214$. 
Find on the basis of above information

(i) The mean values of $X$ and $Y$.

(ii) Correlation coefficient between $X$ and $Y$.

(iii) Standard deviation of $Y$.

3. For 50 students of a class, the regression equation of marks in statistics ($\bar{X}$) on the marks in Accountancy ($\bar{Y}$) is $3\bar{Y} - 5\bar{X} + 180 = 0$. The mean marks in accountancy is 44 and the variance of marks in statistics is $(\frac{9}{16})^2$ of the variance of marks in accountancy. Find the mean marks in statistics and the correlation coefficient between marks in two subjects.

4. For a bivariate data, the regression coefficient of $Y$ on $X$ is 0.4 and the regression coefficient of $X$ on $Y$ is 0.9. Find the value of variance of $Y$ if variance of $X$ is 9.

5. The equations of two regression lines are
   
   \begin{align*}
   2\bar{x} + 3\bar{y} - 6 &= 0 \\
   3\bar{x} + 2\bar{y} - 12 &= 0
   \end{align*}

Find (i) Correlation coefficient

(ii) $\frac{\sigma_x}{\sigma_y}$

6. For a bivariate data: $\bar{x} = 53$, $\bar{y} = 28$, $b_{x\bar{Y}} = -1.5$ and $b_{\bar{x}y} = -0.2$. Estimate $Y$ when $X = 50$.

7. The equations of two regression lines are $x - 4y = 5$ and $16y - x = 64$. Find means of $X$ and $Y$. Also, find correlation coefficient between $X$ and $Y$.

8. In a partially destroyed record, the following data are available: variance of $X = 25$. Regression equation of $Y$ on $X$ is $5y - x = 22$ and Regression equation of $X$ on $Y$ is $64x - 45y = 22$. Find

9. If the two regression lines for a bivariate data are $2\bar{x} = \bar{y} + 15$ ($\bar{X}$ on $\bar{Y}$) and $4\bar{y} = 3\bar{x} + 25$ ($\bar{y}$ on $\bar{x}$), find
   
   (i) $x$, (ii) $y$, (iii) $b_{x\bar{Y}}$,

   (iv) $b_{\bar{x}y}$, (v) $r$ [Given $\sqrt{0.375}$ 0.61]

10. The two regression equations are
    
    $5\bar{x} - 6\bar{Y} + 90 = 0$ and $15\bar{x} - 8\bar{y} - 130 = 0$.
    Find $\bar{x}$, $\bar{y}$, and $r$.

11. Two lines of regression are $10\bar{x} + 3\bar{y} - 62 = 0$ and $6\bar{x} + 5\bar{y} - 50 = 0$. Identify the regression of $\bar{x}$ on $\bar{y}$. Hence find $\bar{x}$, $\bar{y}$ and $r$.

12. For certain $X$ and $Y$ series, which are correlated, find the two lines of regression of $10\bar{y} = 3\bar{x} + 170$ and $5\bar{x} + 70 = 6\bar{y}$. Find the correlation coefficient between them. Find the mean values of $X$ and $Y$.

13. Regression equations of two series are
    
    $2\bar{x} - \bar{y} - 15 = 0$ and $3\bar{x} - 4\bar{y} + 25 = 0$
    Find $\bar{x}$, $\bar{y}$ and regression coefficients. Also find coefficients of correlation.

    \[
    [\text{Given} \sqrt{0.375} \quad 0.61]
    \]

14. The two regression lines between height ($\bar{X}$) in inches and weight ($\bar{Y}$) in kgs of girls are,
    
    $4\bar{y} - 15\bar{x} + 500 = 0$
    
    and $20\bar{x} - 3\bar{y} - 900 = 0$
    
    Find mean height and weight of the group. Also, estimate weight of a girl whose height is 70 inches.
Let's Remember

- Line of regression of $Y$ on $X$ is
  $$Y = a + bX$$
  where $b = b_{yx} =$ regression coefficient of $Y$ on $X$

  $$b_{yx} = \frac{\text{cov}(X,Y)}{\text{var}(X)}$$

  $$= \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sum(x_i - \bar{x})^2}$$

  and $a' = \bar{x} - b'y$

- Line of regression of $Y$ on $X$ is also given as

  $$(Y - \bar{Y}) = b(X - \bar{X})$$

- Line of regression of $X$ on $Y$ is also given as

  $$(X - \bar{X}) = b'(Y - \bar{Y})$$

  $$r^2 = b_{yx} \cdot b_{xy} = b \cdot b'$$

  If $b_{yx} > 1$ then $b_{xy} < 1$

  $$\left| b_{yx} + b_{xy} \right| \geq | r |$$

- Regression coefficients are independent of change of origin but not of scale.

- Lines of regression have a point of intersection ($\bar{x}$, $\bar{y}$)

**Miscellaneous Exercise - 3**

I) Choose the correct alternative.

1. Regression analysis is the theory of
   a) Estimation    b) Prediction    c) Both a and b    d) Calculation

2. We can estimate the value of one variable with the help of other known variable only if they are
   a) Correlated    b) Positively correlated    c) Negatively correlated    d) Uncorrelated

3. There are _________ types of regression equations.
   a) 4    b) 2    c) 3    d) 1
4. In the regression equation of Y on X
   a) X is independent and Y is dependent.
   b) Y is independent and X is dependent.
   c) Both X and Y are independent.
   d) Both X and Y are dependent.

5. In the regression equation of X on Y
   a) X is independent and Y is dependent.
   b) Y is independent and X is dependent.
   c) Both X and Y are independent.
   d) Both X and Y are dependent.

6. $b_{xy}$ is ____________
   a) Regression coefficient of Y on X
   b) Regression coefficient of X on Y
   c) Correlation coefficient between X and Y
   d) Covariance between X and Y

7. $b_{yx}$ is ____________
   a) Regression coefficient of Y on X
   b) Regression coefficient of X on Y
   c) Correlation coefficient between X and Y
   d) Covariance between X and Y

8. ‘r’ is ____________
   a) Regression coefficient of Y on X
   b) Regression coefficient of X on Y
   c) Correlation coefficient between X and Y
   d) Covariance between X and Y

9. $b_{xy}, b_{yx}$ ____________
   a) $m(x)$ (b) $\sigma_x$ (c) $r^2$ (d) $(\sigma_y)^2$

10. If $b_{yx} > 1$ then $b_{xy}$ is ____________
    a) $> 1$ (b) $< 1$ (c) $> 0$ (d) $< 0$

11. $|b_{xy}| + |b_{yx}| \geq $ ____________
    a) $|r|$ (b) $2|r|$ (c) $r$ (d) $2r$

12. $b_{xy}$ and $b_{yx}$ are ____________
    a) Independent of change of origin and scale
    b) Independent of change of origin but not of scale
    c) Independent of change of scale but not of origin
    d) Affected by change of origin and scale

13. If $u = \frac{x - a}{c}$ and $v = \frac{y - b}{d}$ then $b_{xy} = $ ____________
    a) $\frac{d}{c} b_{wy}$
    b) $\frac{c}{d} b_{wy}$
    c) $\frac{a}{b} b_{wy}$
    d) $\frac{b}{a} b_{wy}$

14. If $u = \frac{x - a}{c}$ and $v = \frac{y - b}{d}$ then $b_{yx} = $ ____________
    a) $\frac{d}{c} b_{wy}$
    b) $\frac{c}{d} b_{wy}$
    c) $\frac{a}{b} b_{wy}$
    d) $\frac{b}{a} b_{wy}$

15. Corr $(x, y) = $ ____________
    a) 0  (b) 1  (c) -1  (d) can’t be found

16. Corr $(x, x) = $ ____________
    a) corr$(x, x)$
    b) corr$(y, y)$
    c) corr$(y, x)$
    d) cov$(y, x)$

17. Corr $\left(\frac{x}{c}, \frac{y}{d}\right) = - \text{corr}(x, y)$ if,
    a) c and d are opposite in sign
    b) c and d are same in sign
    c) a and b are opposite in sign
    d) a and b are same in sign

18. Regression equation of X on Y is ____________
    a) $y - \bar{y} = b_{xy}(x - \bar{x})$
    b) $x - \bar{x} = b_{yx}(y - \bar{y})$
    c) $y - \bar{y} = b_{yx}(x - \bar{x})$
    d) $x - \bar{x} = b_{yx}(y - \bar{y})$
19. Regression equation of $Y$ on $X$ is ________
   a) $y - \bar{y} = b_{yx} (x - \bar{x})$
   b) $x - \bar{x} = b_{yx} (y - \bar{y})$
   c) $y - \bar{y} = b_{yx} (x - \bar{x})$
   d) $x - \bar{x} = b_{yx} (y - \bar{y})$

20. $b_{yx} =$ ________
   a) $\frac{\sigma_y}{\sigma_x}$
   b) $\frac{\sigma_y}{\sigma_x}$
   c) $\frac{1}{r \sigma_x}$
   d) $\frac{1}{r \sigma_y}$

21. $b_{xy} =$ ________
   a) $\frac{\sigma_x}{\sigma_y}$
   b) $\frac{\sigma_y}{\sigma_x}$
   c) $\frac{1}{r \sigma_x}$
   d) $\frac{1}{r \sigma_y}$

22. Cov$(x,y) =$ ________
   a) $\sum (x - \bar{x})(y - \bar{y})$
   b) $\frac{\sum (x - \bar{x})(y - \bar{y})}{n}$
   c) $\frac{\sum xy}{n}$
   d) $b$ and $c$ both

23. If $b_{xy} < 0$ and $b_{yx} < 0$ then ‘$r$’ is ________
   a) $> 0$ (b) $< 0$ (c) $> 1$ (d) not found

24. If equations of regression lines are $3x + 2y - 26 = 0$ and $6x + y - 31 = 0$ then means of $x$ and $y$ are ________
   a) $7, 4$ b) $4, 7$ c) $2, 9$ d) $-4, 7$

III) State whether each of the following is True or False.
1. Corr $(x,y) = 1$

2. Regression equation of $X$ on $Y$ is $y - \bar{y} = b_{yx} (x - \bar{x})$

3. Regression equation of $Y$ on $X$ is $y - \bar{y} = b_{yx} (x - \bar{x})$

4. Corr $(x,y) = Corr (y,x)$

5. $b_{xy}$ and $b_{yx}$ are independent of change of origin and scale.

6. ‘$r$’ is regression coefficient of $Y$ on $X$

7. $b_{yx}$ is correlation coefficient between $X$ and $Y$

8. If $u = x - a$ and $v = y - b$ then $b_{uv} = b_{xy}$

9. If $u = x - a$ and $v = y - b$ then $r_{uv} = r_{yx}$

10. In the regression equation of $Y$ on $X$, $b_{yx}$ represents slope of the line.

II) Fill in the blanks:
1. If $b_{xy} < 0$ and $b_{yx} < 0$ then ‘$r$’ is ________

2. Regression equation of $Y$ on $X$ is ________
IV) Solve the following problems.

1. The data obtained on X, the length of time in weeks that a promotional project has been in progress at a small business, and Y, the percentage increase in weekly sales over the period just prior to the beginning of the campaign.

<table>
<thead>
<tr>
<th>X</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>1</th>
<th>3</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>2</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>10</td>
<td>10</td>
<td>18</td>
<td>20</td>
<td>11</td>
<td>15</td>
<td>12</td>
<td>15</td>
<td>17</td>
<td>19</td>
<td>13</td>
</tr>
</tbody>
</table>

Find the equation of regression line to predict the percentage increase in sales if the campaign has been in progress for 1.5 weeks.

2. The regression equation of y on x is given by $3x + 2y - 26 = 0$. Find $b_{yx}$.

3. If for a bivariate data $\bar{x} = 10$, $\bar{y} = 12$, $v(x) = 9$, $\sigma_x = 4$ and $r = 0.6$. Estimate $y$ when $x = 5$.

4. The equation of the line of regression of $y$ on $x$ is $y = \frac{2}{9}x$ and $x$ on $y$ is $x = \frac{y}{2} + \frac{7}{6}$. Find
   (i) $r$
   (ii) $\sigma_y^2$ if $\sigma_x^2 = 4$.

5. Identify the regression equations of $x$ on $y$ and $y$ on $x$ from the following equations,
   $2x + 3y = 6$ and $5x + 7y = 12 = 0$.

6. (i) If for a bivariate data $b_{xy} = -1.2$ and $b_{yx} = -0.3$ then find $r$.
   (ii) From the two regression equations $y = 4x - 5$ and $3x = 2y + 5$, find $\bar{x}$ and $\bar{y}$.

7. The equations of the two lines of regression are $3x + 2y - 26 = 0$ and $6x + y - 31 = 0$. Find
   (i) Means of $X$ and $Y$
   (ii) Correlation coefficient between $X$ and $Y$
   (iii) Estimate of $Y$ for $X = 2$
   (iv) $\text{var}(X)$ if $\text{var}(Y) = 36$

8. Find the line of regression of $X$ on $Y$ for the following data:
   $n = 8$, $\sum \left( x_i - \bar{x} \right)^2 = 36$, $\sum \left( y_i - \bar{y} \right)^2 = 44$
   $\sum \left( x_i - \bar{x} \right) \left( y_i - \bar{y} \right) = 24$, $\sum x_i = 32$, $\sum y_i = 40$

9. Find the equation of line of regression of $Y$ on $X$ for the following data:
   $n = 8$, $\sum \left( x_i - \bar{x} \right) \left( y_i - \bar{y} \right) = 120$,
   $\bar{x} = 20$, $\bar{y} = 36$, $\sigma_x = 2$, $\sigma_y = 3$.

10. The following results were obtained from records of age ($X$) and systolic blood pressure ($Y$) of a group of 10 men.

<table>
<thead>
<tr>
<th></th>
<th>$X$</th>
<th>$Y$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>50</td>
<td>140</td>
</tr>
<tr>
<td>Variance</td>
<td>160</td>
<td>165</td>
</tr>
</tbody>
</table>

and $\sum \left( x_i - \bar{x} \right) \left( y_i - \bar{y} \right) = 1120$

Find the prediction of blood pressure of a man of age 40 years.

11. The equations of two regression lines are $10x - 4y = 80$ and $10y - 9x = -40$.

Find:
   (i) $\bar{x}$ and $\bar{y}$
   (ii) $b_{yx}$ and $b_{xy}$
   (iii) If $\text{var}(Y) = 36$, obtain $\text{var}(X)$
   (iv) $r$

12. If $b_{yx} = -0.6$ and $b_{xy} = -0.216$ then find correlation coefficient between $X$ and $Y$. Comment on it.

**Activities**

1) Consider a group of 70 students of your class to take their heights in cm ($x$) and weights kg ($y$). Hence find both the regression equations.
2) The age in years of 7 young couples is given below:

<table>
<thead>
<tr>
<th>Husband (x)</th>
<th>21</th>
<th>25</th>
<th>26</th>
<th>24</th>
<th>22</th>
<th>30</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wife (y)</td>
<td>19</td>
<td>20</td>
<td>24</td>
<td>20</td>
<td>22</td>
<td>24</td>
<td>18</td>
</tr>
</tbody>
</table>

i) Find the equation of regression line of age of husband on age of wife.

ii) Draw the regression line of \( y \) on \( x \)

iii) Predict the age of wife whose husband’s age is 27 years.

3) The equations of two regression lines are

\[ 10x - 4y = 80 \quad \ldots \ldots \quad (1) \]
\[ 10y - 9x = -40 \quad \ldots \ldots \quad (2) \]

\[ \therefore (\bar{x}, \bar{y}) \text{ is the point of intersection of both the regression lines.} \]

\[ \therefore \text{Solve equations (i) and (ii), we get} \]

\[ \bar{x} = \boxed{ } \text{ and } \bar{y} = \boxed{ } \]

Now, consider \( 10x - 4y = 80 \)

\[ \therefore a = \boxed{ } , \quad b = \boxed{ } \]

\[ \therefore \text{slope}(m_1) = \frac{a}{b} = \boxed{ } \]

Consider, \( 10y - 9x = -40 \)

\[ \therefore a = \boxed{ } , \quad b = \boxed{ } \]

\[ \therefore \text{slope}(m_2) = \frac{a}{b} = \boxed{ } \]

\[ \therefore |m_2| > |m_1| \]

\[ \therefore b_{xy} = \boxed{ } \text{ and } b_{yx} = \frac{1}{\boxed{}} \]

\[ \therefore 10x - 4y = 80 \text{ is the regression equations of } \boxed{ } \text{ on } \boxed{ } \text{ and } \]

\[ \therefore 10y - 9x = -40 \text{ is the regression equations of } \boxed{ } \text{ on } \boxed{ } . \]

Now, \( r = \pm \sqrt{b_{xy} b_{yx}} \)

\[ r = \boxed{ } \]

If \( V(y) = 36 \) then \( \sigma_y = \boxed{ } \)

\[ \therefore b_{xy} = \frac{\sigma_y}{\sigma_x} \times \frac{1}{\boxed{}} \]

\[ \therefore \sigma_x = \boxed{ } \]

\[ \therefore V(x) = \sigma_x^2 = \boxed{ } \]

4) Given \( n = 8, \quad \sum (x_i - \bar{x})^2 = 36, \]

\[ \sum (y_i - \bar{y})^2 = 40, \]

\[ \sum (x_i - \bar{x})(y_i - \bar{y}) = 24 \]

\[ \therefore b_{xy} = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sum (x_i - \bar{x})^2} = \boxed{ } \]

\[ \therefore b_{yx} = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sum (y_i - \bar{y})^2} = \boxed{ } \]

\[ \therefore \text{Regression equation of } Y \text{ on } X : \]

\[ y - \bar{y} = b_{xy}(x - \bar{x}) \]

\[ y - \boxed{ } = \boxed{ } (x - \boxed{}) \]

\[ \therefore \text{Regression equation of } X \text{ on } Y : \]

\[ x - \bar{x} = b_{yx}(y - \bar{y}) \]

\[ x - \boxed{ } = \boxed{ } (y - \boxed{}) \]
5) Consider, given

\[ n = 8 \sum (x, \bar{x})(y, \bar{y}) = 120, \]
\[ \bar{y} = 36, \sigma_x = 2, \sigma_y = 3 \]
\[ \therefore \text{cov}(x, y) = \frac{\sum (x - \bar{x})(y - \bar{y})}{n} \]
\[ = \frac{150}{9} = 16.67 \]
\[ \therefore b_y = \frac{\text{cov}(x, y)}{\sigma_x^2} = \frac{150}{9} = 16.67 \]

\[ b_y = \text{cov}(x, y) \]
\[ = \frac{150}{9} = \frac{150}{9} \]

\[ \therefore \text{Regression equation of Y on X :} \]
\[ y - \bar{y} = b_y(x - \bar{x}) \]
\[ y - \bar{y} = 16.67(x - \bar{x}) \]

\[ \therefore \text{Regression equation of Y on X :} \]
\[ x - \bar{x} = \frac{1}{b_y}(y - \bar{y}) \]
\[ x - \bar{x} = \frac{1}{16.67}(y - \bar{y}) \]
Uses of time series analysis.
Components of a time series.
  - Secular Trend
  - Seasonal Variation
  - Cyclical Variation
  - Irregular Variation
Mathematical Models
  - Additive Model
  - Multiplicative Model
Measurement of Secular Trend
  - Graphical Method
  - Method of Moving Averages
  - Method of Least Squares

Introduction
A manufacturing company wants to predict demand for its product for next year to make a production plan. An investor wants to know fluctuations in share prices so that he can decide if he should purchase or sell certain shares. These and many other situations involve a variable that changes with time. A variable observed over a period of time is called a time series. Analysis of time series is useful in understanding the patterns of changes in the variable over time. Let us now define a time series.

Definition
Time Series is a sequence of observations made on a variable at regular time intervals over a specified period of time.

Data collected arbitrarily or irregularly does not form a time series. Time series analysis involves the use of statistical methods to analyze time series data in order to extract meaningful statistics and understand important characteristics of the observed data.

Time Series Analysis helps us to understand the underlying forces leading to a particular pattern in the time series and helps us in monitoring and forecasting data with help of appropriate statistical models.

Analysis of time series data requires maintaining records of values of the variable over time.

Some examples from day-to-day life may give a better idea of time series.
1. Monthly, quarterly, or yearly production of an industrial product.
2. Yearly GDP (Gross Domestic Product) of a country.
3. Monthly sales in a departmental store.
5. Daily closing price of a share at a stock exchange.
6. Hourly temperature of a city recorded by the Meteorological Department.

4.1 Uses of Time Series Analysis
The main objective of time series analysis is to understand, interpret and assess chronological changes in values of a variable in the past, so that reliable predictions can be made about its future values. For example, the government may be interested in predicting population growth in near future for planning its welfare schemes, the agricultural ministry may be interested in predicting annual crop yield before declaring the MSP (minimum support price) of agricultural produce or an industrialist may be interested in predicting...
the weekly demand for his product for making the production schedule. Following are considered to be some of the important uses of time series analysis.

1. It is useful for studying the past behaviour of a variable.

In a time series, the past observations on a variable are arranged in an orderly manner over a period of time. By simple observation of such a series, one can understand the nature of changes that have taken place in values of the variable during the course of time. Further, by applying appropriate technique of analysis to the series, one can study the general tendency of the variable in addition to seasonal changes, cyclical changes, and irregular or accidental changes in values of the variable.

2. It is useful for forecasting future behaviour of a variable.

Analysis of a time series reveals the nature of changes in the value of a variable during the course of times. This can be useful in forecasting the future values of the variable. Thus, with the help of observations on an appropriate time series, future plans can be made relating to certain matters like purchase, production, sales, etc. This is how a planned economy makes plans for the future development on the basis of time series analysis of the relevant data.

3. It is useful in evaluating the performance.

Evaluation of the actual performances in comparison with predetermined targets is necessary to judge efficiency of the work. For example, the achievements of Five-Year Plans are evaluated by determining the annual rate of growth in the gross national product. Similarly, the national policy of controlling inflation and price rises is evaluated with the help of different price indices. All these are made possible by analysis of time series of the relevant variables.

4. It is useful in making a comparative study.

A comparative study of data relating to two or more periods, regions, or industries reveals a lot of valuable information that can guide management in taking a proper course of action. A time series itself provides a scientific basis for making comparisons between two or more related sets of data. Note that data are arranged chronologically in such a series, and the effects of its various components are gradually isolated, analyzed, and interpreted.

4.2 Components of Time Series

A graphical representation of time series data shows continuous changes in its values over time, giving an impression of fluctuating nature of data. A close look at the graph, however, reveals that the fluctuations are not totally arbitrary, and a part of these fluctuations has a steady behavior and can be related to time. This part is the systematic part of the time series and the remaining part is non systematic or irregular. The systematic part is further divided in the following broad categories: (i) secular trend (T), (ii) seasonal variation (S), and (iii) cyclical variation (C). The non systematic part is also called (iv) irregular variation (I). Every time series has some or all of these components. Of course, only the systematic components of a time series are useful in forecasting its future values.

We now discuss the four components of a time series in detail.

4.2.1 Secular Trend (T)

The secular trend is the long term pattern of a time series. The secular trend can be positive or negative depending on whether the time series exhibits an increasing long term pattern or a decreasing long term pattern. The secular trend shows a smooth and regular long term movement of the time series. The secular trend does not include short term fluctuations, but only consists of a steady movement over a long period of time. It is the movement that the series
would take if there are no seasonal, cyclical or irregular variations. It is the effect of factors that are more or less constant for a long time or that change very gradually and slowly over time.

If a time series does not show an increasing or decreasing pattern, then the series is stationary around the mean.

**SOLVE EXAMPLES**

1. The following table shows annual sales (in lakh Rs.) of a departmental store for years 2011 to 2018.

<table>
<thead>
<tr>
<th>Year</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales</td>
<td>26.2</td>
<td>28.9</td>
<td>33.7</td>
<td>32.1</td>
</tr>
<tr>
<td>Year</td>
<td>2015</td>
<td>2016</td>
<td>2017</td>
<td>2018</td>
</tr>
<tr>
<td>Sales</td>
<td>39.8</td>
<td>38.7</td>
<td>45.4</td>
<td>44.6</td>
</tr>
</tbody>
</table>

The following graph shows the above time series.

![Graph showing time series data]

The above graph shows a **downward trend**.

4.2.2 Seasonal Variation (S)

Many time series related to financial, economic, and business activities consist of monthly or quarterly data. It is observed very often that these time series exhibit seasonal variation in the sense that similar patterns are repeated from year to year. Seasonal variation is the component of a time series that involves patterns of change within a year that repeat from year to year.

Several commodities show seasonal fluctuations in their demand. Warm clothes and woolen products have a market during the winter season. Fans, coolers, cold drinks and ice creams are in great demand during summer. Umbrellas and raincoats are in great demand during the rainy season. Different festivals are associated with different commodities and every festival season is associated with an increase in demand for related commodities. For example, clothes and firecrackers are in great demand.
during Diwali. Most of the seasonal variations in demand reflect changes in climatic conditions or customs and habits of people.

All the above examples have one year as the period of seasonal variation. However, the period of seasonal variation can be a month, a week, a day, or even an hour, depending on the nature of available data. For example, cash withdrawals in a bank show seasonal variation among the days of a month, the number of books borrowed by readers from a library show seasonal variation according to days of a week, passenger traffic at a railway station has seasonal variation during hours of a day, and the temperature recorded in a city exhibits seasonal variation over hours of a day, in addition to seasonal variation with changing seasons in a year.

Seasonal variation is measured with help of seasonal indices, which are useful for short term forecasting. Such short term forecasts are useful for a departmental store in planning its inventory according to months of a year. A bank manager can use such short term forecasts in managing cash flow on different days of a week or a month.

3. The following table shows quarterly sales (in lakh Rs.) of woolen garments in four consecutive years.

<table>
<thead>
<tr>
<th>Year</th>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarter</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Sales</td>
<td>11</td>
<td>16</td>
</tr>
<tr>
<td>Year</td>
<td>III</td>
<td>IV</td>
</tr>
<tr>
<td>Quarter</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Sales</td>
<td>33</td>
<td>39</td>
</tr>
</tbody>
</table>

![Graph showing seasonal variation](image)

Figure 4.3 shows a pattern that is repeated year after year. The values are lowest (in the year) in second quarter and highest (in the year) in fourth quarter of every year. Although the overall graph of the time series in Figure 4.3 shows an increasing trend, the seasonal variation within every year is very clearly visible in the graph.

4.2.3 Cyclical Variation (C)

Cyclical variation is a long term oscillatory movement in values of a time series. Cyclical variation occurs over a long period, usually several years, if seasonal variation occurs within a year. One complete round of oscillation is called a cycle. Cyclical variations need not be periodic in the sense that the length of a cycle or the magnitude of variation within a cycle can change from one cycle to another.
Cyclical variations are observed in almost all time series related to economic or business activities, where a cycle is known as a business cycle or trade cycle. Recurring ups and downs in a business are the main causes of cyclical variation.

A typical business cycle consists of the following four phases: (i) prosperity, (ii) recession, (iii) depression, (iv) recovery. Figure 4.4 depicts these four phases of a business cycle, where every phase changes to the next phase gradually in the order mentioned above.

4.3 Mathematical Models of Time Series

Let \( X_t \) denote the value of the variable at time \( t \). The time series is denoted by the collection of values, \( \{X_t, t = 0, 1, \ldots, T\} \) where \( T \) is the total duration of observation. There are two standard mathematical models for time series based on the four components mentioned earlier, namely, secular trend (T), seasonal variation (S), cyclical variation (C), and irregular variation (I).

4.3.1 Additive Model

The additive model assumes that the value \( X_t \) at time \( t \) is the sum of the four components at time \( t \). Thus,

\[
X_t = T_t + S_t + C_t + I_t
\]

The additive model assumes that the four components of the time series are independent of one another. It is also important to remember that all the four components in the additive model must be measured in the same unit of measurement. The magnitude of the seasonal variation does not depend on the value of the time series in the additive model. In other words, the magnitude of the seasonal variation does no change as the series goes up or down.

The assumption of independence of the components is often not realistic. In such situations, the multiplicative model can be used.

4.3.2 Multiplicative Model

The multiplicative model that the value \( X_t \) at the time \( t \) is obtained by multiplication of the four components at time \( t \). That is,

\[
X_t = T_t \times S_t \times C_t \times I_t
\]

The multiplicative model does not assume independence of the four components of the series and is, therefore, more realistic. Values of the trend are expressed in units of measurements and other components are expressed as percentage or relative values, and hence are free from units of measurements.
It is recommended to choose the multiplicative model when the magnitude of the seasonal variation in the data depends on the magnitude of the data. In other words, the magnitude of the seasonal variation increases as the data values increase, and decreases as the data values decrease.

4.4 Measurement of Secular Trend

4.4.1 Method of Freehand Curve (Graphical Method)

In this method, a graph is drawn for the given time series by plotting \( X_t \) (on Y-axis) against \( t \) (on X-axis). Then a free hand smooth curve is plotted on the same graph to indicate the general trend.

This method is simple and does not require any mathematical calculation. But, in this method, different researchers may draw different trend lines for the same set of data. Forecasting using this method is therefore risky if the person drawing free hand curve is not efficient and experienced. On the other hand, this method is quite flexible and can be used for all types of trends, linear as well as non-linear, and involves minimum amount of work.

**SOLVED EXAMPLES**

1. Fit a trend line to the following data using the graphical method.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of crimes ('000)</th>
<th>Year</th>
<th>Number of crimes ('000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>40</td>
<td>1987</td>
<td>43</td>
</tr>
<tr>
<td>1982</td>
<td>42</td>
<td>1988</td>
<td>46</td>
</tr>
<tr>
<td>1983</td>
<td>43</td>
<td>1989</td>
<td>47</td>
</tr>
<tr>
<td>1984</td>
<td>42</td>
<td>1990</td>
<td>45</td>
</tr>
<tr>
<td>1985</td>
<td>44</td>
<td>1991</td>
<td>46</td>
</tr>
</tbody>
</table>

**Solution:**

2. The publisher of a magazine wants to determine the rate of increase in the number of subscribers. The following table shows the subscription information for eight consecutive years.

<table>
<thead>
<tr>
<th>Year</th>
<th>1976</th>
<th>1977</th>
<th>1978</th>
<th>1979</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of subscribers (in millions)</td>
<td>12</td>
<td>11</td>
<td>19</td>
<td>17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of subscribers (in millions)</td>
<td>19</td>
<td>18</td>
<td>20</td>
<td>23</td>
</tr>
</tbody>
</table>

Fit a trend line by the graphical method.

**Solution:**

Fig. 4.5

Fig. 4.6
4.4.2 Method of moving Averages

The moving average of period \( k \) of a time series forms a time series of arithmetic means of \( k \) successive observations from the original time series. The method begins with the first \( k \) observations and finds the arithmetic mean of these \( k \) observations. The next step leaves the first observation and includes observation number \( k + 1 \) and finds the arithmetic mean of these \( k \) observations. This process continues till the average of the last \( k \) observations is found. In other words, the method of moving averages finds the following.

First moving average \[ X_1 + X_2 + \ldots + X_k \]

Second moving average \[ X_2 + X_3 + \ldots + X_{k+1} \]

Third moving average \[ X_3 + X_4 + \ldots + X_{k+2} \]

and so on.

Each of these averages is written against the time point that is the middle term in the sum. As a result, when \( k \) is an odd integer, moving average values correspond to observed values of the given time series. On the other hand, when \( k \) is an even integer, the moving averages fall mid-way between two observed values of the given time series. In this case, a subsequent two-unit moving average is calculated to make the resulting moving average values correspond to observed values of the given time series.

A moving average with an appropriate period smooths out cyclical variations from the given time series and provides a good estimate of the trend. Cyclical fluctuations with a uniform period and a uniform amplitude can be completely eliminated by taking the period of moving averages that is equal to or a multiple of the period of the cycles as long as the trend is linear.

The method of moving averages is flexible in the sense that even if a few observations are added to the given series, the moving averages calculated earlier are not affected and remain unchanged. However, the method of moving averages does not provide a mathematical equation for the time series and hence cannot be used for the purpose of forecasting. Another drawback of the method of moving averages is that some of the trend values at each end of the given series cannot be estimated by this method.

### SOLVED EXAMPLES

3. The following table shows gross capital formation (in crore Rs) for years 1966 to 1975.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Capital Formation</td>
<td>19.3</td>
<td>20.9</td>
<td>17.8</td>
<td>16.1</td>
<td>17.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Capital Formation</td>
<td>17.8</td>
<td>18.3</td>
<td>17.3</td>
<td>21.4</td>
<td>19.3</td>
</tr>
</tbody>
</table>

(i) Obtain trend values using 5-yearly moving averages.

(ii) Plot the original time series and trend values obtained in (i) on the same graph.

### Solution

<table>
<thead>
<tr>
<th>Year</th>
<th>( X_t )</th>
<th>5-yearly moving total</th>
<th>5-yearly moving averages (trend value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>19.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1967</td>
<td>20.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1968</td>
<td>17.8</td>
<td>91.7</td>
<td>18.34</td>
</tr>
<tr>
<td>1969</td>
<td>16.1</td>
<td>90.2</td>
<td>18.04</td>
</tr>
<tr>
<td>1970</td>
<td>17.6</td>
<td>87.6</td>
<td>17.52</td>
</tr>
<tr>
<td>1971</td>
<td>17.8</td>
<td>87.1</td>
<td>17.42</td>
</tr>
<tr>
<td>1972</td>
<td>18.3</td>
<td>92.4</td>
<td>18.48</td>
</tr>
<tr>
<td>1973</td>
<td>17.3</td>
<td>94.1</td>
<td>18.82</td>
</tr>
<tr>
<td>1974</td>
<td>21.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1975</td>
<td>19.3</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Note that 5-yearly average is not available for the first 2 years and last 2 years.
The following graph shows the original time series and the trend values obtained in Table 4.3.

![Graph showing original time series and trend curve](image)

**Fig. 4.7**

4. Obtain 4-yearly centered moving averages for the following time series.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual sales (in lakh Rs.)</td>
<td>3.6</td>
<td>4.3</td>
<td>4.3</td>
<td>3.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Annual sales (in lakh Rs.)</td>
<td>5.2</td>
<td>3.8</td>
<td>4.9</td>
<td>5.4</td>
<td></td>
</tr>
</tbody>
</table>

**Solution:**

<table>
<thead>
<tr>
<th>Year</th>
<th>(X_t)</th>
<th>4-yearly moving total</th>
<th>4-yearly moving average</th>
<th>2-unit moving total</th>
<th>4-yearly centred moving average (trend value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>3.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td>4.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>4.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>3.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>4.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1992</td>
<td>5.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>3.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td>4.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>5.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Entries in the third and fourth columns are between tabulated time periods, while entries in fifth and sixth columns are in front of tabulated time periods.

4.4.3 Method of Least Squares

This is the most objective and perhaps the best method of determining trend in a given time series. The method begins with selection of an appropriate form of trend equation and then proceeds with estimation of the unknown constants in this equation. It is a common practice to choose a polynomial of a suitable degree and then to determine its unknown coefficients by the method of least squares. The choice of the degree of polynomial is often based on the graphical representation of the given data.

In a linear trend, the equation is given by

\[ X_t = a + bt \]

The method of least squares involves solving the following set of linear equations, commonly known as normal equations.

\[ \sum X_t = na + b \sum t \]
\[ \sum tX_t = a \sum t + b \sum t^2 \]

Where \( n \) is the number of the time periods for which data is available, whereas, \( \sum X_t, \sum tX_t, \sum t \) and \( \sum t^2 \) are obtained from the data. The least squares estimates of \( a \) and \( b \) are obtained by solving the two equations in the two unknowns, namely \( a \) and \( b \). The required equation of the trend line is the obtained by substituting these estimates in equation \( X_t = a + bt \)

**SOLVED EXAMPLES**

5. Fit a trend line by the method of least squares to the time series in Example 1 (Section 4.4.1). Also, obtain the trend value for the number of crimes in the year 1993.
Solution:

Let the trend line be represented by the equation \( y_t = a + bt \). Calculations can be made simpler by transforming from \( t \) to \( u \) using the formula

\[
u = \frac{t - \text{middle } t \text{ value}}{h} \quad \text{......... if } n \text{ is odd}
\]

\[
u = \frac{t - \text{mean of two middle } t \text{ values}}{h} \quad \text{......... if } n \text{ is even}
\]

Where \( h \) is the difference between successive \( t \) values.

In the given problem, \( n = 11 \) (odd), middle \( t \) value is 1986, and \( h = 1 \).

\[\therefore \text{we use the transformation} \]

\[u = \frac{t - 1986}{1} = t - 1986.\]

The equation of the trend line then becomes

\[y_t = a' + b'u\]

The two normal equations are then given by

\[\sum y_t = na' + b' \sum u,\]

\[\sum uy_t = a' \sum u + b' \sum u^2\]

We obtain \( \sum u, \sum u^2, \sum y_t, \text{ and } \sum uy_t \) from the following table.

<table>
<thead>
<tr>
<th>Year</th>
<th>( y_t )</th>
<th>( u )</th>
<th>( u^2 )</th>
<th>( uy_t )</th>
<th>Trend Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>40</td>
<td>-5</td>
<td>25</td>
<td>-200</td>
<td>41.0457</td>
</tr>
<tr>
<td>1982</td>
<td>42</td>
<td>-4</td>
<td>16</td>
<td>-168</td>
<td>41.6002</td>
</tr>
<tr>
<td>1983</td>
<td>43</td>
<td>-3</td>
<td>9</td>
<td>-129</td>
<td>42.1547</td>
</tr>
<tr>
<td>1984</td>
<td>42</td>
<td>-2</td>
<td>4</td>
<td>-84</td>
<td>42.7092</td>
</tr>
<tr>
<td>1985</td>
<td>44</td>
<td>-1</td>
<td>1</td>
<td>-44</td>
<td>43.2637</td>
</tr>
<tr>
<td>1986</td>
<td>44</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>43.8182</td>
</tr>
<tr>
<td>1987</td>
<td>43</td>
<td>1</td>
<td>1</td>
<td>43</td>
<td>44.3727</td>
</tr>
<tr>
<td>1988</td>
<td>46</td>
<td>2</td>
<td>4</td>
<td>92</td>
<td>44.9272</td>
</tr>
<tr>
<td>1989</td>
<td>47</td>
<td>3</td>
<td>9</td>
<td>141</td>
<td>45.4817</td>
</tr>
<tr>
<td>1990</td>
<td>45</td>
<td>4</td>
<td>16</td>
<td>180</td>
<td>46.0362</td>
</tr>
<tr>
<td>1991</td>
<td>46</td>
<td>5</td>
<td>25</td>
<td>230</td>
<td>46.5907</td>
</tr>
</tbody>
</table>

The normal equations are

\[482 = 11a' + b'(0); \quad 61 = a(0) 110 b'\]

\[\therefore a' = \frac{482}{11} = 43.8182; \quad b' = \frac{61}{110} = 0.5545\]

The equation of the trend line is then given by

\[y_t = 43.8182 + (0.5545) u, \text{ where } u = t - 1986\]

Trend values computed using this result are given in the last column of the table.

For the year 1993, \( x = 7 \)

\[y = 43.8182 + 3.8815 = 47.6997\]

6. Fit a trend line by the method of least squares to the time series in Example 2 (Section 4.4.1). Also obtain the trend value for the number of subscribers in the year 1984.

Solution:

Let the equation of the trend line, if the \( n \) is even

\[y_t = a + bt\]

In the given problem, \( n = 8 \) (even), two middle \( t \) values are 1979 and 1980, and \( h = 1 \).

We use the transformation

\[u = \frac{t - 1979.5}{1} = \frac{t}{2} - 3959.\]

The equation of the trend line then becomes

\[y_t = a' + b'u\]

The two normal equations are

\[\sum y_t = na' + b' \sum u, \quad \text{(1)}\]

\[\sum uy_t = a' \sum u + b' \sum u^2 \quad \text{(2)}\]

We obtain \( \sum u, \sum u^2, \sum y_t, \text{ and } \sum uy_t \) from the following table.
Fit a trend line by graphical method to the above data.

2. Use the method of least squares to fit a trend line to the data in Problem 1 above. Also, obtain the trend value for the year 1975.

3. Obtain the trend line for the above data using 5 yearly moving averages.

4. The following table shows the index of industrial production for the period from 1976 to 1985, using the year 1976 as the base year.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Index</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Index</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>10</td>
</tr>
</tbody>
</table>

Fit a trend line to the above data by graphical method.

5. Fit a trend line to the data in Problem 4 above by the method of least squares. Also, obtain the trend value for the index of industrial production for the year 1987.

6. Obtain the trend values for the data in problem 4 using 4-yearly centered moving averages.

7. The following table gives the production of steel (in millions of tonnes) for years 1976 to 1986.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>5</td>
<td>9</td>
<td>4</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

Fit a trend line to the above data by the graphical method.

8. Fit a trend line to the data in Problem 7 by the method of least squares. Also, obtain the trend value for the year 1990.

9. Obtain the trend values for the above data using 3-yearly moving averages.
10. The following table shows the production of gasoline in U.S.A. for the years 1962 to 1976.

<table>
<thead>
<tr>
<th>Year</th>
<th>Production (million Barrels)</th>
<th>Year</th>
<th>Production (million Barrels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1962</td>
<td>0</td>
<td>1970</td>
<td>6</td>
</tr>
<tr>
<td>1963</td>
<td>0</td>
<td>1971</td>
<td>7</td>
</tr>
<tr>
<td>1964</td>
<td>1</td>
<td>1972</td>
<td>8</td>
</tr>
<tr>
<td>1965</td>
<td>1</td>
<td>1973</td>
<td>9</td>
</tr>
<tr>
<td>1966</td>
<td>2</td>
<td>1974</td>
<td>8</td>
</tr>
<tr>
<td>1967</td>
<td>3</td>
<td>1975</td>
<td>9</td>
</tr>
<tr>
<td>1968</td>
<td>4</td>
<td>1976</td>
<td>10</td>
</tr>
<tr>
<td>1969</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(i) Obtain trend values for the above data using 5-yearly moving averages.

(ii) Plot the original time series and trend values obtained above on the same graph.

Let’s Remember

- A time series is a set of observations made at regular intervals of time and therefore arranged chronologically (that is, according to time).
- A time series has the following four components:
  (i) Secular trend
  (ii) Seasonal variation
  (iii) Cyclical variation
  (iv) Irregular variation
- Secular trend of a time series is its smooth and regular long-term movement.
- Seasonal variation involves patterns of change within a year that are repeated from year to year. Seasonal variations often reflect changes in underlying climatic conditions, or customs and habits of people.
- Cyclical variation is a long-term oscillatory movement that occurs over a long period of time, mostly more than two years or more.

- A standard business cycle consists of the following four phases:
  (i) Prosperity  
  (ii) Decline
  (iii) Depression  
  (iv) Recovery
- Irregular variations are caused by either random factors or unforeseen events like floods, famines, earthquakes, strikes, wars, etc.
- Additive Model:
  \[ X_t = T_t + S_t + C_t + I_t \]
  where \( X_t \) is the value of the variable \( X \) at time \( t \) and \( T_t, S_t, C_t \), and \( I_t \) are secular trend, seasonal variation, cyclical variation, and irregular variation at time \( t \), respectively.
- Multiplicative Model:
  \[ X_t = T_t \times S_t \times C_t \times I_t \]
  where the notation is same as in the additive model.
- Secular trend can be measured using
  (i) Graphical method
  (ii) Method of moving averages
  (iii) Method of least squares
- The moving averages of period \( k \) of a time series form a new series of arithmetic means, each of \( k \) successive observations of the given time series.
- Method of least squares involves solving the following two normal equations.
  \[
  \sum X_t = na + b \sum t \\
  \sum tX_t = a \sum t + b \sum t^2
  \]

**MISCELLANEOUS EXERCISE - 4**

I) Choose the correct alternative.

1. Which of the following can’t be a component of a time series?
   (a) Seasonality  
   (b) Cyclical
   (c) Trend  
   (d) Mean
2. The first step in time series analysis is to
   (a) Perform regression calculations
   (b) Calculate a moving average
   (c) Plot the data on a graph
   (d) Identify seasonal variation

3. Time-series analysis is based on the assumption that
   (a) Random error terms are normally distributed.
   (b) The variable to be forecast and other independent variables are correlated.
   (c) Past patterns in the variable to be forecast will continue unchanged into the future.
   (d) The data do not exhibit a trend.

4. Moving averages are useful in identifying
   (a) Seasonal component
   (b) Irregular component
   (c) Trend component
   (d) Cyclical component

5. We can use regression line for past data to forecast future data. We then use the line which
   (a) Minimizes the sum of squared deviations of past data from the line
   (b) Minimizes the sum of deviations of past data from the line.
   (c) Maximizes the sum of squared deviations of past data from the line
   (d) Maximizes the sum of deviations of past data from the line.

6. Which of the following is a major problem for forecasting, especially when using the method of least squares?
   (a) The past cannot be known
   (b) The future is not entirely certain
   (c) The future exactly follows the patterns of the past
   (d) The future may not follow the patterns of the past

7. An overall upward or downward pattern in an annual time series would be contained in which component of the time series
   (a) Trend  (b) Cyclical
   (c) Irregular  (d) Seasonal

8. The following trend line equation was developed for annual sales from 1984 to 1990 with 1984 as base or zero year.
   \[ Y_t = 500 + 60X \] (in 1000 Rs). The estimated sales for 1984 (in 1000 Rs) is:
   (a) Rs 500  (b) Rs 560
   (c) Rs 1,040  (d) Rs 1,100

9. What is a disadvantage of the graphical method of determining a trend line?
   (a) Provides quick approximations
   (b) Is subject to human error
   (c) Provides accurate forecasts
   (d) Is too difficult to calculate

10. Which component of time series refers to erratic time series movements that follow no recognizable or regular pattern.
    (a) Trend  (b) Seasonal
    (c) Cyclical  (d) Irregular

II) Fill in the blanks
1. ___ components of time series is indicated by a smooth line.
2. ___ component of time series is indicated by periodic variation year after year.
3. ___ component of time series is indicated by a long wave spanning two or more years.
4. ___ component of time series is indicated by up and down movements without any pattern.
5. Additive models of time series ___ independence of its components.
6. Multiplicative models of time series ___ independence of its components.
7. The simplest method of measuring trend of time series is ___
8. The method of measuring trend of time series using only averages is ___
9. The complicated but efficient method of measuring trend of time series is _____.
10. The graph of time series clearly shows ____ of it is monotone.

III) State whether each of the following is True or False.
1. The secular trend component of time series represents irregular variations.
2. Seasonal variation can be observed over several years.
3. Cyclical variation can occur several times in a year.
4. Irregular variation is not a random component of time series.
5. Additive model of time series does not require the assumption of independence of its components.
6. Multiplicative model of time series does not require the assumption of independence of its components.
7. Graphical method of finding trend is very complicated and involves several calculations.
8. Moving average method of finding trend is very complicated and involves several calculations.
9. Least squares method of finding trend is very simple and does not involve any calculations.
10. All the three methods of measuring trend will always give the same results.

IV) Solve the following problems.
1. The following table shows the production of pig-iron and ferro-alloys (‘000 metric tonnes)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>0</td>
<td>4</td>
<td>9</td>
<td>9</td>
<td>8</td>
</tr>
</tbody>
</table>

Fit a trend line to the above data by graphical method.
11. Fit a trend line to data in Problem 10 by the method of least squares.

12. Obtain trend values for data in Problem 10 using 3-yearly moving averages.

13. Following table shows the number of traffic fatalities (in a state) resulting from drunken driving for years 1975 to 1983.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of deaths</td>
<td>0</td>
<td>6</td>
<td>3</td>
<td>8</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of deaths</td>
<td>9</td>
<td>4</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

Fit a trend line to the above data by graphical method.

14. Fit a trend line to data in Problem 13 by the method of least squares.

15. Obtain trend values for data in Problem 13 using 4-yearly moving averages.

16. Following table shows the all India infant mortality rates (per ‘000) for years 1980 to 2010.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>IMR</td>
<td>10</td>
<td>7</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2005</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMR</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Fit a trend line to the above data by graphical method.

17. Fit a trend line to data in Problem 16 by the method of least squares.

18. Obtain trend values for data in Problem 16 using 3-yearly moving averages.

19. Following tables shows the wheat yield (‘000 tonnes) in India for years 1959 to 1968.

<table>
<thead>
<tr>
<th>Year</th>
<th>Yield</th>
<th>Year</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1959</td>
<td>0</td>
<td>1964</td>
<td>0</td>
</tr>
<tr>
<td>1960</td>
<td>1</td>
<td>1965</td>
<td>4</td>
</tr>
<tr>
<td>1961</td>
<td>2</td>
<td>1966</td>
<td>1</td>
</tr>
<tr>
<td>1962</td>
<td>3</td>
<td>1967</td>
<td>2</td>
</tr>
<tr>
<td>1963</td>
<td>1</td>
<td>1968</td>
<td>10</td>
</tr>
</tbody>
</table>

20. Obtain trend values for data in Problem 19 using 3-yearly moving averages.

### Activities

Note: You may change the origin and scale in the following problems according to your convenience.

1. Daily SENSEX index values at opening are given for fifty days in the following table. Plot a graph from the data. Find the trend graphically, using moving averages, and by the method of least squares.

<table>
<thead>
<tr>
<th>Date</th>
<th>Index</th>
<th>Date</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Jan-19</td>
<td>36161.8</td>
<td>2-Jan-19</td>
<td>36198.13</td>
</tr>
<tr>
<td>3-Jan-19</td>
<td>35934.5</td>
<td>4-Jan-19</td>
<td>35590.79</td>
</tr>
<tr>
<td>7-Jan-19</td>
<td>35971.18</td>
<td>8-Jan-19</td>
<td>35964.62</td>
</tr>
<tr>
<td>9-Jan-19</td>
<td>36181.37</td>
<td>10-Jan-19</td>
<td>36258</td>
</tr>
<tr>
<td>11-Jan-19</td>
<td>36191.87</td>
<td>14-Jan-19</td>
<td>36113.27</td>
</tr>
<tr>
<td>15-Jan-19</td>
<td>35950.08</td>
<td>16-Jan-19</td>
<td>36370.74</td>
</tr>
<tr>
<td>17-Jan-19</td>
<td>36413.6</td>
<td>18-Jan-19</td>
<td>36417.58</td>
</tr>
<tr>
<td>21-Jan-19</td>
<td>36467.12</td>
<td>22-Jan-19</td>
<td>36649.92</td>
</tr>
<tr>
<td>23-Jan-19</td>
<td>36494.12</td>
<td>24-Jan-19</td>
<td>36146.55</td>
</tr>
<tr>
<td>25-Jan-19</td>
<td>36245.77</td>
<td>28-Jan-19</td>
<td>36099.62</td>
</tr>
<tr>
<td>29-Jan-19</td>
<td>35716.72</td>
<td>30-Jan-19</td>
<td>35819.67</td>
</tr>
<tr>
<td>31-Jan-19</td>
<td>35805.51</td>
<td>1-Feb-19</td>
<td>36311.74</td>
</tr>
<tr>
<td>4-Feb-19</td>
<td>36456.22</td>
<td>5-Feb-19</td>
<td>36573.04</td>
</tr>
<tr>
<td>6-Feb-19</td>
<td>36714.54</td>
<td>7-Feb-19</td>
<td>37026.56</td>
</tr>
<tr>
<td>8-Feb-19</td>
<td>36873.59</td>
<td>11-Feb-19</td>
<td>36585.5</td>
</tr>
<tr>
<td>12-Feb-19</td>
<td>36405.72</td>
<td>13-Feb-19</td>
<td>36279.63</td>
</tr>
<tr>
<td>14-Feb-19</td>
<td>36065.08</td>
<td>15-Feb-19</td>
<td>35985.68</td>
</tr>
<tr>
<td>18-Feb-19</td>
<td>35831.18</td>
<td>19-Feb-19</td>
<td>35543.24</td>
</tr>
<tr>
<td>20-Feb-19</td>
<td>35564.93</td>
<td>21-Feb-19</td>
<td>35837</td>
</tr>
<tr>
<td>22-Feb-19</td>
<td>35906.01</td>
<td>25-Feb-19</td>
<td>35983.8</td>
</tr>
<tr>
<td>26-Feb-19</td>
<td>35975.75</td>
<td>27-Feb-19</td>
<td>36138.83</td>
</tr>
<tr>
<td>28-Feb-19</td>
<td>36025.72</td>
<td>1-Mar-19</td>
<td>36018.49</td>
</tr>
<tr>
<td>5-Mar-19</td>
<td>36141.07</td>
<td>6-Mar-19</td>
<td>6544.86</td>
</tr>
<tr>
<td>7-Mar-19</td>
<td>36744.02</td>
<td>8-Mar-19</td>
<td>36753.59</td>
</tr>
<tr>
<td>8-Mar-19</td>
<td>36753.59</td>
<td>12-Mar-19</td>
<td>37249.65</td>
</tr>
</tbody>
</table>
2. Onion prices (per quintal) in a market are given for fifteen days. Plot a graph of given data. Find the trend graphically, using moving averages, and by the method of least squares.

<table>
<thead>
<tr>
<th>Date</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>24/01/2019</td>
<td>400</td>
</tr>
<tr>
<td>31/01/2019</td>
<td>650</td>
</tr>
<tr>
<td>3/2/19</td>
<td>650</td>
</tr>
<tr>
<td>7/2/19</td>
<td>700</td>
</tr>
<tr>
<td>24/02/2019</td>
<td>550</td>
</tr>
<tr>
<td>28/02/2019</td>
<td>550</td>
</tr>
<tr>
<td>5/3/19</td>
<td>500</td>
</tr>
<tr>
<td>7/3/19</td>
<td>600</td>
</tr>
<tr>
<td>14/03/2019</td>
<td>600</td>
</tr>
<tr>
<td>28/03/2019</td>
<td>600</td>
</tr>
<tr>
<td>7/4/19</td>
<td>800</td>
</tr>
<tr>
<td>11/4/19</td>
<td>801</td>
</tr>
<tr>
<td>14/04/2019</td>
<td>800</td>
</tr>
<tr>
<td>25/04/2019</td>
<td>800</td>
</tr>
<tr>
<td>2/5/19</td>
<td>800</td>
</tr>
</tbody>
</table>

3. Following table gives the number of persons injured in road accidents for 11 years. Plot a graph from the data. Find the trend graphically, using moving averages, and by the method of least squares.

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of injured</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2006</td>
</tr>
<tr>
<td></td>
<td>29955</td>
</tr>
<tr>
<td>Year</td>
<td>2012</td>
</tr>
<tr>
<td></td>
<td>27185</td>
</tr>
</tbody>
</table>

4. Following table gives the number of road accidents due to over-speeding in Maharashtra for 9 years. Plot a graph from the data. Find the trend graphically, using moving averages, and by the method of least squares.

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2008</td>
</tr>
<tr>
<td></td>
<td>38680</td>
</tr>
<tr>
<td>Year</td>
<td>2013</td>
</tr>
<tr>
<td></td>
<td>26931</td>
</tr>
</tbody>
</table>
Let's Study

- Definition of Index Numbers
- Types of Index Numbers
- Terminology and Notation
- Construction of Index Numbers
  - Simple Aggregate Method
  - Weighted Aggregate Method
- Cost of Living Index Number
  - Aggregative Expenditure Method
  - Family Budget Method
- Uses of Cost of Living Index Number

Introduction

The value of money does not remain the same for all the time. It cannot be observed directly, but can be understood by observing the general level of prices. A rise in the price level indicates a fall in the value of money and a fall in the price level indicates a rise in the value of money. Changes in the value of money are reflected in changes in general level of prices over a period of time. Changes in the value of money are found to be inversely related to changes in price levels. So, changes in the value of money can be understood by observing changes in the general level of prices over a specified time period. Changes in the general level of prices are measured using a statistical tool known as index numbers. Index numbers provide one of the most popular statistical tools used in economics.

Index numbers cannot be measured directly, but are constructed with help of some mathematical formula. Index numbers are not expressed in terms of any units of measurement because they are ratios. Index numbers are usually expressed as percentages.

Maslow describes an index number as a numerical value characterizing the change in a complex economic phenomenon over a period of time. According to Spiegel, an index number is a statistical measure designed to show changes in a variable or a group of related variables with respect to time, geographical location or some other characteristic. Gregory and Ward describe it as a measure designed to show an average change, over time, in the price, quantity or value of a group of items. Croxton and Cowden say that an index number is a device that measures differences in the magnitude of a group of related variables. B. L. Bowley describes an index number as a series that reflects in its trend and fluctuations the movements of some quantity to which it is related. Blair puts an index number as a special kind of average.

Let's Learn

5.1 Definition of Index Numbers.

Index Numbers are defined in different ways by different experts. Some of the most popular definitions of Index Numbers are given below.

1. An Index Number is a statistical measure of changes in a variable or a group of variables with respect to time, geographical location, or some other characteristic such as production, income, etc.

2. An Index Number is used for measuring changes in some quantity that can not be measured directly.

3. An Index Number is a single ratio, usually expressed as percentage, that measures aggregate (or average) change in several
variables between two different times, places, or situations.

After reading the above definitions, we can conclude that an Index Number is an ‘economic indicator’ of business activities.

**Examples of index numbers.**

**NIFTY:**

The NIFTY 50 index is National Stock Exchange of India’s benchmark broad based stock market index for the Indian equity market. It represents the weighted average of 50 Indian company stocks in 13 sectors and is one of the two main stock indices used in India, the other being the BSE Sensex.

**SENSEX:**

The BSE SENSEX (also known as the S&P Bombay Stock Exchange Sensitive Index or simply the SENSEX) is a free-float market-weighted stock market index of 30 well-established and financially sound companies listed on Bombay Stock Exchange.

5.2 **Types of Index Numbers**

Following are three major types of index numbers.

1. **Price Index Number**

   Price index numbers measure changes in the level of prices in the economy. It compares the price of the current year with that of the base year to indicate the relative variation. It is a very good measure of inflation in the economy.

2. **Quantity Index Number**

   As the name suggests, quantity index numbers measure changes in the quantities of goods between the two specified years. This can be the number of goods produced, sold, consumed, etc. It is a good indication of the output of an economy.

3. **Value Index Number**

   A value index number is the ratio of the aggregate value of a given commodity (or a group of commodities) in the current year and its value in the base year. A value index number combines prices and quantities by taking the product of price and quantity as the value. The value index number thus measures the percentage change in the value of a commodity or a group of commodities during the current year in comparison to its value during the base year.

5.3 **(a) : Terminology.**

**Base Period:** The base period of an index number is the period against which comparisons are made. For example, the Central Statistical Organisation (CSO) is constructing the Consumer Price Index by taking 2010 as the base year. It means that the prices in 2015 are compared with 2010 prices by taking them as 100. The base period is indicated by subscript Zero.

**Current Period:** The present period is called the current period of an index number. An index number measures the changes between the base period and the current period. The current period is indicated by subscript 1.

**Note:**

The period used in index numbers can be a day, a month, or a year. We shall use a year as the period in our study.

5.3 **(b) : Notation.**

\( \rho_0 \): Price of a commodity in the base year.

\( q_0 \): Quantity (produced, purchased, or consumed) of a commodity in the base year.

\( \rho_1 \): Price of a commodity in the current year.

\( q_1 \): Quantity (produced, purchased, or consumed) of a commodity in the current year.

\( w \): Weight assigned to a commodity according to its relative importance in the group.

\( I \): Simple index number. It is also called the price relative. It is given by
\[ I = \frac{P_1}{P_0} \times 100 \]  \hspace{1cm} (1)

- **\( P_{01} \):** Price index for the current year with respect to the base year.
- **\( Q_{01} \):** Quantity index for the current year with respect to the base year.
- **\( V_{01} \):** Value index for the current year with respect to the base year.

### 5.4 Construction of Index Numbers

Index numbers are constructed by the following two methods:

1. **Simple Aggregate Method.**
2. **Weighted Aggregate Method.**

Let us now learn how index numbers are constructed by these two methods.

#### 5.4.1 Method 1: Simple Aggregate Method

This is the simplest method of constructing index numbers. This method assumes that every commodity is equally important.

(a) **Simple Aggregate Method to find Price Index Number**

The procedure of calculating Price Index Number by the Simple Aggregate Method is as follows.

**Step I:** Prices of all commodities are added for the base year. This total is denoted by \( \sum p_0 \).

**Step II:** Prices of all commodities are added for the current year. This total is denoted by \( \sum p_1 \).

**Step III:** The total obtained in Step II is divided by the total obtained in Step I. The ratio is then multiplied by 100.

Thus, the required price index number is given by

\[ P_{01} = \frac{\sum p_1}{\sum p_0} \times 100. \]

(b) **Simple Aggregate Method to find Quantity Index Number**

Quantity Index Number can be calculated by the same procedure as above, only replacing prices by quantities.

**Step I:** Quantities of all commodities are added for the base year. This total is denoted by \( \sum q_0 \).

**Step II:** Quantities of all commodities are added for the current year. This total is denoted by \( \sum q_1 \).

**Step III:** The total obtained in Step II is divided by the total obtained in Step I. The ratio is then multiplied by 100.

Thus, the required quantity index number is given by

\[ Q_{01} = \frac{\sum q_1}{\sum q_0} \times 100. \]

(c) **Simple Aggregate Method to find Value Index Number**

Value of a commodity is defined as the product of its price and quantity. Value Index Number is then calculated using the same procedure as above, where price or quantity is replaced by value.

**Step I:** Values (that is, products of prices and quantities) of all commodities are added for the base year. This total is denoted by \( \sum p_0q_0 \).

**Step II:** Values (that is, products of prices and quantities) of all commodities are added for the current year. This total is denoted by \( \sum p_1q_1 \).

**Step III:** The total obtained in Step II is divided by the total obtained in Step I. The ratio is then multiplied by 100.

Thus, the required value index number is given by

\[ V_{01} = \frac{\sum p_1q_1}{\sum p_0q_0} \times 100. \]
SOLVED EXAMPLES

1. Calculate the price index number for the following data using the Simple Aggregate Method. Take 2000 as the base year.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price (in Rs.) for 2000</td>
<td>30</td>
<td>35</td>
<td>45</td>
<td>55</td>
<td>25</td>
</tr>
<tr>
<td>Price (in Rs.) for 2003</td>
<td>30</td>
<td>50</td>
<td>70</td>
<td>75</td>
<td>40</td>
</tr>
</tbody>
</table>

Solution:

Let us first tabulate the data in the following tabular form.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Price in 2000 (Base year) $p_0$</th>
<th>Price in 2003 (Current year) $p_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>B</td>
<td>35</td>
<td>50</td>
</tr>
<tr>
<td>C</td>
<td>45</td>
<td>70</td>
</tr>
<tr>
<td>D</td>
<td>55</td>
<td>75</td>
</tr>
<tr>
<td>E</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td>Total</td>
<td>$\sum p_0 = 190$</td>
<td>$\sum p_1 = 275$</td>
</tr>
</tbody>
</table>

Price Index Number is then given by

$$P_{01} = \frac{\sum p_1}{\sum p_0} \times 100$$

$$= \frac{275}{190} \times 100$$

$$= 144.74$$

Interpretation:

If the price of a commodity was Rs.100 in the year 2000, then the price of the same commodity is approximately Rs.145 in the year 2003. Hence, the overall increase in the price level is 45% in three years.

2. Calculate the Quantity Index Number for the following data using Simple Aggregate Method. Take year 2000 as the base year.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity in 2000</td>
<td>30</td>
<td>55</td>
<td>65</td>
<td>70</td>
<td>40</td>
<td>90</td>
</tr>
<tr>
<td>Quantity in 2004</td>
<td>40</td>
<td>60</td>
<td>70</td>
<td>90</td>
<td>55</td>
<td>95</td>
</tr>
</tbody>
</table>

Solution:

We first tabulate the data in the following tabular form.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Quantity in 2000 (Base year) $q_0$</th>
<th>Quantity in 2004 (Current year) $q_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>II</td>
<td>55</td>
<td>60</td>
</tr>
<tr>
<td>III</td>
<td>65</td>
<td>70</td>
</tr>
<tr>
<td>IV</td>
<td>70</td>
<td>90</td>
</tr>
<tr>
<td>V</td>
<td>40</td>
<td>55</td>
</tr>
<tr>
<td>VI</td>
<td>90</td>
<td>95</td>
</tr>
<tr>
<td>Total</td>
<td>$\sum q_0 = 350$</td>
<td>$\sum q_1 = 410$</td>
</tr>
</tbody>
</table>

Quantity Index Number is then given by

$$Q_{01} = \frac{\sum q_1}{\sum q_0} \times 100$$

$$= \frac{410}{350} \times 100$$

$$= 117.14.$$  

This means that the output in terms of quantity rose by approximately 17% in year 2004 from year 2000.
3. Calculate the Value Index Number for the following data using the Simple Aggregate Method.

<table>
<thead>
<tr>
<th>Commodities</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price Rs. $p_0$</td>
<td>Quantity (units) $q_0$</td>
</tr>
<tr>
<td>p</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Q</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>R</td>
<td>30</td>
<td>7</td>
</tr>
<tr>
<td>S</td>
<td>40</td>
<td>8</td>
</tr>
<tr>
<td>T</td>
<td>50</td>
<td>3</td>
</tr>
</tbody>
</table>

**Solution:** First, prepare the following table.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$p_0$</td>
<td>$q_0$</td>
</tr>
<tr>
<td>p</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Q</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>R</td>
<td>30</td>
<td>7</td>
</tr>
<tr>
<td>S</td>
<td>40</td>
<td>8</td>
</tr>
<tr>
<td>T</td>
<td>50</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** that $\sum p_0q_0 = 820$, $\sum p_1q_1 = 2790,$
and, therefore, Value Index Number is given by

$$ V_{01} = \frac{\sum p_1q_1}{\sum p_0q_0} \times 100 $$

$$ = \frac{2790}{820} \times 100 $$

$$ = 340.24 $$

4. Find $x$ in the following table if the Aggregate Price Index Number for year 1998 with respect to Base Year 1995 is 120.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price in 1995</td>
<td>6</td>
<td>15</td>
<td>$x$</td>
<td>4</td>
</tr>
<tr>
<td>Price in 1998</td>
<td>8</td>
<td>18</td>
<td>28</td>
<td>6</td>
</tr>
</tbody>
</table>

**Solution:**

<table>
<thead>
<tr>
<th>Commodity</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price in 1995</td>
<td>6</td>
<td>15</td>
<td>$x$</td>
<td>4</td>
<td>$25 + x$</td>
</tr>
<tr>
<td>Price in 1998</td>
<td>8</td>
<td>18</td>
<td>28</td>
<td>6</td>
<td>60</td>
</tr>
</tbody>
</table>

From the above table, we have

$$ \sum p_0 = 25 + x, \sum p_1 = 60, \text{ and } P_{01} = 120. $$

The value of $x$ is then found from the formula

$$ P_{01} = \frac{\sum p_1}{\sum p_0} \times 100 $$

So that we obtain

$$ 120 = \frac{60}{25 + x} \times 100 $$

$$ \therefore 12(25 + x) = 600 $$

$$ \therefore 300 + 12x = 600 $$

$$ \therefore 12x = 300 $$

$$ \therefore x = 25. $$

Hence, $x = 25$.

5. The Price Index Number for year 2004, with respect to year 2000 as base year, is known to be 130. Find the missing numbers in the following table if

<table>
<thead>
<tr>
<th>Commodity</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price (in Rs.) in 2000</td>
<td>40</td>
<td>50</td>
<td>30</td>
<td>$x$</td>
<td>60</td>
<td>100</td>
</tr>
<tr>
<td>Price (in Rs.) in 2005</td>
<td>50</td>
<td>70</td>
<td>30</td>
<td>85</td>
<td>$y$</td>
<td>115</td>
</tr>
</tbody>
</table>
Solution:

We first tabulate the given data as shown in the following table.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Price in 2000 (Base year) ( p_0 )</th>
<th>Price in 2005 (Current year) ( p_t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>B</td>
<td>50</td>
<td>70</td>
</tr>
<tr>
<td>C</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>D</td>
<td>( x )</td>
<td>85</td>
</tr>
<tr>
<td>E</td>
<td>60</td>
<td>( y )</td>
</tr>
<tr>
<td>F</td>
<td>100</td>
<td>115</td>
</tr>
</tbody>
</table>

From the above table, we have

\[ \sum p_0 = 280 + x, \quad \sum p_t = 350 + y, \]

But it is given that \( \sum p_0 = 320 \), so that

\[ 280 + x = 320 \]

\[ \therefore \quad x = 40 \]

Further, using the formula

\[ P_{01} = \frac{\sum p_t}{\sum p_0} \times 100 \]

We have

\[ 130 = \frac{350 + y}{320} \times 100 \]

\[ \therefore \quad 416 = 350 + y \]

\[ \therefore \quad y = 66. \]

EXERCISE 5.1

Find the Price Index Number using Simple Aggregate Method in each of the following examples.

1. Use 1995 as base year in the following problem.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>P</th>
<th>Q</th>
<th>R</th>
<th>S</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price (in Rs.) in 1995</td>
<td>15</td>
<td>20</td>
<td>24</td>
<td>23</td>
<td>28</td>
</tr>
<tr>
<td>Price (in Rs.) in 2000</td>
<td>27</td>
<td>38</td>
<td>32</td>
<td>40</td>
<td>45</td>
</tr>
</tbody>
</table>

2. Use 1995 as base year in the following problem.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price (in Rs.) in 1995</td>
<td>42</td>
<td>30</td>
<td>58</td>
<td>70</td>
<td>120</td>
</tr>
<tr>
<td>Price (in Rs.) in 2005</td>
<td>60</td>
<td>55</td>
<td>75</td>
<td>110</td>
<td>140</td>
</tr>
</tbody>
</table>

3.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Unit</th>
<th>Base Year Price (in Rs.)</th>
<th>Current Year Price (in Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>kg</td>
<td>28</td>
<td>36</td>
</tr>
<tr>
<td>Rice</td>
<td>kg</td>
<td>40</td>
<td>56</td>
</tr>
<tr>
<td>Milk</td>
<td>litre</td>
<td>32</td>
<td>45</td>
</tr>
<tr>
<td>Clothing</td>
<td>meter</td>
<td>82</td>
<td>104</td>
</tr>
<tr>
<td>Fuel</td>
<td>litre</td>
<td>58</td>
<td>72</td>
</tr>
</tbody>
</table>

4. Use 2000 as base year in the following problem.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Price (in Rs.) for year 2000</th>
<th>Price (in Rs.) for year 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watch</td>
<td>900</td>
<td>1475</td>
</tr>
<tr>
<td>Shoes</td>
<td>1800</td>
<td>2300</td>
</tr>
<tr>
<td>Sunglasses</td>
<td>600</td>
<td>1040</td>
</tr>
<tr>
<td>Mobile</td>
<td>4500</td>
<td>8500</td>
</tr>
</tbody>
</table>

5. Use 1990 as base year in the following problem.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Unit</th>
<th>Price (in Rs.) for 1990</th>
<th>Price (in Rs.) for 1997</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butter</td>
<td>kg</td>
<td>21</td>
<td>33</td>
</tr>
<tr>
<td>Cheese</td>
<td>kg</td>
<td>30</td>
<td>36</td>
</tr>
<tr>
<td>Milk</td>
<td>litre</td>
<td>25</td>
<td>29</td>
</tr>
<tr>
<td>Bread</td>
<td>loaf</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>Eggs</td>
<td>doz</td>
<td>24</td>
<td>36</td>
</tr>
<tr>
<td>Ghee</td>
<td>tin</td>
<td>250</td>
<td>320</td>
</tr>
</tbody>
</table>
6. Assume 2000 to be base year in the following problem.

<table>
<thead>
<tr>
<th>Fruit</th>
<th>Unit</th>
<th>Price (in Rs.) in 2000</th>
<th>Price (in Rs.) in 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mango</td>
<td>doz</td>
<td>250</td>
<td>300</td>
</tr>
<tr>
<td>Banana</td>
<td>doz</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>Apple</td>
<td>kg</td>
<td>80</td>
<td>110</td>
</tr>
<tr>
<td>Peach</td>
<td>kg</td>
<td>75</td>
<td>90</td>
</tr>
<tr>
<td>Orange</td>
<td>doz</td>
<td>33</td>
<td>65</td>
</tr>
<tr>
<td>Sweet Lime</td>
<td>doz</td>
<td>30</td>
<td>45</td>
</tr>
</tbody>
</table>

7. Use 2005 as base year in the following problem.

<table>
<thead>
<tr>
<th>Vegetable</th>
<th>Unit</th>
<th>Price (in Rs.) in 2005</th>
<th>Price (in Rs.) in 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ladies Finger</td>
<td>kg</td>
<td>32</td>
<td>38</td>
</tr>
<tr>
<td>Capsicum</td>
<td>kg</td>
<td>30</td>
<td>36</td>
</tr>
<tr>
<td>Brinjal</td>
<td>kg</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>Tomato</td>
<td>kg</td>
<td>40</td>
<td>62</td>
</tr>
<tr>
<td>Potato</td>
<td>kg</td>
<td>18</td>
<td>28</td>
</tr>
</tbody>
</table>

Find the Quantity Index Number using Simple Aggregate Method in each of the following examples.

8. Find the Quantity Index Number using Simple Aggregate Method in each of the following examples.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Year Quantities</td>
<td>140</td>
<td>120</td>
<td>100</td>
<td>200</td>
<td>220</td>
</tr>
<tr>
<td>Current Year Quantities</td>
<td>100</td>
<td>80</td>
<td>70</td>
<td>150</td>
<td>185</td>
</tr>
</tbody>
</table>

9. Find the Value Index Number using Simple Aggregate Method in each of the following examples.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Year Quantities</td>
<td>360</td>
<td>280</td>
<td>340</td>
<td>160</td>
<td>260</td>
</tr>
<tr>
<td>Current Year Quantities</td>
<td>440</td>
<td>320</td>
<td>470</td>
<td>210</td>
<td>300</td>
</tr>
</tbody>
</table>

10. | Commodity | Base Year | Current Year |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price</td>
<td>Quantity</td>
</tr>
<tr>
<td>A</td>
<td>30</td>
<td>22</td>
</tr>
<tr>
<td>B</td>
<td>40</td>
<td>15</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>38</td>
</tr>
<tr>
<td>D</td>
<td>50</td>
<td>12</td>
</tr>
<tr>
<td>E</td>
<td>20</td>
<td>28</td>
</tr>
</tbody>
</table>

11. | Commodity | Base Year | Current Year |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price</td>
<td>Quantity</td>
</tr>
<tr>
<td>A</td>
<td>50</td>
<td>22</td>
</tr>
<tr>
<td>B</td>
<td>70</td>
<td>16</td>
</tr>
<tr>
<td>C</td>
<td>60</td>
<td>19</td>
</tr>
<tr>
<td>D</td>
<td>120</td>
<td>12</td>
</tr>
<tr>
<td>E</td>
<td>100</td>
<td>22</td>
</tr>
</tbody>
</table>

12. Find x if the Price Index Number by Simple Aggregate Method is 125.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>P</th>
<th>Q</th>
<th>R</th>
<th>S</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Year Price (in Rs.)</td>
<td>8</td>
<td>12</td>
<td>16</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td>Current Year Price (in Rs.)</td>
<td>12</td>
<td>18</td>
<td>x</td>
<td>28</td>
<td>22</td>
</tr>
</tbody>
</table>

13. Find y if the Price Index Number by Simple Aggregate Method is 120, taking 1995 as base year.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price (in Rs.) for 1995</td>
<td>95</td>
<td>y</td>
<td>80</td>
<td>35</td>
</tr>
<tr>
<td>Price (in Rs.) for 2003</td>
<td>116</td>
<td>74</td>
<td>92</td>
<td>42</td>
</tr>
</tbody>
</table>

5.4.2 Method 2: Weighted Aggregate Method

This method assigns suitable weights to different commodities before aggregating their prices, quantities, or values. These weights indicate relative importance of various commodities in the group. If w denotes the weight attached to a commodity, then the Price Index Number is given by
\[ P_{01} = \frac{\sum p_i w}{\sum p_0 w} \times 100 \]

Weights are usually defined in terms of quantities in the weighted aggregate method. Index numbers constructed by the weighted aggregate method are known by names of the developers of these index numbers. Following are most popular price index numbers constructed by the weighted aggregate method.

(a) **Laspeyre’s Price Index Number**

\[ P_{01}(L) = \frac{\sum p_i q_0}{\sum p_0 q_0} \times 100 \]

**Note:** This construction uses base year quantities as weights.

(b) **Paasche’s Price Index Number**

\[ P_{01}(P) = \frac{\sum p_i q_i}{\sum p_0 q_i} \times 100 \]

**Note:** This construction uses current year quantities as weights.

(c) **Dorbish-Bowley’s Price Index Number**

\[ P_{01}(D-B) = \frac{\sum p_i q_0 + \sum p_i q_i}{2} \times 100 \]

(d) **Fisher’s Ideal Price Index Number**

\[ P_{01}(F) = \sqrt{\frac{\sum p_i q_0}{\sum p_0 q_i}} \times \sqrt{\frac{\sum p_i q_i}{\sum p_0 q_i}} \times 100 \]

**Question:**
Can you find any relation among Laspeyre’s, Paasche’s, Dorbish-Bowley’s and Fisher’s Price Index Number?

(e) **Marshall-Edgeworth’s Price Index Number**

\[ P_{01}(M-E) = \frac{\sum p_i (q_0 + q_i)}{\sum p_0 (q_0 + q_i)} \times 100 \]

\[ = \frac{\sum p_i q_0 + \sum p_i q_i}{\sum p_0 q_0 + \sum p_0 q_i} \times 100 \]

**Solution:**

Let us first prepare the following table.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price</td>
<td>Quantity</td>
</tr>
<tr>
<td>p</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>q</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>r</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>s</td>
<td>16</td>
<td>15</td>
</tr>
</tbody>
</table>

**Table 5.6**

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( P_0 )</td>
<td>( P_1 )</td>
</tr>
<tr>
<td>p</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>q</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>r</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>s</td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>728</td>
<td>1032</td>
</tr>
</tbody>
</table>

From the above table, we have

\[ \sum p_0 q_0 = 728, \quad \sum p_1 q_0 = 1032 \]

\[ \sum p_0 q_i = 1056 \quad \sum p_1 q_i = 1484 \]

(a) **Laspeyre’s Price Index Number** is then

\[ P_{01}(L) = \frac{\sum p_i q_0}{\sum p_0 q_0} \times 100 \]

\[ = \frac{1032}{728} \times 100 \]

\[ \therefore P_{01}(L) = 141.76 \]
(b) Paasche’s Price Index Number is given by

\[ P_{01}(P) = \frac{\sum p_1 q_h}{\sum p_0 q_h} \times 100 \]

\[ = \frac{1484}{1056} \times 100 \]

\[ \therefore P_{01}(P) = 140.53 \]

(c) Dorbish-Bowley’s Price Index Number is given by

\[ P_{01}(D - B) = \frac{P_{01}(L) + P_{01}(P)}{2} \]

\[ = \frac{141.76 + 140.53}{2} \]

\[ = 141.15 \]

(d) Marshall-Edgeworth’s Price Index Number is given by

\[ P_{01}(M - E) = \frac{\left(\sum p_1 q_0 + \sum p_0 q_1\right)}{\left(\sum q_0 + \sum q_1\right)} \times 100 \]

\[ = \frac{1032 + 1484}{728 + 1056} \times 100 \]

\[ = \frac{2516}{1784} \times 100 = 141.03 \]

\[ \therefore P_{01}(M - E) = 141.03 \]

2. Calculate Walsh’s Price Index Number for the following data.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Base Year</th>
<th>Current Year</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>20</td>
<td>9</td>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>5</td>
<td>50</td>
<td>5</td>
</tr>
<tr>
<td>C</td>
<td>40</td>
<td>8</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>30</td>
<td>4</td>
<td>20</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5.7

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Base Year</th>
<th>Current Year</th>
<th>( \sqrt{q_0 q_h} )</th>
<th>( \sqrt{q_0 q_h} )</th>
<th>( p_0 \sqrt{q_0 q_h} )</th>
<th>( p_1 \sqrt{q_0 q_h} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>20</td>
<td>9</td>
<td>30</td>
<td>4</td>
<td>6</td>
<td>120</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>5</td>
<td>50</td>
<td>5</td>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>C</td>
<td>40</td>
<td>8</td>
<td>10</td>
<td>2</td>
<td>4</td>
<td>160</td>
</tr>
<tr>
<td>D</td>
<td>30</td>
<td>4</td>
<td>20</td>
<td>1</td>
<td>2</td>
<td>60</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>390</td>
<td>510</td>
</tr>
</tbody>
</table>

From the above table, we get

\[ \sum p_0 \sqrt{q_0 q_h} = 390 \]

\[ \sum p_1 \sqrt{q_0 q_h} = 510 \]

Walsh’s Price Index Number is given by

\[ P_{01}(W) = \frac{\sum p_0 \sqrt{q_0 q_h}}{\sum p_0 q_h} \times 100 \]

\[ = \frac{510}{390} \times 100 \]

\[ = \frac{5100}{39} \]

\[ \therefore P_{01}(W) = 130.77 \]

3. If \( P_{01}(L) = 225 \), \( P_{01}(P) = 144 \), then calculate \( P_{01}(F) \) and \( P_{01}(D - B) \)

**Solution:**

Given \( P_{01}(L) = 225 \), \( P_{01}(P) = 144 \), we obtain

\[ P_{01}(F) = \sqrt{P_{01}(L) \times P_{01}(P)} \]

\[ = \sqrt{225 \times 144} \]

\[ = 15 \times 12 \]

\[ \therefore P_{01}(F) = 180 \]

Next,

\[ P_{01}(D - B) = \frac{P_{01}(L) + P_{01}(P)}{2} \]

\[ = \frac{225 + 144}{2} \]

\[ \therefore P_{01}(D - B) = 184.50 \]
Example 4:
Find the missing price in the following table if Laspeyre’s and Paasche’s Price Index Numbers are the same.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price</td>
<td>Quantity</td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

Solution:
Let us denote the missing value by \( x \), and reconstruct the table as follows.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Base Year</th>
<th>Current Year</th>
<th>Base Year</th>
<th>Current Year</th>
<th>( P_0 q_0 )</th>
<th>( P_0 q_1 )</th>
<th>( P_1 q_0 )</th>
<th>( P_1 q_1 )</th>
<th>( P_0 q_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>5</td>
<td>20</td>
<td>10</td>
<td>20 + 5x</td>
<td>10 + 2x</td>
<td>15</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>5x</td>
<td>2x</td>
<td>2x</td>
<td>2x</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>15</td>
<td></td>
<td>20 + 5x</td>
<td>10 + 2x</td>
<td>7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The above table gives
\[
\sum p_0 q_0 = 15, \quad \sum p_1 q_0 = 20 + 5x \\
\sum p_0 q_1 = 7, \quad \sum p_1 q_1 = 10 + 2x
\]

It is given that
\[
P_{01}(L) = P_{01}(P)
\]
\[
\frac{\sum p_1 q_0}{\sum p_0 q_0} \times 100 = \frac{\sum p_1 q_1}{\sum p_0 q_1} \times 100
\]
\[
\therefore \frac{5x + 20}{15} = \frac{2x + 10}{7}
\]
\[
\therefore \frac{5(x + 4)}{15} = \frac{2x + 10}{7}
\]
\[
\therefore 7(x + 4) = 3(2x + 10)
\]
\[
\therefore 7x + 28 = 6x + 30
\]
\[
\therefore x = 2.
\]
The missing price is 2.

5. If \( \sum p_0 q_0 = 120, \sum p_0 q_1 = 200 \)
\( \sum p_1 q_0 = 300, \) and \( P_{01}(L) = 150, \) find \( P_{01}(M - E). \)

Solution: Note that
\[
P_{01}(L) = \frac{\sum p_1 q_0}{\sum p_0 q_0} \times 100
\]
\[
\therefore 150 = \frac{\sum p_1 q_0}{120} \times 100
\]
\[
\therefore \sum p_1 q_0 = 15 \times 12
\]
\[
\therefore \sum p_1 q_0 = 180.
\]

Now,
\[
P_{01}(M - E) = \left( \frac{\sum p_1 q_0 + \sum p_1 q_1}{\sum p_0 q_0 + \sum p_0 q_1} \right) \times 100
\]
\[
= \left( \frac{180 + 300}{120 + 200} \right) \times 100
\]
\[
= \frac{480}{320} \times 100
\]
\[
\therefore P_{01}(M - E) = 150.
\]

6. If \( \sum p_0 q_0 = 180, \sum p_1 q_0 = 200 \)
\( \sum p_1 q_1 = 280, \) and \( P_{01}(M - E) = 150, \)
find \( P_{01}(P). \)

Solution:
Let us denote \( \sum p_0 q_1 \) by \( x \). Then, using the fact that
\[
P_{01}(M - E) = \left( \frac{\sum p_1 q_0 + \sum p_1 q_1}{\sum p_0 q_0 + \sum p_0 q_1} \right) \times 100
\]
\[
\therefore 150 = \frac{200 + 280}{180 + x} \times 100
\]
\[
\therefore 15(180 + x) = 4800
\]
\[
\therefore 180 + x = \frac{4800}{15} \\
\therefore 180 + x = 320 \\
\therefore x = 140 \\
\therefore \sum p_0q_h = 140.
\]

Now,

\[
P_{o1}(P) = \frac{\sum p_0q_h \times 100}{=} \frac{280}{140} \times 100
\]

\[
\therefore P_{o1}(P) = 200
\]

**EXERCISE 5.2**

Calculate Laspeyre's, Paasche's, Dorbish-Bowley's and Marshall-Edgeworth's Price Index Numbers in Problems 1 and 2

1. | Commodity | Base Year | Current Year |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price</td>
<td>Quantity</td>
</tr>
<tr>
<td>A</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>B</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>50</td>
</tr>
</tbody>
</table>

2. | Commodity | Base Year | Current Year |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price</td>
<td>Quantity</td>
</tr>
<tr>
<td>I</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>II</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>III</td>
<td>30</td>
<td>7</td>
</tr>
<tr>
<td>IV</td>
<td>40</td>
<td>8</td>
</tr>
</tbody>
</table>

Calculate Walsh's Price Index Number in Problem 3 and 4.

3. | Commodity | Base Year | Current Year |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price</td>
<td>Quantity</td>
</tr>
<tr>
<td>L</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>M</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>N</td>
<td>8</td>
<td>28</td>
</tr>
</tbody>
</table>

4. | Commodity | Base Year | Current Year |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price</td>
<td>Quantity</td>
</tr>
<tr>
<td>I</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>II</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>III</td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>IV</td>
<td>60</td>
<td>9</td>
</tr>
</tbody>
</table>

5. If \( P_{o1}(L) = 90 \), and \( P_{o1}(P) = 40 \), find \( P_{o1}(D - B) \) and \( P_{o1}(F) \).

6. If \( \sum p_0q_h = 140 \), \( \sum p_0q_h = 200 \), \( \sum p_0q_h = 350 \), \( \sum p_0q_h = 460 \), find Laspeyre's, Paasche's, Dorbish-Bowley's and Marshall-Edgeworth's Price Index Numbers.

7. Given that Laspeyre's and Dorbish-Bowley's Price Index Numbers are 160.32 and 164.18 respectively. Find Paasche's Price Index Number.

8. Given that \( \sum p_0q_h = 220 \), \( \sum p_0q_h = 380 \), \( \sum p_0q_h = 350 \) and Marshall-Edgeworth's Price Index Number is 150, find Laspeyre's Price Index Number.

9. Find \( x \) in the following table if Laspeyre's and Paasche's Price Index Numbers are equal.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price</td>
<td>Quantity</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

10. If Laspeyre's Price Index Number is four times Paasche's Price Index Number, then find the relation between Dorbish-Bowley's and Fisher's Price Index Numbers.

11. If Dorbish-Bowley's and Fisher's Price Index Numbers are 5 and 4, respectively, then find Laspeyre's and Paasche's Price Index Numbers.
5.5 Cost of Living Index Number

Cost of Living Index Number, also known as Consumer Price Index Number, is an index number of the cost of buying goods and services in day-to-day life for a specific consumer class. Different classes of consumers show different patterns of consumption of goods and services. As a result, a general index number cannot reflect changes in cost of living for a specific consumer class. For example, cost of living index numbers for rural population are different from cost of living index numbers for urban population. The goods and services consumed by members of different consumer classes can be different and therefore cost of living index numbers calculated for different consumer classes can be based on costs of different sets of goods and services.

Steps in Construction of Cost of Living Index Numbers

Construction of cost of living index numbers involves the following steps:

1. Choice of Base Year:
   The first step in preparing cost of living index numbers is choice of base year. Base years defined as that year with reference to which price changes in other years are compared and expressed as percentages. The base year should be a normal year. It should be free from abnormal conditions like wars, famines, floods, political instability, etc.

   Base year can be chosen in two ways:
   (a) Using fixed base method, where the base year remains fixed; and
   (b) Using chain base method, where the base year goes on changing. For example, 1979 will be the base year for 1980, it will be 1978 for 1979, and so on.

2. Choice of Commodities:
   The second step in construction of cost of living index numbers is choosing the commodities. Since all commodities cannot be included, only representative commodities should be chosen according to the purpose of the index number.

   In choosing commodities, the following points must be kept in mind:
   (a) The commodities must represent the tastes, habits and customs of the people.
   (b) Commodities should be recognizable.
   (c) Commodities should have the same quality over different periods and places.
   (d) The economic and social importance of different commodities should be taken in consideration.
   (e) The commodities should be sufficiently large in number,
   (f) All varieties of a commodity should be included that are in common use and are stable in nature.

3. Collection of Prices:
   After choosing the commodities, the next step is collection of their prices. The following points are important while collecting prices of commodities chosen for constructing cost of living index numbers.

   (a) From where prices are to be collected.
   (b) Whether to collect wholesale prices or retail prices.
   (c) Whether to include taxes in prices.

   Following points are to be noted while collecting prices:

   (a) Prices must be collected from places where a particular commodity is traded in large quantities
   (b) If published information on prices is available, it must be used,
   (c) Care should be taken while collecting price quotations from individuals or institutions that they provide correct information.
   (d) Choice of wholesale or retail prices depends on the purpose of preparing...
index numbers. Wholesale prices are used in the construction of general price index, while retail prices are used in the construction of cost of living index.

(e) Prices must be averaged if collected from several sources.

4. Choice of Average:
Since the index numbers are a specialized average, it is important to choose a suitable average. Geometric mean is theoretically the best, but arithmetic mean is used in practice because it is easier to calculate.

5. Choice of Weights:
Generally, all the commodities included in the construction of index numbers are not equally important. Therefore, proper weights must be assigned to the commodities according to their relative importance. For example, cost of living index for teachers will assign higher weightage to prices of books than cost of living index for workers. Weights should be chosen rationally and not arbitrarily.

6. Purpose of Index Numbers:
The most important consideration in the construction of index numbers is their objective. All other steps are to be viewed in light of the purpose for which a particular index number is being prepared. Since every index number is prepared with a specific purpose, no single index number can be 'all purpose' index number. It is important to have a clear idea about the purpose of the index number before it is constructed.

Methods of constructing Cost of Living Index Numbers

5.5.1 Aggregative Expenditure Method (Weighted Aggregate Method)
This method uses quantities consumed in base year as weights, so that Cost of Living Index Number is defined as follows.

\[ CLI = \left( \frac{\text{Total expenditure in current year}}{\text{Total expenditure in base year}} \right) \times 100 \]

\[ = \frac{\sum p_1 q_0}{\sum p_0 q_0} \times 100 \]

The above formula is similar to that of a weighted Index Number. Do you recognize that Index Number?

5.5.2 Family Budget Method (Weighted Relative Method)
Cost of Living Index Number is defined as follows.

\[ CLI = \frac{\sum IW}{\sum W} \]

where

\[ I = \frac{P_1}{P_0} \times 100 \]

= price relative for current year

and

\[ W = p_0 q_0 \]

= base year weightage.

Do you find the above two methods of calculating the Cost of Living Index Numbers to be same?

**SOLVED EXAMPLES**

1. Construct the Cost of Living Index Number for the following data.

<table>
<thead>
<tr>
<th>Group</th>
<th>Base Year</th>
<th>Current Year</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>Quantity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food &amp; Clothing</td>
<td>40</td>
<td>3</td>
<td>70</td>
</tr>
<tr>
<td>Fuel &amp; Lighting</td>
<td>30</td>
<td>5</td>
<td>60</td>
</tr>
<tr>
<td>House Rent</td>
<td>50</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>60</td>
<td>3</td>
<td>90</td>
</tr>
</tbody>
</table>
Solution:

We shall begin by preparing the following table.

<table>
<thead>
<tr>
<th>Group</th>
<th>Base Year</th>
<th>Current Year</th>
<th>$p_0q_0$</th>
<th>$p_1q_0$</th>
<th>$p_0q_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food &amp; Clothing</td>
<td>40</td>
<td>3</td>
<td>70</td>
<td>210</td>
<td>120</td>
</tr>
<tr>
<td>Fuel &amp; Lighting</td>
<td>30</td>
<td>5</td>
<td>60</td>
<td>300</td>
<td>150</td>
</tr>
<tr>
<td>House Rent</td>
<td>50</td>
<td>2</td>
<td>50</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>60</td>
<td>3</td>
<td>90</td>
<td>270</td>
<td>180</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td>880</td>
<td>550</td>
</tr>
</tbody>
</table>

We shall use Aggregative Expenditure Method since $p_0$, $q_0$, and $p_1$ are given.

$$CLI = \frac{\sum p_1q_0}{\sum p_0q_0} \times 100$$

$$= \frac{880}{550} \times 100$$

$$\therefore CLI = 160.$$ 

**Interpretation.** A person earning Rs 100 in the base year, should earn Rs 160 in the current year to maintain the same standard of living.

2. The following table gives the base year weightage (W) and current year price relative (I) for five commodities. Calculate the Cost of Living Index Number.

<table>
<thead>
<tr>
<th>Group</th>
<th>Food</th>
<th>Clothing</th>
<th>Fuel &amp; Lighting</th>
<th>House Rent</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>120</td>
<td>100</td>
<td>140</td>
<td>160</td>
<td>150</td>
</tr>
<tr>
<td>W</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

**Solution:**

We use Family Budget Method since I and W are given. For this, we prepare the following table.

<table>
<thead>
<tr>
<th>Group</th>
<th>Food</th>
<th>Clothing</th>
<th>Fuel &amp; Lighting</th>
<th>House Rent</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I</strong></td>
<td>100</td>
<td>125</td>
<td>174</td>
<td>$x$</td>
<td>90</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td>13</td>
<td>12</td>
<td>10</td>
<td>8</td>
<td>7</td>
</tr>
</tbody>
</table>

### Table 5.10

<table>
<thead>
<tr>
<th>Group</th>
<th>I</th>
<th>W</th>
<th>IW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>120</td>
<td>3</td>
<td>360</td>
</tr>
<tr>
<td>Clothing</td>
<td>100</td>
<td>6</td>
<td>600</td>
</tr>
<tr>
<td>Fuel &amp; Lighting</td>
<td>140</td>
<td>5</td>
<td>700</td>
</tr>
<tr>
<td>House Rent</td>
<td>160</td>
<td>2</td>
<td>320</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>150</td>
<td>4</td>
<td>600</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>-</td>
<td>20</td>
<td>2580</td>
</tr>
</tbody>
</table>

The above table shows that $\sum W = 20$ and $\sum IW = 2580$, and

$$\therefore CLI = \frac{\sum IW}{\sum W} = \frac{2580}{20} = 129.$$ 

3. Find $x$ in the following table if the Cost of Living Index Number is 121.

<table>
<thead>
<tr>
<th>Group</th>
<th>Food</th>
<th>Clothing</th>
<th>Fuel &amp; Lighting</th>
<th>House Rent</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I</strong></td>
<td>100</td>
<td>125</td>
<td>174</td>
<td>$x$</td>
<td>90</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td>13</td>
<td>12</td>
<td>10</td>
<td>8</td>
<td>7</td>
</tr>
</tbody>
</table>

**Solution:**

First, we prepare the following table.

<table>
<thead>
<tr>
<th>Group</th>
<th>I</th>
<th>W</th>
<th>IW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>100</td>
<td>13</td>
<td>1300</td>
</tr>
<tr>
<td>Clothing</td>
<td>125</td>
<td>12</td>
<td>1500</td>
</tr>
<tr>
<td>Fuel &amp; Lighting</td>
<td>174</td>
<td>10</td>
<td>1740</td>
</tr>
<tr>
<td>House Rent</td>
<td>$x$</td>
<td>8</td>
<td>$8x$</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>90</td>
<td>7</td>
<td>630</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>-</td>
<td>50</td>
<td>$5170 + 8x$</td>
</tr>
</tbody>
</table>

It can be found from the above table that...
\[ \sum W = 50 \text{ and } \sum IW = 5170 + 8x \]

\[ \therefore \text{CLI} = \frac{\sum IW}{\sum W} \]

\[ \therefore 121 = \frac{5170 + 8x}{50} \]

\[ \therefore 6050 = 5170 + 8x \]

\[ \therefore x = 110. \]

4. Cost of Living Index Numbers for the years 2000 and 2005 are 120 and 220, respectively. If a person has monthly earnings of Rs 10800 in year 2000, what should be his monthly earnings in year 2005 in order to maintain same standard of living?

**Solution:**

For the year 2000, it is given that CLI = 120, and Income = Rs 10800. These two give us real income as follows.

Real Income = \( \frac{\text{Income}}{\text{CLI}} \times 100 \)

\[ = \frac{10800}{120} \times 100 \]

\[ \therefore \text{Real Income} = 9000. \]

This shows that the real income is Rs 9000.

The CLI for year 2005 is 220.

Real Income = \( \frac{\text{Income}}{\text{CLI}} \times 100 \)

\[ = \frac{9000}{220} \times 100 \]

\[ \therefore \text{Income} = 19800. \]

This shows that the monthly income of the person should be Rs 19800 in year of 2005 in order to maintain the same standard of living as in year 2000.

5. Calculate the Cost of Living Index Number for the year 1999 by Family Budget Method from the following data. Also, find the expenditure of a person in year 1999 if his expenditure in year 1995 was 800.

<table>
<thead>
<tr>
<th>Group</th>
<th>Price in year 1995</th>
<th>Price in year 1999</th>
<th>( I = \frac{P_1}{P_0} \times 100 )</th>
<th>W</th>
<th>IW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>8</td>
<td>24</td>
<td>300</td>
<td>6</td>
<td>1800</td>
</tr>
<tr>
<td>Clothing</td>
<td>18</td>
<td>36</td>
<td>200</td>
<td>12</td>
<td>2400</td>
</tr>
<tr>
<td>Fuel &amp; Lighting</td>
<td>20</td>
<td>40</td>
<td>200</td>
<td>8</td>
<td>1600</td>
</tr>
<tr>
<td>House Rent</td>
<td>15</td>
<td>30</td>
<td>200</td>
<td>4</td>
<td>800</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>10</td>
<td>22</td>
<td>220</td>
<td>10</td>
<td>2200</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
<td><strong>40</strong></td>
<td><strong>8800</strong></td>
</tr>
</tbody>
</table>

By Family Budget Method,

\[ \therefore \text{CLI} = \frac{\sum IW}{\sum W} \]

\[ = \frac{8800}{40} \]

\[ \therefore \text{CLI} = 220 \]

Now, the expenditure in 1995 was Rs 800. In other words, the expenditure is Rs 800 when CLI is 100. The question is to find expenditure when CLI is 220 in 1999.

\[ \therefore \text{Expenditure in 1999} = \frac{220}{100} \times 800 \]

\[ = 1760 \]

Thus, the expenditure in 1999 is Rs 1760.
EXERCISE 5.3

Calculate the cost of living index in problems 1 to 3.

1.

<table>
<thead>
<tr>
<th>Group</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price</td>
<td>Quantity</td>
</tr>
<tr>
<td>Food</td>
<td>120</td>
<td>15</td>
</tr>
<tr>
<td>Clothing</td>
<td>150</td>
<td>20</td>
</tr>
<tr>
<td>Fuel &amp; Lighting</td>
<td>130</td>
<td>30</td>
</tr>
<tr>
<td>House Rent</td>
<td>160</td>
<td>10</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>200</td>
<td>12</td>
</tr>
</tbody>
</table>

2.

<table>
<thead>
<tr>
<th>Group</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price</td>
<td>Quantity</td>
</tr>
<tr>
<td>Food</td>
<td>40</td>
<td>15</td>
</tr>
<tr>
<td>Clothing</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>Fuel &amp; Lighting</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>House Rent</td>
<td>60</td>
<td>20</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>70</td>
<td>20</td>
</tr>
</tbody>
</table>

3.

<table>
<thead>
<tr>
<th>Group</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price</td>
<td>Quantity</td>
</tr>
<tr>
<td>Food</td>
<td>130</td>
<td>10</td>
</tr>
<tr>
<td>Clothing</td>
<td>150</td>
<td>12</td>
</tr>
<tr>
<td>Fuel &amp; Lighting</td>
<td>162</td>
<td>20</td>
</tr>
<tr>
<td>House Rent</td>
<td>170</td>
<td>18</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>120</td>
<td>5</td>
</tr>
</tbody>
</table>

Base year weights (W) and current year price relatives (I) are given in Problems 4 to 8. Calculate the cost of living index in each case.

4.

<table>
<thead>
<tr>
<th>Group</th>
<th>Food</th>
<th>Clothing</th>
<th>Fuel &amp; Lighting</th>
<th>House Rent</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>70</td>
<td>90</td>
<td>100</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>W</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

5.

<table>
<thead>
<tr>
<th>Group</th>
<th>Food</th>
<th>Clothing</th>
<th>Fuel &amp; Lighting</th>
<th>House Rent</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>400</td>
<td>300</td>
<td>150</td>
<td>120</td>
<td>100</td>
</tr>
<tr>
<td>W</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>2</td>
</tr>
</tbody>
</table>

6.

<table>
<thead>
<tr>
<th>Group</th>
<th>Food</th>
<th>Clothing</th>
<th>Fuel &amp; Lighting</th>
<th>House Rent</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>200</td>
<td>150</td>
<td>120</td>
<td>180</td>
<td>160</td>
</tr>
<tr>
<td>W</td>
<td>30</td>
<td>20</td>
<td>10</td>
<td>40</td>
<td>50</td>
</tr>
</tbody>
</table>

7. Find $x$ if the cost of living index is 150.

<table>
<thead>
<tr>
<th>Group</th>
<th>Food</th>
<th>Clothing</th>
<th>Fuel &amp; Lighting</th>
<th>House Rent</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>180</td>
<td>120</td>
<td>300</td>
<td>100</td>
<td>160</td>
</tr>
<tr>
<td>W</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>$x$</td>
<td>3</td>
</tr>
</tbody>
</table>

8. Find $y$ if the cost of living index is 200.

<table>
<thead>
<tr>
<th>Group</th>
<th>Food</th>
<th>Clothing</th>
<th>Fuel &amp; Lighting</th>
<th>House Rent</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>180</td>
<td>120</td>
<td>160</td>
<td>300</td>
<td>200</td>
</tr>
<tr>
<td>W</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>$y$</td>
<td>2</td>
</tr>
</tbody>
</table>

9. The Cost of Living Index Number for years 1995 and 1999 are 140 and 200 respectively. A person earns Rs. 11,200 per month in the year 1995. What should be his monthly earnings in the year 1999 in order to maintain his standard of living as in the year 1995?
5.6 Uses of Cost of Living Index Number

1. Cost of Living Index Number is used to regulate the dearness allowance or the grant of bonus to employees in order to enable them bear the increased cost of living.

2. Cost of Living Index Number is used for settling dispute related to salaries and wages.

3. Cost of Living Index Number is used in calculating purchasing power of money.
   \[
   \text{Purchasing power of money} = \frac{1}{\text{Cost of Living Index Number}}
   \]

4. Cost of Living Index Number is used in determining real wages.
   \[
   \text{Real Wages} = \frac{\text{Money wages}}{\text{Cost of Living Index Number}} \times 100
   \]

5. Cost of Living Index Numbers are widely used in negotiations of wages in wage contracts.

Let’s Remember

- There are three types of index numbers.
  (i) Price Index Number
  (ii) Quantity Index Number
  (iii) Value Index Number

- There are two methods of constructing index numbers.
  (i) Simple Aggregate Method
  (ii) Weighted Aggregate Method

- Price Index Number using Simple aggregate method is calculated by the following formula.
  \[
  P_{01} = \frac{\sum P_1}{\sum p_0} \times 100
  \]

Where

- \( P_{01} \): Price index Number for the current year with respect to base year
- \( P_1 \): Price of the commodity in current year
- \( P_0 \): Price of the commodity in base year

- Price Index Number using Weighted Aggregate Method is calculated by the following formula.
  \[
  P_{01} = \frac{\sum P_1 w_1}{\sum p_0 w_0} \times 100
  \]

Where

- \( w \): Weight assigned to a commodity

- Laspeyre’s Price Index Number
  \[
  P_{01}(L) = \frac{\sum p_1 q_0}{\sum p_0 q_0} \times 100
  \]

- Paasche’s Price Index Number
  \[
  P_{01}(P) = \frac{\sum p_1 q_1}{\sum p_0 q_1} \times 100
  \]

- Dorbish-Bowley’s Price Index Number
  \[
  P_{01}(D-B) = \frac{\sum P_1 q_0 + \sum P_1 q_1}{2} \times 100
  \]

- Fisher’s Price Index Number
  \[
  P_{01}(F) = \sqrt{\frac{\sum p_1 q_0}{\sum p_0 q_0} \times \frac{\sum p_1 q_1}{\sum p_0 q_1}} \times 100
  \]

- Marshall-Edgeworth’s Price Index Number
  \[
  P_{01}(M-E) = \frac{\sum p_1 (q_0 + q_1)}{\sum p_0 (q_0 + q_1)} \times 100
  \]

- Walsh’s Price Index Number
  \[
  P_{01}(W) = \frac{\sum p_1 \sqrt{q_0 q_1}}{\sum p_0 \sqrt{q_0 q_1}} \times 100
  \]
Cost of Living Index Number using Aggregate Expenditure Method

\[ \text{CLI} = \frac{\sum p_1 q_0}{\sum p_0 q_0} \times 100 \]

Cost of Living Index Number using Weighted Relative Method

\[ \text{CLI} = \frac{\sum IW}{\sum W} \]

where \( I = \frac{P_1}{P_0} \times 100 \)

and \( w = \frac{P_0}{P_0} \)

### MISCELLANEOUS EXERCISE - 5

1) Choose the correct alternative.

1. Price Index Number by Simple Aggregate Method is given by
   
   (a) \( \sum \frac{p_1}{p_0} \times 100 \)
   
   (b) \( \sum \frac{p_0}{p_1} \times 100 \)
   
   (c) \( \sum \frac{p_1}{p_0} \times 100 \)
   
   (d) \( \sum \frac{p_0}{p_1} \times 100 \)

2. Quantity Index Number by Simple Aggregate Method is given by
   
   (a) \( \sum \frac{q_1}{q_0} \times 100 \)
   
   (b) \( \sum \frac{q_0}{q_1} \times 100 \)
   
   (c) \( \sum \frac{q_1}{q_0} \times 100 \)
   
   (d) \( \sum \frac{q_0}{q_1} \times 100 \)

3. Value Index Number by Simple Aggregate Method is given by
   
   (a) \( \sum \frac{p_1 q_0}{p_0 q_1} \times 100 \)
   
   (b) \( \sum \frac{p_0 q_1}{p_0 q_0} \times 100 \)
   
   (c) \( \sum \frac{p_1 q_0}{p_1 q_0} \times 100 \)
   
   (d) \( \sum \frac{p_0 q_1}{p_0 q_0} \times 100 \)

4. Price Index Number by Weighted Aggregate Method is given by
   
   (a) \( \sum \frac{p_1 w}{p_0 w} \times 100 \)
   
   (b) \( \sum \frac{p_0 w}{p_1 w} \times 100 \)
   
   (c) \( \sum \frac{p_1 w}{p_0 w} \times 100 \)
   
   (d) \( \sum \frac{p_0 w}{p_1 w} \times 100 \)

5. Quantity Index Number by Weighted Aggregate Method is given by
   
   (a) \( \sum \frac{q_1 w}{q_0 w} \times 100 \)
   
   (b) \( \sum \frac{q_0 w}{q_1 w} \times 100 \)
   
   (c) \( \sum \frac{q_1 w}{q_0 w} \times 100 \)
   
   (d) \( \sum \frac{q_0 w}{q_1 w} \times 100 \)
6. Value Index Number by Weighted Aggregate Method is given by

(a) \[ \frac{\sum p_0 q_0 w}{\sum p_0 q_w} \times 100 \]

(b) \[ \frac{\sum p_0 q_w}{\sum p_0 q_w} \times 100 \]

(c) \[ \frac{\sum p_0 q_w}{\sum p_0 q_w} \times 100 \]

(d) \[ \frac{\sum p_0 q_w}{\sum p_0 q_w} \times 100 \]

7. Laspeyre’s Price Index Number is given by

(a) \[ \frac{\sum p_0 q_0}{\sum p_0 q_0} \times 100 \]

(b) \[ \frac{\sum p_0 q_0}{\sum p_0 q_0} \times 100 \]

(c) \[ \frac{\sum p_0 q_0}{\sum p_0 q_0} \times 100 \]

(d) \[ \frac{\sum p_0 q_0}{\sum p_0 q_0} \times 100 \]

8. Paasche’s Price Index Number is given by

(a) \[ \frac{\sum p_0 q_0}{\sum p_0 q_0} \times 100 \]

(b) \[ \frac{\sum p_0 q_0}{\sum p_0 q_0} \times 100 \]

(c) \[ \frac{\sum p_0 q_0}{\sum p_0 q_0} \times 100 \]

(d) \[ \frac{\sum p_0 q_0}{\sum p_0 q_0} \times 100 \]

9. Dorbish-Bowley’s Price Index Number is given by

(a) \[ \frac{\sum p_1 q_0 + \sum p_0 q_1}{\sum p_0 q_1 + \sum p_1 q_0} \times 100 \]

10. Fisher’s Price Index Number is given by

(a) \[ \sqrt{\frac{\sum q_0 p_0}{\sum q_0 p_0} \times \frac{\sum q_1 p_1}{\sum q_1 p_1}} \times 100 \]

(b) \[ \sqrt{\frac{\sum q_0 p_0}{\sum q_0 p_0} \times \frac{\sum q_1 p_1}{\sum q_1 p_1}} \times 100 \]

(c) \[ \sqrt{\frac{\sum q_0 p_0}{\sum q_0 p_0} \times \frac{\sum q_1 p_1}{\sum q_1 p_1}} \times 100 \]

(d) \[ \sqrt{\frac{\sum q_0 p_0}{\sum q_0 p_0} \times \frac{\sum q_1 p_1}{\sum q_1 p_1}} \times 100 \]

11. Marshall-Edgeworth’s Price Index Number is given by

(a) \[ \frac{\sum q_0 (p_0 + p_1)}{\sum p_0 (q_0 + q_1)} \times 100 \]

(b) \[ \frac{\sum q_0 (p_0 + p_1)}{\sum p_0 (q_0 + q_1)} \times 100 \]

(c) \[ \frac{\sum q_0 (p_0 + p_1)}{\sum q_0 (p_0 + p_1)} \times 100 \]

(d) \[ \frac{\sum q_0 (p_0 + p_1)}{\sum q_0 (p_0 + p_1)} \times 100 \]

12. Walsh’s Price Index Number is given by

(a) \[ \frac{\sum p_1 \sqrt{q_0 q_1}}{\sum p_0 \sqrt{q_0 q_1}} \times 100 \]
13. The Cost of Living Index Number using Aggregate Expenditure Method is given by

\[ \sum \frac{p_0 q_i}{p_0 q_0} \times 100 \]

14. The Cost of Living Index Number using Weighted Relative Method is given by

\[ \sum \frac{I W}{W} \]

\[ \sum W \]

\[ \frac{W}{I W} \]

\[ \frac{I W}{W} \]

13. The Cost of Living Index Number using Aggregate Expenditure Method is given by

\[ \sum \frac{p_0 q_i}{p_0 q_0} \times 100 \]

14. The Cost of Living Index Number using Weighted Relative Method is given by

\[ \sum \frac{I W}{W} \]

\[ \sum W \]

\[ \frac{W}{I W} \]

\[ \frac{I W}{W} \]

II) Fill in the blanks.

1. Price Index Number by Simple Aggregate Method is given by ____________.

2. Quantity Index Number by Simple Aggregate Method is given by ____________.

3. Value Index Number by Simple Aggregate Method is given by ____________.

4. Price Index Number by Weighted Aggregate Method is given by ____________.

5. Quantity Index Number by Weighted Aggregate Method is given by ____________.

6. Value Index Number by Weighted Aggregate Method is given by ____________.

7. Laspeyre’s Price Index Number is given by ____________.

8. Paasche’s Price Index Number is given by ____________.

9. Dorbish-Bowley’s Price Index Number is given by ____________.

10. Fisher’s Price Index Number is given by ____________.

11. Marshall-Edgeworth’s Price Index Number is given by ____________.

12. Walsh’s Price Index Number is given by ____________.

III) State whether each of the following is True or False.

1. \[ \sum \frac{p_1}{p_0} \times 100 \] is the Price Index Number by Simple Aggregate Method.

2. \[ \sum \frac{q_0}{q_1} \times 100 \] is the Quantity Index Number by Simple Aggregate Method.

3. \[ \sum \frac{p_0 q_0}{p_1 q_1} \times 100 \] is Value Index Number by Simple Aggregate Method.

4. \[ \sum \frac{p_0 q_0}{p_1 q_1} \times 100 \] is Paasche’s Price Index Number.

5. \[ \sum \frac{p_1 q_1}{p_0 q_0} \times 100 \] is Laspeyre’s Price Index Number.
6. \( \sum \frac{p_i q_0}{p_0 q_0} \times \sum \frac{p_i q_0}{p_0 q_0} \times 100 \) is Dorbish-Bowley’s Price Index Number.

7. \( \frac{1}{2} \left[ \frac{\sum p_i q_0}{\sqrt{\sum p_i q_0}} + \frac{\sum p_i q_0}{\sqrt{p_i q_0}} \right] \times 100 \) is Fisher’s Price Index Number.

8. \( \sum \frac{p_i (q_0 + q_1)}{p_1 (q_0 + q_1)} \times 100 \) is Marshall-Edgeworth’s Price Index Number.

9. \( \sum \frac{p_0 \sqrt{q_0 q_1}}{p_0 \sqrt{q_0 q_1}} \times 100 \) is Walsh’s Price Index Number.

10. \( \sqrt{\frac{p_0 q_0}{\sum p_0 q_0}} \times \sqrt{\frac{p_1 q_1}{\sum p_1 q_1}} \times 100 \) is Fisher’s Price Index Number.

**IV) Solve the following problems.**

1. Find the Price Index Number using Simple Aggregate Method. Consider 1980 as base year.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Price in 1980 (in Rs.)</th>
<th>Price in 1985 (in Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>22</td>
<td>46</td>
</tr>
<tr>
<td>II</td>
<td>38</td>
<td>36</td>
</tr>
<tr>
<td>III</td>
<td>20</td>
<td>28</td>
</tr>
<tr>
<td>IV</td>
<td>18</td>
<td>44</td>
</tr>
<tr>
<td>V</td>
<td>12</td>
<td>16</td>
</tr>
</tbody>
</table>

2. Find the Quantity Index Number using Simple Aggregate Method.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Based year quantity</th>
<th>Current year quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100</td>
<td>130</td>
</tr>
<tr>
<td>B</td>
<td>170</td>
<td>200</td>
</tr>
<tr>
<td>C</td>
<td>210</td>
<td>250</td>
</tr>
<tr>
<td>D</td>
<td>90</td>
<td>110</td>
</tr>
<tr>
<td>E</td>
<td>50</td>
<td>150</td>
</tr>
</tbody>
</table>

3. Find the Value Index Number using Simple Aggregate Method.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price</td>
<td>Quantity</td>
</tr>
<tr>
<td>I</td>
<td>20</td>
<td>42</td>
</tr>
<tr>
<td>II</td>
<td>35</td>
<td>60</td>
</tr>
<tr>
<td>III</td>
<td>50</td>
<td>22</td>
</tr>
<tr>
<td>IV</td>
<td>60</td>
<td>56</td>
</tr>
<tr>
<td>V</td>
<td>25</td>
<td>40</td>
</tr>
</tbody>
</table>

4. Find \( x \) if the Price Index Number using Simple Aggregate Method is 200.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>P</th>
<th>Q</th>
<th>R</th>
<th>S</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Year</td>
<td>20</td>
<td>12</td>
<td>22</td>
<td>23</td>
<td>13</td>
</tr>
<tr>
<td>Current Year</td>
<td>30</td>
<td>( x )</td>
<td>38</td>
<td>51</td>
<td>19</td>
</tr>
</tbody>
</table>

5. Calculate Laspeyre’s and Paasche’s Price Index Number for the following data.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price</td>
<td>Quantity</td>
</tr>
<tr>
<td>A</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>B</td>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td>C</td>
<td>32</td>
<td>5</td>
</tr>
<tr>
<td>D</td>
<td>12</td>
<td>10</td>
</tr>
</tbody>
</table>

6. Calculate Dorbish-Bowley’s Price Index Number for the following data.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price</td>
<td>Quantity</td>
</tr>
<tr>
<td>I</td>
<td>8</td>
<td>25</td>
</tr>
<tr>
<td>II</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>III</td>
<td>10</td>
<td>12</td>
</tr>
</tbody>
</table>

7. Calculate Marshall-Edgeworth’s Price Index Number for the following data.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price</td>
<td>Quantity</td>
</tr>
<tr>
<td>X</td>
<td>12</td>
<td>35</td>
</tr>
<tr>
<td>Y</td>
<td>29</td>
<td>50</td>
</tr>
</tbody>
</table>
8. Calculate Walsh’s Price Index Number for the following data.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price $p_0$</td>
<td>Quantity $q_0$</td>
</tr>
<tr>
<td>I</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>II</td>
<td>10</td>
<td>4</td>
</tr>
</tbody>
</table>

9. Calculate Laspeyre’s and Paasche’s Price Index Number for the following data.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price $p_0$</td>
<td>Quantity $q_0$</td>
</tr>
<tr>
<td>I</td>
<td>8</td>
<td>30</td>
</tr>
<tr>
<td>II</td>
<td>10</td>
<td>42</td>
</tr>
</tbody>
</table>

10. Find $x$ if Laspeyre’s Price Index Number is same as Paasche’s Price Index Number for the following data.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price $p_0$</td>
<td>Quantity $q_0$</td>
</tr>
<tr>
<td>A</td>
<td>3</td>
<td>$x$</td>
</tr>
<tr>
<td>B</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

11. If find $x$ is Walsh’s Price Index Number is 150 for the following data.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price $p_0$</td>
<td>Quantity $q_0$</td>
</tr>
<tr>
<td>A</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>B</td>
<td>$x$</td>
<td>4</td>
</tr>
<tr>
<td>C</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>D</td>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>

12. Find $x$ if Paasche’s Price Index Number is 140 for the following data.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Base Year</th>
<th>Current Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price $p_0$</td>
<td>Quantity $q_0$</td>
</tr>
<tr>
<td>A</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>B</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>40</td>
<td>15</td>
</tr>
<tr>
<td>D</td>
<td>12</td>
<td>15</td>
</tr>
</tbody>
</table>

13. Given that Laspeyre’s and Paasche’s Price Index Numbers are 25 and 16 respectively, find Dorbish-Bowley’s and Fisher’s Price Index Number.

14. If Laspeyre’s and Dorbish’s Price Index Numbers are 150.2 and 152.8 respectively, find Paasche’s Price Index Number.

15. If $\sum p_0q_0 = 120$, $\sum p_0q_1 = 160$, $\sum p_1q_h = 140$, and $\sum p_1q_0 = 200$ find Laspeyre’s, Paasche’s, Dorbish-Bowley’s, and Marshall-Edgeworth’s Price Index Numbers.

16. Given that $\sum p_0q_0 = 130$, $\sum p_0q_1 = 140$, $\sum p_1q_h = 160$, and $\sum p_1q_0 = 200$, find Laspeyre’s, Paasche’s, Dorbish-Bowley’s, and Marshall-Edgeworth’s Price Index Numbers.

17. Given that $\sum p_1q_h = 300$, $\sum p_0q_h = 320$, $\sum p_0q_0 = 120$, and Marshall-Edgeworth’s Price Index Number is 120, find Laspeyre’s Price Index Number.

18. Calculate the cost of living number for the following data.

<table>
<thead>
<tr>
<th>Group</th>
<th>Base Year</th>
<th>Current Year</th>
<th>Price $p_0$</th>
<th>Quantity $q_0$</th>
<th>Price $p_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>140</td>
<td>13</td>
<td>160</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clothing</td>
<td>120</td>
<td>18</td>
<td>150</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel &amp; Lighting</td>
<td>140</td>
<td>10</td>
<td>190</td>
<td></td>
<td></td>
</tr>
<tr>
<td>House Rent</td>
<td>160</td>
<td>12</td>
<td>210</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>180</td>
<td>15</td>
<td>260</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
19. Find the cost living index number by the weighted aggregate method.

<table>
<thead>
<tr>
<th>Group</th>
<th>Food</th>
<th>Clothing</th>
<th>Fuel &amp; Lighting</th>
<th>House Rent</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>78</td>
<td>80</td>
<td>110</td>
<td>60</td>
<td>90</td>
</tr>
<tr>
<td>W</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>

20. Find the cost of living index number by Family Budget Method for the following data. Also, find the expenditure of a person in the year 2008 if his expenditure in the year 2005 was Rs. 10,000.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>12</td>
<td>60</td>
<td>25</td>
</tr>
<tr>
<td>Clothing</td>
<td>10</td>
<td>45</td>
<td>20</td>
</tr>
<tr>
<td>Fuel &amp; Lighting</td>
<td>20</td>
<td>35</td>
<td>15</td>
</tr>
<tr>
<td>House Rent</td>
<td>25</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>16</td>
<td>48</td>
<td>10</td>
</tr>
</tbody>
</table>

21. Find $x$ if the cost of living index number is 193 for the following data.

<table>
<thead>
<tr>
<th>Group</th>
<th>Food</th>
<th>Clothing</th>
<th>Fuel &amp; Lighting</th>
<th>House Rent</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>221</td>
<td>198</td>
<td>171</td>
<td>183</td>
<td>161</td>
</tr>
<tr>
<td>W</td>
<td>35</td>
<td>14</td>
<td>$x$</td>
<td>8</td>
<td>20</td>
</tr>
</tbody>
</table>

22. The cost of living index number for year 2000 and 2003 are 150 and 210 respectively. A person earns Rs. 13,500 per month in the year 2000. What should be his monthly earning in the year 2003 in order to maintain the same standard of living?

### Activities

Try each of the following activities for better understanding of index numbers.

1. Find weekly prices of any five vegetables for at least six months. Taking the first week of observation as the base period, find price index numbers for the remaining five months for every vegetable.

2. Note the SENSEX for six months. Talking the first month as the base period, find price index numbers for the remaining five months.

3. Note inflation rate for six months. Taking the first month as the base period. Find price index numbers for the remaining five months.

4. Note petrol prices for six months. Taking the first month as the base period, find price index numbers for the remaining five months.

5. Note gold prices for six months. Taking the first month as the base period, find price index numbers for the remaining five months.

✨ ✨ ✨
Linear Programming is a mathematical technique designed to help for planning and decision making. Linear Programming problems are also known as optimization problems. Mathematical programming involves optimization of a certain function, called objective function, subject to given conditions or restrictions known as constraints.

**Meaning of L.P.P.**

Linear implies all the mathematical functions containing variables of index one. A L.P.P. may be defined as the problem of maximizing or minimizing a linear function subject to linear constraints.

These constraints may be equations or inequations.

Now, we formally define the terms related to L.P.P. as follows.

1) Decision Variables: The variables involved in L.P.P. are called decision variables

2) Objective function: A linear function of decision variables which is to be optimized, i.e. either maximized or minimized, is called objective function.

3) Constraints: Conditions under which the objective function is to be optimized, are called constraints. These are in the form of equations or inequations.

4) Non-negativity constraints: In some situations, the values of the variables under considerations may be positive or zero due to the imposed conditions. These constraints are referred as non-negativity constraints.

**6.2 Mathematical Formulation of L.P.P.**

**Step 1:** Identify the decision variables as \((x, y)\) or \((x_1, x_2)\)
Step 2: Identify the objective function and write it as mathematical expression in terms of decision variables.

Step 3: Identify the different constraints and express them as mathematical equations or inequations.

The general mathematical form of L.P.P.

The L.P.P. can be put in the following form.

Maximize $z = c_1x_1 + c_2x_2$ .......... (1).

subject to the constraints.

\[
a_{11}x_1 + a_{12}x_2 \leq b_1
\]
\[
a_{21}x_1 + a_{22}x_2 \leq b_2
\]
\[
.................................
\]
\[
a_{m1}x_1 + a_{m2}x_2 \leq b_m
\]

and each $x_i \geq 0$ for $i = 1, 2$ .......... (3)

1) The linear function in (1) is called the objective function.

2) Conditions in (3) are called non-negativity constraints.

Note:

i) We shall study L.P.P. with only two variables.

ii) We shall restrict ourselves to L.P.P. involving non-negativity constraints.

Solution:

Let $Z$ be the profit, which can be made by manufacturing and selling $x$ tricycles and $y$ bicycles. $x \geq 0, y \geq 0$.

Total profit $= z = 45x + 65y$

Maximize $Z = 45x + 65y$

<table>
<thead>
<tr>
<th>Machine</th>
<th>Tricycles ($x$)</th>
<th>Bicycles ($y$)</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6</td>
<td>4</td>
<td>120</td>
</tr>
<tr>
<td>B</td>
<td>3</td>
<td>10</td>
<td>180</td>
</tr>
</tbody>
</table>

From the above table, remaining conditions are

\[
6x + 4y \leq 120,
3x + 10y \leq 180
\]

$\therefore$ The required formulated L.P.P. is as follows.

Maximize $z = 45x + 65y$ (objective function)

Subject to \[
\begin{align*}
6x + 4y & \leq 120, \\
3x + 10y & \leq 180,
\end{align*}
\]

$\therefore x, y \geq 0 \rightarrow$ (non negativity Constraints)

Ex. 2:

Diet for a sick person must contain at least 4000 units of vitamins, 50 units of minerals and 1500 calories. Two foods F1 and F2 cost Rs. 50 and Rs. 75 per unit respectively. Each unit of food F1 contains 200 units of Vitamins, 1 unit of minerals and 40 calories, whereas each unit of food F2 contain 100 units of vitamins, 2 units of minerals and 30 calories. Formulate the above problem as L.P.P. to satisfy sick person's requirements at minimum cost.
Solution: Let \( x \) units of food \( F_1 \) and \( y \) units of food \( F_2 \) be fed to sick persons to meet his requirements at minimum cost
\[
\therefore x \geq 0, \quad y \geq 0
\]

<table>
<thead>
<tr>
<th>Food/ Product</th>
<th>( F_1(x) ) Per Unit</th>
<th>( F_2(y) ) Per Unit</th>
<th>Minimum requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitamins</td>
<td>200</td>
<td>100</td>
<td>4000</td>
</tr>
<tr>
<td>Minerals</td>
<td>1</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>Calories</td>
<td>40</td>
<td>30</td>
<td>1500</td>
</tr>
<tr>
<td>Cost/Unit Rs.</td>
<td>50</td>
<td>75</td>
<td>0</td>
</tr>
</tbody>
</table>

Sick person's problem is to determine \( x \) and \( y \) so as to minimize the total cost.

Total cost = \( z = 50x + 75y \)

Minimize \( z = 50x + 75y \)

The remaining conditions are

\[
200x + 100y \geq 4000 \\
x + 2y \geq 50 \\
40x + 30y \geq 1500
\]

where \( x, y \) denote units of food \( F_1 \) and \( F_2 \) respectively.

\[
\therefore x, y \geq 0
\]

\[
\therefore \text{The L.P.P. is as follows.}
\]

Minimize \( z = 50x + 75y \) subject to the constraints

\[
200x + 100y \geq 4000, \\
x + 2y \geq 50, \\
40x + 30y \geq 1500, \\
x \geq 0, \quad y \geq 0.
\]

Ex. 3:

Rakesh wants to invest at most Rs. 45000/- in savings certificates and fixed deposits. He wants to invest at least Rs. 5000/- in savings certificates and at least Rs. 15000/- in fixed deposits. The rate of interest on savings certificates is 4% p. a. and that on fixed deposits is 7% p.a. Formulate the above problem as L.P.P. to determine maximum yearly income.

Solution:

Let Rakesh invest Rs. \( x \) in savings certificate and Rs. \( y \) in fixed deposits

\[
\therefore x \geq 0, \quad y \geq 0
\]

Since he has at most Rs. 45,000/- to invest, from the given conditions, \( x + y \leq 45,000 \).

\[
x \geq 5000 \quad \text{and} \quad y \geq 15000
\]

The rate of interest on savings certificate is 4% p.a. and that on fixed deposits is 7% p.a.

\[
\therefore \text{Total annual income} = z = 0.04x + 0.07y
\]

\[
\therefore \text{The L.P.P. is}
\]

Maximize \( z = 0.04x + 0.07y \)

subject to

\[
x \geq 5000, \quad y \geq 15000, \\
x + y \leq 45000, \\
x \geq 0, \quad y \geq 0.
\]

Exercise 6.1

1) A manufacturing firm produces two types of gadgets A and B, which are first processed in the foundry and then sent to machine shop for finishing. The number of man hours of labour required in each shop for production of A and B and the number of man hours available for the firm are as follows.

<table>
<thead>
<tr>
<th>Gadgets</th>
<th>Foundry</th>
<th>Machine Shops</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>B</td>
<td>6</td>
<td>4</td>
</tr>
</tbody>
</table>

Profit on the sale of A is Rs. 30 and B is Rs. 20 per unit. Formulate the LPP to have maximum profit.
2) In a cattle breeding firm, it is prescribed that the food ration for one animal must contain 14, 22 and 1 unit of nutrients A, B and C respectively. Two different kinds of fodder are available. Each unit weight of these two contains the following amounts of these three nutrients.

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>Fodder 1</th>
<th>Fodder 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

The cost of fodder 1 is Rs. 3 per unit and that of fodder 2 is Rs. 2 per unit. Formulate the LPP to minimize the cost.

3) A company manufactures two types of chemicals A and B. Each chemical requires two types of raw material P and Q. The table below shows number of units of P and Q required to manufacture one unit of A and one unit of B.

<table>
<thead>
<tr>
<th>Chemical Raw Material</th>
<th>A</th>
<th>B</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>3</td>
<td>2</td>
<td>120</td>
</tr>
<tr>
<td>Q</td>
<td>2</td>
<td>5</td>
<td>160</td>
</tr>
</tbody>
</table>

The company gets profits of Rs. 350/- and Rs. 400/- by selling one unit of A and one unit of B respectively. Formulate the problem as LPP to maximize the profit.

4) A printing company prints two types of magazines A and B. The company earns Rs. 10 and Rs. 15 on magazine A and B per copy. These are processed on three machines I, II, III. Magazine A requires 2 hours on machine I, 5 hours on machine II, and 2 hours on machine III. Magazine B requires 3 hours on machine I, 2 hours on machine II and 6 hours on machine III. Machines I, II, III are available for 36, 50, 60 hours per week respectively.

5) A manufacturer produces bulbs and tubes. Each of these must be processed through two machines, M1 and M2. A package of bulbs requires 1 hour of work on machine M1 and 3 hours of work on M2. A package of tubes requires 2 hours on machine M1 and 4 hours on machine M2. He earns a profit of Rs. 13.5 per package of bulbs and Rs. 55 per package of tubes. If he operates machine M1 for at most 10 hours a day and machine M2 for at most 12 hours a day then formulate the LPP to maximize the profit.

6) A company manufactures two types of fertilizers F1 and F2. Each type of fertilizer requires two raw materials A and B. The number of units of A and B required to manufacture one unit of fertilizer F1 and F2 and availability of the raw materials A and B per day are given in the table below.

<table>
<thead>
<tr>
<th>Fertilizer Raw Materials</th>
<th>F1</th>
<th>F2</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>3</td>
<td>40</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>4</td>
<td>70</td>
</tr>
</tbody>
</table>

By selling one unit of F1 and one unit of F2, company get a profit of Rs. 500 and Rs. 750 respectively. Formulate the problem as LPP to maximize the profit.

7) A doctor has prescribed two different kinds of foods A and B to form a weekly diet for sick person. The minimum requirement of fats, carbohydrates and proteins is 18, 28, 14 units respectively. One unit of food A has 4 units of fat, 14 units of carbohydrates and 8 units of protein. One unit of food B has 6 units of fat, 12 units of carbohydrates and 8 units of protein. The price of food A is Rs. 4.5 per unit and that of food B is Rs. 3.5 per unit. Form the LPP so that the sick person's diet meets the requirements at a minimum cost.
8) If John drives a car at a speed of 60 kms/hour he has to spend Rs. 5 per km on petrol. If he drives at a faster speed of 90 kms/hour, the cost of petrol increases to Rs. 8 per km. He has Rs. 600 to spend on petrol and wishes to travel the maximum distance within an hour. Formulate the above problem as L.P.P.

9) The company makes concrete bricks made up of cement and sand. The weight of a concrete brick has to be at least 5 kg. cement costs Rs. 20 per kg. and sand cost Rs. 6 per kg. strength consideration dictate that a concrete brick should contain minimum 4kg of cement and not more than 2 kg of sand. Formulate the LPP for the cost to be minimum.

6.2.1 Convex set and feasible region.

Definition: A set of points in a plane is said to be a convex set if the line segment joining any two points of the set entirely lies within the same set.

The following sets are convex sets

[Fig. 6.1 and Fig. 6.2]

The following sets are not convex sets

[Fig. 6.3 and Fig. 6.4]

Note:

i) The convex sets may be bounded. Following are bounded convex sets.

[Fig. 6.5 and Fig. 6.6]

ii) Convex sets may be unbounded. Following are unbounded convex sets

[Fig. 6.7 and Fig. 6.8]

Solution of L.P.P:

There are two methods to find the solution of L.P.P. 1) Graphical method 2) Simplex method.

Note: We shall restrict ourselves to graphical method.

Some definitions:

1) Solution: A set of values of variable which satisfies all the constraints of the LPP, is called the solution of the LPP.

2) Feasible Solution: Solution which satisfy all constraints is called feasible solution.

3) Optimum feasible solution: A feasible solution which optimizes i.e. either maximizes or minimizes the objective function of LPP is called optimum feasible solution.

4) Feasible Region: The common region determined by all the constraints and non-negativity restrictions of the linear programming problem is called the feasible region.

Note: The boundaries of the region may or may not be included in the feasible region.

Theorems (without proof)

Theorem 1: The set of all feasible solutions of LPP is a convex set.

Convex polygon theorem:

Theorem 2: The objective function of LPP attains its optimum value (either maximum or minimum) at, at least one of the vertices of convex polygon.
Note: If a LPP has optimum solutions at more than one point then the entire line joining those two points will give optimum solutions. Hence the problem will have infinite solutions.

Solution of LPP by Corner point method (convex polygon theorem) Algorithm:

Step:

i) Convert all inequation of the constraints into equations.

ii) Draw the lines in $xy$ plane, by using $x$ intercept and $y$ intercept of the line from its equation.

iii) Locate common region indicated by the constraints. This common region is called feasible region.

iv) Find the vertices of the feasible region.

v) Find the value of the objective function $z$ at all vertices of the feasible region.

vi) If the objective function is of maximization (or minimization) type, then the co-ordinates, of the vertex (Vertices) for which $z$ is maximum (or minimum) gives (give) the optimum solution/solutions.

**SOLVED EXAMPLES**

**Ex.1.** Maximize $z = 9x + 13y$ Subject to

\[ 2x + 3y \leq 18, \quad 2x + y \leq 10, \quad x \geq 0, \quad y \geq 0 \]

Solution: To draw $2x + 3y = 18$, and $2x + y = 10$.

\[
\begin{array}{|c|c|c|c|}
\hline
\text{Equation of line} & \text{Intercept} & \text{Constraint type} & \text{Feasible Region} \\
\hline
2x + 3y = 18 & x : 9 \quad y : 6 & \leq & \text{Origininside} \\
2x + y = 10 & x : 5 \quad y : 10 & \leq & \text{Origininside} \\
\hline
\end{array}
\]

The common shaded region OABC0 is the feasible region with vertices 0(0,0), A(5,0), B(3,4), C (0,6).

**Fig. 6.9**

From the table, maximum value of $z = 79$ occurs at B (3, 4) i.e. when $x = 3, \quad y = 4$.

**Ex. 2.** Solve graphically the following LPP

Minimize $z = 5x + 2y$ Subject to

\[ 5x + y \geq 10, \quad x + y \geq 6, \quad x \geq 0, \quad y \geq 0. \]

Solution: To draw $5x + y \geq 10$, and $x + y \geq 6$.

\[
\begin{array}{|c|c|c|c|}
\hline
\text{Equation of line} & \text{Intercept} & \text{Constraint type} & \text{Feasible Region} \\
\hline
5x + y = 10 & x : 2 \quad y : 10 & \geq & \text{Non-origininside} \\
x + y = 6 & x : 6 \quad y : 6 & \geq & \text{Non-origininside} \\
\hline
\end{array}
\]
The common shaded region is feasible region with vertices A(6,0), B (1, 5), C (0,10)

From the table, we observe the following.

The minimum value of $z = 15$ occurs at B (1,5) i.e. when $x = 1, y = 5$.

**Ex. 3.** Maximize $z = 3x + 4y$ Subject to

$x - y \geq -1, \ 2x - y \leq 2, \ x \geq 0, \ y \geq 0.$

**Solution:** To draw $x - y \geq -1, \ 2x - y \leq 2,$

Draw lines $x - y = -1, \ 2x - y = 2$.

<table>
<thead>
<tr>
<th>Vertex</th>
<th>Lines through vertex</th>
<th>Value of objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>(3, 4)</td>
<td>$x - y = -1$ $2x - y = 2$</td>
<td>25</td>
</tr>
<tr>
<td>(1, 0)</td>
<td>$2x - y = 2$ $y = 0$</td>
<td>3</td>
</tr>
</tbody>
</table>

From graph, we can see that the common shaded area is feasible region.

which is unbounded (not a closed polygon)

**Fig. 6.10**

There is no finite maximum value of $z$ since the feasible region is unbounded.

**Fig. 6.11**

**EXERCISE 6.2**

Solve the following LPP by graphical method

1. Maximize $z = 11x + 8y$ Subject to

$x \leq 4, \ y \leq 6 \ x + y \leq 6, \ x \geq 0, \ y \geq 0.$

2. Maximize $z = 4x + 6y$ Subject to

$3x + 2y \leq 12 \ x + y \geq 4, \ x, y \geq 0.$

3. Maximize $z = 7x + 11y$ Subject to

$3x + 5y \leq 26, \ 5x + 3y \leq 30, \ x \geq 0, \ y \geq 0.$

4. Maximize $z = 10x + 25y$

Subject to $0 \leq x \leq 3, \ 0 \leq y \leq 3, \ x + y \leq 5.$

5. Maximize $z = 3x + 5y$

Subject to $x + 4y \leq 24, \ 3x + y \leq 21$

$x + y \leq 9, \ x \geq 0, \ y \geq 0.$

6. Minimize $z = 7x + y$ Subject to

$5x + y \geq 5, \ x + y \geq 3, \ x \geq 0, \ y \geq 0.$

7. Minimize $z = 8x + 10y$ Subject to

$2x + y \geq 7, \ 2x + 3y \geq 15, y \geq 2, \ x \geq 0, \ y \geq 0.$

8. **minimize** $z = 6x + 2y$ Subject to $x + 2y \geq 3,$

$x + 4y \geq 4 \ 3x + y \geq 3 \ x \geq 0, \ y \geq 0.$
Working Rule to formulate the LPP.

Step 1: Identify the decision variables and assign the symbols $x$, $y$ or $x_i$, $x_j$ to them. Introduce non-negativity constraints.

Step 2: Identify the set of constraints and express them as linear inequations in terms of the decision variables.

Step 3: Identify the objective function to be optimized (i.e., maximized or minimized) and express it as a linear function of decision variables.

* Let $R$ be the feasible region (convex polygon) for a LPP and let $z = ax + by$ be the objective function then the optimum value (maximum or minimum) of $z$ occurs at, at least one of the corner points (vertex) of the feasible region.

Corner point method for solving the LPP graphically.

Step 1: Find the feasible region of the LPP.

Step 2: Determine the vertices of the feasible region either by inspection or by solving the two equations of the lines intersecting at that points.

Step 3: Find the value of the objective function $z$, at all vertices of feasible region.

Step 4: Determine the feasible solution which optimizes the value of the objective function.

Working rule to formulate and solve the LPP Graphically.

Identify the decision variables and assign the symbols $x$, $y$ or $x_i$, $x_j$ to them.

Identify the objective function (maximized or minimized) and express it as a linear function of decision variables.

Convert inequations (constraints) into equations, find out intercept points on them.

Draw the graph.

Identify the feasible region (convex polygon) of the L.P.P. and shade it.

Find all corner points of the feasible region.

Find the value of $z$ at all the corner points.

State the optimum value of $z$ (maximum or minimum).

**MISCELLANEOUS EXERCISE - 6**

I Choose the correct alternative.

1. The value of objective function is maximize under linear constraints.
   a) at the centre of feasible region
   b) at $(0, 0)$
   c) at some vertex of feasible region.
   d) The vertex which is at maximum distance from $(0, 0)$.

2. Which of the following is correct?
   a) Every LPP has an optimal solution
   b) Every LPP has unique optimal solution.
   c) If LPP has two optimal solutions then it has infinitely many optimal solutions.
   d) The set of all feasible solutions of LPP may not be a convex set.

3. Objective function of LPP is
   a) a constraint
   b) a function to be maximized or minimized
   c) a relation between the decision variables
   d) a feasible region.

4. The maximum value of $z = 5x + 3y$.
   subject to the constraints $3x + 5y = 15$;
   $5x + 2y \leq 10$, $x, y \geq 0$ is.
   a) $235$  
   b) $235/9$
   c) $235/19$
   d) $235/3$

5. The maximum value of $z = 10x + 6y$.
   subject to the constraints $3x + y \leq 12$,
   $2x + 5y \leq 34$, $x \geq 0$, $y \geq 0$ is.
   a) $56$  
   b) $65$
   c) $55$
   d) $66$
6. The point at which the maximum value of \( z = x + y \) subject to the constraints
\[ x + 2y \leq 70, \ 2x + y \leq 95, \ x \geq 0, \ y \geq 0 \] is
a) (36, 25) b) (20, 35) c) (35, 20) d) (40, 15)

7. Of the feasible region the optimal value of \( z \) is obtained at a point
a) inside the feasible region.
b) at the boundary of the feasible region.
c) at vertex of feasible region.
d) on \( x \)-axis.

8. Feasible region; the set of points which satisfy.
a) The objective function.
b) All of the given function.
c) Some of the given constraints.
d) Only non-negative constraints.

9. Solution of LPP to minimize \( z = 2x + 3y \) st.
\[ x \geq 0, \ y \geq 0, \ 1 \leq x + 2y \leq 10 \] is
a) \( x = 0, y = 1/2 \) b) \( x = 1/2, y = 0 \) c) \( x = 1, y = -2 \) d) \( x = y = 1/2 \).

10. The corner points of the feasible region given by the inequations \( x + y \leq 4 \),
\[ 2x + y \leq 7, \ x \geq 0, \ y \geq 0, \] are
a) \( (0, 0), (4, 0), (3, 1), (0, 4) \).
b) \( (0, 0), (7/2, 0), (3, 1), (0, 4) \).
c) \( (0, 0), (7/2, 0), (3, 1), (5, 7) \).
d) \( (6, 0), (4, 0), (3, 1), (0, 7) \).

11. The corner points of the feasible region are \( (0, 0), (2, 0), (12/7, 3/7) \) and \( (0, 1) \) then the point of maximum \( z = 6.5x + y \)
a) \( (0, 0) \) b) \( (2, 0) \) c) \( (11/7, 3/7) \) d) \( (0, 1) \).

12. If the corner points of the feasible region are \( (0, 0), (3, 0), (2, 1) \) and \( (0, 7/3) \) the maximum value of \( z = 4x + 5y \) is .
a) 12 b) 13 c) 35/2 d) 0

13. If the corner points of the feasible region are \( (0, 10), (2, 2), \) and \( (4, 0) \) then the point
of minimum \( z = 3x + 2y \) is.
a) \( 2, 2 \) b) \( 0, 10 \) c) \( 4, 0 \) d) \( 2, 4 \)

14. The half plane represented by \( 3x + 2y \leq 0 \) contains the point.
a) \( (1, 5/2) \) b) \( (2, 1) \) c) \( (0, 0) \) d) \( (5, 1) \)

15. The half plane represented by \( 4x + 3y \geq 24 \) contains the point.
a) \( (0, 0) \) b) \( (2, 2) \) c) \( (3, 4) \) d) \( (1, 1) \)

II. Fill in the blanks.

1) Graphical solution set of the inequations \( x \geq 0, \ y \geq 0 \) is in .......quadrants.
2) The region represented by the inequations \( x \geq 0, \ y \geq 0 \) lies in .......quadrants.
3) The optimal value of the objective function is attained at the .......points of feasible region.
4) The region represented by the inequality \( y \leq 0 \) lies in .........quadrants.
5) The constraint that a factory has to employ more women (\( y \)) than men (\( x \)) is given by.......
6) A garage employs eight men to work in its showroom and repair shop. The constants that there must be not least 3 men in showroom and repair shop. The constrains that there must be at least 3 men in showroom and at least 2 men in repair shop are.......and ...........respectively.
7) A train carries at least twice as many first class passengers (\( y \)) as second class passengers (\( x \)). The constraint is given by.......
8) A dish washing machine holds up to 40 pieces of large crockery (\( x \)). This constraint is given by..........
III State whether each of the following is True or False.

1) The region represented by the inequalities \( x \geq 0, y \geq 0 \) lies in first quadrant.

2) The region represented by the inequalities \( x \leq 0, y \leq 0 \) lies in first quadrant.

3) The optimum value of the objective function of LPP occurs at the center of the feasible region.

4) Graphical solution set of \( x \leq 0, y \geq 0 \) in \( xy \) system lies in second quadrant.

5) Saina wants to invest at most Rs. 24000 in bonds and fixed deposits. Mathematically this constraints is written as \( x + y \leq 24000 \) where \( x \) is investment in bond and \( y \) is in fixed deposits.

6) The point (1, 2) is not a vertex of the feasible region bounded by \( 2x + 3y \leq 6, 5x + 3y \leq 15, x \geq 0, y \geq 0 \).

7) The feasible solution of LPP belongs to only quadrant I The Feasible region of graph \( x + y \leq 1 \) and \( 2x + 2y \geq 6 \) exists.

IV) Solve the following problems.

1) Maximize \( z = 5x_1 + 6x_2 \) Subject to
\[ 2x_1 + 3x_2 \leq 18, \ 2x_1 + x_2 \leq 12, \ x \geq 0, \ y \geq 0 \]

2) Minimize \( z = 4x + 2y \) Subject to
\[ 3x + y \geq 27, \ x + y \geq 21, \ x + 2y \geq 30 \]
\[ x \geq 0, \ y \geq 0 \]

3) Maximize \( z = 6x + 10y \) Subject to
\[ 3x + 5y \leq 10, \ 5x + 3y \leq 15, \ x \geq 0, \ y \geq 0 \]

4) Minimize \( z = 2x + 3y \) Subject to
\[ x - y \leq 1, \ x + y \geq 3, \ x \geq 0, \ y \geq 0 \]

5) Maximize \( z = 4x_1 + 3x_2 \) Subject to
\[ 3x_1 + x_2 \leq 15, \ 3x_1 + 4x_2 \leq 24, \ x \geq 0, \ y \geq 0 \]

6) Maximize \( z = 60x + 50y \) Subject to
\[ x + 2y \leq 40, \ 3x + 2y \leq 60, \ x \geq 0, \ y \geq 0 \]

7) Minimize \( z = 4x + 2y \) Subject to
\[ 3x + y \geq 27, \ x + y \geq 21, \ x + 2y \geq 30 \]
\[ x \geq 0, \ y \geq 0 \]

8) A carpenter makes chairs and tables profits are Rs. 140 per chair and Rs. 210 per table Both products are processed on three machine, Assembling, Finishing and Polishing the time required for each product in hours and availability of each machine is given by following table.

<table>
<thead>
<tr>
<th>Product / Machines</th>
<th>Chair ((x))</th>
<th>Table ((y))</th>
<th>Available time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembling</td>
<td>3</td>
<td>3</td>
<td>36</td>
</tr>
<tr>
<td>Finishing</td>
<td>5</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>Polishing</td>
<td>2</td>
<td>6</td>
<td>60</td>
</tr>
</tbody>
</table>

Formulate and solve the following Linear programming problems using graphical method.

9) A company manufactures bicycles and tricycles, each of which must be processed through two machines A and B Maximum availability of machine A and B is respectively 120 and 180 hours. Manufacturing a bicycle requires 6 hours on machine A and 3 hours on machine B Manufacturing a tricycle requires 4 hours on machine A and 10 hours on machine B. If profits are Rs. 180 for a bicycle and Rs. 220 on a tricycle, determine the number of bicycles and tricycles that should be manufacturing in order to maximize the profit.

10) A factory produced two types of chemicals A and B The following table gives the units of ingredients P & Q (per kg) of Chemicals A and B as well as minimum requirements of P and Q and also cost per kg. of chemicals A and B.
Find the number of units of chemicals A and B should be produced so as to minimize cost.

11) A Company produces mixers and processors Profit on selling one mixer and one food processor is Rs. 2000 and Rs. 3000 respectively. Both the products are processed through three machines A, B, C. The time required in hours by each product and total time available in hours per week on each machine are as follows:

<table>
<thead>
<tr>
<th>Product</th>
<th>Mixer per unit</th>
<th>Food processor per unit</th>
<th>Available time</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3</td>
<td>3</td>
<td>36</td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>6</td>
<td>60</td>
</tr>
</tbody>
</table>

How many mixers and food processors should be produced to maximize the profit?

12) A Chemical company produces a chemical containing three basic elements A, B, C so that it has at least 16 liters of A, 24 liters of B and 18 liters of C. This chemical is made by mixing two compounds I and II. Each unit of compound I has 4 liters of A, 12 liters of B, 2 liters of C Each unit of compound II has 2 liters of A, 2 liters of B and 6 liters of C. The cost per unit of compound I is Rs. 800 and that of compound II is Rs. 640. Formulate the problem as LPP and solve it to minimize the cost.

13) A person makes two types of gift items A and B requiring the services of a cutter and a finisher. Gift item A requires 4 hours of cutter’s time and 2 hours of finisher’s time. B requires 2 hours of cutters time, 4 hours of finishers time. The cutter and finisher have 208 hours and 152 hours available times respectively every month. The profit of one gift item of type A is Rs. 75 and on gift item B is Rs. 125. Assuming that the person can sell all the items produced, determine how many gift items of each type should be made every month to obtain the best returns?

14) A firm manufactures two products A and B on which profit earned per unit is Rs. 3 and Rs. 4 respectively. The product A requires one minute of processing time on M₁ and 2 minutes on M₂. B requires one minutes on M₁ and one minute on M₂. Machine M₁ is available for use for 450 minutes while M₂ is available for 600 minutes during any working day. Find the number of units of product A and B to be manufactured to get the maximum profit.

15) A firm manufacturing two types of electrical items A and B, can make a profit of Rs. 20 per unit of A and Rs. 30 per unit of B. Both A and B make use of two essential components, a motor and a transformer. Each unit of A requires 3 motors and 2 transformers and each unit of B requires 2 motors and 4 transformers. The total supply of components per month is restricted to 210 motors and 300 transformers. How many units of A and B should be manufactured per month to maximize profit? How much is the maximum profit?

### Activities

1) Find the graphical solution for the following system of linear inequalities.

\[8x + 5y \leq 40, \quad 4x + 5y \leq 40, \quad x \geq 0, \quad y \geq 0\]

Solution to draw \(8x + 5y \leq 40\)

**Draw line \(L\) \(8x + 5y = 40\)**

<table>
<thead>
<tr>
<th>(x)</th>
<th>(y)</th>
<th>((x, y))</th>
<th>Sign</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>(0, 0)</td>
<td>(\leq)</td>
<td>On origin side of line</td>
</tr>
</tbody>
</table>
The common shaded region OABO is graphical solution, with vertices O( ), A( ), B( ).

3) Shraddha wants to invest at most 25,000/- in savings certificates and fixed deposits. She wants to invest at least Rs. 10,000/- in savings certificate and at least Rs. 15,000/- in fixed deposits. The rate of interest on saving certificate is 5% per annum and that on fixed deposits is 7% per annum. Formulate the above problem as LPP to determine maximum yearly income.

**Solution:** Let \( x_1 \) amount (in Rs.) invest in saving cerificate.
\( x_2 \) amount (in Rs.) invest in fixed deposits.
\( x_1 \geq 0, x_2 \geq 0 \)

From given conditions \( x_1 + x_2 = 25,000 \)
She wants to invest at least Rs. 10000/- in saving certificate \\
\( \therefore x_1 \geq 10,000 \)
Shradha want to invest at least Rs. 15,000/- in fixed deposits.
\( x_2 \geq 15,000 \)

Total interest = \( z = \ldots \ldots \ldots \) Subject to.
\( \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \)

4) The graphical solution of LPP is shown by following figure. Find the maximum value of \( z = 3x_1 + 2y \) subject to the conditions given in graphical solution.

**Solution:** From Fig. 6.14. The common Shaded region OABCO is feasible region with vertices O( ), A( ), B(4, 3) C( )
From the above table, maximum value of $z = x + y$ occurs at point $A(5, 0)$.

5) Formulate and solve the following LPP.
A company manufactures bicycles and tricycles, each of which must be processed through two machines A and B. Machine A has maximum of 120 hours available and machine B has a maximum of 180 hours available. Manufacturing a bicycle requires 6 hours on machine A and 3 hours on machine B. Manufacturing a tricycle requires 4 hours on machine A and 10 hours on machine B. If profits are Rs. 180/- for a bicycle and Rs. 220/- for a tricycle, determine the number of bicycles and tricycles that should be manufactured in order to maximize the profit.

Sol. Let $x$ no of bicycles and $y$ no. of tricycles be manufactured $x \geq 0$, $y \geq 0$ ....1

Total profit = $z = 3x + 2y$

Maximize $z = 3x + 2y$

The remaining conditions are:

\[
\begin{align*}
\therefore \text{LPP is maximize } z &= \ldots\ldots \\
&\text{subject to } x \geq 0, y \geq 0, \\
&\text{To draw } 6x + 4y \leq 120 \\
&\text{Draw line } L_1: 6x + 4y = 120
\end{align*}
\]

<table>
<thead>
<tr>
<th>$x$</th>
<th>$y$</th>
<th>$(x, y)$</th>
<th>Sign</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>(0, 0)</td>
<td>$\leq$</td>
<td>origin side of line $L_1$</td>
</tr>
</tbody>
</table>

To draw $3x + 10y \leq 180$

Draw line $L_2: 3x + 10y = 180$

<table>
<thead>
<tr>
<th>$x$</th>
<th>$y$</th>
<th>$(x, y)$</th>
<th>Sign</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>(0, 0)</td>
<td>$\leq$</td>
<td>--</td>
</tr>
</tbody>
</table>

The common shaded region $\square$ is feasible region with vertices O(0, 0), A(5, 0), B(10, 15), C(0, 18).

\[
\begin{align*}
\therefore \text{LPP is maximize } z &= \ldots\ldots \\
&\text{subject to } x \geq 0, y \geq 0, \\
&\text{To draw } 6x + 4y \leq 120 \\
&\text{Draw line } L_1: 6x + 4y = 120
\end{align*}
\]

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>$(x, y)$</th>
<th>Value of $z = 3x + 2y$ at $(x, y)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1)</td>
<td>(0, 0)</td>
<td>$z = 0$</td>
</tr>
<tr>
<td>2)</td>
<td>A(5, 0)</td>
<td>$z = 10$</td>
</tr>
<tr>
<td>3)</td>
<td>B(10, 15)</td>
<td>$z = 18$</td>
</tr>
<tr>
<td>4)</td>
<td>C(0, 18)</td>
<td>$z = 36$</td>
</tr>
</tbody>
</table>

Maximum value of $z = 36$ occurs at point $B(10, 15)$, that is when $x = 10, y = 15$

Thus company gets maximum profit $z = \text{Rs. 36}$ when $x = 10$ no of bicycles and $y = 15$ no of tricycles are manufactured.
Assignment Problem and Sequencing

Let's Study

- Definition of Assignment Problem
- Assignment model
- Hungarian method of solving Assignment Problem
- Special cases of Assignment Problem
- Sequencing Problem
- Types of Sequencing Problem
- Finding an optimal sequence

Let's Recall

Linear Programming Problem

Let's Learn

Introduction to Assignment Problem:

We often come across situations in which we have to assign n jobs to n workers. All n workers are capable of doing all jobs, but with a varying cost. Hence our task is to find the best possible assignment that gives maximum efficiency and minimum cost e.g. assigning activities to students, subjects to teachers, different routes of pizza delivery boys, salesmen to different regions, jobs to machines, products to factories, research problems to teams, vehicles and drivers to different routes etc. A problem of this nature is called an assignment problem.

7.1 Definition of Assignment Problem:

Assignment problem is a special type of problem which deals with allocation of various resources to various activities on one to one basis. It is done in such a way that the total cost or time involved in the process is minimum or the total profit is maximum.

Conditions:

i) Number of jobs is equal to number of machines or workers.

ii) Each worker or machine is assigned to only one job.

iii) Each worker or machine is independently capable of handling any job.

iv) Objective of the assignment is clearly specified (minimizing cost or maximizing profit)

Assignment Model:

Given n workers and n jobs with the cost of every worker for every job, the problem is to assign each worker to one and only one job so as to optimize the total cost.

Let $C_{ij}$ be the cost of assigning $i^{th}$ worker to $j^{th}$ job, $x_{ij}$ be the assignment of $i^{th}$ worker to $j^{th}$ job and $x_{ij} = 1$, if $i^{th}$ worker is assigned to $j^{th}$ job

and $x_{ij} = 0$, otherwise

Following table represents the cost of assigning n workers to n jobs.

<table>
<thead>
<tr>
<th>Worker</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>...</th>
<th>...</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$C_{11}$</td>
<td>$C_{12}$</td>
<td>$C_{13}$</td>
<td>...</td>
<td>...</td>
<td>$C_{1n}$</td>
</tr>
<tr>
<td>2</td>
<td>$C_{21}$</td>
<td>$C_{22}$</td>
<td>$C_{23}$</td>
<td>...</td>
<td>...</td>
<td>$C_{2n}$</td>
</tr>
<tr>
<td>3</td>
<td>$C_{31}$</td>
<td>$C_{32}$</td>
<td>$C_{33}$</td>
<td>...</td>
<td>...</td>
<td>$C_{3n}$</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>n</td>
<td>$C_{n1}$</td>
<td>$C_{n2}$</td>
<td>$C_{n3}$</td>
<td>...</td>
<td>...</td>
<td>$C_{nn}$</td>
</tr>
</tbody>
</table>

The objective is to make assignments that minimize the total cost.

Thus, an assignment problem can be represented by n x n matrix which covers all the n! possible ways of making assignments.
Assignment Problem is a special case of Linear Programming Problem.

Assignment problem can be expressed symbolically as follows:

Minimize \( Z = \sum_{i=1}^{n} \sum_{j=1}^{n} C_{ij} x_{ij} \)

Subject to constraints

\( \sum_{j=1}^{n} x_{ij} = 1; \ i = 1, 2, 3, n \)  
(exactly one job is assigned to \( i^{th} \) worker)

\( \sum_{i=1}^{n} x_{ij} = 1; \ i = 1, 2, 3, n \)  
(exactly one worker is assigned to \( j^{th} \) job)

where \( x_{ij} \) takes a value 0 or 1.

Let's Discuss ...

Let us consider the following problem.

Due to neglect, your home is in serious need of repair. You approach 3 contractors for remodeling and repairing. Suppose you get quotations as shown below:

<table>
<thead>
<tr>
<th>Contractors</th>
<th>Home Repairs (Cost) Price (in Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amar</td>
<td>27,980</td>
</tr>
<tr>
<td>Akbar</td>
<td>31,640</td>
</tr>
<tr>
<td>Anthony</td>
<td>29,330</td>
</tr>
</tbody>
</table>

Naturally, we may think of Amar as he is giving the best overall price. However, if we think of individual items and get the prices per repair item from our contractors, this would be more beneficial in two ways:

1. We may save time since all contractors will be working on different repair items simultaneously.
2. We may get a better price by hiring contractors based on their lowest item cost.

Take a look at the following table containing prices of individual items:

<table>
<thead>
<tr>
<th>Contractors</th>
<th>Flooring</th>
<th>Painting</th>
<th>Aluminum Sliding Window</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amar</td>
<td>14440</td>
<td>8500</td>
<td>5040</td>
<td>Rs. 27,980</td>
</tr>
<tr>
<td>Akbar</td>
<td>13840</td>
<td>13300</td>
<td>4500</td>
<td>Rs. 31,640</td>
</tr>
<tr>
<td>Anthony</td>
<td>14080</td>
<td>11200</td>
<td>4050</td>
<td>Rs. 29,330</td>
</tr>
</tbody>
</table>

We wish to hire one contractor for one job to minimize both the time and cost. For example, we may choose the following:

<table>
<thead>
<tr>
<th>Contractors</th>
<th>Flooring</th>
<th>Painting</th>
<th>Aluminum Sliding Window</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amar</td>
<td>14440</td>
<td>8500</td>
<td>5040</td>
<td>Rs. 26,390</td>
</tr>
<tr>
<td>Akbar</td>
<td>13840</td>
<td>13300</td>
<td>4500</td>
<td></td>
</tr>
<tr>
<td>Anthony</td>
<td>14080</td>
<td>11200</td>
<td>4050</td>
<td></td>
</tr>
</tbody>
</table>

By this strategy, we can minimize the total cost and also the total time required to complete the job. Though this looks simple, the problem is difficult to solve for larger number of contractors and many more repairs.

An assignment problem can be represented by \( n \times n \) matrix which constitutes \( n! \) possible ways of making assignments. Finding an optimal solution by writing all the \( n! \) possible arrangements is time consuming. Hence there is a need of an efficient computational technique for solving such problems.

There is an interesting and easy method to solve this type of problems called Hungarian Method.

The Hungarian Method is an optimization algorithm that solves an Assignment Problem.

7.2 Hungarian Method:

Hungarian method is based on the following properties:

1) If a constant (positive or negative) is added to every element of any row or column in the given cost matrix, an assignment that minimizes the total cost in the original
matrix also minimizes the total cost in the revised matrix.

2) In an assignment problem, a solution having zero total cost of assignment is an optimal solution.

The Hungarian algorithm can be explained with the help of the following example.

Consider an example where 4 jobs need to be performed by 4 workers, one job per worker. The matrix below shows the cost of assigning a certain worker to a certain job. The objective is to minimize the total cost of assignment.

<table>
<thead>
<tr>
<th>Workers</th>
<th>Jobs</th>
</tr>
</thead>
<tbody>
<tr>
<td>J₁</td>
<td>J₂</td>
</tr>
<tr>
<td>W₁</td>
<td>62</td>
</tr>
<tr>
<td>W₂</td>
<td>57</td>
</tr>
<tr>
<td>W₃</td>
<td>21</td>
</tr>
<tr>
<td>W₄</td>
<td>18</td>
</tr>
</tbody>
</table>

Let us solve this problem by Hungarian method.

**Step 1:** Subtract the smallest element of each row from every element of that row.

<table>
<thead>
<tr>
<th>Workers</th>
<th>Jobs</th>
</tr>
</thead>
<tbody>
<tr>
<td>J₁</td>
<td>J₂</td>
</tr>
<tr>
<td>W₁</td>
<td>12</td>
</tr>
<tr>
<td>W₂</td>
<td>22</td>
</tr>
<tr>
<td>W₃</td>
<td>6</td>
</tr>
<tr>
<td>W₄</td>
<td>0</td>
</tr>
</tbody>
</table>

**Step 2:** Subtract the smallest element of each column from every element of that column.

<table>
<thead>
<tr>
<th>Workers</th>
<th>Jobs</th>
</tr>
</thead>
<tbody>
<tr>
<td>J₁</td>
<td>J₂</td>
</tr>
<tr>
<td>W₁</td>
<td>12</td>
</tr>
<tr>
<td>W₂</td>
<td>22</td>
</tr>
<tr>
<td>W₃</td>
<td>6</td>
</tr>
<tr>
<td>W₄</td>
<td>0</td>
</tr>
</tbody>
</table>

**Step 3:** Assign through zeros.

<table>
<thead>
<tr>
<th>Workers</th>
<th>Jobs</th>
</tr>
</thead>
<tbody>
<tr>
<td>J₁</td>
<td>J₂</td>
</tr>
<tr>
<td>W₁</td>
<td>12</td>
</tr>
<tr>
<td>W₂</td>
<td>22</td>
</tr>
<tr>
<td>W₃</td>
<td>6</td>
</tr>
<tr>
<td>W₄</td>
<td>0</td>
</tr>
</tbody>
</table>

Observe that third row does not contain an assignment.

**Step 4:**

1. Mark (✓) the row (R₃).
2. Mark (✓) the columns (C₃) having zeros in the marked rows.
3. Mark (✓) the row (R₃) which contains assignment in marked column.
4. Draw straight lines through marked columns and unmarked rows.

**Step 4:**

- All zeros can be covered using 3 lines.
- Therefore, number of lines required = 3 and order of matrix = 4
- Hence, the number of lines required is not equal to order of matrix.
- Therefore we continue with the next step to create additional zeros.

**Step 4:**

(i) Find the smallest uncovered element (6)
(ii) Subtract this number from all uncovered elements and add it to all elements which lie at the intersection of two lines and other elements on the lines remain unchanged.
**Step 5:** Assigning through zeros we get.

<table>
<thead>
<tr>
<th>Workers</th>
<th>Jobs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$J_1$</td>
</tr>
<tr>
<td>$W_1$</td>
<td>6</td>
</tr>
<tr>
<td>$W_2$</td>
<td>22</td>
</tr>
<tr>
<td>$W_3$</td>
<td>0</td>
</tr>
<tr>
<td>$W_4$</td>
<td>0</td>
</tr>
</tbody>
</table>

Now, each row and each column contains an assignment.

Hence, optimal solution is obtained and the optimal assignment is as follows.

Worker 1 should perform job 3, worker 2 job 2, worker 3 job 1 worker 4 job 4 i.e. $W_1 \rightarrow J_3$, $W_2 \rightarrow J_2$, $W_3 \rightarrow J_1$, $W_4 \rightarrow J_4$

Total Minimum Cost = 50 + 35 + 21 + 23 = Rs. 129

**Steps of the Hungarian Method:**

Following steps describe the Hungarian Method.

**Step 1.** Subtract the minimum cost in each row of the cost matrix from all the elements in the respective row.

**Step 2.** Subtract the minimum cost in each column of the cost matrix from all the elements in the respective column.

**Step 3.** Starting with the first row, examine the rows one by one until a row containing exactly single zero is found. Make an assignment by marking ($\square$) that zero. Then cross ($\times$) all other zeros in the column in which the assignment was made. This eliminates the possibility of making further assignments in that column.

**Step 4.** After examining all the rows, repeat the same procedure for columns, i.e. examine the columns one by one until a column containing exactly one zero is found. Make an assignment by marking ($\square$) that zero. Then cross ($\times$) all other zeros in the row in which the assignment was made.

**Step 5.** Continue these successive operations on rows and columns until all the zeros have been either assigned or crossed out and there is exactly one assignment in each row and in each column. In such case optimal solution is obtained.

**Step 6.** There may be some rows (or columns) without assignments i.e. the total number of marked zeros is less than the order of the cost matrix. In such case, proceed to step 7.

**Step 7.** Draw the least possible number of horizontal and vertical lines to cover all zeros. This can be done as follows:

i) Mark ($\checkmark$) the rows in which no assignment has been made.

ii) Mark ($\checkmark$) the column having zeros in the marked rows.

iii) Mark ($\checkmark$) rows which contain assignments in marked columns.

iv) Repeat 2 and 3 until the chain of marking is completed.

v) Draw straight lines through marked columns.

vi) Draw straight lines through unmarked rows.

By this way we draw the minimum number of horizontal and vertical lines required to cover all zeros. If the number of lines is less than the order of matrix, then there is no solution. And if the minimum number of lines is equal to the order of matrix, then there is a solution and it is optimal.

**Step 8.** If minimum number of lines < order of matrix, then

a) Select the smallest element not covered by any of the lines of the table.
Flow Chart of Hungarian Method:

1. Start
2. Construct the cost matrix if not given
3. Row Reduction
4. Column Reduction
5. Draw minimum number of horizontal and vertical lines covering all zeros
6. Is No. of required lines of matrix = Order of matrix?
   - No: Choose the least uncovered element, Subtract this from the uncovered elements and add it to the elements at intersection of lines.
   - Yes: Assignment
5.1. 1) Examine the rows successively until a row with exactly single zero is found. Mark (□) this zero and cross out (×) all other zeros of the corresponding column.
      2) Repeat the same procedure for all columns.
5.2. Solution
      Add the elements of the given cost matrix corresponding to mark (□)
6. Stop
b) Subtract this value from all the uncovered elements in the matrix and add it to all those elements which lie at the intersection of horizontal and vertical lines.

**Step 9.** Repeat steps 4, 5 and 6 until we get the number of lines covering all zeros equal to the order of matrix. In this case, optimal solution can be obtained.

**Step 10.** We now have exactly one marked (\(\infty\)) zero in each row and each column of the cost matrix. The assignment schedule corresponding to these zeros is the optimal assignment.

**Let’s Note:**

The Hungarian Method was developed and published in 1955 by Harold Kuhn, who gave the name ‘Hungarian Method’ as the algorithm was largely based on the earlier works of two Hungarian mathematicians: Dénes König and Jenő Egerváry.

### Solved Examples

**Ex.1.**

A departmental store has four workers to pack their goods. The times (in minutes) required for each worker to complete the packings per item sold is given below. How should the manager of the store assign the jobs to the workers, so as to minimize the total time of packing.

<table>
<thead>
<tr>
<th>Workers</th>
<th>Packing of</th>
<th>Books</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>B</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Workers</th>
<th>Packing of</th>
<th>Toys</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Workers</th>
<th>Packing of</th>
<th>Crockery</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Workers</th>
<th>Packing of</th>
<th>Cutlery</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>(\infty)</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

**Step 2:** Since all column minimums are zero, no need to subtract anything from columns.

**Step 3:** Assigning through zeros we get,

<table>
<thead>
<tr>
<th>Workers</th>
<th>Packing of</th>
<th>Books</th>
<th>Toys</th>
<th>Crockery</th>
<th>Cutlery</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>8</td>
<td>7</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>11</td>
<td>0</td>
<td>10</td>
<td>(\infty)</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>(\infty)</td>
<td>11</td>
<td>0</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

:: Optimal assignment schedule is:

A \(\rightarrow\) Books, B \(\rightarrow\) Toys, C \(\rightarrow\) Cutlery, D \(\rightarrow\) Crockery. Total Minimum Time = 3 + 2 + 4 + 1 = 10 minutes.

**Ex.2.**

Solve the following assignment problem for minimization.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Machine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>3</td>
<td>22</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
</tr>
</tbody>
</table>

**Solution:**

Let us solve this problem by Hungarian method.

**Step 1:** Subtract the smallest element of each row from every element of that row.

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>6</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>
**Step 2:** Subtract the smallest element of each column from every element of that column.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>6</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

**Step 3:** Draw minimum number of lines (horizontal and vertical) that are required to cover all zeros in the matrix.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>[0]</td>
<td>6</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>[0]</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>3</td>
<td>[0]</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>[0]</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>[0]</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

Here, minimum number of lines (4) < order of matrix (5). Therefore we continue with the next step to create additional zeros.

**Step 4:**

(i) Find the smallest uncovered element (1)

(ii) Subtract this number from all uncovered elements and add it to all elements which lie at the intersection of two lines.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>[0]</td>
<td>6</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>[0]</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>3</td>
<td>[0]</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>[0]</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>[0]</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

Optimal Solution:

1→I, 2→IV, 3→III, 4→II, 5→V

Minimum Value = 18 + 18 + 20 +18 + 21 = 95

**7.3 Special Cases of Assignment Problem:**

The assignment problem is generally defined as a problem of minimization. In practice, some situations are like Assignment Problem but with some variations. The following four variations are more common and can be solved using the Hungarian method.

I. **Unbalanced assignment problem:**

An unbalanced assignment problem is one in which the number of resources is not equal to the number of activities i.e. the cost matrix of an assignment problem is not a square matrix (no. of rows ≠ no. of columns).

An unbalanced assignment problems can be balanced by adding dummy resources/tasks (row/column) with zero costs.

II. **Maximization Problem:**

Sometimes the assignment problem may deal with maximization of the objective function. To solve such a problem, we need to convert it to minimization so that we can solve it using Hungarian Method. This conversion to minimization problem can be done in either of the following ways:

(i) by subtracting all the elements from the largest element of the matrix
(ii) by multiplying all the elements of the matrix by ‘-1’

Then this equivalent minimization problem can be solved using Hungarian method.

III. Restricted assignment problem:

An assignment problem involving restrictions on allocation due to personal, technical, legal or other reasons is called a restricted assignment problem. A restricted assignment problem does not allow some worker(s) to be assigned to some job(s). It can be solved by assigning a very high cost (or infinite cost) to the restricted cells where assignment cannot be made.

IV. Alternative optimal solutions:

An alternate (multiple) solution exists for an assignment problem when the final assignment matrix contains more than the required number of zeros. In this case, assignments can be made through zeros arbitrarily, keeping in mind that each row and each column can contain only one assignment.

[SOLVED EXAMPLES]

Ex.1. [Unbalanced assignment problem]

A departmental head has four subordinates, and three tasks to be performed. The subordinates differ in efficiency. Estimated time for that task would take to perform each given in the matrix below. How should the tasks be allotted so as to minimize the total man hours?

<table>
<thead>
<tr>
<th>Job</th>
<th>Man</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M_1</td>
</tr>
<tr>
<td>A</td>
<td>7</td>
</tr>
<tr>
<td>B</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>5</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
</tr>
</tbody>
</table>

**Solution:**

**Step1:** Observe that the number of rows is not equal to number of columns in the above matrix. Therefore it is an unbalanced assignment problem. It can be balanced by introducing a dummy job D with zero cost.

**Step2:** Subtract the smallest element of each row from every elements of that row.

<table>
<thead>
<tr>
<th>Job</th>
<th>Man</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M_1</td>
</tr>
<tr>
<td>A</td>
<td>5</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
</tr>
</tbody>
</table>

**Step3:** Since all the column minimums are zeros, no need to subtract anything from columns. 

**Step4:** Assigning through zeros we get,

<table>
<thead>
<tr>
<th>Job</th>
<th>Man</th>
<th>Man</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M_1</td>
<td>M_2</td>
</tr>
<tr>
<td>A</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Optimal Solution:

<table>
<thead>
<tr>
<th>Job</th>
<th>Man</th>
<th>Man hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>M_1</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>M_2</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>M_3</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>

Ex.2. [Maximization Case and Alternative Optimal Solutions]

A marketing manager has list of salesmen and towns. Considering the capabilities of the salesmen and the nature of towns, the marketing manager estimates amounts of sales per month (in thousand rupees) for each salesman in each town. Suppose these amounts are as follows:
Find the assignment of salesmen to towns that will result in maximum sale.

**Solution:** The above maximization problem can be converted into the equivalent minimization problem by subtracting all the matrix elements from the largest element which is 46. Then the resulting matrix is.

<table>
<thead>
<tr>
<th>Salesman</th>
<th>Town</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_1$</td>
</tr>
<tr>
<td>$S_1$</td>
<td>37</td>
</tr>
<tr>
<td>$S_2$</td>
<td>45</td>
</tr>
<tr>
<td>$S_3$</td>
<td>46</td>
</tr>
<tr>
<td>$S_4$</td>
<td>27</td>
</tr>
<tr>
<td>$S_5$</td>
<td>34</td>
</tr>
</tbody>
</table>

**Step 3:** Draw minimum number of lines (horizontal and vertical) that are required to cover all zeros in the matrix.

<table>
<thead>
<tr>
<th></th>
<th>$T_1$</th>
<th>$T_2$</th>
<th>$T_3$</th>
<th>$T_4$</th>
<th>$T_5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_1$</td>
<td>18</td>
<td>0</td>
<td>6</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>$S_2$</td>
<td>0</td>
<td>14</td>
<td>12</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>$S_3$</td>
<td>0</td>
<td>12</td>
<td>8</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>$S_4$</td>
<td>19</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>$S_5$</td>
<td>11</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Therefore, number of lines required (4) $< \text{order of matrix (5)}$

Therefore we continue with next step to create additional zeros.

**Step 4:**

(i) Find the smallest uncovered elements (4).

(ii) Subtract this number from all uncovered elements and add it to all elements which lie at the intersection of two lines.

<table>
<thead>
<tr>
<th></th>
<th>$T_1$</th>
<th>$T_2$</th>
<th>$T_3$</th>
<th>$T_4$</th>
<th>$T_5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_1$</td>
<td>12</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$S_2$</td>
<td>0</td>
<td>10</td>
<td>8</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>$S_3$</td>
<td>0</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>$S_4$</td>
<td>23</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>$S_5$</td>
<td>15</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

**Step 5:** We return to step 3 i.e. again we determine the minimum number of lines required to cover all zeros in the matrix.

<table>
<thead>
<tr>
<th></th>
<th>$T_1$</th>
<th>$T_2$</th>
<th>$T_3$</th>
<th>$T_4$</th>
<th>$T_5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_1$</td>
<td>12</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$S_2$</td>
<td>0</td>
<td>10</td>
<td>8</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>$S_3$</td>
<td>0</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>$S_4$</td>
<td>23</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>$S_5$</td>
<td>15</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Number of lines required (5) = Order of matrix

Therefore optimal assignment can be made.

**Optimal assignment:** Optimal assignment can be made through zeros.
Note that after assigning $S_1 \to T_1$, each row and column more than one zeros. Therefore alternate optimal solutions exist. Assigning through zeros in different ways, we get two different assignments:

(i)

<table>
<thead>
<tr>
<th></th>
<th>$T_1$</th>
<th>$T_2$</th>
<th>$T_3$</th>
<th>$T_4$</th>
<th>$T_5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_1$</td>
<td>12</td>
<td>0</td>
<td>$\infty$</td>
<td>7</td>
<td>$\infty$</td>
</tr>
<tr>
<td>$S_2$</td>
<td>$\infty$</td>
<td>10</td>
<td>8</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>$S_3$</td>
<td>0</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>$\infty$</td>
</tr>
<tr>
<td>$S_4$</td>
<td>23</td>
<td>1</td>
<td>$\infty$</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>$S_5$</td>
<td>15</td>
<td>5</td>
<td>0</td>
<td>$\infty$</td>
<td>1</td>
</tr>
</tbody>
</table>

$S_1 \to T_2$, $S_2 \to T_3$, $S_3 \to T_4$, $S_4 \to T_4$, $S_5 \to T_3$

Maximum Sale = $43 + 41 + 46 + 41 + 45$

= 216 thousand rupees.

(ii)

<table>
<thead>
<tr>
<th></th>
<th>$T_1$</th>
<th>$T_2$</th>
<th>$T_3$</th>
<th>$T_4$</th>
<th>$T_5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_1$</td>
<td>12</td>
<td>0</td>
<td>$\infty$</td>
<td>7</td>
<td>$\infty$</td>
</tr>
<tr>
<td>$S_2$</td>
<td>0</td>
<td>10</td>
<td>8</td>
<td>10</td>
<td>$\infty$</td>
</tr>
<tr>
<td>$S_3$</td>
<td>$\infty$</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>$S_4$</td>
<td>23</td>
<td>1</td>
<td>0</td>
<td>$\infty$</td>
<td>5</td>
</tr>
<tr>
<td>$S_5$</td>
<td>15</td>
<td>5</td>
<td>0</td>
<td>$\infty$</td>
<td>1</td>
</tr>
</tbody>
</table>

$S_1 \to T_2$, $S_2 \to T_1$, $S_3 \to T_5$, $S_4 \to T_3$, $S_5 \to T_4$

Maximum Sale = $43 + 45 + 42 + 46 + 40$

= 216 thousand rupees.

- **Observe that the amount of Maximum Sale is same in both the cases.**

Ex.3. [Restricted assignment problem]

Three new machines $M_1$, $M_2$, $M_3$ are to be installed in a machine shop. There are four vacant places A, B, C, D. Due to limited space, machine $M_2$ can not be placed at B.

The cost matrix (in hundred rupees) is as follows:

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_1$</td>
<td>13</td>
<td>10</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>$M_2$</td>
<td>15</td>
<td>$\infty$</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>$M_3$</td>
<td>5</td>
<td>7</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>$M_4$</td>
<td>5</td>
<td>7</td>
<td>10</td>
<td>6</td>
</tr>
</tbody>
</table>

Determine the optimum assignment schedule.

**Solution:**

**Step1:**

(a) Observe that the number of rows is not equal to number of columns in the above matrix. Therefore it is an unbalanced assigned problem. It can be balanced by introducing a dummy job D with zero cost.

(b) Also, it is a restricted assignment problem. So we assign a very high cost $\infty$ to the prohibited cell.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_1$</td>
<td>13</td>
<td>10</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>$M_2$</td>
<td>15</td>
<td>$\infty$</td>
<td>13</td>
<td>20</td>
</tr>
<tr>
<td>$M_3$</td>
<td>5</td>
<td>7</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>$M_4$</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Step2:** Subtract the smallest element of each row from every element of that row.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_1$</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>$M_2$</td>
<td>2</td>
<td>$\infty$</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>$M_3$</td>
<td>0</td>
<td>2</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>$M_4$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Step3:** Since all the column minimums are zeros, no need to subtract anything from columns.
Step 4: Assigning through zeros we get,

<table>
<thead>
<tr>
<th>Machines</th>
<th>Places</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>$M_1$</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>$M_2$</td>
<td>2</td>
<td>$\infty$</td>
</tr>
<tr>
<td>$M_3$</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>$M_4$</td>
<td>$\infty$</td>
<td>$\infty$</td>
</tr>
</tbody>
</table>

Optimal Solution:

<table>
<thead>
<tr>
<th>Machine</th>
<th>Place</th>
<th>Man hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_1$</td>
<td>B</td>
<td>10</td>
</tr>
<tr>
<td>$M_2$</td>
<td>C</td>
<td>13</td>
</tr>
<tr>
<td>$M_3$</td>
<td>A</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>28</td>
</tr>
</tbody>
</table>

Therefore, Total Minimum Cost = 28 hundred rupees.

Let's Remember

- Assignment Problem is a special case of LPP in which every worker or machine is assigned only one job.
- Objective of the assignment is clearly specified (minimizing cost or maximizing profit).
- Hungarian Method is used to solve a minimization assignment problem.
- Special Cases of Assignment Problem:

1) Unbalanced assignment problem:
   (No. of rows ≠ No of columns)

An unbalanced assignment problem can be balanced by adding dummy row/column with zero costs.

2) Maximization Problem:

Such problem is converted to minimization by subtracting all the elements from the largest element of the matrix. Then this can be solved by Hungarian method.

3) Restricted assignment problem:

It can be solved by assigning a very high cost (infinite cost) to the restricted cell.

4) Alternative optimal solutions:

If the final assignment matrix contains more than the required number of zeros, assign through zeros arbitrarily.

EXERCISE 7.1

1. A job production unit has four jobs A, B, C, D which can be manufactured on each of the four machines P, Q, R and S. The processing cost of each job for each machine is given in the following table:

<table>
<thead>
<tr>
<th>Job</th>
<th>(Processing Cost in Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>P</td>
<td>31</td>
</tr>
<tr>
<td>Q</td>
<td>25</td>
</tr>
<tr>
<td>R</td>
<td>19</td>
</tr>
<tr>
<td>S</td>
<td>38</td>
</tr>
</tbody>
</table>

Find the optimal assignment to minimize the total processing cost.

2. Five wagons are available at stations 1, 2, 3, 4 and 5. These are required at 5 stations I, II, III, and IV and V. The mileage between various stations are given in the table below. How should the wagons be transported so as to minimize the mileage covered?

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>5</td>
<td>9</td>
<td>18</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>9</td>
<td>6</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>18</td>
<td>9</td>
<td>12</td>
<td>17</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>6</td>
<td>14</td>
<td>19</td>
<td>10</td>
</tr>
</tbody>
</table>

3. Five different machines can do any of the five required jobs, with different profits resulting from each assignment as shown below:
<table>
<thead>
<tr>
<th>Job</th>
<th>Machines (Profit in Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td>5</td>
<td>29</td>
</tr>
</tbody>
</table>

Find the optimal assignment schedule.

4. Four new machines M₁, M₂, M₃ and M₄ are to be installed in a machine shop. There are five vacant places A, B, C, D and E available. Because of limited space, machine M₁ cannot be placed at C and M₃ cannot be placed at A. The cost matrix is given below.

<table>
<thead>
<tr>
<th>Machines</th>
<th>Places</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>M₁</td>
<td>4</td>
</tr>
<tr>
<td>M₂</td>
<td>7</td>
</tr>
<tr>
<td>M₃</td>
<td>-</td>
</tr>
<tr>
<td>M₄</td>
<td>9</td>
</tr>
</tbody>
</table>

Find the optimal assignment schedule.

5. A company has a team of four salesmen and there are four districts where the company wants to start its business. After taking into account the capabilities of salesmen and the nature of districts, the company estimates that the profit per day in rupees for each salesman in each district is as below:

<table>
<thead>
<tr>
<th>Salesman</th>
<th>District</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>A</td>
<td>16</td>
</tr>
<tr>
<td>B</td>
<td>12</td>
</tr>
<tr>
<td>C</td>
<td>15</td>
</tr>
<tr>
<td>D</td>
<td>13</td>
</tr>
</tbody>
</table>

Find the assignment of salesman to various districts which will yield maximum profit.

6. In the modification of a plant layout of a factory four new machines M₁, M₂, M₃ and M₄ are to be installed in a machine shop. There are five vacant places A, B, C, D and E available. Because of limited space, machine M₂ can not be placed at C and M₃ can not be placed at A the cost of locating a machine at a place (in hundred rupees) is as follows.

<table>
<thead>
<tr>
<th>Machines</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>M₁</td>
<td>9</td>
</tr>
<tr>
<td>M₂</td>
<td>12</td>
</tr>
<tr>
<td>M₃</td>
<td>-</td>
</tr>
<tr>
<td>M₄</td>
<td>14</td>
</tr>
</tbody>
</table>

Find the optimal assignment schedule.

**SEQUENCING PROBLEM**

**Introduction to Sequencing Problem:**

Suppose we have two machines - A : Cutting and B : Sewing machine Suppose there are two items I and II to be processed on these machines in the order A-B.

The machines can handle only one job at a time and the time taken in hours by the machines to complete the jobs is given by following table.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>I</td>
</tr>
<tr>
<td>B</td>
<td>3</td>
</tr>
</tbody>
</table>

Then there are two ways of completing this task

(i) Processing in the order I-II
(ii) Processing in the order II-I

Case i. Let us start with item I at 0 hours. Then we get

<table>
<thead>
<tr>
<th>Item</th>
<th>Machine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>In</td>
<td>1</td>
</tr>
</tbody>
</table>

Processing of item I starts at 0 hrs and is completed at 6 hrs,
Note that during this time, though machine B is idle, it can not process job II, since cutting is required completed before sewing.

Once the processing of item I is completed on machine A at 6 hours, it is shifted to machine B for sewing immediately.

Machine B being idle, item I is immediately taken for processing on machine B without any wastage of time.

Therefore, ‘time in’ for item I on machine B is 6 and time out is 6 + 3 = 9; where 3 hrs is the time required for the processing of item I on machine B.

While item I is being processed on machine B. Machine A is free and hence, it can take item II for processing.

Thus, item II enters machine A at 6 hrs and since it needs 3 hrs for cutting (refer to table 1) it gets out at 9 hrs from machine A.

At 9 hrs machine B is available, and hence can take, item II for processing at that time.

Item II requires 6 hrs on machine B, and will be out from machine B at 9 + 6 = 15 hrs. as shown below:

<table>
<thead>
<tr>
<th>Item</th>
<th>Machine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>In</td>
</tr>
<tr>
<td>I</td>
<td>0</td>
</tr>
<tr>
<td>II</td>
<td>6</td>
</tr>
</tbody>
</table>

Thus, the processing of items I and II in the order I - II takes 15 hours.

Case ii.

Let us now see what happens if we change the order of processing the two items i.e. processing item II first and item I second, (II-I)

Repeating the same process as in case (i) we get

<table>
<thead>
<tr>
<th>Item</th>
<th>Machine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>In</td>
</tr>
<tr>
<td>II</td>
<td>0</td>
</tr>
<tr>
<td>I</td>
<td>3</td>
</tr>
</tbody>
</table>

Therefore, processing of items in the order II-I takes 12 hours.

Observe that -

<table>
<thead>
<tr>
<th>Order of processing the items</th>
<th>Time required to complete the task</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-II</td>
<td>15 hrs</td>
</tr>
<tr>
<td>II-I</td>
<td>12 hrs</td>
</tr>
</tbody>
</table>

By a mere change in the order of processing of the two jobs, we could save 3 hrs.

Thus, it is very important to decide the order in which the jobs should be lined up for processing so as to complete the entire schedule in minimum time.

Such type of problem where, one has to determine the order or sequence in which the jobs are to be processed through machines so as to minimize the total processing time is called a ‘sequencing problem.’

Conditions:
1) No machine can process more than one job at a time.
2) Each job, once started, must be processed till its completion.
3) The processing times are independent of the order of processing the jobs.
4) Each machine is of different type.
5) The time required to transfer a job from one machine to another is negligible.

Terminology:
1) Total Elapsed Time:
   It is the time required to complete all the jobs i.e. the entire task.
Thus, total elapsed time is the time between the beginning of the first job on the first machine till the completion of the last job on the last machine.

2) **Idle Time:**

Idle time is the time when a machine is available but not being used, i.e., the machine is available but is waiting for a job to be processed.

**General Sequencing Problem:**

Let there be ‘n’ jobs, to be performed one at a time, on each of ‘m’ different machines, where the order of processing on machines and the processing time of jobs on machines is known to us. Then our aim is to find the optimal sequence of processing jobs that minimizes the total processing time or cost.

Hence our job is to find that sequence out of (n!)^m sequences, which minimizes the total elapsed time.

### NOTATION

- **A<sub>i</sub>, B<sub>i</sub>:** Processing time required by i<sup>th</sup> job on machine A and machine B (i = 1, 2, 3...n)
- **T:** Total elapsed time
- **X<sub>a</sub>, X<sub>b</sub>:** Idle times on machines A, B from end of (i-1)<sup>th</sup> job to the start of i<sup>th</sup> job

**Type of sequencing problems:**

I. Sequencing n jobs on two machine.

II. Sequencing n jobs on three machine.

#### 7.4.1 Sequencing n jobs on Two Machine:

Let there be ‘n’ job each of which is to be processed through two machines say A and B in the order AB. Let the processing time A<sub>1</sub>, A<sub>2</sub>, A<sub>3</sub>, ...A<sub>n</sub>, B<sub>1</sub>, B<sub>2</sub>, B<sub>3</sub>...B<sub>n</sub> be given.

**Algorithm to find Optimal Sequence:**

1) Find out Min {A<sub>i</sub>, B<sub>i</sub>}

2) (a) If the minimum processing time is A<sub>i</sub>, then process i<sup>th</sup> job first.

(b) If the minimum processing time is B<sub>i</sub>, then process i<sup>th</sup> job in the last.

3) Case of tie: Tie can be broken arbitrarily.

4) Cross off the jobs already placed in the sequence and repeat steps 1 to 3 till all the jobs are placed in the sequence.

5) Once the sequence is decided, prepare the work table and find total elapsed time.

### SOLVED EXAMPLES

**Ex.1.** We have five jobs each of which has to go through the Machine M<sub>1</sub> and M<sub>2</sub> in the order M<sub>1</sub>, M<sub>2</sub>. Processing time (in hours) are given as:

<table>
<thead>
<tr>
<th>Job</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine A</td>
<td>3</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Machine B</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

Determine a sequence of these jobs that will minimize the total elapsed time T, idle time for machine M<sub>1</sub> and idle time for machine M<sub>2</sub>.

**Solution:**

Observe that Min {A<sub>i</sub>, B<sub>i</sub>} = 1, which corresponds to job IV on machine B.

Therefore, job IV is placed last in the sequence.

Then the problem reduces to:

<table>
<thead>
<tr>
<th>Job</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine A</td>
<td>3</td>
<td>3</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Machine B</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

Now,

Min{A<sub>i</sub>, B<sub>i</sub>} = 2, which corresponds to job V on machine A & job III on machine B is placed. Therefore, job V is placed first and job III is placed next to last.

Then the problem reduces to:

<table>
<thead>
<tr>
<th>Job</th>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine A</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Machine B</td>
<td>6</td>
<td>4</td>
</tr>
</tbody>
</table>

Now, Min{A<sub>i</sub>, B<sub>i</sub>} = 3, which corresponds to job I and job II on machine A.
Therefore, job I and II can be placed after job V in any order. i.e.

\[
\begin{array}{ccccc}
V & I & II & III & IV \\
\end{array}
\]
or

\[
\begin{array}{ccccc}
V & II & I & III & IV \\
\end{array}
\]

Therefore, the optimal sequence is: V-I-II-III-IV or V-II-I-III-IV

(i) Total elapsed time for sequence V-I-II-III-IV

<table>
<thead>
<tr>
<th>Job</th>
<th>Machine A</th>
<th>Machine B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In</td>
<td>Out</td>
</tr>
<tr>
<td>V</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>I</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>II</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>III</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>IV</td>
<td>15</td>
<td>20</td>
</tr>
</tbody>
</table>

(ii) Total elapsed time for sequence V-II-I-III-IV

<table>
<thead>
<tr>
<th>Job</th>
<th>Machine A</th>
<th>Machine B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In</td>
<td>Out</td>
</tr>
<tr>
<td>V</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>II</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>I</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>III</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>IV</td>
<td>15</td>
<td>20</td>
</tr>
</tbody>
</table>

(Observable that, through the optimal sequence are different, total elapsed time is same i.e. 21 hrs)

\[
\therefore \text{Total elapsed time} = 21 \text{ hrs.}
\]

Idle time for machine A = T - (sum of processing times of all jobs on M₁)
= 21 - 20
= 1 hrs.

Idle time for machine B = T - (sum of processing times of all jobs on M₂)
= 21 - (6 + 4 + 2 + 1 + 5)
= 21 - 18
= 3 hrs.

Ex. 2. A book has one printing machine, one binding machine and manuscripts of 7 different books. The times required for performing printing and binding operations for different books are shown below:

<table>
<thead>
<tr>
<th>Book</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Printing time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
</tr>
<tr>
<td>Binding time (hours)</td>
</tr>
<tr>
<td>25</td>
</tr>
</tbody>
</table>

Decide the optimum sequence of processing of books in order to minimize the total time required to bring out all the books.

Solution:

Let A be the printing machine and
B be the binding machine

Observe that Min\{A₁, B₁\} = 20, which corresponds to 1st Book on machine A

Therefore, book 1 is processed first on machine M₁.

\[
\begin{array}{ccccccc}
   &   &   &   &   &   & \\
1 &   &   &   &   &   & \\
\end{array}
\]

Then the problem reduces to:

<table>
<thead>
<tr>
<th>Book</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>110</td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>55</td>
</tr>
</tbody>
</table>

Now, Min\{A₂, B₂\} = 24, which corresponds to 4th book on machine B.

\[
\begin{array}{ccccccccc}
   &   &   &   &   &   &   &   &   \\
1 &   &   &   &   &   &   &   & 4 \\
\end{array}
\]

Therefore, book 4 is processed in the last.

Then the problem reduces to:

<table>
<thead>
<tr>
<th>Book</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>110</td>
</tr>
<tr>
<td>25</td>
</tr>
<tr>
<td>55</td>
</tr>
</tbody>
</table>

Now, Min\{A₃, B₃\} = 25, which corresponds to book 6 on machine A.

\[
\begin{array}{ccccccccc}
   &   &   &   &   &   &   &   &   \\
1 & 6 &   &   &   &   &   &   & \\
\end{array}
\]

Min\{A₄, B₄\} = 40, which corresponds to book 2 and 7 are processed last but before 4th book in any order i.e.
Then the problem reduces to

<table>
<thead>
<tr>
<th>Book</th>
<th>3</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>50</td>
<td>110</td>
</tr>
<tr>
<td>B</td>
<td>45</td>
<td>80</td>
</tr>
</tbody>
</table>

Now, Min \( \{A_i, B_i\} \) = 45, which corresponds to book 3 on machine B. Therefore, book 3 is processed after book 6 and at the remaining.

Optional Sequence is:

1 6 3 5 2 7 4

or

1 6 3 5 7 2 4

Total elapsed time.

<table>
<thead>
<tr>
<th>Job</th>
<th>Machine A</th>
<th>Machine B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In</td>
<td>Out</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>45</td>
</tr>
<tr>
<td>3</td>
<td>45</td>
<td>95</td>
</tr>
<tr>
<td>5</td>
<td>95</td>
<td>205</td>
</tr>
<tr>
<td>2</td>
<td>205</td>
<td>265</td>
</tr>
<tr>
<td>7</td>
<td>265</td>
<td>320</td>
</tr>
<tr>
<td>4</td>
<td>320</td>
<td>350</td>
</tr>
</tbody>
</table>

\[ \therefore \] Total elapsed time = 389 hrs.

Idle time for machine A = 389 - 350 = 39 hrs.

Idle time for machine B = 20 + 15 + 65 = 100 hrs. or = 389 - 289 = 100 hrs.

7.4.2 Sequencing ‘n’ Jobs on Three Machines:
Let there be ‘n’ jobs each of which is to be processed through three machines say A, B and C in the order ABC. To solve this problem -
(i) first reduce it to the ‘n job 2 machine’ problem and determine the optimal sequence.
(ii) once the sequence is determined, go back to the original 3 machines and prepare the work table for 3 machines.

Conditions for reducing a 3 machine problem to a 2 machine problem:
To convert a 3 machine problem into a 2 machine problem, at least one of the following conditions must hold true.

1) The minimum processing time for machine A is greater than or equal to the maximum processing time for machine B.
\[ \text{i.e. } \min A_i \geq \max B_i, \quad i = 1, 2, 3, \ldots n \]
OR

2) The minimum processing time for machine C is greater than or equal to the maximum processing time for machine B.
\[ \text{i.e. } \min C_i \geq \max B_i, \quad i = 1, 2, 3, \ldots n \]

PROCEDURE

Step 1. If either one of the above conditions holds, go to step 2. If not, the method fails.

Step 2. Introduce two fictitious machines say G and H such that
\[ G_i = A_i + B_i \]
\[ H_i = B_i + C_i, \quad i = 1, 2, 3, \ldots n \]

Where \( G_i \) and \( H_i \) are the processing times of \( i^{th} \) job on machines G and H respectively. Now, solve the problem as \( n \) jobs 2 machines (G, H) problem as before.

SOLVED EXAMPLES

Ex.1. Determine the optimal sequence of job that minimizes the total elapsed time for the data given below (processing time on machines is given in hours). Also find total elapsed time \( T \) and the idle time for three machines.

<table>
<thead>
<tr>
<th>Job</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine A</td>
<td>3</td>
<td>8</td>
<td>7</td>
<td>4</td>
<td>9</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Machine B</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Machine C</td>
<td>6</td>
<td>7</td>
<td>5</td>
<td>11</td>
<td>5</td>
<td>6</td>
<td>12</td>
</tr>
</tbody>
</table>

Solution: Here, \( \min A = 3 \), \( \min C = 5 \), and \( \max B = 5 \)
Since \( \min C \geq \max B \) is satisfied, the problem can be converted into a two machine problem.

Let \( G \) and \( H \) be two fictitious machines such that \( G = A + B \) and \( H = B + C \).

Then the problem can be written as:

<table>
<thead>
<tr>
<th>Job</th>
<th>Machine G</th>
<th>Machine H</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>II</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>III</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>IV</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>V</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>VI</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>VII</td>
<td>10</td>
<td>15</td>
</tr>
</tbody>
</table>

Using the optimal sequence algorithm, the following optimal sequence can be obtained:

<table>
<thead>
<tr>
<th>Job</th>
<th>Machine G</th>
<th>Machine H</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>13</td>
<td>9</td>
</tr>
<tr>
<td>II</td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td>III</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>IV</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>V</td>
<td>15</td>
<td>19</td>
</tr>
</tbody>
</table>

Using the optimal sequence algorithm, the following optimal sequence can be obtained:

<table>
<thead>
<tr>
<th>Job</th>
<th>Machine G</th>
<th>Machine H</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>II</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>III</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

\[ \therefore \text{Total elapsed time} = 59 \text{ hrs.} \]

Idle time for machine \( A \) = 59 - 46 = 13 hrs.

Idle time for machine \( B \) = 59 - 22 = 37 hrs.

Idle time for machine \( C \) = 59 - 52 = 7 hrs.

**Ex. 2.** Find the sequence that minimizes the total times required in performing following jobs on three machines in the order ABC. Processing times (in hrs.) are given in the following table.

<table>
<thead>
<tr>
<th>Job</th>
<th>Machine A</th>
<th>Machine B</th>
<th>Machine C</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>II</td>
<td>3</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>III</td>
<td>7</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>IV</td>
<td>14</td>
<td>22</td>
<td>16</td>
</tr>
<tr>
<td>V</td>
<td>30</td>
<td>37</td>
<td>46</td>
</tr>
<tr>
<td>VI</td>
<td>37</td>
<td>46</td>
<td>47</td>
</tr>
</tbody>
</table>

\[ \therefore \text{Total elapsed time} = 59 \text{ hrs.} \]

Idle time for machine \( A \) = 59 - 46 = 13 hrs.

Idle time for machine \( B \) = 59 - 22 = 37 hrs.

Idle time for machine \( C \) = 59 - 52 = 7 hrs.

\[ \text{Idle time for machine } A = \{59 - 46\} = 9 \text{ hrs.} \]

\[ \text{Idle time for machine } B = \{59 - 22\} = 37 \text{ hrs.} \]

\[ \text{Idle time for machine } C = \{59 - 52\} = 19 \text{ hrs.} \]

\[ \text{Idle time for machine } C = \{59 - 52\} = 19 \text{ hrs.} \]

\[ \therefore \text{Total elapsed time} = 59 \text{ hrs.} \]

Idle time for machine \( A \) = 59 - 46 = 13 hrs.

Idle time for machine \( B \) = 59 - 22 = 37 hrs.

Idle time for machine \( C \) = 59 - 52 = 7 hrs.

\[ \text{Idle time for machine } A = \{59 - 46\} = 9 \text{ hrs.} \]

\[ \text{Idle time for machine } B = \{59 - 22\} = 37 \text{ hrs.} \]

\[ \text{Idle time for machine } C = \{59 - 52\} = 19 \text{ hrs.} \]

\[ \therefore \text{Total elapsed time} = 59 \text{ hrs.} \]

Idle time for machine \( A \) = 59 - 46 = 13 hrs.

Idle time for machine \( B \) = 59 - 22 = 37 hrs.

Idle time for machine \( C \) = 59 - 52 = 7 hrs.

**Let's Remember**

- **Sequencing problem**: In sequencing problems, one has to determine the order or sequence in which the jobs are to be processed through machines so as to minimize the total processing time.

- **Total Elapsed Time**: It is the time required to complete all the jobs i.e. the entire task.

- **Idle Time**: Idle time is the time when a machine is available, but is not being used.
• Types of sequencing problems:
• Sequencing n jobs on Two machines:
• Sequencing n jobs on Three machines:

To convert a 3 machine problem into a 2 machine problem, at least one of the following conditions must hold true.
1) \( \text{Min } A_i \geq \text{Max } B_i \) OR 2) \( \text{Min } C_i \geq \text{Max } B_i \)
\( i = 1, 2, 3, \ldots n \)

If either one of the above conditions hold, introduce two fictitious machines say
• \( G \) and \( H \) such that: \( G_i = A_i + B_i \)
\( H_i = B_i + C_i, \ i = 1, 2, 3, \ldots n \)

If not, the problem cannot be solved.

**EXERCISE 7.2**

1. A machine operator has to perform two operations, turning and threading on 6 different jobs. The time required to perform these operations (in minutes) for each job is known. Determine the order in which the jobs should be processed in order to minimize the total time required to complete all the jobs. Also find the total processing time and idle times for turning and threading operations.

<table>
<thead>
<tr>
<th>Job</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time for turning</td>
<td>3</td>
<td>12</td>
<td>5</td>
<td>2</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>Time for threading</td>
<td>8</td>
<td>10</td>
<td>9</td>
<td>6</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

2. A company has three jobs on hand. Each of these must be processed through two departments, in the order AB where
Department A: Press shop and
Department B: Finishing
The table below gives the number of days required by each job in each department

<table>
<thead>
<tr>
<th>Department</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department A</td>
<td>8</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Department B</td>
<td>8</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

Find the sequence in which the three jobs should be processed so as to take minimum time to finish all the three jobs. Also find idle time for both the departments.

3. An insurance company receives three types of policy application bundles daily from its head office for data entry and filing. The time (in minutes) required for each type for these two operations is given in the following table:

<table>
<thead>
<tr>
<th>Policy</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Entry</td>
<td>90</td>
<td>120</td>
<td>180</td>
</tr>
<tr>
<td>Filing</td>
<td>140</td>
<td>110</td>
<td>100</td>
</tr>
</tbody>
</table>

Find the sequence that minimizes the total time required to complete the entire task. Also find the total elapsed time and idle times for each operation.

4. There are five jobs, each of which must go through two machines in the order XY. Processing times (in hours) are given below. Determine the sequence for the jobs that will minimize the total elapsed time. Also find the total elapsed time and idle time for each machine.

<table>
<thead>
<tr>
<th>Job</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine X</td>
<td>10</td>
<td>2</td>
<td>18</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>Machine Y</td>
<td>4</td>
<td>12</td>
<td>14</td>
<td>16</td>
<td>8</td>
</tr>
</tbody>
</table>

5. Find the sequence that minimizes the total elapsed time to complete the following jobs in the order AB. Find the total elapsed time and idle times for both the machines.

<table>
<thead>
<tr>
<th>Job</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine A</td>
<td>7</td>
<td>16</td>
<td>19</td>
<td>10</td>
<td>14</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Machine B</td>
<td>12</td>
<td>14</td>
<td>14</td>
<td>10</td>
<td>16</td>
<td>5</td>
<td>7</td>
</tr>
</tbody>
</table>

6. Find the optimal sequence that minimizes total time required to complete the following jobs in the order ABC. The processing times are given in hrs.

(i)

<table>
<thead>
<tr>
<th>Job</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine A</td>
<td>6</td>
<td>7</td>
<td>5</td>
<td>11</td>
<td>6</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>Machine B</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Machine C</td>
<td>3</td>
<td>8</td>
<td>7</td>
<td>4</td>
<td>9</td>
<td>8</td>
<td>7</td>
</tr>
</tbody>
</table>
7. A publisher produces 5 books on Mathematics. The books have to go through composing, printing and binding done by 3 machines P, Q, R. The time schedule for the entire task in proper unit is as follows.

<table>
<thead>
<tr>
<th>Book</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine P</td>
<td>4</td>
<td>9</td>
<td>8</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Machine Q</td>
<td>5</td>
<td>6</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Machine R</td>
<td>8</td>
<td>10</td>
<td>6</td>
<td>7</td>
<td>11</td>
</tr>
</tbody>
</table>

Determine the optimum time required to finish the entire task.

**MISCELLANEOUS EXERCISE - 7**

1. Choose the correct alternative.

1. In sequencing, an optimal path is one that minimizes ...............
   (a) Elapsed time    (b) Idle time
   (c) Both (a) and (b) (d) Ready time

2. If job A to D have processing times as 5, 6, 8, 4 on first machine and 4, 7, 9, 10 on second machine then the optimal sequence is :
   (a) CDAB    (b) DBCA
   (c) BCDA    (d) ABCD

3. The objective of sequencing problem is
   (a) to find the order in which jobs are to be made
   (b) to find the time required for the completing all the job on hand
   (c) to find the sequence in which jobs on hand are to be processed to minimize the total time required for processing the jobs
   (d) to maximize the cost

4. If there are n jobs and m machines, then there will be ............ sequences of doing the jobs.
   (a) mn      (b) m(n!)
   (c) n^m     (d) (n!)^m

5. The Assignment Problem is solved by
   (a) Simplex method,
   (b) Hungarian method
   (c) Vector method,
   (d) Graphical method,

6. In solving 2 machine and n jobs sequencing problem, the following assumption is wrong
   (a) No passing is allowed
   (b) Processing times are known
   (c) Handling time is negligible
   (d) The time of passing depends on the order of machining

7. To use the Hungarian method, a profit maximization assignment problem requires
   (a) Converting all profits to opportunity losses
   (b) A dummy person or job
   (c) Matrix expansion
   (d) Finding the maximum number of lines to cover all the zeros in the reduced matrix

8. Using Hungarian method the optimal assignment obtained for the following assignment problem to minimize the total cost is :

<table>
<thead>
<tr>
<th>Agent</th>
<th>Job</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
</tr>
</tbody>
</table>

(a) 1 — C; 2 — B, 3 — D, 4 — A
(b) 1 — B, 2 — C, 3 — A, 4 — D
(c) 1 — A, 2 — B, 3 — C, 4 — D
(d) 1 — D, 2 — A, 3 — B, 4 — C
9. The assignment problem is said to be unbalanced if
   (a) Number of rows is greater than number of columns
   (b) Number of rows is lesser than number of columns
   (c) Number of rows is equal to number of columns
   (d) Both (a) and (b)

10. The assignment problem is said to be balanced if
    (a) Number of rows is greater than number of columns
    (b) Number of rows is lesser than number of columns
    (c) Number of rows is equal to number of columns
    (d) If the entry of row is zero

11. The assignment problem is said to be balanced if it is a
    (a) Square matrix  (b) Rectangular matrix
    (c) Unit matrix    (d) Triangular matrix

12. In an assignment problem if number of rows is greater than number of columns then
    (a) Dummy column is added
    (b) Dummy row is added
    (c) Row with cost 1 is added
    (d) Column with cost 1 is added

13. In a 3 machine and 5 jobs problem, the least of processing times on machine A, B and C are 5, 1, and 3 hours and the highest processing times are 9, 5, and 7 respectively, then it can be converted to a 2 machine problem if order of the machines is:
    (a) B-A-C,   (b) A-B-C
    (c) C - B - A   (d) Any order

14. The objective of an assignment problem is to assign
    (a) Number of jobs to equal number of persons at maximum cost
    (b) Number of jobs to equal number of persons at minimum cost
    (c) Only the maximize cost
    (d) Only to minimize cost

II) Fill in the blanks.
1. An assignment problem is said to be unbalanced when ..................

2. When the number of rows is equal to the number of columns then the problem is said to be .................. assignment problem.

3. For solving an assignment problem the matrix should be a ................. matrix.

4. If the given matrix is not a ................. matrix, the assignment problem is called an unbalanced problem.

5. A dummy row(s) or column(s) with the cost elements as ................. the matrix of an unbalanced assignment problem as a square matrix.

6. The time interval between starting the first job and completing the last job including the idle time (if any) in a particular order by the given set of machines is called ...............

7. The time for which a machine j does not have a job to process to the start of job i is called ...............

8. Maximization assignment problem is transformed to minimization problem by subtracting each entry in the table from the ................. value in the table.

9. When an assignment problem has more than one solution, then it is ................. optimal solution.

10. The time required for printing of four books A, B, C and D is 5, 8, 10 and 7 hours. While its data entry requires 7, 4, 3 and 6 hrs respectively. The sequence that minimizes total elapsed time is .................. 

III) State whether each of the following is True or False.
1. One machine - one job is not an assumption in solving sequencing problems.
2. If there are two least processing times for machine A and machine B, priority is given for the processing time which has lowest time of the adjacent machine.

3. To convert the assignment problem into a maximization problem, the smallest element in the matrix is deducted from all other elements.

4. The Hungarian method operates on the principle of matrix reduction, whereby the cost table is reduced to a set of opportunity costs.

5. In a sequencing problem, the processing times are dependent of order of processing the jobs on machines.

6. Optimal assignments are made in the Hungarian method to cells in the reduced matrix that contain a zero.

7. Using the Hungarian method, the optimal solution to an assignment problem is found when the minimum number of lines required to cover the zero cells in the reduced matrix equals the no of persons.

8. In an assignment problem, if number of column is greater than number of rows, then a dummy column is added.

9. The purpose of dummy row or column in an assignment problem is to obtain balance between total number of activities and total number of resources.

10. One of the assumptions made while sequencing n jobs on 2 machines is : two jobs must be loaded at a time on any machine.

| PART - I |

IV) Solve the following problems.

1. A plant manager has four subordinates, and four tasks to be performed. The subordinates differ in efficiency and the tasks differ in their intrinsic difficulty. This estimate of the times each man would take to perform each task is given in the effectiveness matrix below.

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>7</td>
<td>25</td>
<td>26</td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>12</td>
<td>27</td>
<td>3</td>
<td>25</td>
</tr>
<tr>
<td>C</td>
<td>37</td>
<td>18</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>D</td>
<td>18</td>
<td>25</td>
<td>23</td>
<td>9</td>
</tr>
</tbody>
</table>

How should the tasks be allocated, one to a man, as to minimize the total man hours?

2. A dairy plant has five milk tankers, I, II, III, IV & V. These milk tankers are to be used on five delivery routes A, B, C, D & E. The distances (in kms) between the dairy plant and the delivery routes are given in the following distance matrix.

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>150</td>
<td>120</td>
<td>175</td>
<td>180</td>
<td>200</td>
</tr>
<tr>
<td>B</td>
<td>125</td>
<td>110</td>
<td>120</td>
<td>150</td>
<td>165</td>
</tr>
<tr>
<td>C</td>
<td>130</td>
<td>100</td>
<td>145</td>
<td>160</td>
<td>175</td>
</tr>
<tr>
<td>D</td>
<td>40</td>
<td>40</td>
<td>70</td>
<td>70</td>
<td>100</td>
</tr>
<tr>
<td>E</td>
<td>45</td>
<td>25</td>
<td>60</td>
<td>70</td>
<td>95</td>
</tr>
</tbody>
</table>

How should the milk tankers be assigned to the chilling center so as to minimize the distance travelled?

3. Solve the following assignment problem to maximize sales:

<table>
<thead>
<tr>
<th>Salesmen</th>
<th>Territories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>A</td>
<td>11</td>
</tr>
<tr>
<td>B</td>
<td>7</td>
</tr>
<tr>
<td>C</td>
<td>9</td>
</tr>
<tr>
<td>D</td>
<td>13</td>
</tr>
</tbody>
</table>

4. The estimated sales (tons) per month in four different cities by five different managers are given below:

<table>
<thead>
<tr>
<th>Manager</th>
<th>Cities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P</td>
</tr>
<tr>
<td>I</td>
<td>34</td>
</tr>
<tr>
<td>II</td>
<td>33</td>
</tr>
<tr>
<td>III</td>
<td>37</td>
</tr>
<tr>
<td>IV</td>
<td>36</td>
</tr>
<tr>
<td>V</td>
<td>35</td>
</tr>
</tbody>
</table>
Find out the assignment of managers to cities in order to maximize sales.

5. Consider the problem of assigning five operators to five machines. The assignment costs are given in the following table.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Machine</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td>6</td>
<td>6</td>
<td>-</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>8</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>10</td>
<td>4</td>
<td>6</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td>8</td>
<td>3</td>
<td>7</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>E</td>
<td></td>
<td>7</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>

Operator A cannot be assigned to machine 3 and operator C cannot be assigned to machine 4. Find the optimal assignment schedule.

6. A chartered accountant’s firm has accepted five new cases. The estimated number of days required by each of their five employees for each case is given below, where - means that the particular employee cannot be assigned the particular case. Determine the optimal assignment of cases of the employees so that the total number of days required to complete these five cases will be minimum. Also find the minimum number of days.

<table>
<thead>
<tr>
<th>Employee</th>
<th>Cases</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>E₁</td>
<td></td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>E₂</td>
<td></td>
<td>7</td>
<td>-</td>
<td>8</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>E₃</td>
<td></td>
<td>8</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>E₄</td>
<td></td>
<td>5</td>
<td>7</td>
<td>-</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>E₅</td>
<td></td>
<td>9</td>
<td>5</td>
<td>3</td>
<td>10</td>
<td>-</td>
</tr>
</tbody>
</table>

PART - II

1. A readymade garments manufacturer has to process 7 items through two stages of production, namely cutting and sewing. The time taken in hours for each of these items in different stages are given below:

<table>
<thead>
<tr>
<th>Items</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time for Cutting</td>
<td>5</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>Time for Sewing</td>
<td>2</td>
<td>6</td>
<td>7</td>
<td>5</td>
<td>9</td>
<td>5</td>
<td>8</td>
</tr>
</tbody>
</table>

Find the sequence in which these items are to be processed through these stages so as to minimize the total processing time. Also find the idle time of each machine.

2. Five jobs must pass through a lathe and a surface grinder, in that order. The processing times in hours are shown below. Determine the optimal sequence of the jobs. Also find the idle time of each machine.

<table>
<thead>
<tr>
<th>Job</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lathe</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Surface grinder</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>

3. Find the sequence that minimizes the total elapsed time to complete the following jobs. Each job is processed in order AB.

<table>
<thead>
<tr>
<th>Jobs (Processing times in minutes)</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine A</td>
<td>12</td>
<td>6</td>
<td>5</td>
<td>11</td>
<td>5</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Machine B</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>4</td>
<td>7</td>
<td>8</td>
<td>3</td>
</tr>
</tbody>
</table>

Determine the sequence for the jobs so as to minimize the processing time. Find the total elapsed time and the idle times for both the machines.

4. A toy manufacturing company produces five types of toys. Each toy has to go through three machines A, B, C in the order ABC. The time required in hours for each process is given in the following table.

<table>
<thead>
<tr>
<th>Type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine A</td>
<td>16</td>
<td>20</td>
<td>12</td>
<td>14</td>
<td>22</td>
</tr>
<tr>
<td>Machine B</td>
<td>10</td>
<td>12</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Machine C</td>
<td>8</td>
<td>18</td>
<td>16</td>
<td>12</td>
<td>10</td>
</tr>
</tbody>
</table>

Solve the problem for minimizing the total elapsed time.
5. A foreman wants to process 4 different jobs on three machines: a shaping machine, a drilling machine and a tapping machine, the sequence of operations being shaping-drilling-tapping. Decide the optimal sequence for the four jobs to minimize the total elapsed time. Also find the total elapsed time and the idle time for every machine.

<table>
<thead>
<tr>
<th>Job</th>
<th>Shaping (minutes)</th>
<th>Drilling (minutes)</th>
<th>Trapping (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13</td>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td>2</td>
<td>18</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>23</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>

**Activities...I**

1. Given below the costs of assigning 3 workers to 3 jobs. Find all possible assignments by trial and error method.

<table>
<thead>
<tr>
<th>Workers</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>11</td>
<td>16</td>
<td>21</td>
</tr>
<tr>
<td>B</td>
<td>20</td>
<td>13</td>
<td>17</td>
</tr>
<tr>
<td>C</td>
<td>13</td>
<td>15</td>
<td>12</td>
</tr>
</tbody>
</table>

Among these assignments, find the optimal assignment that minimizes the total cost.

2. Show that the optimal solution of an assignment problem is unchanged if we add or subtract the same constant to the entries of any row or column of the cost matrix.

3. Construct a $3 \times 3$ cost matrix by taking the costs as the first 9 natural numbers and arranging them row wise in ascending order. Find all possible assignments that will minimize the total sum.

4. Given below the costs (in hundred rupees) of assigning 3 operators to 3 different machines. Find the assignment that will minimize the total cost. Also find the minimum cost.

<table>
<thead>
<tr>
<th>Operators</th>
<th>Machines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>A</td>
<td>$3i + 4j$</td>
</tr>
<tr>
<td>B</td>
<td>$i^3 + 8j$</td>
</tr>
<tr>
<td>C</td>
<td>$2i^2 - 1$</td>
</tr>
</tbody>
</table>

Where, $i$ stands for number of row and $j$ stands for number of column.

5. A firm marketing a product has four salesmen $S_1$, $S_2$, $S_3$ and $S_4$. There are three customers $C_1$, $C_2$ and $C_3$. The probability of making a sale to a customer depends upon the salesman customer support. The Table below represents the probability with which each of the salesmen can sell to each of the customers.

<table>
<thead>
<tr>
<th>Customers</th>
<th>Salesmen</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S1</td>
</tr>
<tr>
<td>C1</td>
<td>0.7</td>
</tr>
<tr>
<td>C2</td>
<td>0.5</td>
</tr>
<tr>
<td>C3</td>
<td>0.3</td>
</tr>
</tbody>
</table>

If only one salesman is to be assigned to one customer, what combination of salesmen and customers shall be optimal? Profit obtained by selling one unit to $C_1$ is Rs. 500, to $C_2$ is Rs.450 and to $C_3$ is Rs. 540. What is the total expected profit?

**Activities...II**

1. Give two different examples of sequencing problems from your daily life.

2. Let there be five jobs I, II, III, IV & V to be processed on two machines A and B in the order AB. Take the first 5 composite numbers as the processing times on machine A for jobs I, II, III, IV, V respectively and the first five odd numbers as the processing times on machine B for jobs V, IV, III, II, I respectively. Find the sequence that minimizes the total elapsed time. Also find the total elapsed time and idle times on both the machines.
3. Determine the optimal sequence of jobs that minimizes the total elapsed time. Processing times are given in hours. Also find total elapsed time and idle times for the machines.

<table>
<thead>
<tr>
<th>Job</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine A</td>
<td>2 \frac{1}{2}</td>
<td>5 \frac{1}{2}</td>
<td>1 \frac{1}{2}</td>
<td>2 \frac{3}{4}</td>
<td>3 \frac{1}{4}</td>
<td>9 \frac{1}{4}</td>
</tr>
<tr>
<td>Machine B</td>
<td>3 \frac{1}{2}</td>
<td>4 \frac{1}{2}</td>
<td>7 \frac{1}{4}</td>
<td>2 \frac{1}{4}</td>
<td>5 \frac{1}{4}</td>
<td>1 \frac{1}{2}</td>
</tr>
</tbody>
</table>

4. Consider 4 jobs to be processed on 3 machines A, B and C in the order ABC. Assign processing times to jobs and find the optimal sequence that minimizes the total processing time. Also find the elapsed time and idle times for all the three machines.

5. (a) Determine the optimal sequence of jobs that minimizes the total elapsed time based on the following information. Processing time on machines is given in hours, and passing is not allowed. Find total elapsed time and idle times for the machines.

<table>
<thead>
<tr>
<th>Job</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine X</td>
<td>13</td>
<td>18</td>
<td>17</td>
<td>14</td>
<td>19</td>
<td>18</td>
<td>17</td>
</tr>
<tr>
<td>Machine Y</td>
<td>14</td>
<td>13</td>
<td>12</td>
<td>15</td>
<td>11</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>Machine Z</td>
<td>16</td>
<td>17</td>
<td>14</td>
<td>21</td>
<td>14</td>
<td>16</td>
<td>22</td>
</tr>
</tbody>
</table>

(b) What happens if we change the processing times on machine Z corresponding to jobs C and E and take them as 15 instead of 14?
8.1 Random variables:

We have already studied random experiments and sample spaces corresponding to random experiments. As an example, consider the experiment of tossing two fair coins. The sample space corresponding to this experiment contains four points, namely \{HH, HT, TH, TT\}.

We have already learnt to construct the sample space of any random experiment. However, the interest is not always in a random experiment and its sample space. We are often not interested in the outcomes of a random experiment, but only in some number obtained from the outcome. For example, in case of the experiment of tossing two fair coins, our interest may be only in the number of heads when two coins are tossed.

In general, it is possible to associate a unique real number with very possible outcome of a random experiment. The number obtained from an outcome of a random experiment can take different values for different outcomes. This is why such a number is a variable. The value of this variable depends on the outcome of the random experiment, and is therefore called a random variable. A random variable is usually denoted by capital letters like \(X, Y, Z, \ldots\).

Consider the following examples to understand the concept of random variables.

- When we throw two dice, there are 36 possible outcomes, but if we are interested in the sum of the numbers on the two dice, then there are only 11 different possible values, from 2 to 12.
- If we toss a coin 10 times, then there are \(2^{10} = 1024\) possible outcomes, but if we are interested in the number of heads among the 10 tosses of the coin, then there are only 11 different possible values, from 0 to 10.
- In the experiment of randomly selecting four items from a lot of 20 items that contains 6 defective items, the interest is in the number of defective items among the selected four items. In this case, there are only 5 different possible outcomes, from 0 to 4.
In all the above examples, there is a rule to assign a unique value to every possible outcome of the random experiment. Since this number can change from one outcome to another, it is a variable. Also, since this number is obtained from outcomes of a random experiment, it is called a random variable.

A random variable is formally defined as follows:

**Definition**: A random variable is a real-valued function defined on the sample space of a random experiment. In other words, the domain of a random variable is the sample space of a random experiment, while its co-domain is the real line.

Thus $X: S \rightarrow R$ is a random variable.

We often use the abbreviation r.v. for random variable.

Consider an experiment where three seeds are sown in order to find how many of them germinate. Every seed will either germinate or will not germinate. Let us use the letter Y when a seed germinates. The sample space of this experiment can then be written as $S = \{YYY, YYN, YNY, NYY, YNN, NYN, NNY, NNN\}$ and $n(S) = 8$.

None of these outcomes is a number. We shall try to represent every outcome by a number. Consider the number of times the letter $Y$ appears is a possible outcome and denote it by $X$. Then, we have $X(YYY) = 3$, $X(YYN) = X(YNY) = X(YYN) = 2$, $X(YNN) = X(NYN) = X(NNY) = 1$, $X(NNN) = 0$.

The variable $X$ has four possible values, namely 0, 1, 2 and 3. The set of possible values of $X$ is called the range of $X$. Thus, in this example, the range of $X$ is the set $\{0, 1, 2, 3\}$.

A random variable is denoted by a capital letter, like $X$ and $Y$. A particular value taken by the random variable is denoted by the small letter $x$. Note that $x$ is a real number and the set of all possible outcomes corresponding to a particular value $x$ of $X$ is denoted by the event $[X = x]$. For example, in the experiment of three seeds, the random variable $X$ has four possible values, namely 0, 1, 2, 3. The four events are then defined as follows.

- $[X = 0] = \{NNN\}$,
- $[X = 1] = \{YNN, NYN, NNY\}$,
- $[X = 2] = \{YYN, YNY, NYY\}$,
- $[X = 3] = \{YYY\}$.

Note that the sample space in this experiment is finite and so is the random variable defined on it.

A sample space need not be finite. Consider, for example, the experiment of tossing a coin until a head is obtained. The sample space for this experiment is $S = \{H, TH, TTH, TTTH, \ldots\}$. Note that $S$ contains an unending sequence of tosses required to get a head. Here, $S$ is countably infinite. The random variable $X: S \rightarrow R$, denoting the number of tosses required to get a head, has the range $\{1, 2, 3, \ldots\}$ which is also countably infinite.

### 8.2 Types of Random Variables:

There are two types of random variables, namely discrete and continuous.

#### 8.2.1 Discrete Random Variable:

**Definition**: A random variable is a discrete random variable if its possible values form a countable set, which may be finite or infinite.

The values of a discrete random variable are usually denoted by non-negative integers, that is, 0, 1, 2, ....... . Examples of discrete random variables include the number of children in a family, the number of patients in a hospital ward, the number of cars sold by a dealer, and so on.

**Note**: The values of a discrete random variable are obtained by counting.

#### 8.2.2 Continuous Random Variable

**Definition**: A random variable is a continuous random variable if its possible values form an interval of real numbers.
A continuous random variable has uncountably infinite possible values and these values form an interval of real numbers. Examples of continuous random variables include heights of trees in a forest, weights of students in a class, daily temperature of a city, speed of a vehicle, and so on.

The value of a continuous random variable is obtained by measurement. This value can be measured to any degree of accuracy, depending on the unit of measurement. This measurement can be represented by a point in an interval of real numbers.

The purpose of defining a random variable is to study its properties. The most important property of a random variable is its probability distribution. Many other properties of a random variable are obtained with help of its probability distribution. We shall now learn the probability distribution of a random variable. We shall first learn the probability distribution of a discrete random variable, and then learn the probability distribution of a continuous random variable.

8.3 Probability Distribution of a Discrete Random Variable

Let us consider the experiment of throwing two dice and noting the numbers on the uppermost faces of the two dice. The sample space of this experiment is \( S = \{(1,1), (1,2), \ldots, (6,6)\} \) and \( n(S) = 36 \).

Let \( X \) denote the sum of the two numbers in a single throw. Then the set of possible values of \( X \) is \( \{2, 3, \ldots, 12\} \). Further,

\[
\begin{align*}
[X = 2] &= \{(1,1)\}, \\
[X = 3] &= \{(1,2), (2,1)\}, \\
&\quad \ldots \\
[X = 12] &= \{(6,6)\}
\end{align*}
\]

Next, all of the 36 possible outcomes are equally likely if the two dice are fair. That is, each of the six faces has the same probability of being uppermost when a die is thrown.

As the result, each of these 36 possible outcomes has the probability \( \frac{1}{36} \).

This leads to the following results.

\[
\begin{align*}
P[X = 2] &= P(\{(1,1)\}) = \frac{1}{36} \\
P[X = 3] &= P(\{(1,2), (2,1)\}) = \frac{2}{36} \\
P[X = 4] &= P(\{(1,3), (2,2),(3,1)\}) = \frac{3}{36}, \\
\end{align*}
\]

and so on.

The following table shows the probabilities of all possible values of \( X \):

<table>
<thead>
<tr>
<th>( x )</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P(x) )</td>
<td>( \frac{1}{36} )</td>
<td>( \frac{2}{36} )</td>
<td>( \frac{3}{36} )</td>
<td>( \frac{4}{36} )</td>
<td>( \frac{5}{36} )</td>
<td>( \frac{6}{36} )</td>
</tr>
<tr>
<td>( x )</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>( P(x) )</td>
<td>( \frac{5}{36} )</td>
<td>( \frac{4}{36} )</td>
<td>( \frac{3}{36} )</td>
<td>( \frac{2}{36} )</td>
<td>( \frac{1}{36} )</td>
<td></td>
</tr>
</tbody>
</table>

Such a description of the possible values of a random variable \( X \) along with corresponding probabilities is called the probability distribution of the random variable \( X \).

In general, the probability distribution of a discrete random variable \( X \) is defined as follows.

**Definition**: The probability distribution of a discrete random variable \( X \) is defined by the following system. Let the possible values of \( X \) be denoted by \( x_1, x_2, x_3, \ldots \), and the corresponding probabilities be denoted by \( p_1, p_2, p_3, \ldots \). Then, the set of ordered pairs \( \{(x_1, p_1), (x_2, p_2), (x_3, p_3), \ldots\} \) is called the probability distribution of the random variable \( X \).

For example, consider the coin-tossing experiment where the random variable \( X \) is defined as the number of tosses required to get a head. Let the probability of getting head be \( \ell \) and that of not getting head be \( 1 - \ell \). The possible values of \( X \) are given by the set of natural numbers, \( \{1, 2, 3, \ldots\} \) and \( P[X = i] = (1 - \ell)^{i-1}\ell \), for \( i = 1, 2, 3, \ldots \). This result can be verified by noting that if head is obtained for the first time
on the \( i \)th toss, then the first \( i - 1 \) tosses have resulted in tail. In other words, \([X = i]\) represents the event of having \( i - 1 \) tails followed by the first head on the \( i \)th toss.

\[ p_i = P[X = x_i] \quad \text{for} \quad i = 1, 2, 3, \ldots. \]

**Note:** A discrete random variable can have finite or infinite possible values, but they are countable.

The probability distribution of a discrete random variable is sometimes presented in a tabular form as follows.

<table>
<thead>
<tr>
<th>( x_i )</th>
<th>( p_1 )</th>
<th>( p_2 )</th>
<th>( p_3 )</th>
<th>( \ldots )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P[X = x_i] )</td>
<td>( \frac{1}{16} )</td>
<td>( \frac{1}{4} )</td>
<td>( \frac{3}{8} )</td>
<td>( \frac{1}{4} )</td>
</tr>
</tbody>
</table>

**Note:** If \( x_i \) is a possible value of \( X \) and \( p_i = P[X = x_i] \), then there is an event \( E_i \) in the sample space \( S \) such that \( p_i = P[E_i] \). Since \( x_i \) is a possible value of \( X \), \( p_i = P[X = x_i] > 0 \). Also, all possible values of \( X \) cover all sample points in the sample space \( S \), and hence the sum of their probabilities is 1. That is \( \sum p_i = 1 \).

### 8.3.1 Probability Mass Function (p. m. f.)

The probability \( p_i \) of \( X \) taking the value \( x_i \) is sometimes a function of \( x_i \) for all possible values of \( X \). In such cases, it is sufficient to specify all possible values of \( X \) and the function that gives probabilities of these values. Such a function is called the probability mass function (p. m. f.) of the discrete random variable \( X \).

For example, consider the coin-tossing experiment where the random variable \( X \) is defined as the number of tosses required to get a head. Let probability of getting a head be \( \theta \) and that of not getting a head be \( 1 - \theta \). The possible values of \( X \) are given by the set of natural numbers \( \{1, 2, 3, \ldots \} \) and \( P[X = i] = (1 - \theta)^{i-1} \theta \), for \( i = 1, 2, 3, \ldots \) is a function of \( i \).

The probability mass function (p. m. f.) of a discrete random variable is defined as follows.

**Definition.** Let the possible values of a discrete random variable \( X \) be denoted by \( x_1, x_2, \ldots \), with the corresponding probabilities \( p_1 = P[X = x_1], p_2 = P[X = x_2], \ldots \). If there is a function \( f \) such that \( f(x_i) = p_i = P[X = x_i] \) for all possible values of \( X \), then \( f \) is called the probability mass function (p. m. f.) of \( X \).

For example, consider the experiment of tossing a coin 4 times and defining the random variable \( X \) as the number of heads in 4 tosses. The possible values of \( X \) are 0, 1, 2, 3, 4, and the probability distribution of \( X \) is given by the following table.

\[
\begin{array}{ccccc}
\hline
x & 0 & 1 & 2 & 3 & 4 \\
--- & --- & --- & --- & --- & --- \\
\hline
P[X = x] & \frac{1}{16} & \frac{1}{4} & \frac{3}{8} & \frac{1}{4} & \frac{1}{16} \\
\hline
\end{array}
\]

Note that \( P[X = x] = \binom{4}{x} \left( \frac{1}{2} \right)^4 \), for \( x = 0, 1, 2, 3, 4 \), where \( \binom{4}{x} \) is the number of ways of getting \( x \) heads in 4 tosses.

### 8.3.2 Cumulative Distribution Function (c. d. f.)

The probability distribution of a discrete random variable can be specified with help of the p. m. f. It is sometimes more convenient to use the cumulative distribution function (c. d. f.) of the random variable.

The cumulative distribution function (c. d. f.) of a discrete random variable is defined as follows.

**Definition:** The cumulative distribution function (c. d. f.) of a discrete random variable \( X \) is denoted by \( F \) and is defined as follows.

\[
F(x) = P[X \leq x] = \sum_{x \leq x} P[X = x] = \sum_{x \leq x} f(x)
\]

where \( f \) is the probability mass function (p. m. f.) of the discrete random variable \( X \).

For example, consider the experiment of tossing 4 coins and counting the number of heads.
We can form the following table for the probability distribution of $X$.

<table>
<thead>
<tr>
<th>$x$</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f(x) = P(X = x)$</td>
<td>$\frac{1}{16}$</td>
<td>$\frac{1}{4}$</td>
<td>$\frac{3}{8}$</td>
<td>$\frac{1}{4}$</td>
<td>$\frac{1}{16}$</td>
</tr>
<tr>
<td>$F(x) = P(X \leq x)$</td>
<td>$\frac{1}{16}$</td>
<td>$\frac{5}{16}$</td>
<td>$\frac{11}{16}$</td>
<td>$\frac{15}{16}$</td>
<td>1</td>
</tr>
</tbody>
</table>

As another example, consider the experiment of tossing a coin till a head is obtained. The following table shows the p. m. f. and the c. d. f. of the random variable $X$, defined as the number of tosses required for the first head.

<table>
<thead>
<tr>
<th>$x$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>……</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f(x)$</td>
<td>$\frac{1}{2}$</td>
<td>$\frac{1}{4}$</td>
<td>$\frac{1}{8}$</td>
<td>$\frac{1}{16}$</td>
<td>$\frac{1}{32}$</td>
<td>……</td>
</tr>
<tr>
<td>$F(x)$</td>
<td>$\frac{1}{2}$</td>
<td>$\frac{3}{4}$</td>
<td>$\frac{7}{8}$</td>
<td>$\frac{15}{16}$</td>
<td>$\frac{31}{32}$</td>
<td>……</td>
</tr>
</tbody>
</table>

It is possible to define several random variables on the same sample space. If two or more random variables are defined on the same sample space, their probability distributions need not be the same.

For example, consider the simple experiment of tossing a coin twice. The sample space of this experiment is $S = \{HH, HT, TH, TT\}$.

Let $X$ denote the number of heads obtained in two tosses, then $X$ is a discrete random variable and its values for the possible outcomes of the experiment are obtained as follows.

$X(HH) = 2$, $X(HT) = X(TH) = 1$, $X(TT) = 0$.

Let $Y$ denote the number of heads minus the number of tails in two tosses. Then $Y$ is also a discrete random variable and its values for the possible outcomes of the experiment are obtained as follows.

$Y(HH) = 2$, $Y(HT) = Y(TH) = 0$,

$Y(TT) = -2$.

Let $Z = \frac{\text{number of heads}}{\text{number of tails} + 1}$. Then $Z$ is also a discrete random variable and its values for the possible outcomes of the experiment are obtained as follows.

\[ Z(HH) = 2, \ Z(HT) = Z(TH) = \frac{1}{2}, \ Z(TT) = 0. \]

These examples show that it is possible to define many discrete random variables on the same sample space. Possible values of a discrete random variable can be positive or negative, integer or fraction, and so on, as long as they are countable.

**SOLVED EXAMPLES**

**Ex. 1.** Two persons A and B play a game of tossing a coin thrice. If a toss results in a head, A gets Rs. 2 from B. If a toss results in tail, B gets Rs. 1.5 from A. Let $X$ denote the amount gained or lost by A. Show that $X$ is a discrete random variable and it can be defined as a function on the sample space of the experiment.

**Solution:** $X$ is a number whose value depends on the outcome of a random experiment. Therefore, $X$ is a random variable. Since the sample space of the experiment has only 8 possible outcomes, $X$ is a discrete random variable. Now, the sample space of the experiment is $S = \{HHH, HHT, HTT, THH, THT, TTH, TTT\}$. The values of $X$ corresponding to these outcomes of the experiment are as follows.

\[
X(HHH) = 3 \\
= 6 \\
X(HHT) = X(HTH) \\
= X(THH) \\
= 2 \times 2 - 1.50 \times 1 \\
= 2.50 \\
X(HTT) = X(THT) \\
= X(TTH) \\
= 2 \times 1 - 1.50 \times 2 \\
= -1.00
\]
\[ X(TTT) = -1.50 \times 3 = -4.50 \]

Here, a negative amount shows a loss to player A. This example shows that \( X \) takes a unique value for every element of the sample space and therefore \( X \) is a function on the sample space. Further, possible values of \( X \) are \(-4.50\), \(-1\), 2.50, 6.

**Ex. 2.** A bag contains 1 red and 2 green balls. One ball is drawn from the bag at random, its colour is noted, and the ball is put back in the bag. One more ball is drawn from the bag at random and its colour is also noted. Let \( X \) denote the number of red balls drawn. Derive the probability distribution of \( X \).

**Solution:** Let the balls in the bag be denoted by \( r, g_1, g_2 \). The sample space of the experiment is then given by \( S = \{rr, rg_1, rg_2, g_1r, g_1g_1, g_1g_2, g_2r, g_2g_1, g_2g_2\} \).

Since \( X \) is the number of red balls, we have

\[
\begin{align*}
X(\{rr\}) &= 2 \\
X(\{rg_1\}) &= X(\{rg_2\}) = X(\{g_1r\}) = X(\{g_2r\}) = 1 \\
X(\{g_1g_1\}) &= X(\{g_1g_2\}) = X(\{g_2g_1\}) = X(\{g_2g_2\}) = 0
\end{align*}
\]

Thus \( X \) is a discrete random variable with possible values, 0, 1 and 2. The probability distribution of \( X \) is obtained as follows.

<table>
<thead>
<tr>
<th>( x )</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P[X = x] )</td>
<td>( \frac{144}{169} )</td>
<td>( \frac{24}{169} )</td>
<td>( \frac{1}{169} )</td>
</tr>
</tbody>
</table>

**Ex. 3.** Two cards are randomly drawn, with replacement, from a well shuffled deck of 52 playing cards. Find the probability distribution of the number of aces drawn.

**Solution:** Let \( X \) denote the number of aces among the two cards drawn with replacement. Clearly, 0, 1 and 2 are the possible values of \( X \). Since the draws are with replacement, the outcomes of the two draws are independent of each other. Also, since there are 4 aces in the deck of 52 cards, \( P[\text{an ace}] = \frac{4}{52} = \frac{1}{13} \) and \( P[\text{a non-ace}] = \frac{12}{13} \).

Then

\[
egin{align*}
P[X = 0] &= P[\text{non-ace and non-ace}] \\
&= \frac{12}{13} \times \frac{12}{13} \\
&= \frac{144}{169} \\
\end{align*}
\]

\[
egin{align*}
P[X = 1] &= P[\text{ace and non-ace}] + P[\text{non-ace and ace}] \\
&= \frac{1}{13} \times \frac{12}{13} + \frac{12}{13} \times \frac{1}{13} \\
&= \frac{24}{169} \\
\end{align*}
\]

and \( P[X = 2] = P[\text{ace and ace}] \\
= \frac{1}{13} \times \frac{1}{13} \\
= \frac{1}{169} \)

The required probability distribution is then as follows.

**Ex. 4.** A fair die is thrown. Let \( X \) denote the number of factors of the number on the upper face. Find the probability distribution of \( X \).

**Solution:** The sample space of the experiment is \( S = \{1, 2, 3, 4, 5, 6\} \). The values of \( X \) for the possible outcomes of the experiment are as follows. \( X(1) = 1, X(2) = 2, X(3) = 2, X(4) = 3, X(5) = 2, X(6) = 4 \). Therefore,
\[ p_1 = P[X = 1] = P\{1\} = \frac{1}{6} \]
\[ p_2 = P[X = 2] = P\{2,3,5\} = \frac{3}{6} \]
\[ p_3 = P[X = 3] = P\{4\} = \frac{1}{6} \]
\[ p_4 = P[X = 4] = P\{6\} = \frac{1}{6} \]

The probability distribution of \( X \) is as shown in the following table.

<table>
<thead>
<tr>
<th>( x )</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P[X = x] )</td>
<td>( \frac{1}{6} )</td>
<td>( \frac{3}{6} )</td>
<td>( \frac{1}{6} )</td>
<td>( \frac{1}{6} )</td>
</tr>
</tbody>
</table>

**Ex. 5.** Find the probability distribution of the number of doubles in three throws of a pair of dice.

**Solution:** Let \( X \) denote the number of doubles. The possible doubles in a single throw of a pair of dice are given by \((1, 1), (2, 2), (3, 3), (4, 4), (5, 5), (6, 6)\).

Since the dice are thrown thrice, 0, 1, 2, and 3 are possible values of \( X \). Probability of getting a doublet in a single throw of a pair of dice is \( p = \frac{1}{6} \) and \( q = 1 - \frac{1}{6} = \frac{5}{6} \).

\[
P[X = 0] = P[\text{no doublet}]
=qqq = \frac{5}{6} \cdot \frac{5}{6} \cdot \frac{5}{6} = \frac{125}{216}
\]
\[
P[X = 1] = P[\text{one doublets}]
= pqq + qpp + qqp
= 3pq^2 = \frac{75}{216}
\]
\[
P[X = 2] = P[\text{two doublets}]
= ppm + pqp + qpp
= 3p^2q = \frac{15}{216}
\]
\[
P[X = 3] = P[\text{three doublets}]
= ppp = \frac{1}{216}
\]

**Ex. 6.** The probability distribution of \( X \) is as follows.

<table>
<thead>
<tr>
<th>( x )</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P[X = x] )</td>
<td>0.1</td>
<td>( k )</td>
<td>2k</td>
<td>2k</td>
<td>( k )</td>
</tr>
</tbody>
</table>

Find (i) \( k \), (ii) \( P[X < 2] \), (iii) \( P[X \geq 3] \), (iv) \( P[1 \leq X < 4] \), (v) \( F(2) \).

**Solution:** The table gives a probability distribution and therefore.

\[
\]

That is, \( 0.1 + k + 2k + 2k + k = 1 \)
That is, \( 6k = 0.9 \) Therefore \( k = 0.15 \).

(i) \( k = 0.15 \)
(ii) \( P[X < 2] = P[X = 0] + P[X = 1] = 0.1 + k = 0.1 + 0.15 = 0.25 \)
(iii) \( P[X \geq 3] = P[X = 3] + P[X = 4] = 2k + k = 3(0.15) = 0.45 \)
(iv) \( P[1 \leq X < 4] = P[X = 1] + P[X = 2] + P[X = 3] = k + 2k + 2k + 5k = 5(0.15) = 0.75 \)
v) \( F(2) = P[X \leq 2] = P[X = 0] + P[X = 1] + P[X = 2] = 0.1 + k + 2k = 0.1 + 3k = 0.1 + 3(0.15) = 0.1 + 0.45 = 0.55 \).

8.3.3 **Expected value and variance of a random variable.**

In many problems, the interest is in some feature of a random variable computed from its probability distribution. Some such numbers are mean, variance and standard deviation. We shall discuss mean and variance in this section. Mean is a measure of location in the sense that it is the average value of the random variable.

**Definition:** Let \( X \) be a random variable whose possible values \( x_1, x_2, x_3, \ldots, x_n \) occur with probabilities \( p_1, p_2, p_3, \ldots, p_n \) respectively. The expected value or arithmetic mean of \( X \), denoted by \( E(X) \) or \( \mu \) is defined by

\[
\mu = E(X) = \left( x_1 p_1 + x_2 p_2 + \ldots + x_n p_n \right) = \sum_{i=1}^{n} x_i p_i
\]
The mean or expected value of a random variable \(X\) is the sum of products of possible values of \(X\) and their respective probabilities.

**Definition:** Let \(X\) be a random variable whose possible values \(x_1, x_2, \ldots, x_n\) occur with probabilities \(p_1, p_2, p_3, \ldots, p_n\) respectively. The variance of \(X\), denoted by \(\text{Var}(X)\) or \(\sigma^2\) is defined as

\[
\sigma^2 = \text{Var}(X) = \sum_{i=1}^{n} (x_i - \mu)^2 p_i.
\]

The non-negative square root of \(\text{Var}(X)\) is called the standard deviation of the random variable \(X\). That is, \(\sigma = \sqrt{\text{Var}(X)}\).

Another formula to find the variance of a random variable. We can also use the simplified form of \(\text{Var}(X) = \sum_{i=1}^{n} x_i^2 p_i - \left(\sum_{i=1}^{n} x_i p_i\right)^2\)
or \(\text{Var}(X) = E(X^2) - [E(X)]^2\).

### SOLVED EXAMPLES

**Ex. 1.** Three coins are tossed simultaneously. \(X\) is the number of heads. Find expected value and variance of \(X\).

**Solution.** Let \(S = \{HHH, HHT, HT, TTH, THT, TH, TTT\}\) and \(X = \{0, 1, 2, 3\}\).

<table>
<thead>
<tr>
<th>(x_i)</th>
<th>(p_i)</th>
<th>(x_i^2 p_i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(\frac{1}{8})</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>(\frac{3}{8})</td>
<td>(\frac{3}{8})</td>
</tr>
<tr>
<td>2</td>
<td>(\frac{3}{8})</td>
<td>(\frac{6}{8})</td>
</tr>
<tr>
<td>3</td>
<td>(\frac{1}{8})</td>
<td>(\frac{9}{8})</td>
</tr>
</tbody>
</table>

Then \(E(X) = \sum_{i=1}^{n} x_i p_i = \frac{12}{8} = 1.5\).

\[
\text{Var}(X) = \sum_{i=1}^{n} x_i^2 p_i - \left(\sum_{i=1}^{n} x_i p_i\right)^2 = \frac{24}{8} - (1.5)^2 = 3 - 2.25 = 0.75.
\]

**Ex. 2.** Let a pair of dice be thrown and the random variable \(X\) be sum of numbers on the two dice. Find the mean and variance of \(X\).

**Solution:** The sample space of the experiment consists of 36 elementary events in the form of ordered pairs \((x, y)\), where \(x = 1, 2, 3, 4, 5, 6\) and \(y = 1, 2, 3, 4, 5, 6\). The random variable \(X\) has the possible values \(2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12\).

<table>
<thead>
<tr>
<th>(x_i)</th>
<th>(p_i)</th>
<th>(x_i p_i)</th>
<th>(x_i^2 p_i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>(\frac{1}{36})</td>
<td>(\frac{2}{36})</td>
<td>(\frac{4}{36})</td>
</tr>
<tr>
<td>3</td>
<td>(\frac{2}{36})</td>
<td>(\frac{6}{36})</td>
<td>(\frac{18}{36})</td>
</tr>
<tr>
<td>4</td>
<td>(\frac{3}{36})</td>
<td>(\frac{12}{36})</td>
<td>(\frac{48}{36})</td>
</tr>
<tr>
<td>5</td>
<td>(\frac{4}{36})</td>
<td>(\frac{20}{36})</td>
<td>(\frac{100}{36})</td>
</tr>
<tr>
<td>6</td>
<td>(\frac{5}{36})</td>
<td>(\frac{30}{36})</td>
<td>(\frac{180}{36})</td>
</tr>
<tr>
<td>7</td>
<td>(\frac{6}{36})</td>
<td>(\frac{42}{36})</td>
<td>(\frac{294}{36})</td>
</tr>
<tr>
<td>8</td>
<td>(\frac{5}{36})</td>
<td>(\frac{40}{36})</td>
<td>(\frac{320}{36})</td>
</tr>
<tr>
<td>9</td>
<td>(\frac{4}{36})</td>
<td>(\frac{36}{36})</td>
<td>(\frac{324}{36})</td>
</tr>
<tr>
<td>10</td>
<td>(\frac{3}{36})</td>
<td>(\frac{30}{36})</td>
<td>(\frac{300}{36})</td>
</tr>
<tr>
<td>11</td>
<td>(\frac{2}{36})</td>
<td>(\frac{22}{36})</td>
<td>(\frac{242}{36})</td>
</tr>
<tr>
<td>12</td>
<td>(\frac{1}{36})</td>
<td>(\frac{12}{36})</td>
<td>(\frac{144}{36})</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
\sum_{i=1}^{n} x_i p_i &= \frac{\sum_{i=1}^{n} x_i}{36} = 7 \\
\sum_{i=1}^{n} x_i^2 p_i &= \frac{1974}{36} = 54.83
\end{align*}
\]

\[
E(X) = \sum_{i=1}^{n} x_i p_i = 7.
\]

\[
\text{Var}(X) = \sum_{i=1}^{n} x_i^2 p_i - \left(\sum_{i=1}^{n} x_i p_i\right)^2 = 5.83.
\]

**Ex. 3.** Find the mean and variance of the number randomly selected from 1 to 15.

**Solution.** The sample space of the experiment is \(S = \{1, 2, 3, \ldots, 15\}\).

Let \(X\) denote the selected number. Then \(X\) is a random variable with possible values 1, 2, 3, ..., 15. Each of these numbers is equiprobable.

Therefore, \(P(1) = P(2) = P(3) = \ldots = P(15) = \frac{1}{15}\).

\[
\mu = E(X) = \sum_{i=1}^{n} x_i p_i = 1 \times \frac{1}{15} + 2 \times \frac{1}{15} + \ldots
\]
\[ + 15 \times \frac{1}{15} = (1 + 2 + \ldots + 15) \times \frac{1}{15} \]

\[ = \left( \frac{15 \times 16}{2} \right) \times \frac{1}{15} = 8. \]

\[ \text{Var}(X) = \sum_{i=1}^{n} x_i^2 p_i - \left( \sum_{i=1}^{n} x_i p_i \right)^2 \]

\[ = 1^2 \times \frac{1}{15} + 2^2 \times \frac{1}{15} + \ldots + 15^2 \times \frac{1}{15} - (8)^2 \]

\[ = \left( 1^2 + 2^2 + \ldots + 15^2 \right) \times \frac{1}{15} - (8)^2 \]

\[ = \left( \frac{15 \times 16 \times 31}{6} \right) \times \frac{1}{15} - (8)^2 \]

\[ = 82.67 - 64 = 18.67. \]

**Ex. 4.** Two cards are drawn without replacement from a well shuffled pack of 52 cards. Find the mean and variance of the number of kings drawn.

**Solution:** Let \( X \) denote the number of kings in a draw of two cards. \( X \) is a random variable with possible values 0, 1 or 2. Then

\[
P(\text{both cards are not king}) = \frac{48}{52} \times \frac{47}{51} = \frac{188}{221}. \]

\[
P(\text{one card is king and other card is not king}) = \frac{4}{52} \times \frac{48}{51} = \frac{32}{221}. \]

\[
P(\text{both cards are king}) = \frac{4}{52} \times \frac{3}{51} = \frac{1}{221}. \]

Therefore,

\[ \mu = \mathbb{E}(X) = \sum_{i=1}^{n} x_i p_i \]

\[ = 0 \times \frac{188}{221} + 1 \times \frac{32}{221} + 2 \times \frac{1}{221} = \frac{34}{221}, \]

\[ \text{Var}(X) = \sum_{i=1}^{n} x_i^2 p_i - \left( \sum_{i=1}^{n} x_i p_i \right)^2 \]

\[ = (0^2 \times \frac{188}{221} + 1^2 \times \frac{32}{221} + 2^2 \times \frac{1}{221}) \]

\[ = \frac{34}{221} = 0.1392. \]

---

**EXERCISE 8.1**

1. Let \( X \) represent number of heads minus number of tails obtained when a coin is tossed 6 times. What are the possible values of \( X? \)

2. An urn contains 5 red and 2 black balls. Two balls are drawn at random. \( X \) denotes number of black balls drawn. What are the possible values of \( X? \)

3. Determine whether each of the following is a probability distribution. Give reasons for your answer.

   (i)

   \[
   \begin{array}{c|c|c|c}
   x & 0 & 1 & 2 \\
   \hline
   P(x) & 0.4 & 0.4 & 0.2 \\
   \end{array}
   \]

   (ii)

   \[
   \begin{array}{c|c|c|c|c|c}
   x & 0 & 1 & 2 & 3 & 4 \\
   \hline
   P(x) & 0.1 & 0.5 & 0.2 & -0.1 & 0.3 \\
   \end{array}
   \]

   (iii)

   \[
   \begin{array}{c|c|c|c}
   x & 0 & 1 & 2 \\
   \hline
   P(x) & 0.1 & 0.6 & 0.3 \\
   \end{array}
   \]

   (iv)

   \[
   \begin{array}{c|c|c|c|c|c}
   z & 3 & 2 & 1 & 0 & -1 \\
   \hline
   P(z) & 0.3 & 0.2 & 0.4 & 0.05 & 0.05 \\
   \end{array}
   \]
4. Find the probability distribution of (i) number of heads in two tosses of a coin, (ii) number of tails in three tosses of a coin, (iii) number of heads in four tosses of a coin.

5. Find the probability distribution of the number of successes in two tosses of a die if success is defined as getting a number greater than 4.

6. A sample of 4 bulbs is drawn at random with replacement from a lot of 30 bulbs which includes 6 defective bulbs. Find the probability distribution of the number of defective bulbs.

7. A coin is biased so that the head is 3 times as likely to occur as tail. Find the probability distribution of number of tails in two tosses.

8. A random variable $X$ has the following probability distribution:

<table>
<thead>
<tr>
<th>$x$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P(x)$</td>
<td>$k$</td>
<td>$2k$</td>
<td>$2k$</td>
<td>$3k$</td>
<td>$k^2$</td>
<td>$2k^2$</td>
<td>$7k^2+k$</td>
</tr>
</tbody>
</table>

Determine (i) $k$, (ii) $P(X<3)$, (iii) $P(0<X<3)$, (iv) $P(X>4)$.

9. Find expected value and variance of $X$ using the following p. m. f.

<table>
<thead>
<tr>
<th>$x$</th>
<th>-2</th>
<th>-1</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P(x)$</td>
<td>0.2</td>
<td>0.3</td>
<td>0.1</td>
<td>0.15</td>
<td>0.25</td>
</tr>
</tbody>
</table>

10. Find expected value and variance of $X$, the number on the uppermost face of a fair die.

11. Find the mean of number of heads in three tosses of a fair coin.

12. Two dice are thrown simultaneously. If $X$ denotes the number of sixes, find the expectation of $X$.

13. Two numbers are selected at random (without replacement) from the first six positive integers. Let $X$ denote the larger of the two numbers. Find $E(X)$.

14. Let $X$ denote the sum of the numbers obtained when two fair dice are rolled. Find the variance of $X$.

15. A class has 15 students whose ages are 14, 17, 15, 14, 21, 17, 19, 20, 16, 18, 20, 17, 16, 19 and 20 years. If $X$ denotes the age of a randomly selected student, find the probability distribution of $X$. Find the mean and variance of $X$.

16. 70% of the members favour and 30% oppose a proposal in a meeting. The random variable $X$ takes the value 0 if a member opposes the proposal and the value 1 if a member is in favour. Find $E(X)$ and $\text{Var}(X)$.

### 8.4 Probability Distribution of a Continuous Random Variable

The possible values of a continuous random variable form an interval of real numbers. The probability distribution of a continuous random variable is represented by a continuous function called the probability density function (p. d. f.). A continuous random variable also has a cumulative distribution function (c. d. f.).

Suppose the possible values of the continuous random variable $X$ form the interval $(a, b)$, where $a$ and $b$ are real numbers such that $a < b$. The interval $(a, b)$ is called the support of the continuous random variable $X$.

We shall now define the probability density function (p. d. f.) and cumulative distribution function (c. d. f.) of a continuous random variable.

#### 8.4.1 Probability Density Function (p. d. f.)

Let $X$ be a continuous random variable with the interval $(a, b)$ as its support. The probability density function (p. d. f.) of $X$ is an integrable function $f$ that satisfies the following conditions.
1. \( f(x) \geq 0 \) for all \( x \in (a, b) \).

2. \( \int_a^b f(x) \, dx = 1 \)

3. For any real numbers \( c \) and \( d \) such that \( a \leq c < d \leq b \),

\[
P[X \in (c, d)] = \int_c^d f(x) \, dx
\]

It is easy to notice that the p. d. f. of a continuous random variable is different from the p. m. f. of a discrete random variable. Both the p. m. f. and p. d. f. are positive at possible values of the random variable. However, the p. d. f. is positive over an entire interval that is, over an uncountably infinite set of points.

### 8.4.2: Cumulative Distribution Functions (c.d.f)

The cumulative distribution function (p. d. f.) of a continuous random variable is defined as follows.

**Definition.** The cumulative distribution function (c. d. f.) of a continuous random variable \( X \) is denoted by \( F \) and defined by

\[
F(x) = \begin{cases} 
0 & \text{for all } x \leq a, \\
\int_a^x f(t) \, dt & \text{for all } x \geq a.
\end{cases}
\]

**Note:** The c. d. f. of a continuous random variable is a non-decreasing continuous function. The c. d. f. of a discrete random variable is a step function, while the c. d. f. of a continuous random variable is a continuous function.

### SOLVED EXAMPLES

**Ex. 1.** Let \( X \) be a continuous random variable with probability function (p. d. f.) \( f(x) = 3x^2 \) for \( 0 < x < 1 \). Can we claim that \( f(x) = P[X = x] \)?

**Solution.** Note, for example, that \( f(0.9) = 3(0.9)^2 = 2.43 \), which is not a probability. This example shows that the p. d. f. of a continuous random variable does not represent the probability of a possible value of the random variable. In case of a continuous random variable, the probability of an interval is obtained by integrating the p. d. f. over the specified interval. In this case, the probability is given by the area under the curve of the p. d. f. over the interval.

Let us now verify whether \( f \) is a valid probability density function (p. d. f.). This is done through the following steps.

1. \( f(x) = 3x^2 > 0 \) for all \( x \in (0, 1) \).

2. \( \int_0^1 f(x) \, dx = 1 \)

Therefore, the function \( f(x) = 3x^2 \) for \( 0 < x < 1 \) is a proper probability density function. Also, for real numbers \( c \) and \( d \) such that \( 0 \leq c < d \leq 1 \), note that \( P[c < X < d] = \int_c^d f(x) \, dx = \int_c^d 3x^2 \, dx = \left[ x^3 \right]^d_c = d^3 - c^3 > 0 \).

What is the probability that \( X \) falls between 1/2 and 1?

That is, what is \( P(1/2 < X < 1) \)?

Take \( c = 1/2 \) and \( d = 1 \) in the above integral to obtain

\[
P[1/2 < X < 1] = 1 - (1/2)^3 = 1 - 1/8 = 7/8.
\]

What is \( P(X = 1/2) \)?

It is easy to see that the probability is 0.

This is so because

\[
\int_c^d f(x) \, dx = \int_{1/2}^{1} 3x^2 \, dx = (1/2)^3 - (1/2)^3 = 0.
\]

As a matter of fact, the probability that a continuous random variable \( X \) takes any specific value \( x \) is 0. That is, when \( X \) is a continuous random variable, \( P[X = x] = 0 \) for all real \( x \).

**Ex. 2.** Let \( X \) be a continuous random variable with probability density function \( f(x) = x^2/4 \) for an interval \( 0 < x < c \). What is the value of the constant \( c \) that makes \( f(x) \) a valid probability density function?

**Solution.** Note that the internal of the p. d. f. over the support of the random variable must be 1. That is \( \int_0^c f(x) \, dx = 1 \). That is, \( \int_0^c \frac{x^3}{4} \, dx = 1 \). But, \( \int_0^c \frac{x^3}{4} \, dx = \frac{c^4}{16} \). Since this integral must
be equal to 1, we have \( \frac{e^4}{16} = 1 \), or equivalently \( c^4 = 16 \), so that \( c = 2 \) since \( c \) must be positive.

**Ex. 3.** Let's return to the example in which \( X \) has the following probability density function.

\[ f(x) = 3x^2 \quad \text{for} \quad 0 < x < 1. \]

Find the cumulative distribution function \( F(x) \).

**Solution:**

\[ F(x) = \int_0^x 3t^2 \, dt = \left[ x^3 \right]_0^x = x^3 \quad \text{for} \quad x \in (0,1). \]

Therefore,

\[ f(x) = \begin{cases} 0 & \text{for } x \leq 0, \\ x^2 & \text{for } 0 < x < 1, \\ 1 & \text{for } x \geq 1. \end{cases} \]

**Ex. 4.** Let's return to the example in which \( X \) has the following probability density function.

\[ f(x) = \frac{x^2}{4} \quad \text{for} \quad 0 < x < 2. \]

Find the cumulative distribution function of \( X \).

**Solution:**

\[ F(x) = \int_0^x f(t) \, dt = \int_0^x \frac{t^2}{4} \, dt = \frac{1}{4} \left[ \frac{t^3}{3} \right]_0^x = \frac{x^3}{12} \quad \text{for} \quad 0 < x < 2. \]

Therefore,

\[ F(x) = \begin{cases} 0 & \text{for } x < 0, \\ \frac{x^3}{16} & \text{for } 0 \leq x < 2, \\ 1 & \text{for } x \geq 2. \end{cases} \]

**Ex. 5.** Verify whether each of the following functions is p. d. f. of a continuous r. v. \( X \).

(i) \[ f(x) = \begin{cases} e^{-x} & \text{for } 0 < x < \infty, \\ 0 & \text{otherwise}. \end{cases} \]

(ii) \[ f(x) = \begin{cases} x & \text{for } 2 < x < 2, \\ 0 & \text{otherwise}. \end{cases} \]

**Solution:**

(i) \( e^{-x} \geq 0 \) for all real values of \( x \), because \( e > 0 \). Therefore, \( e^{-x} > 0 \) for \( 0 < x < \infty \).

Also,

\[
\int_0^\infty e^{-x} \, dx = \left[ -e^{-x} \right]_0^\infty = 1 \cdot (-0 - 1) = 1.
\]

Both the conditions of p. d. f. are satisfied and hence \( f(x) \) is p. d. f. of a continuous r. v.

(ii) \( f(x) \) is negative for \(-2 < x < 0\), and therefore \( f(x) \) is not a valid p. d. f.

**Ex. 6.** Find \( k \) if the following function is the p. d. f. of a r. v. \( X \).

\[ f(x) = \begin{cases} kx^2 & \text{for } 0 < x < 1, \\ 0 & \text{otherwise}. \end{cases} \]

**Solution.** Since \( f(x) \) is the p.d.f. of r. v. \( X \),

\[
\int_0^1 kx^2 \, dx = 1 \\
\int_0^1 kx^3 \, dx = 1 \\
1 \left[ \frac{x^4}{4} \right]_0^1 = 1 \\
k \left[ \frac{1}{3} \right] = 1 \\
\therefore k \times 12 = 1 \\
\therefore k = 12
\]

**Ex. 7.** In each of the following cases, find \( P(X < 1) \) and \( P(|X| < 1) \).

(a) \( f(x) = \begin{cases} \frac{x^2}{18} & \text{for } 3 < x < 3, \\ 0 & \text{otherwise}. \end{cases} \)

(ii) \( f(x) = \begin{cases} \frac{x+2}{18} & \text{for } 2 < x < 4, \\ 0 & \text{otherwise}. \end{cases} \)
Solution:

(i) \( P(X < 1) = \int_{\frac{3}{18}}^{1} \frac{x^2}{18} \, dx = \left[ \frac{1}{18} \left( \frac{x^3}{3} \right) \right]_{\frac{3}{18}}^{1} \)

\[ = \frac{1}{54} \left[ 1 - (-3)^2 \right] = \frac{1}{54} \left( 1 + 27 \right) = \frac{28}{54} = \frac{14}{27} \]

(b) \( P(|X| < 1) = P(-1 < X < 1) = \int_{\frac{1}{18}}^{1} \frac{x^2}{18} \, dx \)

\[ = \left[ \frac{1}{18} \left( \frac{x^3}{3} \right) \right]_{\frac{1}{18}}^{1} = \frac{1}{54} \left[ 1 - (-1)^2 \right] \]

\[ = \frac{1}{54} \left( 1 + 1 \right) = \frac{2}{54} = \frac{1}{27} \]

Ex. 8. Find the c. d. f. \( F(x) \) associated with the p. d. f. \( f(x) \) or r. v. \( X \) where

\[ f(x) = \begin{cases} 3(1 - 2x^2) & \text{for } 0 < x < 1, \\ 0 & \text{otherwise} \end{cases} \]

Solution: Since \( f(x) \) is a p. d. f., the c. d. f. is given by

\[ F(x) = \int_{0}^{x} 3(1 - 2x^2) \, dx = \left[ x - \frac{2x^3}{3} \right]_{0}^{x} = 3x - 2x^3 \text{ for } 0 < x < 1. \]

Therefore,

\[ F(x) = \begin{cases} 0 & \text{for } x \leq 0, \\ 3x - 2x^3 & \text{for } 0 < x < 1, \\ 1 & \text{for } x \geq 1. \end{cases} \]

EXERCISE 8.2

1. Check whether each of the following is a p. d. f.
   i) \( f(x) = \begin{cases} x & \text{for } 0 \leq x \leq 1, \\ 2x & \text{for } 1 < x \leq 2. \end{cases} \)
   ii) \( f(x) = 2 \text{ for } 0 < x < 1. \)

2. The following is the p. d. f. of a r. v. \( X \).
   \[ f(x) = \begin{cases} \frac{x}{8} & \text{for } 0 < x < 4, \\ 0 & \text{otherwise} \end{cases} \]

   Find (i) \( P(x < 1.5) \), (ii) \( P(1 < x < 2) \), (iii) \( P(x > 2) \).

3. It is felt that error in measurement of reaction temperature (in celsius) in an experiment is a continuous r. v. with p. d. f.
   \[ f(x) = \begin{cases} \frac{x^3}{64} & \text{for } 0 \leq x \leq 4, \\ 0 & \text{otherwise} \end{cases} \]

   (i) Verify whether \( f(x) \) is a p. d. f.
   (ii) Find \( P(0 < x \leq 1) \).
   (iii) Find probability that \( X \) is between 1 and 3.

4. Find \( k \) if the following function represents the p. d. f. of a r. v. \( X \).
   \[ f(x) = \begin{cases} kx & \text{for } 0 < x < 2, \\ 0 & \text{otherwise} \end{cases} \]

   Also find \( P \left[ \frac{1}{4} < X < \frac{1}{2} \right] \).
(ii) \( f(x) = \begin{cases} \frac{kx}{1 - x} & \text{for } 0 < x < 1, \\ 0 & \text{otherwise} \end{cases} \)

Also find (a) \( P\left[\frac{1}{4} < X < \frac{1}{2}\right] \),

(b) \( P\left[X < \frac{1}{2}\right] \)

5. Let \( X \) be the amount of time for which a book is taken out of library by a randomly selected student and suppose that \( X \) has p. d. f.

\[ f(x) = \begin{cases} 0.5x & \text{for } 0 \leq x \leq 2, \\ 0 & \text{otherwise} \end{cases} \]

Calculate (i) \( P(X \leq 1) \), (ii) \( P(0.5 \leq X \leq 1.5) \), (iii) \( P(X \geq 1.5) \).

6. Suppose \( X \) is the waiting time (in minutes) for a bus and its p. d. f. is given by

\[ f(x) = \begin{cases} \frac{1}{5} & \text{for } 0 \leq x \leq 5, \\ 0 & \text{otherwise} \end{cases} \]

Find the probability that (i) waiting time is between 1 and 3 minutes, (ii) waiting time is more than 4 minutes.

7. Suppose error involved in making a certain measurement is a continuous r. v. \( X \) with p. d. f.

\[ f(x) = \begin{cases} k(4 - x^2) & \text{for } 2 \leq x \leq 2, \\ 0 & \text{otherwise} \end{cases} \]

Compute (i) \( P(X > 0) \), (ii) \( P(-1 < X < 1) \), (iii) \( P(X < -0.5 \text{ or } X > 0.5) \).

8. Following is the p. d. f. of a continuous r. v. \( X \)

\[ f(x) = \begin{cases} \frac{x}{8} & \text{for } 0 < x < 4, \\ 0 & \text{otherwise} \end{cases} \]

(i) Find expression for the c. d. f. of \( X \).
(ii) Find \( F(x) \) at \( x = 0.5, 1.7, \text{and } 5 \).

9. The p. d. f. of a continuous r. v. \( X \) is

\[ f(x) = \begin{cases} \frac{3x^2}{8} & \text{for } 0 < x < 2, \\ 0 & \text{otherwise} \end{cases} \]

Determine the c. d. f. of \( X \) and hence find (i) \( P(X < 1) \), (ii) \( P(X < -2) \), (iii) \( P(X > 0) \), (iv) \( P(1 < X < 2) \).

10. If a r. v. \( X \) has p. d. f.

\[ f(x) = \begin{cases} \frac{c}{x} & \text{for } 1 < x < 3, \\ c > 0 \end{cases} \]

Find \( c, E(X), \) and \( \text{Var}(X) \). Also find \( F(x) \).

---

**Let’s Remember**

A random variable (r. v.) is a real-valued function defined on the sample space of a random experiment.

The domain of a random variable is the sample space of a random experiment, while its co-domain is the real line.

Thus \( X: S \rightarrow R \) is a random variable.

There are two types of random variables, namely discrete and continuous.

**Discrete random variable:**

Let the possible values of a discrete random variable \( X \) be denoted by \( x_1, x_2, \ldots \) with the corresponding probabilities \( p_i = P(X = x_i) \), \( i = 1, 2, \ldots \). If there is a function \( f \) such that \( p_i = P(X = x_i) \), \( f(x_i) \) for all possible values of \( X \), then \( f \) is called the probability mass function (p. m. f.) of \( X \).

**Note:** If \( x_i \) is a possible value of \( X \) and \( p_i = P(X = x_i) \), then there is an event \( E_i \) in the sample space \( S \) such that \( p_i = P[E_i] \). Since \( x_i \) is a possible value of \( X \), \( p_i = P[X = x_i] > 0 \). Also, all possible values of \( X \) cover all sample points in the sample space \( S \) and hence the sum of their probabilities is 1. That is, \( p_i > 0 \) for all \( i \) and \( \Sigma p_i = 1 \).
The cumulative distribution function (c. d. f.) of a discrete random variable \( X \) is denoted by \( F \) and is defined as follows.

\[
F(x) = P[X \leq x] = \sum_{x_i \leq x} P[X = x_i]
\]

\[
= \sum_{x_i \leq x} f(x_i).
\]

**Expected Value or Mean of a Discrete r. v.**

Let \( X \) be a random variable whose possible values \( x_1, x_2, x_3, ..., x_n \) occur with respective probabilities \( p_1, p_2, p_3, ..., p_n \). The expected value or arithmetic mean of \( X \), denoted by \( E(X) \) or \( \mu \), is defined by

\[
\mu = E(X) = \sum_{i=1}^{n} (x_i p_i) = x_1 p_1 + x_2 p_2 + ... + x_n p_n
\]

In other words, the mean or expectation of a random variable \( X \) is the sum of products of all possible values of \( X \) and their respective probabilities.

**Variance of a Discrete r. v.**

Let \( X \) be a random variable whose possible values \( x_1, x_2, ..., x_n \) occur with respective probabilities \( p_1, p_2, p_3, ..., p_n \). The variance of \( X \), denoted by \( \text{Var}(X) \) or \( \sigma_X^2 \), is defined as:

\[
\sigma_X^2 = \sum_{i=1}^{n} (x_i - \mu)^2 p_i
\]

The non-negative square-root of the variance \( \sigma_X = \sqrt{\text{Var}(X)} \) is called the standard deviation of the random variable \( X \).

Another formula to find the variance of a random variable. We can also use the simplified form \( \text{Var}(X) = \sum_{i=1}^{n} x_i^2 p_i - \left( \sum_{i=1}^{n} x_i p_i \right)^2 \), or

\[
\text{Var}(X) = E(X^2) - [E(X)]^2;
\]

where \( E(X^2) = \sum_{i=1}^{n} x_i^2 p_i \).

**Probability Density Function (p. d. f.)**

Let \( X \) be a continuous random variable defined on the interval \( (a, b) \). A non-negative integrable function \( f \) is called the probability density function (p. d. f.) of \( X \) if it satisfies the following conditions. (i) \( f(x) > 0 \) for all \( x \in S \). (ii) The area under the curve \( f(x) \) over \( S \) is 1. That is, \( \int_{a}^{b} f(x) \, dx = 1 \). (iii) The probability that \( X \) takes a value in some interval \( A \) is given by the integral of \( f(x) \) over \( A \). That is \( P[X \in A] = \int_{A} f(x) \, dx \).

The cumulative distribution function (c. d. f.) of a continuous random variable \( X \) is defined as follows.

\[
F(x) = \int_{a}^{x} f(t) \, dt \text{ for } a < x < b.
\]

**8.5 Binomial Distribution**

Many experiments are dichotomous in nature. An experiment is dichotomous if it has only two possible outcomes. For example, a tossed coin shows 'head' or 'tail', the result of a student is 'pass' or 'fail', a manufactured item is 'defective' or 'non-defective', the response to a question is 'yes' or 'no', an egg has 'hatched' or 'not hatched', the decision is 'yes' or 'no' etc. In such cases, it is customary to call one of the outcomes 'success' and the other 'failure'. For example, in tossing a coin, if the occurrence of head is considered success, then occurrence of tail is failure.

**8.5.1 Bernoulli Trial**

An experiment that can result in one of two possible outcomes is called a dichotomous experiment. One of the two outcomes is called success and the other outcome is called failure.

**Definition of Bernoulli Trial**: A dichotomous experiment is called a Bernoulli trial.

Every time we toss a coin or perform a dichotomous experiment, we call it a trial. If a coin is tossed 4 times, the number of trials is 4, each having exactly two possible outcomes, namely success and failure. The outcome of any trial is independent of the outcome of other trials. In all such trials, the probability of success (and hence of failure) remains the same.
Definition of Sequence of Bernoulli Trials: A sequence of dichotomous experiments is called a sequence of Bernoulli trials if it satisfies the following conditions.

- The trials are independent.
- The probability of success remains the same in all trials.

The probability of success in a Bernoulli trial is denoted by \( p \) and the probability of failure is denoted by \( q = 1 - p \). For example, if we throw a die and define success as getting an even number and failure as getting an odd number, we have a Bernoulli trial. Successive throws of the die are independent trials and form a sequence of Bernoulli trials. If the die is fair, then \( p = 1/2 \) and \( q = 1 - p = 1 - 1/2 = 1/2 \).

**Ex. 1.** Six balls are drawn successively from an urn containing 7 red and 9 black balls. Decide whether the trials of drawing balls are Bernoulli trials if, after each draw, the ball drawn is (i) replaced (ii) not replaced in the urn.

**Solution.**

(i) When the drawing is done with replacement, the probability of success (say, red ball) is \( p = 7/16 \) which remains the same for all six trials (draws). Hence, drawing balls with replacement are Bernoulli trials.

(ii) When the drawing is done without replacement, the probability of success (i.e. red ball) in first trial is 7/16. In second trial, it is 6/15 if first ball drawn is red and is 7/15 if first ball drawn is black, and so on. Clearly probability of success is not same for all trials, and hence the trials are not Bernoulli trials.

8.5.2 Binomial distribution

Consider a sequence of Bernoulli trials, where we are interested in the number successes, \( X \), in a given number of trials, \( n \). The total number of possible outcomes is \( 2^n \). We want to find the number of outcomes that result in \( X \) successes in order to find the probability of getting \( X \) successes in \( n \) Bernoulli trials. We use the binomial theorem and derive a formula for counting the number of favorable outcomes for all possible values of \( X \).

Consider the situation where we are interested in one success in 6 trials. Clearly, six possible cases are \{FFFFF, FSFFFF, FFSFFF, FFSFFF, FFFFFS, FFFFFS\}. Counting the number of outcomes with two successes is possible by listing favorable outcomes. However, it will be time-consuming to list all of these outcomes. As a result, calculating probabilities of getting 0, 1, 2, ..., 6 successes in 6 trials will be time consuming. Lengthy calculations that require listing of all favorable outcomes for calculating probabilities of number of successes in \( n \) Bernoulli trials can be avoided by deriving a formula.

For illustrating this formula, let us take the experiment made up of three Bernoulli trials with probabilities \( p \) and \( q = 1 - p \) of success and failure, respectively, in each trial. The sample space of the experiment is the set.

\( S = \{SSS, SSF, SFS, FSS, SFF, FSF, FFT, FFF\} \)

The number of successes is a random variable \( X \) and can take values 0, 1, 2, and 3. The probability distribution of the number of successes is as follows.

\[
P(X = 0) = P(\text{no success}) = P(\{FFF\}) = P(F)P(F)P(F) = q \cdot q \cdot q = q^3,
\]

since trials are independent.

\[
P(X = 1) = P(\text{one success}) = P(\{SFF, FSF, FFS\})
\]

\[
= P(\{SFF\}) + P(\{FSF\}) + P(\{FFS\})
\]

\[
= P(S)P(F)P(F) + P(F)P(S)P(F) + P(F)P(F)P(S)
\]

\[
= p \cdot q \cdot q + q \cdot p \cdot q + q \cdot q \cdot p = 3pq^2
\]
\[ P(X = 2) = P(\text{two successes}) \\
= P(SSF, SFS, FSS) \\
= P(SSF) + P(SFS) + P(FSS) \\
= P(S)P(S)P(F) + P(S)P(F)P(S) + P(F)P(S)P(S) \\
= p \cdot q \cdot p + p \cdot q \cdot p + q \cdot p \cdot p = 3p^2q \\
\text{and } P(X = 3) = P(\text{three successes}) \\
= P(SSF) \\
= P(S) \cdot P(S) \cdot P(S) = p^3. \\
\]

Thus, the probability distribution of \( X \) is as shown in the following table.

<table>
<thead>
<tr>
<th>( x )</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P(x) )</td>
<td>( q^3 )</td>
<td>( 3q^2p )</td>
<td>( 3qp^2 )</td>
<td>( p^3 )</td>
</tr>
</tbody>
</table>

Note that the binomial expansion of \((q+p)^3 = q^3 + 3q^2p + 3qp^2 + p^3\) and the probabilities of 0, 1, 2 and 3 successes are respectively the 1\(^{st}\), 2\(^{nd}\), 3\(^{rd}\) and 4\(^{th}\) term in the expansion of \((q+p)^3\). Also, since \( q + p = 1 \), it follows that the sum of these probabilities, as expected, is 1. Thus, we may conclude that in an experiment of \( n \) Bernoulli trials, the probabilities of 0, 1, 2, ..., \( n \) successes can be obtained as \( 1^{\text{st}}, 2^{\text{nd}}, ..., (n+1)^{\text{th}} \) terms in the expansion of \((q+p)^n\). To prove this assertion (result), let us find the probability of \( x \) successes in an experiment of \( n \) Bernoulli trials.

In an experiment with \( n \) trials, if there are \( x \) successes (\( S \)), there will be \( ( n - x ) \) failure (\( F \)). Now \( x \) successes (\( S \)) and \( ( n - x ) \) failure (\( F \)) can be obtained in \( \frac{n!}{x!(n-x)!} \) ways. In each of these ways, the probability of \( x \) successes and \( ( n - x ) \) failure, that is, \( P(x \text{ successes}) \cdot P(n-x \text{ failure}) \) is given by

\[
( P(S) \cdot P(S) \ldots P(S) \text{ x times} ) ( P(F) \cdot P(F) \ldots P(F) \text{ (n-x) times} ) \\
= (p \cdot p \ldots p \text{ x times}) (q \cdot q \ldots q \text{ (n-x) times} ) \\
= p^xq^{n-x}. \\
\]

Thus, the probability of \( x \) successes in \( n \) Bernoulli trials is

\[
P(x \text{ successes out of } n \text{ trials}) \\
= \frac{n!}{x!(n-x)!} p^xq^{n-x} = \binom{n}{x} p^xq^{n-x} \\
\]

Note that

\[
P(x \text{ successes}) = \binom{n}{x} p^xq^{n-x} \text{ is the } (x+1)^{\text{th}} \text{ term in the binomial expansion of } (q+p)^n. \\
\]

Thus, the probability distribution of number of successes in an experiment consisting of \( n \) Bernoulli trials can be obtained by the binomial expansion of \((q+p)^n\). This distribution of \( X \) successes in \( n \) Bernoulli trials can be written as follows.

<table>
<thead>
<tr>
<th>( X )</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P(X) )</td>
<td>( \binom{n}{0} p^0q^n )</td>
<td>( \binom{n}{1} p^1q^{n-1} )</td>
<td>( \binom{n}{2} p^2q^{n-2} )</td>
<td>...</td>
</tr>
<tr>
<td>( X )</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>n</td>
</tr>
<tr>
<td>( P(X) )</td>
<td>( \frac{n!}{x!(n-x)!} p^xq^{n-x} )</td>
<td>( \binom{n}{0} p^0q^n )</td>
<td>( \binom{n}{1} p^1q^{n-1} )</td>
<td>( \binom{n}{n} p^nq^0 )</td>
</tr>
</tbody>
</table>

The above probability distribution is known as the **binomial distribution** with parameters \( n \) and \( p \). We can find the complete probability distribution of the random variable using the given values of \( n \) and \( p \). The fact that the r. v. \( X \) follows the binomial distribution with parameters \( n \) and \( p \) is written in short as \( X \sim B(n, p) \) and read as "\( X \) follows the binomial distribution with parameters \( n \) and \( p \)."

The probability of \( x \) successes \( P(X = x) \) is also denoted by \( P(x) \) and is given by

\[ P(x) = \binom{n}{x} q^{n-x} p^x, \quad x = 0, 1, \ldots, n, \quad (q = 1 - p). \]

This \( P(x) \) is the probability mass function of the binomial distribution.

A binomial distribution with \( n \) Bernoulli trials and \( p \) as probability of success in each trial is denoted by \( B(n,p) \) or written as \( X \sim B(n,p) \).
Let us solve some examples.

**Ex. 2.** If a fair coin is tossed 10 times, find the probability of obtaining.

(i) exactly six heads
(ii) at least six heads
(iii) at most six heads

**Solution:** The repeated tosses of a coin are Bernoulli trails. Let $X$ denote the number of heads in an experiment of 10 trials.

Clearly, $X \sim B(n,p)$ with $n = 10$ and $p = \frac{1}{2}$, and $q = 1 - p = \frac{1}{2}$.

$$P(X = x) = \binom{n}{x} p^x q^{n-x}$$

(i) Exactly six successes means $X = 6$.

$$P(X = 6) = \binom{10}{6} \left(\frac{1}{2}\right)^6 \left(\frac{1}{2}\right)^4$$

$$= \frac{10!}{6!(10-6)!} \cdot \left(\frac{1}{2}\right)^6 \cdot \left(\frac{1}{2}\right)^4$$

$$= \frac{10 \times 9 \times 8 \times 7}{6 \times 5 \times 4 \times 3 \times 2 \times 1} \cdot \left(\frac{1}{2}\right)^6$$

$$= \frac{105}{512}$$

(ii) At least six successes means $X \geq 6$.

$$P(X \geq 6) = P(X = 6) + P(X = 7) + P(X = 8) + P(X = 9) + P(X = 10)$$

$$= \left(\frac{10}{6}\right) \left(\frac{1}{2}\right)^6 \times \left(\frac{1}{2}\right)^4 + \left(\frac{10}{7}\right) \left(\frac{1}{2}\right)^7 \times \left(\frac{1}{2}\right)^3$$

$$+ \left(\frac{10}{8}\right) \left(\frac{1}{2}\right)^8 \times \left(\frac{1}{2}\right)^2$$

$$+ \left(\frac{10}{9}\right) \left(\frac{1}{2}\right)^9 \times \left(\frac{1}{2}\right)$$

$$+ \left(\frac{10}{10}\right)$$

$$= \frac{10 \times 9 \times 8 \times 7 \times 6}{4 \times 3 \times 2 \times 1 \times 2} \times \left(\frac{1}{2}\right)^{10}$$

$$= \frac{386}{1024} = \frac{193}{512}$$

(iii) At most six successes means $X \leq 6$.

$$P(X \leq 6) = 1 - P(X > 6)$$

$$= 1 - \left[ P(X = 7) + P(X = 8) + P(X = 9) + P(X = 10) \right]$$

$$= 1 - \left[ \left(\frac{10}{7}\right) \left(\frac{1}{2}\right)^7 \times \left(\frac{1}{2}\right)^3 + \left(\frac{10}{8}\right) \left(\frac{1}{2}\right)^8 \times \left(\frac{1}{2}\right) \right.$$

$$\times \left(\frac{1}{2}\right)^2 + \left(\frac{10}{9}\right) \left(\frac{1}{2}\right)^9 \times \left(\frac{1}{2}\right)^1$$

$$\left. + \left(\frac{10}{10}\right) \right]$$

$$= 1 - \left[ \frac{10 \times 9 \times 8 \times 7 \times 6}{3 \times 2 \times 1 \times 2} \times \left(\frac{1}{2}\right)^{10} + \frac{10 \times 9 \times 8 \times 7 \times 6}{2 \times 1 \times 2} \times \left(\frac{1}{2}\right)^{10} \right.$$$$+ \left(\frac{10}{10}\right) \right]$$

$$= 1 - \left[ \frac{169}{1024} \right]$$

$$= \frac{176}{1024} = \frac{11}{64} \frac{53}{64}$$

**Ex. 3.** The eggs are drawn successively with replacement from a lot containing 10% defective eggs. Find the probability that there is at least one defective egg.

**Solution:** Let $X$ denote the number of defective eggs in the 10 eggs drawn. Since the drawing is done with replacement, the trials are Bernoulli trials.

Probability of success = $\frac{1}{10}$
\[ P = \frac{1}{10}, \quad q = 1 - p = 1 - \frac{1}{10} = \frac{9}{10}, \quad \text{and} \quad n = 10. \]

\[ X \sim B(10, \frac{1}{10}). \]

\[ P(X = x) = \binom{10}{x} \left( \frac{1}{10} \right)^x \left( \frac{9}{10} \right)^{10-x} \]

Here, \( X \geq 1. \)

\[ P(X \geq 1) = 1 - P(X < 1) = 1 - P(X = 0) \]

\[ = 1 - \binom{10}{0} \left( \frac{1}{10} \right)^0 \left( \frac{9}{10} \right)^{10} \]

\[ = 1 - 1 \times \left( \frac{9}{10} \right)^{10} \]

\[ = 1 - \left( \frac{9}{10} \right)^{10} \]

**Example 6.** If \( E(X) = 6 \) and \( \text{Var}(X) = 4.2 \), find \( n \) and \( p. \)

**Solution:** \( E(x) = 6 \). Therefore, \( np = 6 \).

\( \text{Var}(X) = 4.2. \)

Therefore, \( npq = 4.2. \)

\[ \frac{npq}{np} = \frac{4.2}{6} \]

\[ \therefore q = 0.7, \quad p = 1 - q = 1 - 0.7 = 0.3 \]

\[ np = 6 \quad \therefore n \times 0.3 = 6 \quad \therefore n = \frac{6}{0.3} = 20 \]

**Exercise 8.3**

1. A die is thrown 4 times. If 'getting an odd number' is a success, find the probability of
   
   (i) 2 successes
   (ii) at least 3 successes
   (iii) at most 2 successes.

2. A pair of dice is thrown 3 times. If getting a doublet is considered a success, find the probability of two successes.

3. There are 10% defective items in a large bulk of items. What is the probability that a sample of 4 items will include not more than one defective item?

4. Five cards are drawn successively with replacement from a well-shuffled deck of 52 cards. Find the probability that
   
   (i) all the five cards are spades.
   (ii) only 3 cards are spades.
   (iii) none is a spade.

5. The probability that a bulb produced by a factory will fuse after 200 days of use is 0.2. Let \( X \) denote the number of bulbs (out of 5) that fuse after 200 days of use. Find the probability of
   
   (i) \( X = 0 \), (ii) \( X \leq 1 \), (iii) \( X > 1 \), (iv) \( X \geq 1 \).

6. 10 balls are marked with digits 0 to 9. If four balls are selected with replacement. What is the probability that none is marked 0?
7. In a multiple choice test with three possible answers for each of the five questions, what is the probability of a candidate getting four or more correct answers by random choice?

8. Find the probability of throwing at most 2 sixes in 6 throws of a single die.

9. Given that $X \sim B(n,p)$,
   (i) if $n = 10$ and $p = 0.4$, find $E(X)$ and $Var(X)$.
   (ii) if $p = 0.6$ and $E(X) = 6$, find $n$ and $Var(X)$.
   (iii) if $n = 25$, $E(X) = 10$, find $p$ and $Var(X)$.
   (iv) if $n = 10$, $E(X) = 8$, find $Var(X)$.

8.6 Poisson Distribution

Poisson distribution is a discrete probability distribution that gives the probability of number of occurrences of an event in a fixed interval of time, if these events occur with a known average rate and are independent of the time since the last occurrence. For instance, suppose someone receives 4 emails per day on an average. There will be, however, variation in the number of emails, sometimes more, sometimes fewer, once in a while no email at all. The Poisson distribution was first introduced by Simeon Denis Poisson (1781-1840) and published in 1837. The work focused on certain random variables $N$ that count the number of discrete occurrences of an event that take place during a time-interval of given length.

**Definition:** A discrete random variable $X$ is said to have the Poisson distribution with parameter $m > 0$, if its p.m. is given by

$$P(X = x) = \frac{e^{-m}m^x}{x!} = 0, 1, 2, \ldots$$

**Note.**

(i) we use the notation $X \sim \lambda \mu$ to show that $X$ follows the Poisson distribution with parameter $m$.

(ii) Observe that $P(\lambda) > 0$ for all non-negative integers $\lambda$ and $\sum_{\lambda = 0}^{\infty} P(\lambda) = 1$.

(iii) For the Poisson distribution, $E(\lambda) = m$ and $Var(\lambda) = m$.

(iv) When $n$ is very large and $p$ is very small in the binomial distribution, then $X$ follows the Poisson distribution with parameter $m = np$.

---

**SOLVED EXAMPLES**

**Ex. 1.** If $X \sim \mu \lambda$ with $\mu = 5$ and $\lambda = 0.0067$, then find

(i) $P(X = 5)$, (ii) $P(X \geq 2)$.

**Solution:** $P(X = x) = \frac{e^{-\lambda} \lambda^x}{x!}$, for $x = 0, 1, 2, \ldots$.

(i) Here $\mu = 5$ and $\lambda = 5$

$$P(X = 5) = \frac{e^{-5}5^5}{5!} = \frac{0.0067 \times 3125}{5 \times 4 \times 3 \times 2 \times 1} = 0.1745$$

(ii) $P(X \geq 2) = 1 - P(X < 2)$

$$= 1 - [P(X = 0) + P(X = 1)]$$

$$= 1 - \left[ \frac{e^{-5}5^0}{0!} + \frac{e^{-5}5^1}{1!} \right]$$

$$= 1 - \left[ \frac{0.0067 \times 1}{1} + \frac{0.0067 \times 5}{1} \right]$$

$$= 1 - [0.0067 + 0.0335]$$

$$= 1 - 0.0402$$

$$= 0.9598$$

**Ex. 2.** If $X \sim \mu \lambda$ with $P(X = 1) = P(X = 2)$, then find the mean and $P(X = 2)$ given that $\lambda = 0.1353$.

**Solution:** Since $P(X = 1) = P(X = 2)$,
\[ \therefore \frac{e^{-m}m^1}{1!} + \frac{e^{-m}m^2}{2!} \]
\[ \therefore \quad m = 2 \]

Then
\[ P(X = 2) = \frac{e^{-2}2^2}{2!} = \frac{0.1353 \times 4}{2} = 0.2706. \]

**Ex. 3.** In a town, 10 accidents take place in the span of 50 days. Assuming that the number of accidents follows Poisson distribution, find the probability that there will be 3 or more accidents on a day.

(given that \( e^{-0.2} = 0.8187 \))

**Solution:** Here \( m = \frac{10}{50} = 0.2 \), and hence

\[ X \sim P(m) \] with \( m = 0.2 \). The p. m. f. of \( X \) is

\[ P(X = x) = \frac{e^{-m}m^x}{x!}, \quad x = 0, 1, 2, \ldots \]

\[ P(X \geq 3) = 1 - P(X < 3) = 1 - [P(X = 0) + P(X = 1) + P(X = 2)] \]

\[ = 1 - \left[ e^{-0.2}(0.2)^0 + \frac{e^{-0.2}(0.2)^1}{1!} + \frac{e^{-0.2}(0.2)^2}{2!} \right] \]

\[ = 1 - \left[ 0.8187 \times 1 + 0.8187 \times 0.2 + 0.8187 \times 0.004 \right] \]

\[ = 1 - [0.8187 + 0.16374 + 0.016374] \]

\[ = 1 - 0.9988 = 0.0012 \]

**EXERCISE 8.4**

1. If \( X \) has Poisson distribution with \( m = 1 \), then find \( P(X \leq 1) \) given \( e^1 = 0.3678 \).

2. If \( X \sim P(1/2) \), then find \( P(X = 3) \) given \( e^{-0.5} = 0.6065 \).

3. If \( X \) has Poisson distribution with parameter \( m \) and \( P(X = 2) = P(X = 3) \), then find \( P(X \geq 2) \). Use \( e^{-3} = 0.0497 \).

4. The number of complaints which a bank manager receives per day follows a Poisson distribution with parameter \( m = 4 \). Find the probability that the manager receives (i) only two complaints on a given day, (ii) at most two complaints on a given day. Use \( e^4 = 0.0183 \).

5. A car firm has 2 cars, which are hired out day by day. The number of cars hired on a day follows Poisson distribution with mean 1.5. Find the probability that (i) no car is used on a given day, (ii) some demand is refused on a given day, given \( e^{-1.5} = 0.2231 \).

6. Defects on plywood sheets occur at random with the average of one defect per 50 sq. ft. Find the probability that such a sheet has (i) no defects, (ii) at least one defect. Use \( e^1 = 0.3678 \).

7. It is known that, in a certain area of a large city, the average number of rats per bungalow is five. Assuming that the number of rats follows Poisson distribution, find the probability that a randomly selected bungalow has (i) exactly 5 rats (ii) more than 5 rats (iii) between 5 and 7 rats, inclusive. Given \( e^{-5} = 0.0067 \).

Let’s Remember

Trials of a random experiment are called Bernoulli trials, if they satisfy the following conditions.

- Each trial has two possible outcomes, success and failure.
- The probability of success remains the same in all trials.

Thus, the probability of getting \( X \) successes in \( n \) Bernoulli trials is

\[ P(X \text{ successes in } n \text{ trials}) = \binom{n}{x} p^x (1 - p)^{n-x} \]

Clearly, \( P(X \text{ successes}) = \binom{n}{x} p^x (1 - p)^{n-x} \) is the \( (x+1)^{th} \) term in the binomial expansion of \( (q + p)^n \).
Let \( X \sim B(n, p) \). Then the mean or expected value of \( X \) is denoted by \( \mu \). It is also denoted by \( E(X) \) and is given by \( \mu = E(X) = np \). The variance is denoted by \( \text{Var}(X) \) and is given by \( \text{Var}(X) = npq \).

A discrete random variable \( X \) is said to follow the Poisson distribution with parameter \( m > 0 \) if its p.m.f. is given by

\[
P(X = x) = \frac{e^{-m}m^x}{x!}, \quad x = 0, 1, 2, \ldots
\]

**Note.**
1. We use the notation \( X \sim P(m) \). That is, \( X \) follows Poisson distribution with parameter \( m \).
2. Observe that \( P(x) > 0 \) for all non-negative integers \( x \) and \( \sum_{x=0}^{\infty} \frac{e^{-m}m^x}{x!} = 1 \)
3. For the Poisson distribution, Mean \( E(X) = m \) and Variance \( = \text{Var}(X) = m \).
4. If \( n \) is very large and \( p \) is very small then \( X \) follows Poisson distribution with \( m = np \).

**MISCELLANEOUS EXERCISE - 8**

1. **Choose the correct alternative.**

   1. \( F(x) \) is c.d.f. of discrete r.v. \( X \) whose p.m.f. is given by \( P(x) = k \left( \frac{4}{x} \right) \), for \( x = 0, 1, 2, 3 \), \( 4 \) & \( P(x) = 0 \) otherwise then \( F(5) = \ldots \)

      (a) \( \frac{1}{16} \)  (b) \( \frac{1}{8} \)  (c) \( \frac{1}{4} \)  (d) \( 1 \)

   2. \( F(x) \) is c.d.f. of discrete r.v. \( X \) whose distribution is

<table>
<thead>
<tr>
<th>( x )</th>
<th>-2</th>
<th>-1</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_x )</td>
<td>0.2</td>
<td>0.3</td>
<td>0.15</td>
<td>0.25</td>
<td>0.1</td>
</tr>
</tbody>
</table>

   then \( F(-3) = \ldots \)

      (a) \( 0 \)  (b) \( 1 \)  (c) \( 0.2 \)  (d) \( 0.15 \)

3. \( X \) is number obtained on upper most face when a fair die is thrown then \( E(X) = \ldots \)

   (a) \( 3.0 \)  (b) \( 3.5 \)  (c) \( 4.0 \)  (d) \( 4.5 \)

4. If p.m.f. of r.v. \( X \) is given below.

<table>
<thead>
<tr>
<th>( x )</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P(x) )</td>
<td>( q^3 )</td>
<td>2pq</td>
<td>( p^2 )</td>
</tr>
</tbody>
</table>

   then \( \text{Var}(X) = \ldots \)

   (a) \( p^2 \)  (b) \( q^2 \)  (c) \( pq \)  (d) \( 2pq \)

5. The expected value of the sum of two numbers obtained when two fair dice are rolled is \( \ldots \)

   (a) \( 5 \)  (b) \( 6 \)  (c) \( 7 \)  (d) \( 8 \)

6. Given p.d.f. of a continuous r.v. \( X \) as

   \( f(x) = \frac{x^2}{3} \) for \( -1 < x < 2 \)

   \( = 0 \) otherwise then

   \( F(1) = \ldots \)

   (a) \( \frac{1}{9} \)  (b) \( \frac{2}{9} \)  (c) \( \frac{3}{9} \)  (d) \( \frac{4}{9} \)

7. \( X \) is r.v. with p.d.f. \( f(x) = \frac{k}{\sqrt{x}} \), \( 0 < x < 4 \)

   then \( E(x) = \ldots \)

   (a) \( \frac{1}{3} \)  (b) \( \frac{4}{3} \)  (c) \( \frac{2}{3} \)  (d) \( 1 \)

8. If \( X \sim B(20, \frac{1}{10}) \) then \( E(x) = \ldots \)

   (a) 2  (b) 5  (c) 4  (d) 3

9. If \( E(x) = m \) and \( \text{Var}(x) = m \) then \( X \) follows

   (a) Binomial distribution
   (b) Possion distribution
   (c) Normal distribution
   (d) none of the above
10. If $E(x) > Var(x)$ then $X$ follows ............
   (a) Binomial distribution
   (b) Poisson distribution
   (c) Normal distribution
   (d) none of the above

II) Fill in the blanks.
1. The values of discrete r.v. are generally obtained by .................
2. The values of continuous r.v. are generally obtained by .................
3. If $X$ is discrete random variable takes the values $x_1, x_2, x_3, ... x_n$ then $\sum_{i=1}^{n} P(x_i) =$ ...........
4. If $F(x)$ is distribution function of discrete r.v. $X$ with p.m.f. $P(x) = \frac{x-1}{3}$ for $x = 1, 2, 3, \& P(x) = 0$ otherwise then $F(4) =$ .................
5. If $F(x)$ is distribution function of discrete r.v. $X$ with p.m.f. $P(x) = k \binom{4}{x}$ for 
   $x = 0, 1, 2, 3, 4, \text{ and } P(x) = 0$ otherwise then $F(-1) =$ .................
6. $E(x)$ is considered to be .................. of the probability distribution of $X$.
7. If $x$ is continuous r.v. and $F(x) = P(X \leq x) = \int_{-\infty}^{x} f(x) \, dx$ then $F(x)$ is called .................
8. In Binomial distribution probability of success ............ from trial to trial.
9. In Binomial distribution if $n$ is very large and probability success of $p$ is very small such that $np = m$ (constant) then ............. distribution is applied.

III) State whether each of the following is True or False.
1. If $P(X = x) = k \binom{4}{x}$ for $x = 0, 1, 2, 3, 4$, then $F(5) = \frac{1}{4}$ when $F(x)$ is c.d.f.
2. 

<table>
<thead>
<tr>
<th>$X$</th>
<th>$-2$</th>
<th>$-1$</th>
<th>$0$</th>
<th>$1$</th>
<th>$2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P(X = x)$</td>
<td>0.2</td>
<td>0.3</td>
<td>0.15</td>
<td>0.25</td>
<td>0.1</td>
</tr>
</tbody>
</table>

If $F(x)$ is c.d.f. of discrete r.v. $X$ then $F(-3) = 0$.
3. $X$ is the number obtained on upper most face when a die is thrown then $E(x) = 3.5$.
4. If p.m.f. of discrete r.v. $X$ is

<table>
<thead>
<tr>
<th>$X$</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P(X = x)$</td>
<td>$q^2$</td>
<td>$2pq$</td>
<td>$p^2$</td>
</tr>
</tbody>
</table>

then $E(x) = 2p$.
5. The p.m.f. of a r.v. $X$ is

$P(x) = \frac{2x}{n(n+1)}$, $x = 1, 2, ........ n$

= 0 otherwise,

Then

$E(x) = \frac{2n+1}{3}$

6. If $f(x) = k x (1-x)$ for $0 < x < 1$

= 0 otherwise then $k = 12$
7. If $X \sim B(n, p)$ and $n = 6 \& P(x = 4)$

= $P(x = 2)$ then $p = \frac{1}{2}$.
8. If r.v. $X$ assumes values $1, 2, 3, ......., n$ with equal probabilities then $E(x) = \frac{(n+1)}{2}$
9. If r.v. $X$ assumes the values $1, 2, 3, ......., 9$ with equal probabilities, then $E(x) = 5$. 
**IV) Solve the following problems.**

**PART - I**

1. Identify the random variable as discrete or continuous in each of the following. Identify its range if it is discrete.
   (i) An economist is interested in knowing the number of unemployed graduates in the town with a population of 1 lakh.
   (ii) Amount of syrup prescribed by a physician.
   (iii) A person on high protein diet is interested in the weight gained in a week.
   (iv) Twelve of 20 white rats available for an experiment are male. A scientist randomly selects 5 rats and counts the number of female rats among them.
   (v) A highway safety group is interested in the speed (km/hr) of a car at a check point.

2. The probability distribution of a discrete r. v. $X$ is as follows.

<table>
<thead>
<tr>
<th>$x$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P(X=x)$</td>
<td>$k$</td>
<td>$2k$</td>
<td>$3k$</td>
<td>$4k$</td>
<td>$5k$</td>
<td>$6k$</td>
</tr>
</tbody>
</table>

   (i) Determine the value of $k$.
   (ii) Find $P(X \leq 4)$, $P(2 < X < 4)$, $P(X \geq 3)$.

3. Following is the probability distribution of a r. v. $X$.

<table>
<thead>
<tr>
<th>$x$</th>
<th>$-3$</th>
<th>$-2$</th>
<th>$-1$</th>
<th>$0$</th>
<th>$1$</th>
<th>$2$</th>
<th>$3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P(X=x)$</td>
<td>0.05</td>
<td>0.1</td>
<td>0.15</td>
<td>0.20</td>
<td>0.25</td>
<td>0.15</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Find the probability that
   (i) $X$ is positive.
   (ii) $X$ is non-negative
   (iii) $X$ is odd.
   (iv) $X$ is even.

4. The p. m. f of a r. v. $X$ is given by

   $$P(X = x) = \begin{cases} \frac{5}{x^2}, & x = 0,1,2,3,4,5. \\ 0 & \text{otherwise} \end{cases}$$

Show that $P(X \leq 2) = P(X \geq 3)$.

5. In the following probability distribution of a r. v. $X$.

<table>
<thead>
<tr>
<th>$x$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P(x)$</td>
<td>$1/20$</td>
<td>$3/20$</td>
<td>$a$</td>
<td>$2a$</td>
<td>$1/20$</td>
</tr>
</tbody>
</table>

Find $a$ and obtain the c. d. f. of $X$.

6. A fair coin is tossed 4 times. Let $X$ denote the number of heads obtained. Identify the probability distribution of $X$ and state the formula for p. m. f. of $X$.

7. Find the probability of the number of successes in two tosses of a die, where success is defined as (i) number greater than 4 (ii) six appears in at least one toss.

8. A random variable $X$ has the following probability distribution.

<table>
<thead>
<tr>
<th>$x$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P(x)$</td>
<td>$k$</td>
<td>$2k$</td>
<td>$2k$</td>
<td>$3k$</td>
<td>$k^2$</td>
<td>$2k^2$</td>
<td>$7k^2 + k$</td>
</tr>
</tbody>
</table>

Determine (i) $k$, (ii) $P(X < 3)$, (iii) $P(X > 6)$, (iv) $P(0 < X < 3)$.

9. The following is the c. d. f. of a r. v. $X$.

<table>
<thead>
<tr>
<th>$x$</th>
<th>$-3$</th>
<th>$-2$</th>
<th>$-1$</th>
<th>$0$</th>
<th>$1$</th>
<th>$2$</th>
<th>$3$</th>
<th>$4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F(x)$</td>
<td>0.1</td>
<td>0.3</td>
<td>0.5</td>
<td>0.65</td>
<td>0.75</td>
<td>0.85</td>
<td>0.9</td>
<td>1</td>
</tr>
</tbody>
</table>

Find the probability distribution of $X$ and $P(-1 \leq X \leq 2)$.

10. Find the expected value and variance of the r. v. $X$ if its probability distribution is as follows.

   (i)

<table>
<thead>
<tr>
<th>$x$</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P(X=x)$</td>
<td>$1/5$</td>
<td>$2/5$</td>
<td>$2/5$</td>
</tr>
</tbody>
</table>
11. A player tosses two coins. He wins Rs. 10 if 2 heads appear, Rs. 5 if 1 head appears, and Rs. 2 if no head appears. Find the expected value and variance of winning amount.

12. Let the p. m. f. of the r. v. \( X \) be
\[
P(x) = \begin{cases} 
\frac{3}{10} & \text{for } x = 1, 0, 1, 2, \\
0 & \text{otherwise}
\end{cases}
\]
Calculate \( E(X) \) and \( \text{Var}(X) \).

13. Suppose error involved in making a certain measurement is a continuous r. v. \( X \) with p. d. f.
\[
f(x) = \begin{cases} 
\frac{k(4x^2)}{10} & \text{for } 2 \leq x \leq 2, \\
0 & \text{otherwise}
\end{cases}
\]
Compute (i) \( P(X > 0) \), (ii) \( P(-1 < x < 1) \), (iii) \( P(X < 0.5 \text{ or } X > 0.5) \).

14. The p. d. f. of the r. v. \( X \) is given by
\[
f(x) = \begin{cases} 
\frac{1}{2a} & \text{for } 0 < x < 2a, \\
0 & \text{otherwise}
\end{cases}
\]
Show that \( P(X < a/2) = P(X > 3a/2) \).

15. Determine \( k \) if the p. d. f. of the r. v. is
\[
f(x) = \begin{cases} 
ke^{-kx} & \text{for } 0 \leq x < \infty, \\
0 & \text{otherwise}
\end{cases}
\]
Find \( P(X > \frac{1}{\theta}) \) and determine \( M \) if \( P(0 < X < M) = \frac{1}{2} \).

16. The p. d. f. of the r. v. \( X \) is given by
\[
f(x) = \begin{cases} 
kx^k \sqrt{x} & \text{for } 0 < x < 4, \\
0 & \text{otherwise}
\end{cases}
\]
Determine \( k \), the c. d. f. of \( X \), and hence find \( P(X \leq 2) \) and \( P(x \geq 1) \).

17. Let \( X \) denote the reaction temperature in celsius of a certain chemical process. Let \( X \) have the p. d. f.
\[
f(x) = \begin{cases} 
\frac{1}{10} & \text{for } 5 \leq x < 5, \\
0 & \text{otherwise}
\end{cases}
\]
Compute \( P(X < 0) \).

**PART - II**

1. Let \( X \sim B(10,0.2) \). Find (i) \( P(X = 1) \), (ii) \( P(X \geq 1) \), (iii) \( P(X \leq 8) \).

2. Let \( X \sim \text{Bin}(n,p) \). (i) If \( n = 10 \) and \( E(X) = 5 \), find \( p \) and \( \text{Var}(X) \). (ii) If \( E(X) = 5 \) and \( \text{Var}(X) = 2.5 \), find \( n \) and \( p \).

3. If a fair coin is tossed 4 times, find the probability that it shows (i) 3 heads, (ii) head in the first 2 tosses and tail in last 2 tosses.

4. The probability that a bomb will hit the target is 0.8. Find the probability that, out of 5 bombs, exactly 2 will miss the target.

5. The probability that a lamp in the classroom will burn is 0.3. 3 lamps are fitted in the classroom. The classroom is unusable if the number of lamps burning in it is less than 2. Find the probability that the classroom can not be used on a random occasion.

6. A large chain retailer purchases an electric device from the manufacturer. The manufacturer indicates that the defective rate of the device is 10%. The inspector of the retailer randomly selects 4 items from a shipment. Find the probability that the inspector finds at most one defective item in the 4 selected items.
7. The probability that a component will survive a check test is 0.6. Find the probability that exactly 2 of the next 4 components tested survive.

8. An examination consists of 5 multiple choice questions, in each of which the candidate has to decide which one of 4 suggested answers is correct. A completely unprepared student guesses each answer completely randomly. Find the probability that this student gets 4 or more correct answers.

9. The probability that a machine will produce all bolts in a production run within the specification is 0.9. A sample of 3 machines is taken at random. Calculate the probability that all machines will produce all bolts in a production run within the specification.

10. A computer installation has 3 terminals. The probability that anyone terminal requires attention during a week is 0.1, independent of other terminals. Find the probabilities that (i) 0 (ii) 1 terminal requires attention during a week.

11. In a large school, 80% of the students like mathematics. A visitor asks each of 4 students, selected at random, whether they like mathematics. (i) Calculate the probabilities of obtaining an answer yes from all of the selected students. (ii) Find the probability that the visitor obtains the answer yes from at least 3 students.

12. It is observed that it rains on 10 days out of 30 days. Find the probability that (i) it rains on exactly 3 days of a week. (ii) it rains on at most 2 days of a week.

13. If $X$ follows Poisson distribution such that $P(X = 1) = 0.4$ and $P(X = 2) = 0.2$, find variance of $X$.

14. If $X$ follows Poisson distribution with parameter $m$ such that $\frac{P(X = x + 1)}{P(X = x)} = \frac{2}{x + 1}$ find mean and variance of $X$. 
**Exercise 1.1**

1. ₹ 5760, ₹ 42,240
2. ₹ 7500
3. 22
4. ₹ 50,000
5. ₹ 80,000
6. 20%
7. ₹ 5800, 6%
8. ₹ 1,00,000
9. Cash Sales = ₹ 66,000, Credit Sales = ₹ 36,000
10. 11.75%
11. Rs 47,500
12. ₹ 10,200
13. C.P. = ₹ 6400, marked price = ₹ 10,000
14. ₹ 4,464
15. ₹ 1,140

**Exercise 1.2**

1. ₹ 10500
2. ₹ 8333.33
3. ₹ 7560, ₹ 7000
4. 5 years.
5. 10 % p. a.
6. T. D. = ₹ 182.60, B. D = ₹ 190.80, B. G. = ₹ 8.20
7. 6% p. a.
8. B. D = ₹ 313.12, C. V. = ₹ 6621.88
9. 15th April 1998
10. ₹ 43800
11. 5 months
12. T.D. = ₹ 1200, B.D. = ₹ 1220, Amount = ₹ 73200

13. B. G. = ₹ 20, T. D. = 1000
14. r = 20%
15. ₹ 12,000

**MISCELLANEOUS EXERCISE - 1**

I) 1. b. Del credere agent
2. a. factor
3. c. nominal due date
4. a. The legal due date
5. a. Face Value
6. b. Present worth
7. d. True discount
8. c. List Price
9. b. Invoice price = Net selling price
10. b. True discount

II) 1. Drawer
2. Auctioneer
3. Catalogue/list
4. Commercial Discount
5. higher
6. Bankers Gain
7. Legal due date
8. A broker
9. Trade, Catalogue / list
10. Invoice Price

III) 1. Flase
2. False
3. True
4. False
5. True
6. False
7. False
8. True
9. False
10. True.

**Exercise 2.2**

1. ₹ 2,597
2. ₹ 23,205
3. ₹ 1,05,000
4. ₹ 42,475
5. ₹ 91,120
6. ₹ 1,83,555
7. ₹ 1,00,000
8. ₹ 1,50,000
9. 200% p. a.
10. 3 years
11. ₹ 3,641
12. ₹ 824.16
13. ₹ 2,146.50
14. ₹ 2,400
15. ₹ 31,944
16. ₹ 3,703.70

**MISCELLANEOUS EXERCISE - 2**

**I)**
1. c
2. d
3. d
4. d
5. c
6. b
7. c
8. b
9. b
10. d

**II)**
1. premium
2. life
3. property value
4. policy value
5. annuitant
6. installment
7. payment period
8. perpetuity
9. annuity due
10. immediate annuity OR ordinary annuity.

**III)**
1. F
2. T
3. F
4. T
5. T
6. T
7. F
8. T
9. F
10. T.

**IV)**
1. ₹ 432
2. ₹ 96,000
3. ₹ 18,00,000
4. ₹ 85,000
5. ₹ 1,07,000
6. ₹ 32,800
7. ₹ 26,000
8. ₹ 16,000 kg
9. ₹ 875
10. ₹ 58,800
11. ₹ 78,000, ₹ 144
12. ₹ 38,400, ₹ 17,052
13. ₹ 2,07,400
14. ₹ 13,435
15. ₹ 23,201.85
16. 12 years
17. 5% p.a.
18. ₹ 41,250
19. ₹ 49,740
20. ₹ 4550, ₹ 1930
21. ₹ 2,00,000
22. ₹ 52,500
23. ₹ 4 years
24. ₹ 21,778.60

**Exercise 3.1**

1) (i) \( y = 2 + 0.75x \)
   (ii) \( y = ₹ 11750 \)
2) (i) \( x = y + 6 \) (ii) \( y = 0.87x - 4.18 \)
3) (i) \( -0.8 \) (ii) \( -0.4 \), \( -0.4 \) (iii) \( -0.4 \)
4) 12.73
5) (i) \( y = 1.16y - 10.4 \)
   Estimate of \( y = 99.8 \)
   (ii) \( x = 0.59x + 26.65 \),
   Estimate of \( x = 70.9 \)
6) \( y = -1.34x + 18.04 \)
7) \( y = 0.3x + 62.1 \)
8) \( y = 2x + 3, x = 0.5y - 1.5 \)
9) \( y = -0.65x + 11.9, \)
   \( x = 0.3y + 16.4 \)
10) (i) \( y = 2x - 1 \), (ii) \( y = 7 \)
11) (i) \( y = 0.63x + 2.8, (ii) y = 9.1 \)
12) \( y = 6.6x + 38.36 \)

**Exercise 3.2**

1) (i) \( -0.6 \) (ii) \( 31.6 \) (iii) \( 53.9 \)
2) (i) \( 5x + 24y = 3251 \)
   (ii) \( 6x + 5y = 1664 \) (iii) \( -\frac{5}{12} \)
3) (i) \( y = 0.36x + 35.6 \) (ii) \( x = 2.19y - 64.21 \)

**Exercise 3.3**

1) \( \bar{x} = 2, \bar{y} = 8.25, r = 0.6 \)
2) (i) \( \bar{x} = 13, \bar{y} = 17 \) (ii) \( 0.6 \) (iii) \( \sigma_y = 4 \)
3) \( \bar{x} = 62.4, r = 0.8 \)
4) 4
5) (i) \( r = -\frac{2}{3} \) (ii) \( \frac{\sigma_x}{\sigma_y} = 1 \)
6) 32.5
7) \( \bar{x} = 28, \bar{y} = 5.75, r = 0.5 \)
8) (i) \( \bar{x} = 4, \bar{y} = 5.2 \) (ii) \( 0.375 \) (iii) \( \frac{8}{3} \)
9) (i) \( \bar{x} = 17 \) (ii) \( \bar{y} = 19 \) (iii) \( b_{xy} = \frac{3}{4} \)
   iv) \( b_{xy} = \frac{1}{2} \) (v) \( r = 0.61 \)
10) (i) \( \bar{x} = 30, \bar{y} = 40 \) (ii) \( r = \frac{2}{3} \)
11) (i) \( x \) on \( y \) is \( 10x + 3y - 62 = 0 \)
(ii) \( \overline{x} = 5, \overline{y} = 4 \) (iii) \( r = 0.6 \)

12) (i) \( r = 0.6 \) (ii) \( \overline{x} = 10, \overline{y} = 20 \)

13) (i) \( \overline{x} = 17 \) (ii) \( \overline{y} = 19 \) (iii) \( b_{yx} = \frac{3}{4} \)
(iv) \( b_{xy} = \frac{1}{2} \) (v) \( r = 0.61 \)

14) (i) \( \overline{x} = 60 \) (ii) \( \overline{y} = 100 \) (ii) \( \overline{y} = 137.5 \text{kg} \)

**MISCELLANEOUS EXERCISE - 3**

I) 1) c 2) a 3) b 4) a 5) b 6) b 7) a 8) c 9) c 10) b 11) b 12) b 13) a 14) b 15) b 16) c 17) a 18) b 19) a 20) b 21) a 22) d 23) b 24) b

II) 1) Negative
2) \( y = b_{yx} (x - \overline{x}) \)
3) \( x \quad \overline{x} \quad b_{xy} (y - \overline{y}) \)
4) 2
5) -1
6) \( \frac{c}{d} = b_{xy} \)
7) \( \frac{d}{c} = b_{yx} \)
8) \( 2|\tau| \)
9) <1
10) \( r^2 \)

III) 1) True 2) False 3) True 4) True 5) False 6) False 7) False 8) True 9) True 10) True

IV)
1) \( y = 2.588x + 8.2 \) For \( x = 1.5 \) \( y = 12.082 \)
2) \( b_{yx} = -\frac{3}{2} \)
3) \( y = 8 \)

4) i) \( r = \frac{1}{3} \) (ii) \( \sigma_y^2 = \frac{16}{9} \)
5) Equation of \( y \) on \( x \) is \( 2x + 3y = 6 \) and equation of \( x \) on \( y \) is \( 5x + 7y = 12 = 0 \)
6) (i) \( r = 0.6 \) (ii) \( \overline{x} = 1, \overline{y} = 1 \)
7) (i) \( \overline{x} = 4, \overline{y} = 7 \) (ii) \( r = -0.5 \) (iii) \( \overline{x} = 4 \) (iv) \( 1 \)
8) \( (x - 4) = \frac{6}{11} (y - 5) \)
9) \( y = 3.75x - 39 \)
10) \( y = 0.7x + 105, y = 133 \)
11) (i) \( \overline{x} = 10, \overline{y} = 5 \) (ii) \( b_{yx} = 0.9, b_{xy} = 0.4 \)
(iii) \( V(X) = 16 \) (iv) \( r = 0.6 \)
12) \( r = -0.36 \) moderate negative correlation

**Exercise 4.1**

2. Equation of trend line:
\( y_t = 4.182 + (1.036)u \) where \( u = t - 1967 \).

<table>
<thead>
<tr>
<th>Year</th>
<th>Trend Value</th>
<th>Year</th>
<th>Trend Value</th>
</tr>
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<tbody>
<tr>
<td>1962</td>
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<td>4.1818</td>
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<td>1968</td>
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</tr>
<tr>
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<td>1.0727</td>
<td>1969</td>
<td>6.2545</td>
</tr>
<tr>
<td>1965</td>
<td>2.1091</td>
<td>1970</td>
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<td>1966</td>
<td>3.1455</td>
<td>1971</td>
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For the year 1975, trend value = 12.4732 (in ‘000 tones)

3.

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</tr>
<tr>
<td>1967</td>
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</table>
5. Equation of trend line:

\[ y_t = 4.2 + (0.4485)u, \text{ where } u = 2t - 3961 \]

<table>
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<th>Year</th>
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<tbody>
<tr>
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<td>2.8545</td>
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<td>1980</td>
<td>3.7515</td>
<td>1985</td>
<td>8.2364</td>
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For the year 1987, trend value = 10.0305.

6. |

<table>
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<tbody>
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<tr>
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</tr>
<tr>
<td>1984</td>
<td>—</td>
</tr>
<tr>
<td>1985</td>
<td>—</td>
</tr>
</tbody>
</table>

8. Equation of Trend line:

\[ y_t = 5.6364 + (0.7909)u, \text{ where, } u = t - 1981 \]

<table>
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<th>Year</th>
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</thead>
<tbody>
<tr>
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<td>1.1618</td>
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<td>6.4273</td>
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<td>2.4727</td>
<td>1983</td>
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<td>3.2636</td>
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<tr>
<td>1979</td>
<td>4.0545</td>
<td>1985</td>
<td>8.8000</td>
</tr>
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<td>1981</td>
<td>5.6364</td>
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The trend value for the year 1990 = 12.7545 (in million tonnes.)

9. |

<table>
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<td>8.0000</td>
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<td>5.3333</td>
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</tr>
<tr>
<td>1981</td>
<td>6.3333</td>
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10. (i)

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<table>
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<tbody>
<tr>
<td>1966</td>
<td>2.2</td>
<td>1973</td>
<td>8.2</td>
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MISCELLANEOUS EXERCISE - 4

I) 1. (d) 2. (c) 3. (c) 4. (c) 5. (a) 6. (d) 7. (a) 8. (a) 9. (b) 10. (d)

II) 1. trend 2. seasonal 3. cyclical 4. irregular 5. assume 6. does not assume 7. graphical 8. moving average 9. least square 10. trend


IV) 2. Equation of trend line.

\[ y_t = 6.3333 + (0.6333)u, \text{ where } u = t - 1978 \]
### 3.

<table>
<thead>
<tr>
<th>Year</th>
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<th>Year</th>
<th>Trend Value</th>
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<td>1974</td>
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<td>1976</td>
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<td>1981</td>
<td>–</td>
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<td>1977</td>
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<td>1982</td>
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</tr>
<tr>
<td>1978</td>
<td>7</td>
<td>1986</td>
<td>–</td>
</tr>
</tbody>
</table>

### 5.

Equation of trend line:
\[ y_t = 3.1667 + (0.2797)u, \text{ where } u = 2t - 3953. \]

<table>
<thead>
<tr>
<th>Year</th>
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<td>1.2086</td>
<td>1979</td>
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<tr>
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<td>1981</td>
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<tr>
<td>1976</td>
<td>2.8867</td>
<td>1982</td>
<td>6.2436</td>
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</tbody>
</table>

### 8.

Equation of trend line:
\[ y_t = 5.1 + (0.4758)u, \text{ where } u = \frac{2t-3965}{5} \]

<table>
<thead>
<tr>
<th>Year</th>
<th>Trend Value</th>
<th>Year</th>
<th>Trend Value</th>
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<tbody>
<tr>
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<tr>
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<td>1.7697</td>
<td>1990</td>
<td>6.5273</td>
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<td>1970</td>
<td>2.7212</td>
<td>1995</td>
<td>7.4788</td>
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<tr>
<td>1975</td>
<td>3.6727</td>
<td>2000</td>
<td>8.4303</td>
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Trend value for the year 2010 = 10.3338%

### 9.

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<td>3</td>
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<tr>
<td>1975</td>
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<td>1980</td>
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<td>1985</td>
<td>5.25</td>
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<tr>
<td>1990</td>
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<tr>
<td>2000</td>
<td>–</td>
</tr>
<tr>
<td>2005</td>
<td>–</td>
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</tbody>
</table>

### 11.

Equation of trend line:
\[ y_t = 4.8750 + (0.4702)u, \text{ where } u = 2t - 3961 \]

<table>
<thead>
<tr>
<th>Year</th>
<th>Trend Value</th>
<th>Year</th>
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</tr>
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<tbody>
<tr>
<td>1977</td>
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<td>5.3452</td>
</tr>
<tr>
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<td>2.5238</td>
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<td>6.2857</td>
</tr>
<tr>
<td>1979</td>
<td>3.4634</td>
<td>1983</td>
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<tr>
<td>1980</td>
<td>4.4048</td>
<td>1984</td>
<td>8.1667</td>
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</table>

Trend value for the year 1988 = 11.928 (in ten thousands).
12. | Year | Trend Value | Year | Trend Value |
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>1977</td>
<td>–</td>
<td>1981</td>
<td>7.3333</td>
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<tr>
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<tr>
<td>1980</td>
<td>7.0000</td>
<td>1984</td>
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</table>

14. Equation of trend line:
\[ y_t = 5.2222 + (0.667) u, \text{ where } u = t - 1979 \]

15. | Year | Trend Value |
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1975</td>
<td>–</td>
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<tr>
<td>1976</td>
<td>–</td>
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<td>5.625</td>
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<td>1980</td>
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<tr>
<td>1981</td>
<td>6</td>
</tr>
<tr>
<td>1982</td>
<td>–</td>
</tr>
<tr>
<td>1983</td>
<td>–</td>
</tr>
</tbody>
</table>

18. | Year | Trend Value | Year | Trend Value |
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<tbody>
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<tr>
<td>1995</td>
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19. Equation of trend line:
\[ y_t = 2.4 + (0.2848) u, \text{ where } u = 2t - 3927 \]

20. | Year | Trend Value | Year | Trend Value |
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
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17. Equation of trend line:
\[ y_t = 4.286 + (-1.571)u, \text{ where } u = \frac{t-1995}{5} \]

18. | Year | Trend Value | Year | Trend Value |
<table>
<thead>
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<tr>
<td>1995</td>
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Trend value for the year 1984 = 8.5557.

Exercise 5.1

1. 165.45 2. 137.5
3. 130.41 4. 170.7
5. 130 6. 132.08
7. 140 8. 75
9. 124.29 10. 130.71
11. 155.28 12. \( x = 15 \)
13. \( y = 60 \)

Exercise 5.2

1. \( P_{OT}(L) = 164.29, \) \( P_{OT}(P) = 164.18, \)
\( P_{OT}(D - B) = 164.24, \)
\( P_{OT}(M - E) = 164.24. \)
2. \( P_{a1}(L) = 161.11, P_{a1}(P) = 161.82, P_{a1}(D-B) = 161.46, P_{a1}(A1 - E) = 161.42. \)

3. \( P_{a1}(w) = 72.11 \)

4. \( P_{a1}(w) = 132.07 \)

5. \( P_{a1}(D-B) = 65, P_{a1}(F) = 60. \)

6. \( P_{a1}(L) = 250, P_{a1}(P) = 230, P_{a1}(D-B) = 240, P_{a1}(M-E) = 238.24. \)

7. \( P_{a1}(P) = 168.04 \)

8. \( P_{a1}(L) = 250. \)

9. \( x = 2. \)

10. \( P_{a1}(D-B) = \frac{5}{4} P_{a1}(F) \)

11. \( P_{a1}(P) = 8 \) and \( P_{a1}(L) = 2 \) or vice versa

**Exercise 5.3**

1. 135.04
2. 116.25
3. 113.3
4. 77
5. 205.88
6. 169.33
7. \( x = 18 \)
8. \( y = 6 \)
9. ₹ 16000

**MISCELLAEOUS EXERCISE - 5**

I) 1. (c) 2. (c) 3. (d) 4. (c) 5. (c) 6. (d) 7. (c) 8. (d) 9. (c) 10. (a) 11. (a) 12. (a) 13. (a) 14. (a) .

II) 1. \( \sum \frac{p_i}{g_0} \times 100 \)

2. \( \sum \frac{q_i}{g_0} \times 100 \)

3. \( \sum \frac{p_i q_i}{g_0 q_i} \times 100 \)

4. \( \sum \frac{p_i w}{g_0 w} \times 100 \)


IV) 1. 154.55 2. 135.48 3. 121.43 4. 42 5. \( P_{a1}(L) = 136.19, P_{a1}(P) = 137 \)

6. \( P_{a1}(D-B) = 182 \)

7. \( P_{a1}(M-E) = 107.14 \)

8. \( P_{a1}(W) = 170 \)

9. \( P_{a1}(L) = 181.82, P_{a1}(P) = 172.22 \)

10. \( x = 6 \)

11. \( x = 16.6 \)

12. 10.75

13. P01(D-B) = 20.5, P01(F) = 20

14. \( P_{a1}(P) = 155.4 \)
15. \( P_{01}(L) = 166.67, \)
    \( P_{01}(P) = 87.5, P_{01}(D - B) = 127.085, \)
    \( P_{01}(M - E) = 121.42. \)
16. \( P_{01} = 153.85, P_{01}(P) = 87.5. \)
    \( P_{01}(D - B) = 120.68, \)
    \( P_{01}(M - E) = 117.24. \)
17. \( \sum p_i q_i = 228, P_{01}(L) = 190 \)
18. 131
19. 86.5
20. 295.25, Its. 29,525
21. \( x = 15 \)
22. \( \₹ 18,900 \)

Exercise 6.1

1. Maximize \( z = 30x + 20y \) Subject to
   \( 10x + 6y \leq 60, 5x + 4y \leq 35, x \geq 0, y \geq 0 \)
2. Minimize \( z = 3x + 2y \) Subject to
   \( 2x + y \geq 14, 2x + 3y \geq 22, x + y \geq 1, \)
   \( x \geq 0, y \geq 0 \)
3. Maximize \( P = 350x + 400y \) subject to
   \( 3x + 2y \leq 120, 2x + 5y \leq 160, x \geq 0, y \geq 0 \)
4. Maximize \( z = 10x + 15y \) Subject to
   \( 2x + 3y \leq 36, 5x + 2y \leq 50, 2x + 6y \leq 60 \)
   \( x \geq 0, y \geq 0 \)
5. Maximize \( P = 13.5x + 55y \) Subject to
   \( x + 2y \leq 10, 3x + 4y \leq 12, \)
   \( x \geq 0, y \geq 0 \)
6. Maximize \( z = 500x + 750y \) Subject to
   \( 2x + 3y \leq 40, x + 4y \leq 70, x \geq 0, y \geq 0 \)
7. Minimize \( z = 4.5x + 3.5y \) Subject to
   \( 4x + 6y \geq 18, 14x + 12y \geq 28, 8x + 8y \geq 14 \)
   \( x \geq 0, y \geq 0 \)
8. Maximize \( z = x_1 + x_2 \) Subject to
   \( x_1/60 + x_2/90 \leq 1, 5x_1 + 8x_2 \leq 600, \)
   \( x_1 \geq 0, x_2 \geq 0 \)
9. Minimize \( C = 20x_1 + 6x_2 \) Subject to
   \( x_1 \geq 4, x_2 \leq 2, x_1 + x_2 \geq 5, x_1 \geq 0, x_2 \geq 0 \)

Exercise 6.2

1. \( x = 4, y = 2, z = 60 \)
2. \( x = 0, y = 6, z = 36 \)
3. \( x = 4.5, y = 2.5, z = 59 \)
4. \( x = 2, y = 3, z = 95 \)
5. \( x = 4, y = 5, z = 37 \)
6. \( x = 0, y = 5, z = 5 \)
7. \( x = 1.5, y = 4, z = 52 \)
8. \( x = 2, y = 0.5, z = 22.5 \)

MISCELLAEOUS EXERCISE - 6

I)

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<td>b</td>
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<td>d</td>
<td>c</td>
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<td>b</td>
<td>b</td>
<td>b</td>
<td>a</td>
<td>c</td>
<td>c</td>
<td></td>
</tr>
</tbody>
</table>

II) 1) I 2) III 3) corner 4) III and IV 5) \( y > x \)
6) \( x \geq 3, y \geq 2, \) 7) \( x \geq 2y \)
8) \( x \leq 40 \)

III) 1), 4), 5), 6), 7) are true and 2), 3) are false.

IV)

1. \( x_1 = 4.5, x_2 = 3 \) Max \( z = 40.5 \)
2. \( x = 3, y = 18, \) Min \( z = 48 \)
3. infinite number of optimum solutions on the line \( 3x + 5y = 10 \) between
   A (45/16, 5/16) and B(0,2)
4. \( x_1 = 2, x_2 = 1 \) Min. \( z = 7. \)
5. \( x = 4, y = 3 \) Max \( z = 25 \)
6. \( x = 10, y = 15 \) Max \( z = 1350 \)
7. \( x = 3, y = 18 \) Min \( z = 48. \)
8. Max \( z = 140x + 210y \) Subject to
   \( 3x + 3y \leq 36, 5x + 2y \leq 50, 2x + 6y \leq 60 \)
9. Maximize \( z = 180x + 220y \) Subject to
   \[ 6x + 4y \leq 120, \ 3x + 10y \leq 180 \]
   \( x \geq 0, \ y \geq 0 \) Ans. \( x = 10, \ y = 15 \).

10. Minimize \( z = 4x + 6y \) Subject to
    \[ x + 2y \geq 80, \ 3x + y \geq 75, \ x \geq 0, \ y \geq 0 \]
    Ans. \( x = 14, \ y = 33 \).

11. Maximize \( z = 2000x + 3000y \) Subject to
    \[ 3x + 3y \leq 36, \ 5x + 2y \leq 50, \ 2x + 6y \leq 60, \]
    \( x \geq 0, \ y \geq 0 \) Ans. \( x = 3, \ y = 9 \).

12. Minimize \( z = 800x + 640y \) Subject to
    \[ 4x + 2y \geq 16, \ 12x + 2y \geq 24 \]
    \[ 2x + 6y \geq 18, \ x \geq 0, \ y \geq 0 \]
    Ans. Minimum cost = ₹ 3680/-
    when \( x = 3, \ y = 2 \).

13. Maximize \( z = 75x + 125y \) subject to
    \[ 4x + 2y \leq 208, \ 2x + 4y \leq 152, \ x \geq 0, \ y \geq 0 \]
    Ans \( x = 44, \ y = 16 \).

14) Max \( z = 3x + 4y \), s.t. \( x + y \leq 450 \),
    \[ 2x + y \leq 600, \ x, y \geq 0 \]
    Maximum Profit = ₹ 1800/- at \( (0, 450) \).

15. Max \( z = 20x + 30y \), s.t. \( 3x + 2y \leq 210 \),
    \[ 2x + 4y \leq 300, \ x, y \geq 0 \]
    Maximum Profit = ₹ 2400/- at \( (30, 60) \).

### Exercise 7.1

1. \( P \rightarrow II \ \ Q \rightarrow IV, \ R \rightarrow I, \ S \rightarrow III \)
   Total cost = ₹ 99

2. \( 1 \rightarrow I, \ 2 \rightarrow III, \ 3 \rightarrow IV, \ 4 \rightarrow II, \ 5 \rightarrow V \)
   Total mileage = 39 miles

3. \( 1 \rightarrow C, \ 2 \rightarrow E \rightarrow A, \ 4 \rightarrow D, \ 5 \rightarrow B \)
   Total profit = ₹ 214

4. \( M1 \rightarrow A, \ M2 \rightarrow B, \ M3 \rightarrow E, \ M4 \rightarrow D, \)
   \( M5 \rightarrow C \)
   Total cost = ₹ 12

5. \( 1 \rightarrow A, \ 2 \rightarrow C, \ 3 \rightarrow B, \ 4 \rightarrow D \)

### Exercise 7.2

1. Optimal sequence is: \( 4 \rightarrow 1 \rightarrow 3 \rightarrow 2 \rightarrow 5 \rightarrow 6 \)
   Idle time for turning operation = 1 min
   Total elapsed time = 43 minutes
   Idle time for threading = 6 minutes

2. Optimal sequence is: \( I \rightarrow III \rightarrow II \)
   Idle time for department A = 4 days
   Elapsed time = 23 days
   Idle time for department B = 8 days

3. Optimal sequence is: \( 1 \rightarrow 2 \rightarrow 3 \)
   Idle time for data entry operation = 100 min.
   Total elapsed time = 490 minutes
   Idle time for filing = 140 min.

4. Optimal sequence is: \( B \rightarrow D \rightarrow C \rightarrow E \rightarrow A \)
   Idle time for machine \( X \) = 4 hrs
   Total elapsed time = 60 hrs.
   Idle time for machine \( Y \) = 6 hrs.

5. Optimal sequence is: \( VII \rightarrow I \rightarrow IV \rightarrow V \rightarrow III \rightarrow II \rightarrow VI OR VII \rightarrow I \rightarrow IV \rightarrow V \rightarrow II \rightarrow III \rightarrow VI \)
   Idle time for machine A = 5 units.
   Idle time for machine B = 13.
   Total elapsed time = 91 units.

6. 1) Optimal sequence is: \( V \rightarrow III \rightarrow II \rightarrow VI \rightarrow VII \rightarrow IV \rightarrow I \ OR III \rightarrow V \rightarrow II \rightarrow VI \rightarrow VII \rightarrow IV \rightarrow I \)
   Total elapsed time = 61 hrs.
   Idle time for machine B = 38 hrs.
   Idle time for machine A = 7 hrs.
   Idle time for machine C = 15 hrs.

2) Total elapsed time = 40
   \( 5 \rightarrow 4 \rightarrow 3 \rightarrow 2 \rightarrow 1 \ OR \)
2 – 5 – 4 – 3 – 1 Total elapsed time = 40 hrs.
Idle times for machine A = 8 hrs, machine C = 12 hrs and machine B = 25 hrs.

7. Optimal sequence is : D → A → E → B → C OR A → D → E → B → C OR E → D → A → B → C
Total elapsed time = 51 hrs. Idle time for machine P = 19 hrs. Idle time for machine Q = 31 hrs. Ideal time for machine R = 9 hrs.

MISCELLANEOUS EXERCISE - 7

I)

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II)

1. Number of rows is not equal to the number of columns.
2. Balanced
3. Square
4. Square
5. Zero
6. Total elapsed time
7. Idle time
8. Maximum
9. Multiple
10. A→D→B→C


PART - I

IV)

1. A → I, B → III, C → II, D → IV;
Minimum man hours = 37
2. A → II, B → III, C → V, D → I, E → IV;
Minimum distance travelled = 525 kms
3. A → V, B → II, C → IV, D → III, E → I;
Maximum Sale = 65 units
4. P→IV, Q→III, R→V, S→I, T→II;
5. A → IV, B → III, C → II, D → V, E → I
A → IV, B→III, C → V, D → II E → I;
6. E₁→1, E₂→IV, E₃→II, E₄→V, E₅→III
Minimum number of days = 27.

PART - II

1. Optimal sequence: 3→4→5→7→2→6→1;
Idle time for cutting = 2 hrs;
Total elapsed time = 46 hrs;
Idle time for sewing = 4 hrs.
2. Optimal sequence: II→IV→V→III→I;
Idle time for Lathe = 4 hrs;
Total elapsed time = 21 hrs
Idle time for surface grinder = 3 hrs
3. Optimal sequence: III→V→II→VI→I→IV→VII;
Idle time for machine A = 3 hrs;
Total elapsed time 55 hrs
Idle time for machine B = 9 hrs
4. Optimal sequence: 3→2→5→4→1; OR
3→2→1→4→5 OR 3→2→5→1→4
Idle time for machine A = 18 hrs;
Idle time for machine B = 62 hrs
Idle time for machine C = 38 hrs
Total elapsed time 102 hrs.
5. Optimal sequence is : 3→1→4→2;
Idle time for Shaping = 12 min.;
Idle time for Trapping = 31 min.
Idle time for Drilling = 51 min.
Total elapsed time = 74 min.

Exercise 8.1

1. {−6, −4, −2, 0, 2, 4, 6}
2. {0, 1, 2}

4. (i)

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(ii)

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(iii)

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6.

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<td>P(x)</td>
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7.

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<td>3/8</td>
<td>1/16</td>
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15. | x | 14 | 15 | 16 | 17 |
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<td>2/15</td>
<td>3/15</td>
<td>1/15</td>
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</table>

Mean = 17.5333, Variance = 4.9

16. 0.7, 0.21

Exercise 8.2

2. (i) 2.25/16, (ii) 3/16 (iii) 3/4
3. (i) p. d. f. (ii) 1/256 (iii) 5/16
4. (i) 1/2, 3/64 (ii) 6, (a) 11/32, (b) 1/2
5. (i) 1/4 (ii) 1/2 (iii) 7/16
6. (i) 2/5 (ii) 1/5
7. k = 3/32 (i) 1/2 (ii) 11/16 (iii) 81/128
8. (i) x^2/16 for 0 < x < 4 (ii) 1/64, 2.89/16, 1
9. (i) 1/8 (ii) 0, (iii) 1 (iv) 7/8
10. (i) 1/log(3), (ii) 2/log (3),

(iii) \( \frac{4[\log 3 - 1]}{[\log 3]^2} \)

Exercise 8.3

1. (i) 0.375 (ii) 0.3125 (iii) 0.6875
2. 5/72
3. 1.3 \times (0.9)^3 = 0.9477
4. (i) 1/1024 (ii) 45/512 (iii) (3/4)^5 = 0.2373
5. (i) (0.8)^5 (ii) (1.8)(0.8)^4 (iii) 1 – (1.8)(0.8)^4 (iv) 1 – (0.8)^3
6. (9/10)^4
7. 11/243
8. \( \frac{70}{36} \left( \frac{5}{6} \right)^4 \)
9. (i) 4, 2.4 (ii) 10, 2.4 (iii) 2/5, 6 (iv) 1.6
Exercise 8.4

1. 0.7357
2. 0.0126
3. 0.8012
4. (i) 0.1465  (ii) 0.2381
5. (i) 0.2231  (ii) 0.1911
6. (i) 0.3678  (ii) 0.6322
7. (i) 0.1744  (ii) 0.3875  (iii) 0.4236

MISCELLANEOUS EXERCISE - 8

I) 1. d 2. a 3. b 4. d 5. c
6. b 7. b 8. a 9. b 10. a

3. 1 4. 1
5. 0 6. Centre of gravity
7. Distribution function
8. Remains constant / independent
9. Poisson


SOLVED EXAMPLES

PART - I

1. (i) Discrete, \( \{0,1,2,\ldots,100000\} \)
   (ii) Continuous (iii) Continuous
   (iv) Discrete \( \{0,1,2,3,4,5\} \). (v) Continuous.
2. (i) 1/21 (ii) 10/21, 1/7, 6/7
3. (i)0.5 (ii) 0.7 (iii) 0.55 (iv) 0.45
4. Both probabilities are 1/2 and therefore are equal.

5. \( a = 1/4 \)

<table>
<thead>
<tr>
<th>( x )</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P(x) )</td>
<td>1/20</td>
<td>3/20</td>
<td>1/4</td>
<td>1/2</td>
<td>1/20</td>
</tr>
<tr>
<td>( F(x) )</td>
<td>1/20</td>
<td>1/5</td>
<td>9/20</td>
<td>19/20</td>
<td>1</td>
</tr>
</tbody>
</table>

6. The distribution of \( X \) is binomial with \( n = 4 \) and \( p = 1/2 \). The formula of its p. m. f.
   is as follows. \( F(X = x) = \binom{4}{x} \frac{1}{2^4} \).

The probability distribution of \( X \) is tabulated below.

<table>
<thead>
<tr>
<th>( x )</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P(x) )</td>
<td>1/16</td>
<td>1/4</td>
<td>3/8</td>
<td>1/4</td>
<td>1/16</td>
</tr>
</tbody>
</table>

7. (i)

<table>
<thead>
<tr>
<th>( x )</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P(x) )</td>
<td>4/9</td>
<td>4/9</td>
<td>1/9</td>
</tr>
</tbody>
</table>

(ii)

<table>
<thead>
<tr>
<th>( x )</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P(x) )</td>
<td>25/36</td>
<td>10/36</td>
<td>1/36</td>
</tr>
</tbody>
</table>

8. (i) 1/10 (ii) 3/10 (iii) 17/100 (iv) 3/10
9. \( P(-1 \leq x \leq 2) = 0.55 \)

<table>
<thead>
<tr>
<th>( x )</th>
<th>-3</th>
<th>-2</th>
<th>-1</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F(x) )</td>
<td>0.1</td>
<td>0.3</td>
<td>0.5</td>
<td>0.65</td>
<td>0.75</td>
<td>0.85</td>
<td>0.9</td>
<td>1</td>
</tr>
<tr>
<td>( P(x) )</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.15</td>
<td>0.10</td>
<td>0.10</td>
<td>0.05</td>
<td>0.10</td>
</tr>
</tbody>
</table>

10. (i) 11/5, 14/25 (ii) 1/5, 14/25
    (iii) \((n + 1)/2, (n^2 - 1)/12 \) (iv) 2.5, 1.25
11. \( \text{₹} 5.5, \text{₹} 8.25 \)
12. 0, 1
13. (i) 1/2 (ii) 11/16 (iii) 81/128
14. Both probabilities are 1/4 and hence are equal.
15. \( k = \theta, \frac{1}{\theta} \log 2 \)
16. \( k = 1/4, F(2) = \frac{1}{\sqrt{2}}, F(X \geq 1) = 1/2 \)
17. 1/2
1. (i) $2(0.8)^9$ (ii) $1 - (0.8)^{10}$
   (iii) $1 - (8.2)(0.2)^9$
2. (i) $p = 1/2$, $\text{Var}(X) = 2.5$
   (ii) $n = 10$, $p = 1/2$
3. (i) $1/4$, (ii) $1/16$
4. $\frac{128}{625}$
5. 0.784
6. 0.9477
7. 0.3456
8. $\frac{1}{64}$
9. (i) 0.729
10. (i) 0.729 (ii) 0.243
11. (i) 0.4096
   (ii) 0.8192
12. (i) $\frac{560}{2187}$ (ii) $\frac{416}{729}$
13. $m = 1$, $v(x) = 1$
14. $m = 2$
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