MECHANICAL ENGINEERING

Industrial & Maintenance Engineering

Comprehensive Theory
with Solved Examples *and* Practice Questions

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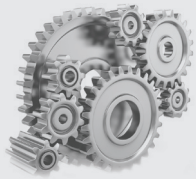
Email : infomep@madeeasy.in | **Web :** www.madeeasypublications.org

Industrial & Maintenance Engineering



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CONTENTS

SECTION A Industrial Engineering

SECTION B Maintenance Engineering

CHAPTER 10

Practices & Principles of Maintenance Engineering 246

CHAPTER 11

Instrumentation and Digital Signal Processing 277

CHAPTER 12

Fundamentals of Vibration, Fault Detection and Signature Analysis 289

CHAPTER

1

Introduction & Break Even Analysis

1.1 INTRODUCTION

Industrial engineering is concerned with bringing together and effective utilization of various resources to facilitate efficient production operation. Effective utilization of resources means that input to the production - operation system (Example: people, material, equipment and information) are used in the correct manner so that they form an integrated combination to meet production or operation objectives.

- Industrial engineering is not only concerned with the system of material, equipment and processes but also with the people interacting with this sytem both from within and from outside. Example: workers and operators with-in the sysem for work study, time and motion study etc. and customers outside the system to determine demand and feedback.
- Industrial engineering is not only restricted to manufacturing but also includes service sectors.

1.2 PRODUCTION

It is a step by step value addition process of converting one form of material into another form to increase the utility of the product for a user.

It should be noted that in a narrow sense production is understood to be producing tangible goods (products) as in manufacturing. However, a new definition also includes intangibles (services).

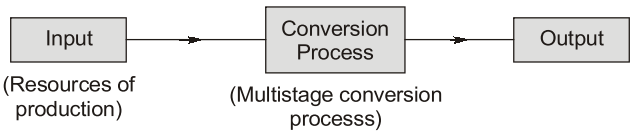


Figure: Production process

Production and operations management concerns itself with the conversion of inputs into outputs, using physical resources, so as to provide the desired utility of form, place, possesion or state or a combination to the customers while meeting the other organisational objectives of effectiveness, efficiency and adaptability.

1.3 PRODUCTION SYSTEM

It is an organised process of converting raw material into final product with a feedback loop.

Production system can be defined as the methods, procedure or arrangement which includes all functions required to accumulate the inputs, processes or reprocess the inputs and deliver the marketable output."

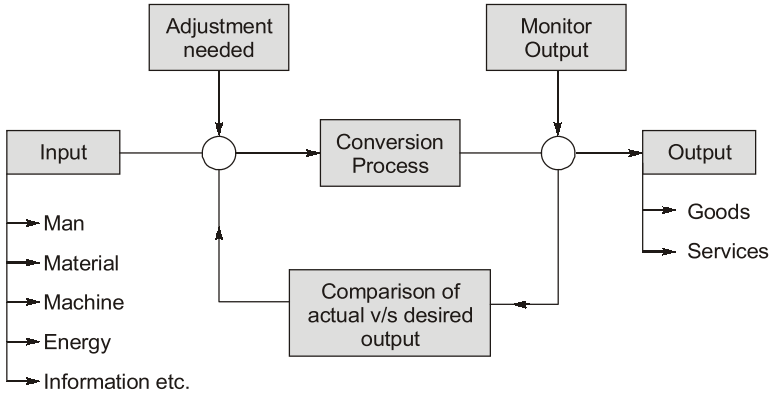


Figure: Production system

It is very crucial to convert resources of production into produced goods economically and efficiently. A measure of effectiveness of production process is productivity.

1.4 PRODUCTIVITY

Production and productivity are two different terms having different meanings. Higher production does not mean higher productivity, and vice versa. Production is related to the activity of producing goods or services. It is a process of converting inputs into some useful, value-added products/services. Productivity is concerned with how effectively the resources are utilized to increase the output of production. The productivity can be improved by increasing the output for same inputs or keeping constant output for decreased amount of inputs or increasing the output in greater proportion than the increase in inputs. Productivity may be calculated using the following formula:

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}}$$

Productivity relates the efficient utilization of input resources for producing goods or services. Production is a measure of the output of volume produced. The emphasis is only on volume of production and not on how well the inputs or resources are utilized. In contrast, productivity emphasizes only on the ratio of the output produced to the inputs used.

1.5 TYPES OF COSTS ASSOCIATED WITH PRODUCTION

(i) Prime or direct cost: Direct costs are incurred in relation to a specific product, process or job. They consist of direct materials, direct labour and direct expenses. The total of all direct costs is called prime cost.

Direct cost = Direct material + Direct labour + Direct expenses (Excise duty, royalty etc.)

(ii) Factory overhead or factory expenses: Indirect costs are general expenses incurred for two or more products, processes or jobs. They include indirect materials, indirect labour and other indirect expenses. The sum of all indirect expenses in relation to production activity is called factory overhead or production overhead.

Factory overhead = Indirect Material + Indirect Labour + Indirect Expenses

- Indirect Material: Not part of final Material Ex.: Cutting fluids, Lubricants, Cotton, Jute, Stationary items.
- Indirect Labour: Ex. Watchman, Supervisor, Higher officials
- Indirect Expenses: Rent of building, telephone bills, facility development and electricity bills

(iii) Factory cost

$$\text{Factory cost} = \text{Prime cost} + \text{Factory overhead}$$

Final cost of product just at the outlet of factory.

(iv) Total cost

Total cost = Factory cost + Marketing, Advertising, Transportation cost etc.

(v) Selling cost

$$\text{Selling cost} = \text{Total cost} + \text{profit}$$

1.6 BREAK EVEN ANALYSIS (BEA)

Cost-volume and profit analysis examines the interaction of a firm's sales volume, selling price, cost structure and profitability. It is a powerful tool in making managerial decisions, for example: minimum number of units to produce to earn profit and number of units to be produced to earn a specific amount of profit and other investment decisions.

Target profit analysis is concerned with estimating the level of sales required to attain a specific target profit whereas break-even is a special case of target profit analysis with zero target profit.

For Break-even analysis costs are divided into variable and fixed elements.

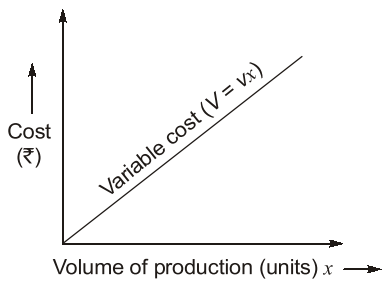
Assumptions of Break even analysis:

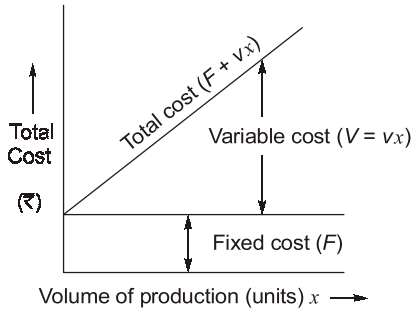
- Selling price is constant.
- Costs are linear and divided into variables and fixed.
- Inventories do not change.
- In multi-product companies, sales mix is constant.

(a) Fixed Cost: This cost remains fixed or constant irrespective of volume of production. It includes cost of machine, rent of building, salary of watchman, higher officials, advertisement cost, insurance cost, interest etc.

(b) Variable Cost ($V = vx$): This cost increases directly and proportionally with the volume of production and it includes direct material, direct labour and running cost.

(c) Total Cost: It indicates the total expenditure made in order to produce a certain number of units and it is the sum of fixed and variable cost.





It comprises of variable and fixed cost elements.

Notations:

F = Fixed cost in rupees; x = Number of units produced in order to earn profit 'P'.

v = Variable cost/unit (₹/unit); V = Total variable cost in ₹ ($v \times x$)

s = Selling price/unit (₹/unit); S = Total sale or revenue in ₹ ($s \times x$)

EXAMPLE : 1.1

A product can be produced by 4 proceses as given below. In order to produce 100 units which process should be preferred?

Process	F(₹)	v (₹/unit)
I	20	3
II	30	2
III	10	4
IV	40	1

(a) Process I (b) Process II

(c) Process III (d) Process IV

Solution: (d)

We know that,

$$TC = F + vx$$

If $x = 100$

(i) $20 + (3 \times 100) = 320$

(ii) $30 + (2 \times 100) = 230$

(iii) $10 + (4 \times 100) = 410$

(iv) $40 + (1 \times 100) = 140$

So, Total cost is minimum for process (iv). So, we will prefer process (iv).

EXAMPLE : 1.2

An organization has decided to produce a new product. Fixed cost for producing the product is estimated as ₹ 100000. Variable cost for producing the product is ₹ 100. Market survey indicated that the product selling price could be ₹ 200. The break even quantity is_____ units.

Solution: (1000)

At break even point

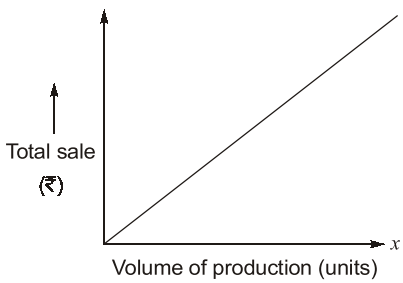
$$\text{Fixed cost} + \text{Variable cost} = \text{Sales}$$

$$100000 + 100x = 200x$$

$$\Rightarrow \quad x = 1000 \text{ units}$$

1.6.1 Total Sales or Revenue

It is directly proportional to the volume of production. Total sale, indicates the return obtained by selling out the quantity to be produced.



1.6.2 Break Even Chart

A break even chart is a chart that shows tha sales volume level at hich total costs equal sales. Brake even point is the volume of production where total sales is equal to the total cost and organisation neither earns profit nor suffers loss. It is also known as no profit and no loss point.

$$\text{Total sale} = \text{Total cost} + \text{profit}$$

$$\text{Total sale} = S = sx$$

$$\text{Total cost} = F + V = F + vx$$

$$\text{Profit} = P$$

$$S = F + vx + P$$

or $$s.x = F + vx + P$$

$$(s - v)x = F + P$$

$$x = \frac{F+P}{(s-v)}$$

Number of units produced for profit 'P'.

$$x = \frac{F+P}{(s-v)}$$

At BEP, Profit, $P = 0$

$$x_{BEP} = \frac{F}{(s-v)} \text{ units}$$

$$(BEP)_{sale} = x_{BEP} \cdot s = \frac{F}{(s-v)} \cdot s$$

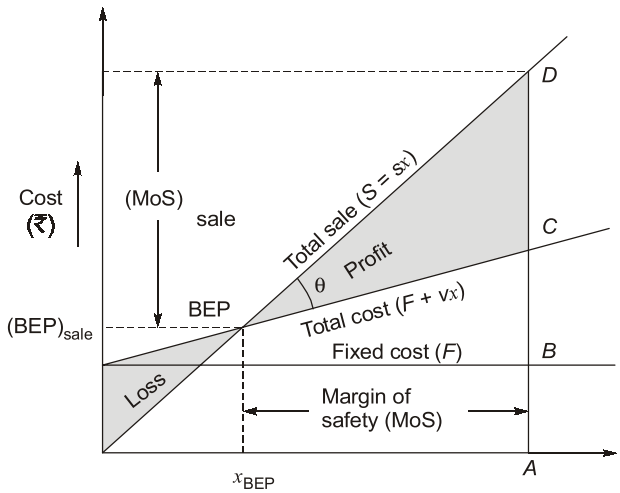


Figure: Break even chart

NOTE: Break even point is least affected by "volume of production". It depends on total cost, selling cost and variable cost.

EXAMPLE : 1.3

Two alternative methods can produce a product, first method has a fixed cost of ₹ 2000 and variable cost of ₹ 20/piece. The second method has fixed cost of ₹ 1500 and variable cost of ₹ 30/piece. The break even quantity between the two alternative is _____ units.

Solution: (50) (50 to 50)

$$2000 + 20x = 1500 + 30x$$

$$10x = 500$$

$$x = 50 \text{ units}$$

EXAMPLE : 1.4

A standard machine tool and an automatic machine tool are being compared for the production of component. Following data refers to the two machine

	Standard machine tool	Automatic machine tool
Setup time	45 min.	2.5 hours
Machining time per piece	25 min.	5 min.
Machine rate	₹ 200/hour	₹ 800/hour

What is the breakeven production batch size above which the automatic machine tool will be economical to use?

(a) 111 units (b) 101 units

(c) 98 units (d) 91 units

Solution: (a)

$$(TC)_1 = \left(\frac{45}{60}+\frac{25}{60}x\right)200$$

$$(TC)_2 = \left(2.5+\frac{5x}{60}\right)800$$

At *BEP*: $(TC)_1 = (TC)_2$

or $$\left(\frac{45}{60}+\frac{25}{60}x\right)200 = \left(2.5+\frac{5x}{60}\right)800$$

or $$\frac{45}{60}+\frac{25x}{60} = 10+\frac{20x}{60}$$

or $5x = 600 - 45 = 555$

or $x = 111$ units

EXAMPLE : 1.5

For production of a toy car the company has three alternatives as shown in the table below:

Method	Fixed cost	Variable cost/unit	Sale/unit
1st	Rs. 1000	Rs. 20	Rs. 20
2nd	Rs. 20000	Rs. 15	Rs. 30
3rd	Rs. 30000	Rs. 10	Rs. 30

For manufacturing 1400 units of toy car which of the above method is used by company?

(a) 1st method (b) 2nd method

(c) 3rd method (d) both 2nd and 3rd method

Solution: (b)

For 1st method, $$\text{BEP} = \frac{10000}{30-20} = 1000 \text{ units}$$

1.6.3 Angle of Incidence (θ)

It is the angle at which total sales line cuts the total cost line on break even chat. A larger θ indicates more profit at a higher rate. A larger angle of incidence at a high margin of safety marks extremely favourable business position.

1.6.4 Contribution Margin

Contribution margin represents the portion of a products sales revenue that is not used up by variable costs and thus available to cover fixed expenses and provide profit to the company.

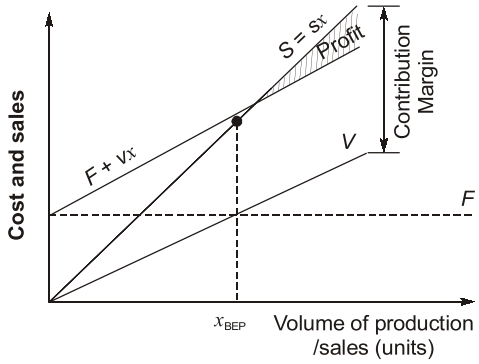


Figure: Contribution margin on break even chart

$$\text{C.M.} = \text{Total sales} - \text{Total variable costs}$$

$$\text{C.M.} = S - V = (s - v) \cdot x$$

$$\text{Contribution} = (s - v)$$

It represents contribution of producing one more unit in our profit $= (s - v)$

Also, $$S = F + V + P$$

$$S - V = F + P = CM$$

$$CM = F + P = (s - v)\, x$$

Also known as marginal profit or gross margin.

1.6.5 Profit-Volume Graph

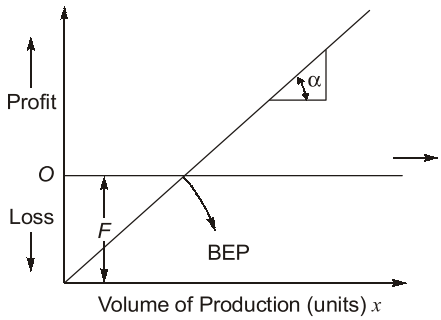


Figure: Profit-volume graph

$$sx = F + vx + P$$

$$P = sx - vx - F = (s - v)\, x - F$$

At $x = 0$, loss will be maximum i.e., equal to fixed cost.

1.6.6 Profit-Volume Ratio

(P/V) ratio: It is a term used to represent profitability related to sales. This ratio always remains constant for a particular product and it is ratio of contribution margin to the volume of sales. It shows the rate at which profit increases with the increases in volume.

$$(P/V)_{\text{ratio}} = \frac{CM}{S}$$

$$(P/V)_{\text{ratio}} = \frac{CM}{S} = \frac{(s - v)}{s} = \frac{F + P}{S}$$

$$\frac{F + P_1}{S_1} = \frac{F + P_2}{S_2}$$

For increasing the sales, highest $(P/V)_{ratio}$ product should be preferred.

For decreasing the sales, lowest $(P/V)_{ratio}$ product should be preferred.

If we want to increase the sales by 1 lakh rupees, then profit will increase maximum for the product which is having highest $(P/V)_{ratio}$.

$$(P/V)_{ratio} = \frac{\Delta P}{\Delta S}$$

1.6.7 Margin of Safety (MOS)

It is the difference of output at full capacity compared to output at break even point. It is the difference between the expected level of sales and break-even sales. It helps in understanding cushion level that the company has and making decision about altering the selling price and investment to increase the sales.

$$(MOS)_{sales} = (Sale)_x - (Sale)_{BEP}$$

$$(MOS)_{sales} = S_x - S_{BEP}$$

$$MOS\% = \left(\frac{S_x - S_{BEP}}{S_x}\right) \times 100$$

REMEMBER

- No. of units to be produced for profit 'P', $x = \frac{F+P}{(s-v)}$
- $x_{BEP} = \frac{F}{(s-v)}$ units
- $(BEP)_{sale} = x_{BEP} \cdot s = \frac{F}{(s-v)} \cdot s$

EXAMPLE : 1.6

A company requires a product for which they have 3 options

(i) Purchase @ ₹10/unit

(ii) Produce by semi-automatic machine; F = ₹ 3400, v = ₹ 6/unit

(iii) Produce by fully automatic machine; F = ₹ 20,200 v = ₹ 3/unit

Find the decision rule.

Solution:

(i) Total cost = $10 \times x$

(ii) Total cost = $3400 + 6x$

(iii) Total cost = $20,200 + 3x$

Taking (i) and (ii) and equating their total cost

$$\Rightarrow \quad 10x = 3400 + 6x$$

$$4x = 3400$$

$$x = 850,$$

means after 850 units process (ii) will be more profitable.

Taking (ii) and (iii) and equating their total cost

$$3400 + 6x = 20,200 + 3x; \quad 3x = 16800$$

$$x = \frac{16800}{3} = 5600,$$

means after 5600 units process (iii) will be more profitable.

At x_1, $(T.C.)_I = (T.C.)_{II}$

$10x = 3400 + 6x$

$4x = 3400$

$x = 850 \rightarrow x_1$

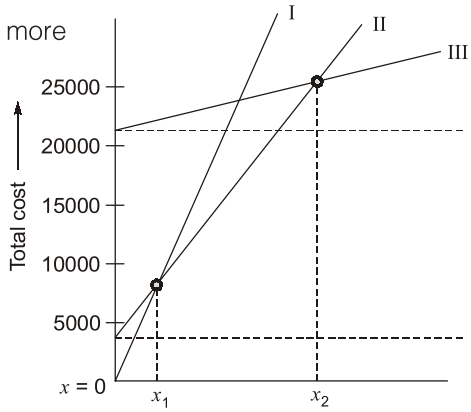
At x_2, $3400 + 6x = 20{,}200 + 3x$

$x = 5600 \rightarrow x_2$

$0 < x \le 850$ = I[st] option

$850 \le x \le 5600$ = II[nd] option

$5600 \le x$ = III[rd] option



EXAMPLE : 1.7

In a production system, fixed cost is ₹ 9000. Total variable cost (V) is ₹ 15000. Total sales ($F + V + P$) is ₹ 30,000 and number of units produced are 5000. Then determine

(i) $(BEP)_{unit}$ (ii) (MoS) (iii) Quantity to be produced for profit of ₹ 30000.

Solution:

F = ₹ 9000; $V = vx$ = ₹ 15000; $x = 5000$; v = ₹ 3; $F + V + P$ = ₹ 30,000

$P = 30000 - 15000 - 9000$ = ₹ 6000

(i) $x_{BEP} = \frac{F}{s - v} = \frac{9000}{6 - 3} = \frac{9000}{3} = 3000$ units

(ii) $(MOS) = (Sales)_x - (Sales)_{BEP}$

$= 30{,}000 - 18000$

= ₹ 12000 $[\because (Sales)_{BEP} = x_{BEP} \times s$ = ₹ 18000$]$

(MOS)% = 40%

(iii) $x = \frac{F + P}{s - v} = \frac{9000 + 30000}{6 - 3} = 13000$ units

■■■■

OBJECTIVE BRAIN TEASERS

Q.1 Two machines of the same production rate are available for use. On machine 1, the fixed cost is ₹ 100 and the variable cost is ₹ 2 per piece produced. The corresponding numbers for the machine 2 are ₹ 200 and ₹ 1 respectively. For certain strategic reasons both the machines are to be used concurrently. The sale price of the first 800 units is ₹ 3.50 per unit and subsequently it is only ₹ 3.00. The breakeven production rate for each machine is

(a) 75 (b) 100
(c) 150 (d) 600

Q.2 A company sells 44,000 units of a product. It has variable cost of ₹ 45 per unit. Fixed cost is ₹ 2,47,000 and the required profit is ₹ 2,23,000, then per unit product price will be_____ ₹. [Correct upto 2 decimal places]

Q.3 If product's demand is price-inelastic, the firm raises the price of the product from ₹ 250 to ₹ 300 with the same variable cost of ₹150 and the unchanged fixed cost of ₹ 1,50,000. The change in *BEP* would be

(a) +500 units (b) +1000 units
(c) –1000 units (d) –500 units

Q.4 The break-even point is least affected by

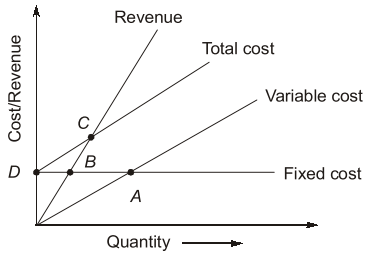
(a) product mix (b) selling price
(c) fixed cost (d) volume of production

Q.5 If the fixed cost of the assets for a given period doubles and selling prices and variable costs decreases by half each, then how much will the break even quantity become?

(a) half (b) same
(c) twice (d) four

Q.6 The fixed cost of ₹ 24000 and a break-even-quantity of 40000 units are estimated for a production. The profit at a sales volume of 50000 units is ____₹. [Round off to nearest integer]

Q.7 Which point will indicate break even point in the figure shown below?



(a) Point A (b) Point B
(c) Point C (d) Point D

Q.8 *ABC* company plan to sell an article at a local market. The article is purchased at ₹ 5. The rent for the space is ₹ 2000. The article will be sold at ₹ 9. If the company sells 750 articles, the margin of safety will be _____ %.

Q.9 Consider the following statements:

1. The break even point can lowered by increasing the variable cost.
2. The shortest processing time prioritization rule is used for reducing a queue size in front of a single server.
3. In a quantity discount model of inventory control, the relevant costs are annual purchase cost, annual order cost and annual carrying cost.

Which of the above statements are correct?

(a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

Q.10 **Statement (I):** At break even point, inventory carrying cost is equal to preparatory cost.
Statement (II): The break-even point can be lowered by reducing the variable cost.

(a) Both Statement (I) and Statement (II) are true and Statement (II) is the correct explanation of Statement (I).
(b) Both Statement (I) and Statement (II) are true but Statement (II) is not a correct explanation of Statement (I).
(c) Statement (I) is true but Statement (II) is false.
(d) Statement (I) is false but Statement (II) is true.

■■■■

ANSWER KEY

1. (a) 2. (55.68) (55 to 60) 3. (d) 4. (d)
5. (d) 6. (6000) (6000 to 6000) 7. (c)
8. (33.3) (32 to 34) 9. (b) 10. (b)

HINTS & EXPLANATIONS

1. (a)

Let n quantities are produced by each machine.

The total cost in production

$= 100 + 2 \times n + 200 + n$

$= 300 + 3n$

For the first 800 units, selling price is 3.50 ₹/Units

Hence for breakeven point

$300 + 3n = 3.5 \times 2n$

$\therefore \quad 7n = 300 + 3n$

or $\quad n = 75$

2. (55.68) (55 to 60)

Let the price be S,

$\text{Profit} = \text{Sales} - \text{Total cost}$

$\Rightarrow \quad P = Sx - (Vx + F)$

$\Rightarrow \quad 223000 = S \times 44000 - (45 \times 44000 + 247000)$

$S = ₹\,55.68$

3. (d)

Profit, $\quad P = Sx - (Vx + F)$

At BEP, $\quad P = 0$

$$\Rightarrow \quad x_{(At\,BEP)} = \frac{F}{S - V}$$

$$BEP_1 = \frac{F}{S - V} = \frac{150000}{250 - 150} = 1500 \text{ units}$$

$$BEP_2 = \frac{1,50,000}{300 - 150} = 1000 \text{ units}$$

Change in $BEP = BEP_2 - BEP_1 = 1000 - 1500$

$= -500$ units

4. (d)

$$BEP = \frac{F}{S - V}$$

So, BEP is dependent on

(i) Fixed cost

(ii) Selling price

(iii) Variable cost which mainly depends on varieties of input i.e. product mix.

5. (d)

$$BEP = \frac{2F}{\frac{S}{2} - \frac{V}{2}} = \left(\frac{4F}{S - V}\right)$$

6. (6000) (6000 to 600)

$$P/V \text{ ratio} = \frac{\text{Fixed cost}}{\text{Break-even-quantity}}$$

$$= \frac{24000}{40000} = \frac{3}{5} = 0.6$$

$$P/V \text{ ratio} = \frac{\text{Fixed cost} + \text{Profit}}{Q}$$

$$0.6 = \frac{24000 + \text{Profit}}{50000}$$

$\text{Profit} = 30000 - 24000 = ₹\,6000$

8. (33.3)(32 to 34)

$$BEP = \frac{F}{S - V} = \frac{2000}{9 - 5} = 500 \text{ units}$$

$$\text{Margin of safety} = \frac{\text{Sales} - \text{Sales at } BEP}{\text{Sales}} \times 100$$

$$= \frac{750 - 500}{750} \times 100 = 33.3\%$$

9. (b)

As BEP $= \frac{F}{s - v}$, so from this equation it is clear that BEP can be lowered by either increasing the selling price or decreasing the variable cost.

10. (b)

As $\quad \text{BEP} = \frac{F}{s - v}$

So, as $\quad v\downarrow = \text{BEP}\downarrow$

■■■■

CONVENTIONAL BRAIN TEASERS

Q.1 The cost of producing between 1500 units and 2500 units of a product consists of Rs. 25,000 fixed cost and Rs. 10 per unit variable cost. With the selling price at Rs. 20 per unit, what is the break-even point? Suppose the price per unit was increased to Rs. 25. Illustrate with a neat sketch how does this affect the break-even point.

Solution:

Given: Fixed cost, $f = 25000$; Variable cost, $v = 10$ per unit, Selling price, $s = 20$

At break-even points,

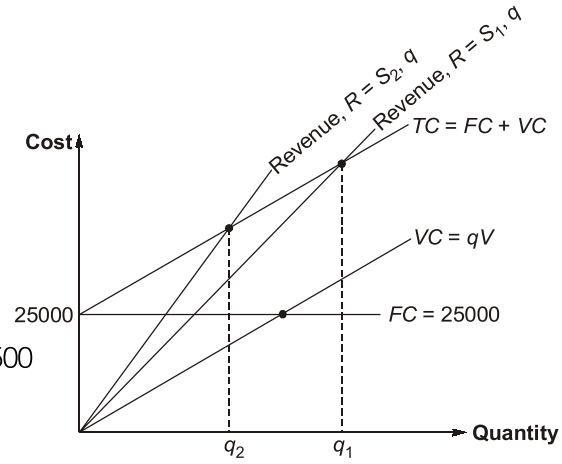
$$\text{Total cost} = \text{Total revenue}$$

$$f + v.q_1 = s.q_1$$

$$\Rightarrow \quad q_1 = \frac{f}{(s-v)} = \frac{25000}{(20-10)} = 2500$$

Now price becomes, $s = 25$

$$\therefore \quad q_2 = \frac{f}{s-v} = \frac{25000}{25-10} = 1667$$



Q.2 Following is information regarding a manufacturing enterprise:
Total fixed costs = Rs. 4,500; Total variable costs = Rs. 7,500; Total sales = Rs. 15,000; Units sold = 5,000
Find out:

(i) Break-even point in units
(ii) Margin of safety
(iii) Profit
(iv) Volume of sales to earn a profit of Rs 6,000

Solution:

Given: Total fixed cost, $f = 4500$, Total variable cost, $v = 7500$, Total sales, $s = 15000$, Units sold = 5000

$$\therefore \quad \text{Selling price of one unit, } s = \frac{15000}{5000} = 3$$

$$\text{Variable cost of one unit, } v = \frac{75000}{5000} = 1.5$$

(i) Break - even points,

$$F_c + q \cdot v = s \cdot q$$

$$\Rightarrow \quad q = \frac{FC}{(s-v)} = \frac{4500}{(3-1.5)} = 3000$$

(ii) Margin safety = Budgeted sale – Breakeven sales

Sales = $15000 - (3000 \times 3) = 6000$

$$\text{Margin of safety ratio} = \frac{\text{Margin safety}}{\text{Budgeted sale}} \times 100 = \frac{6000}{15000} \times 100 = 40\%$$

(iii) Profit = Total sales – Total cost
= 15000 – (4500 + 7500) = 3000

(iv) $6000 = 3q - (4500 + 1.5q)$

$\Rightarrow q = 7000$ units.

Q.3 Three processes viz. automatic, semi-automatic and manual can be used to produce an item. The initial annual fixed cost and variable cost/unit for each of them is given below:

Process	Actual fixed cost ₹	Variable cost / unit ₹
Automatic A	2,50,000	10
Semi-automatic S	1,50,000	20
Manual M	50,000	60

(i) Draw the total annual cost curves for the processes.

(ii) Find the range of production volume for each process when it is most economical.

(iii) Which process will you recommend if the forecasted production is 8000 units/annum?

(iv) What is the most economic unit cost if the production is 8000 units/annum?

Solution:

(i) Total annual cost,

$T_A = 250000 + 10q$ ... (i)

$T_B = 150000 + 20q$ ... (ii)

$T_C = 50000 + 60q$ ... (iii)

(ii) Range of production volume

From (i) and (ii)

$\Rightarrow T_A = T_B$

$\Rightarrow 250000 + 10q = 150000 + 20q$

$\Rightarrow q_{AB} = 10000$

From (ii) and (iii)

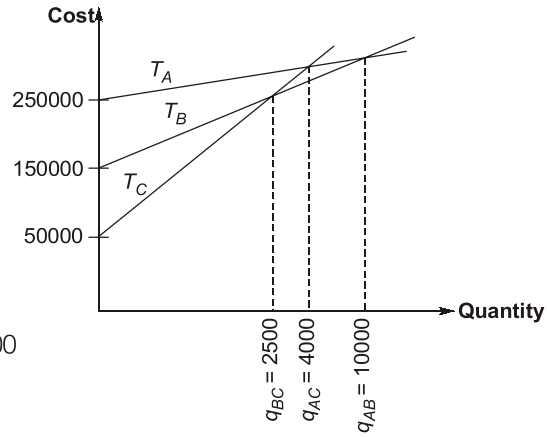
$\Rightarrow T_B = T_C$

$\Rightarrow q_{BC} = 2500$

From (i) and (iii)

$\Rightarrow T_A = T_C$

$\Rightarrow q_{AC} = 4000$



(iii) for $q = 8000$ units/annum, Machine 'B' should be recommended.

(iv) Total cost, $T_B = 150000 + 20 \times 8000$
$= 310000$

$\therefore$ Unit production cost $= \dfrac{310000}{8000} = 38.75$

Range	Most economical
$0 \le q \le 2500$	C
$2500 \le q \le 4000$	B
$4000 \le q \le 10000$	B
$q \ge 10000$	A

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