Engineering Management

Strategic Capacity Planning for Products and Services

Capacity Planning

- **Capacity** refers to an upper limit or ceiling on the load that an operating unit can handle.

  - The load might be in terms of the number of **physical units produced** (e.g., bicycles assembled per hour) or the number of **services performed** (e.g., computers upgraded per hour).

  - The operating unit might be a **plant**, **department**, **machine**, **store**, or **worker**.

  - Capacity needs include **equipment**, **space**, and **employee skills**.

Capacity Planning

- The key questions in capacity planning are the following:
  - What kind of capacity is needed?
  - How much is needed to match demand?
  - When is it needed?

Capacity Decisions are Strategic

- For several reasons, capacity decisions are among the most fundamental of all the design decisions that managers must make.
- In fact, capacity decisions can be critical for an organization.

Capacity Decisions are Strategic

- Capacity decisions have a real impact on the ability of the **organization to meet future demands for products and services**; capacity essentially limits the rate of output possible.
- Capacity decisions affect **operating costs**. Ideally, capacity and demand requirements will be matched, which will tend to minimize operating costs.
- Capacity is usually a major determinant of the **initial cost**.

Typically, the greater the capacity of a productive unit, the greater its cost.

Capacity Decisions are Strategic

- Capacity decisions often involve a **long-term commitment of resources**, and once they are implemented, those decisions may be difficult or impossible to modify without incurring major costs.
- Capacity decisions can affect **competitiveness**. If a firm has excess capacity, or can quickly add capacity, that fact may serve as a barrier to entry by other firms. Then, too, capacity can affect delivery speed, which can be a competitive advantage.

Capacity Decisions are Strategic

- Capacity affects the **ease of management**; having appropriate capacity makes management easier than when capacity is mismatched.
- **Globalization has increased the importance and the complexity of capacity decisions**. Far-flung supply chains and distant markets add to the uncertainty about capacity needs.

Capacity Decisions are Strategic

- Because capacity decisions often involve **substantial financial and other resources**, it is necessary to plan for them far in advance.

For example, it may take years for a new power-generating plant to be constructed and become operational.

However, this increases the risk that the designated amount of capacity will not match actual demand or reserve requirements when the capacity becomes available.

DEFINING AND MEASURING CAPACITY

Useful Definitions of Capacity

- **Design capacity:** The maximum output rate or service capacity an operation, process, or facility is designed for.
- **Effective capacity:** Design capacity minus allowances such as personal time, preventive maintenance, and scrap.

The design capacity is the maximum rate of output achieved under ideal conditions.

Effective capacity is always less than design capacity, owing to the realities of changing product mix, the need for periodic maintenance of equipment, lunch breaks, coffee breaks, problems in scheduling and balancing operations, and similar circumstances.

Useful Definitions of Capacity

👉 **Actual output** cannot exceed effective capacity and is often less because of machine breakdowns, absenteeism, shortages of materials, and quality problems, as well as factors that are outside the control of the operations managers.

Useful Definitions of Capacity

These different measures of capacity are useful in defining two measures of system effectiveness: **efficiency** and **utilization**.

- ☛ **Efficiency** is the ratio of actual output to effective capacity.
- ☛ **Capacity utilization** is the ratio of actual output to design capacity.

Computing Capacity and Utilization

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

$$\text{Utilization} = \frac{\text{Actual Output}}{\text{Design Capacity}} \times 100\%$$

Both measures are expressed as percentages.

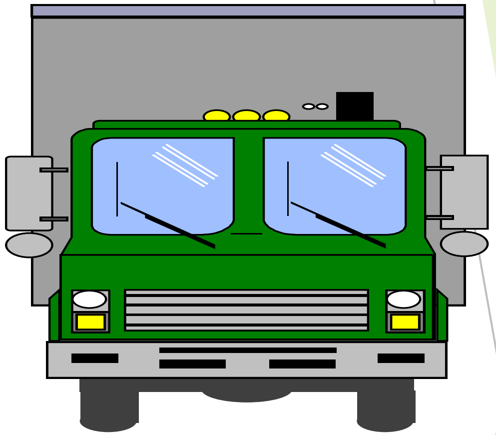
Computing Capacity and Utilization

Given the following information, compute the efficiency and utilization of the vehicle repair department:

Design capacity = 50 trucks per day

Effective capacity = 40 trucks per day

Actual output = 36 trucks per day



$$\text{Efficiency} = \frac{\text{Actual output}}{\text{Effective capacity}} \times 100\% = \frac{36 \text{ trucks per day}}{40 \text{ trucks per day}} \times 100\% = 90\%$$

$$\text{Utilization} = \frac{\text{Actual output}}{\text{Design capacity}} \times 100\% = \frac{36 \text{ trucks per day}}{50 \text{ trucks per day}} \times 100\% = 72\%$$

Computing Capacity and Utilization

- Compared to the effective capacity of 40 units per day, 36 units per day looks pretty good.
- However, compared to the design capacity of 50 units per day, 36 units per day is much **less impressive**, although probably more meaningful.
- Because effective capacity acts as a lid on actual output, the real key to improving capacity utilization is to increase effective capacity by correcting quality problems, maintaining equipment in good operating condition, fully training employees, and improving bottleneck operations that constrain output.
- **Eliminating waste**, which is a key aspect of a lean operation, can also help to improve effective capacity.

Determinants of Effective Capacity

Determinants of Effective Capacity

- **Facilities**

The **design of facilities**, including size and provision for expansion, is key.

Locational factors, such as transportation costs, distance to market, labor supply, energy sources, and room for expansion, are also important.

Likewise, the layout of the work area often determines how smoothly work can be performed, and environmental factors such as heating, lighting, and ventilation also play a significant role in determining whether personnel can perform effectively or whether they must struggle to overcome poor design characteristics.

Determinants of Effective Capacity

- **Product and Service Factors**

Product or service design can have a tremendous influence on capacity.

For example, when items are similar, the ability of the system to produce those items is generally much greater than when successive items differ.

Thus, a restaurant that offers a limited menu can usually prepare and serve meals at a faster rate than a restaurant with an extensive menu.

Generally speaking, the more uniform the output, the more opportunities there are for the standardization of methods and materials, which leads to greater capacity.

Determinants of Effective Capacity

- **Process Factors**

instance, if the quality of output does not meet standards, the rate of output will be slowed by the need for inspection and rework activities. Productivity also affects capacity.

Process improvements that increase quality and productivity can result in increased capacity.

Also, if multiple products or multiple services are processed in batches, the time to change equipment settings must be taken into account.

The quantity capability of a process is an obvious determinant of capacity.

A more subtle determinant is the influence of output quality.

Determinants of Effective Capacity

- **Human Factors**

The tasks that make up a job, the variety of activities involved, and the training, skill, and experience required to perform a job all have an impact on the potential and actual output.

In addition, employee motivation has a very basic relationship to capacity, as do absenteeism and labor turnover.

- **Policy Factors**

Management policy can affect capacity by allowing or not allowing capacity options such as overtime or second or third shifts.

Determinants of Effective Capacity

- **Operational Factors**

Scheduling problems may occur when an organization has differences in equipment capabilities among alternative pieces of equipment or differences in job requirements.

Inventory stocking decisions, late deliveries, purchasing requirements, acceptability of purchased materials and parts, and quality inspection and control procedures also can have an impact on effective capacity.

Inventory shortages of even one component of an assembled item (e.g., computers, refrigerators, automobiles) can cause a temporary halt to assembly operations until the components become available.

This can have a major impact on effective capacity.

Thus, insufficient capacity in one area can affect overall capacity.

Determinants of Effective Capacity

Supply Chain Factors

Supply chain factors must be considered in capacity planning if substantial capacity changes are involved.

Key questions include:

What impact will the changes have on suppliers, warehousing, transportation, and distributors?

If capacity is increased, will these elements of the supply chain be able to handle the increase?

Conversely, if capacity is to be decreased, what impact will the loss of business have on these elements of the supply chain?

Determinants of Effective Capacity

- **External Factors**

Product standards, especially minimum quality and performance standards, can restrict management's options for increasing and using capacity.

Thus, pollution standards on products and equipment often reduce effective capacity, as does paperwork required by government regulatory agencies by engaging employees in non-productive activities.

Calculating Processing Requirements

Calculating Processing Requirements

- A necessary piece of information is the capacity requirements of products that will be processed.
- To get this information, one must have reasonably accurate demand forecasts for each product and know the standard processing time per unit for each product, the number of work days per year, and the number of shifts that will be used.

Determining Needed Capacity

Determining Needed Capacity

A department works one 8-hour shift, 250 days a year, and has these figures for usage of a machine that is currently being considered:

Product	Annual Demand	Standard Processing Time per Unit (hr)	Processing Time Needed (hr)
1	400	5.0	2,000
2	300	8.0	2,400
3	700	2.0	1,400
			5,800

$$\text{Units of capacity needed} = \frac{\text{Processing time needed}}{\text{Processing time capacity per unit}} \qquad (5\text{–}3)$$

Working one 8-hour shift 250 days a year provides an annual capacity of $8 \times 250 = 2{,}000$ hours per year. Consequently, three of these machines would be needed to handle the required volume:

$$\frac{5{,}800 \text{ hours}}{2{,}000 \text{ hours/machine}} = 2.90 \text{ machines}$$

Evaluating Alternatives

Evaluating Alternatives

- A number of techniques are useful for evaluating capacity alternatives from an economic standpoint.
- Some of the more common are cost–volume analysis, financial analysis, decision theory, and waiting-line analysis.

Cost-Volume Analysis

- **Cost–volume analysis** focuses on relationships between cost, revenue, and volume of output.
  - The purpose of cost–volume analysis is to estimate the income of an organization under different operating conditions.
  - It is particularly useful as a tool for comparing capacity alternatives.

Cost-Volume Analysis

- The use of the technique requires the identification of all costs related to the production of a given product.
- These costs are then designated as **fixed costs** or **variable costs**.
- **Fixed costs** tend to remain constant regardless of the volume of output.
- Examples include rental costs, property taxes, equipment costs, heating and cooling expenses, and certain administrative costs.

Cost-Volume Analysis

- **Variable costs** vary directly with volume of output.
- The major components of variable costs are generally materials and labor costs.
- We will assume that variable cost per unit remains the same regardless of volume of output, and that all output can be sold.

Cost-Volume Analysis

☛ The total cost associated with a given volume of output is equal to the sum of the fixed cost and the variable cost per unit times volume:

$$TC = FC + VC$$

$$VC = Q \times v$$

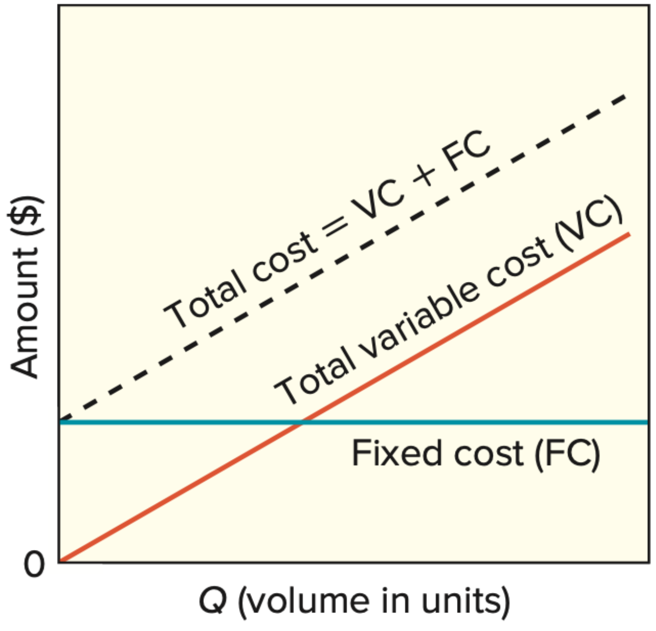
where v = variable cost per unit

Cost-Volume Analysis

☛ Figure 5.6A shows the relationship between the volume of output and fixed costs, total variable costs, and total (fixed plus variable) costs.

FIGURE 5.6

Cost–volume relationships

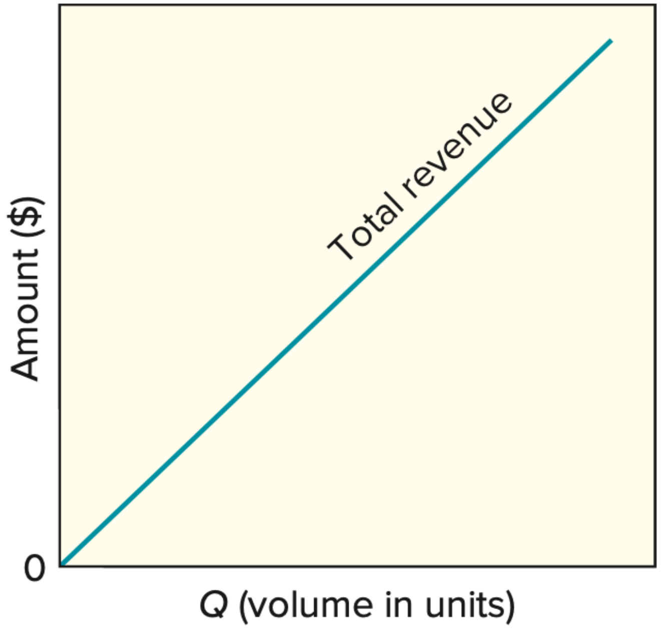


A. Fixed, variable, and total costs

Cost-Volume Analysis

- Revenue per unit, like variable cost per unit, is assumed to be the same regardless of the quantity of output.
- Total revenue will have a linear relationship to output, as illustrated in Figure 5.6B.
- The total revenue associated with a given quantity of output, Q, is

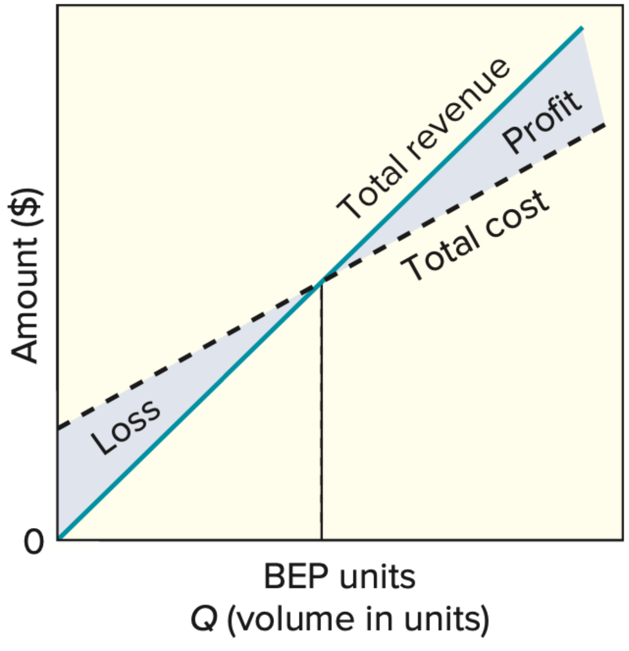
$TR = R \times Q$



B. Total revenue increases linearly with output

Cost-Volume Analysis

- Figure 5.6C describes the relationship between profit - which is the difference between total revenue and total (i.e., fixed plus variable) cost and volume of output.
- The volume at which total cost and total revenue are equal is referred to as the **break-even point (BEP)**
- When volume is less than the break-even point, there is a loss; when the volume is greater than the break-even point, there is a profit.
- The greater the deviation from this point, the greater the profit or loss.



C. Profit = TR − TC

Cost-Volume Analysis

- Figure shows the total profit or loss relative to the break-even point.
- Figure can be obtained from Figure 5.6C by drawing a horizontal line through the point where the total cost and total revenue lines intersect.
- Total profit can be computed using the formula

$$P = TR - TC \quad R \times Q - (FC + v \times Q)$$

Rearranging terms, we have

$$P = Q(R - v) - FC$$

The difference between revenue per unit and variable cost per unit,

$R - v$, is known as the **contribution margin**.

Cost-Volume Analysis

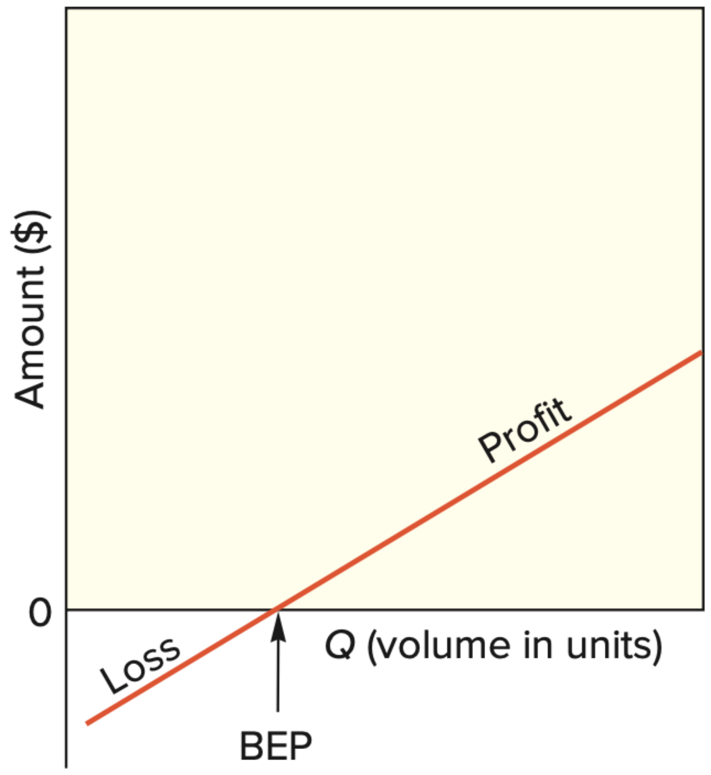
The required volume, Q, needed to generate a specified profit is

$$Q = \frac{P + FC}{R - v}$$

A special case of this is the volume of output needed for total revenue to equal total cost.

This is the break-even point, computed using the formula

$$Q_{BEP} = \frac{FC}{R - v}$$



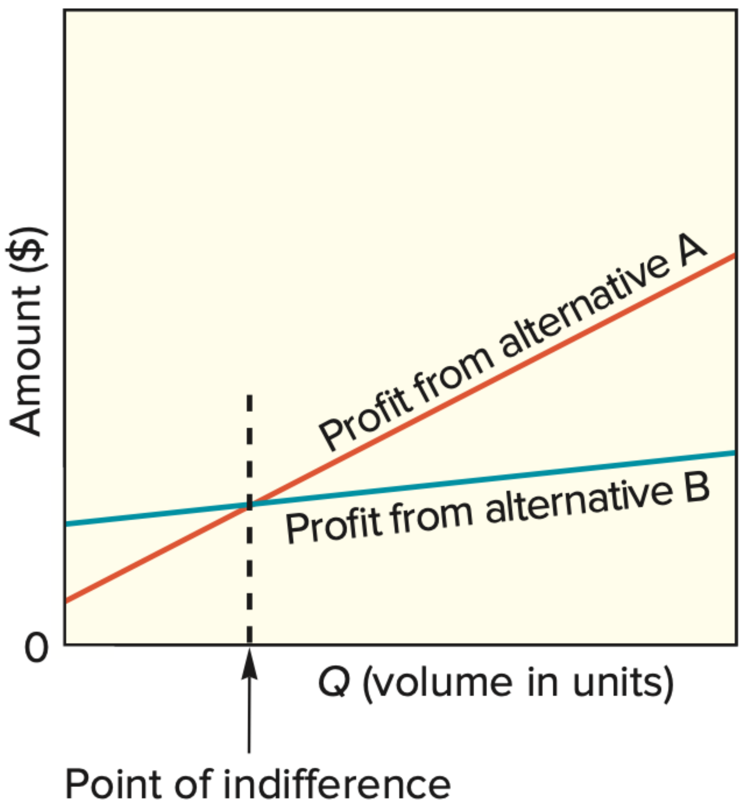
D. Profit versus loss

Cost-Volume Analysis

Different alternatives can be compared by plotting the profit lines for the alternatives, as shown.

The figure illustrates the concept of an **indifference point** the quantity at which a decision maker would be indifferent between two competing alternatives.

In this illustration, a quantity less than the point of indifference would favor choosing alternative B because its profit is higher in that range, while a quantity greater than the point of indifference would favor choosing alternative A.



E. Point of indifference for two alternatives

Cost volume analysis (Contd.)

1. Total Cost (TC) = Fixed Cost (FC) + Variable Cost (VC)
2. Profit (P) = Rev-Costs= QR-Qv-FC= Q (R – v) – FC

   Q(R-v) = P+FC Hence Q= (P+FC)/(R-v)

1. Quantity to generate specific profit, Q = (P + FC) / (R – v)
2. Q_{BEP} = FC / (R – v) As at BEP P=0

Where,

v = Variable cost per unit

R = Price per unit (Also called revenue)

Cost-Volume Analysis

Break-even Point and Profit Analysis

The owner of Old-Fashioned Berry Pies, S. Simon, is contemplating adding a new line of pies, which will require leasing new equipment for a monthly payment of $6,000. Variable costs would be $2 per pie, and pies would retail for $7 each.

a. How many pies must be sold in order to break even?
b. What would the profit (loss) be if 1,000 pies are made and sold in a month?
c. How many pies must be sold to realize a profit of $4,000?
d. If 2,000 can be sold, and a profit target is $5,000, what price should be charged per pie?

Cost-Volume Analysis

Break-even Point and Profit Analysis

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SOLUTION

$$\text{FC} = \$6{,}000, \text{VC} = \$2 \text{ per pie}, \text{R} = \$7 \text{ per pie}$$

a. $$Q_{\text{BEP}} = \frac{\text{FC}}{\text{R} - \text{VC}} = \frac{\$6{,}000}{\$7 - \$2} = 1{,}200 \text{ pies/month}$$

b. For $Q = 1{,}000$, $P = Q(R - v) - \text{FC} = 1{,}000\,(\$7 - \$2) - \$6{,}000 = -\$1{,}000$

c. $P = \$4{,}000$; solve for Q using Formula 5–8:

$$Q = \frac{\$4{,}000 + \$6{,}000}{\$7 - \$2} = 2{,}000 \text{ pies}$$

d. $$\text{Profit} = Q(R - v) - \text{FC}$$

$$\$5{,}000 = 2{,}000(R - \$2) - \$6{,}000$$

$$R = \$7.50$$

Do it In-house or Outsource It?

SOLVED PROBLEMS

Problem 1

eXcel

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A firm's manager must decide whether to make or buy a certain item used in the production of vending machines. Making the item would involve annual lease costs of $150,000. Cost and volume estimates are as follows:

	Make	Buy
Annual fixed cost	$150,000	None
Variable cost/unit	$ 60	$ 80
Annual volume (units)	12,000	12,000

a. Given these numbers, should the firm buy or make this item?

b. There is a possibility that volume could change in the future. At what volume would the manager be indifferent between making and buying?

Solution

a. Determine the annual cost of each alternative:

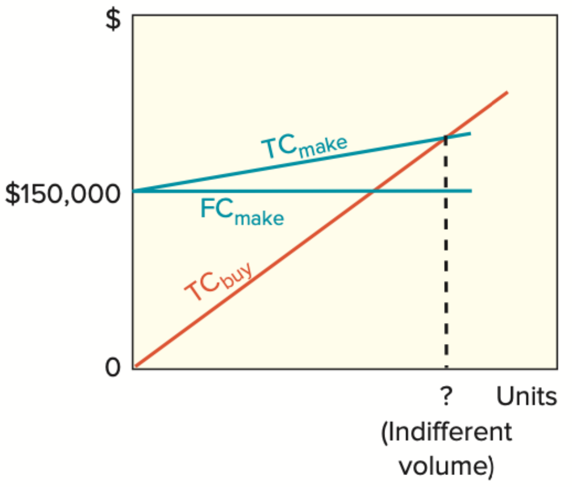
Total cost = Fixed cost + Volume × Variable cost

Make: $150, 000 + 12,000($60) = $870,000

Buy: 0 + 12,000($80) = $960,000

Because the annual cost of making the item is less than the annual cost of buying it, the manager would reasonably choose to make the item. *Note:* If the unit cost to buy had been *less than* the *variable cost* to make, there would be no need to even consider fixed costs; it would simply have been better to buy.

b. To determine the volume at which the two choices would be equivalent, set the two total costs equal to each other and solve for volume: $TC_{make} = TC_{buy}$. Thus, $150,000 + Q($60) = 0 + Q($80). Solving, Q = 7,500 units. Therefore, at a volume of 7,500 units a year, the manager would be indifferent between making and buying. For lower volumes, the choice would be to buy, and for higher volumes, the choice would be to make.



Problem 2

eXcel

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A small firm produces and sells automotive items in a five-state area. The firm expects to consolidate assembly of its battery chargers line at a single location. Currently, operations are in three widely scattered locations. The leading candidate for location will have a monthly fixed cost of $42,000 and variable costs of $3 per charger. Chargers sell for $7 each. Prepare a table that shows total profits, fixed costs, variable costs, and revenues for monthly volumes of 10,000, 12,000, and 15,000 units. What is the break-even point?

Solution

$$\begin{aligned}
\text{Revenue} &= \$7 \text{ per unit} \\
\text{Variable cost} &= \$3 \text{ per unit} \\
\text{Fixed cost} &= \$42,000 \text{ per month} \\
\text{Profit} &= Q(R - v) - \text{FC} \\
\text{Total cost} &= \text{FC} + v + Q
\end{aligned}$$

Volume	Total Revenue	Total VC	Fixed Cost	Total Cost	Total Profit
10,000	$ 70,000	$30,000	$42,000	$72,000	$(2,000)
12,000	84,000	36,000	42,000	78,000	6,000
15,000	105,000	45,000	42,000	87,000	18,000

$$Q_{\text{BEP}} = \frac{\text{FC}}{R - v} = \frac{\$42,000}{\$7 - \$3} = 10,500 \text{ units per month}$$

Problem 3

Refer to Problem 2. Determine profit when volume equals 22,000 units.

Solution

$$\text{Profit} = Q(R - v) - \text{FC} = Q(\$7 - \$3) - \$42{,}000 = \$4Q - \$42{,}000$$

For $Q = 22{,}000$, profit is

$$\$4(22{,}000) - \$42{,}000 = \$46{,}000$$

Sample Practice#1

A small firm intends to increase the capacity of a bottleneck operation by adding a new machine.

The annual fixed cost would be Tk. 42,000/-, variable cost per unit would be Tk. 15/- and revenue per unit would be Tk. 22/-.

i. Write down the cost, revenue, and profit function.
ii. What annual volume is required to break even?
iii. What would be the profit if 5,000 units were made?
iv. How many units must be sold to realize a profit of Tk. 7,000/-?
v. 1000 units can be sold and profit target is Tk. 4,000/-, what price should be charged per unit?

Sample Practice#1 (Contd.)

(i) No of units produced and sold = **q**

Cost Function, $C(q) = FC+VC$

$= \mathbf{42{,}000+15q}$

Revenue Function, $R(q) = \mathbf{22q}$

Profit function $P(q) = R-C = 22q - (42{,}000 + 15q)$

$= 22q - 42{,}000 - 15q$

$= \mathbf{7q - 42{,}000}$

Sample Practice#1 (Contd.)

(ii) For break even, R=C

Q_{BEP} = FC/R-V

= 42,000/22 - 15

= 6,000 units

(iii) P = Q (R-V) - FC

= 5,000 (22-15) – 42,000

= 5,000 (7) – 42,000 = 35,000 – 42,000 = **-7,000**

if 5,000 units are sold there will be no profit rather loss of Tk. 7,000/-

Sample Practice#1 (Contd.)

(iv) $\mathbf{Q = \dfrac{P + FC}{R - v}}$

$= \dfrac{7{,}000+42{,}000}{22-15}$

$= \dfrac{49{,}000}{7}$

Q = 7,000 units

To make a profit of Tk. 7,000/-, 7,000 units must be sold.

(v) Given, Q=1000 units and Profit, P= Tk. 4,000/-

$P = Q\,(R - v) - FC$

$4000=1000(R - 15) - 42000$

$4000= 1000R - 15000 - 42000 = 1000R= 4000+57000$

$R= 61000/1000$ **R= Tk. 61**

To sell 1000 units and to make a profit of Tk. 4,000/-, the selling price per unit must be Tk. 61/-.

Sample Practice#2

A producer of pottery is considering the addition of a new plant to absorb the backlog of demand that now exists. The primary location being considered will have fixed costs of $9,200 per month and variable costs of 70 cents per unit produced. Each item is sold to retailers at a price that averages 90 cents.

a. What volume per month is required in order to break even?

b. What profit would be realized on a monthly volume of 61,000 units? 87,000 units?

c. What volume is needed to obtain a profit of $16,000 per month?

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(i) For break even, R=C

Q_{BEP} = FC/R-V

= 9,200/0.90-0.70

= 46,000 units

(iia) P = Q (R-V) - FC

= 61000 (0.90-0.70) – 9,200

=\$ 3,000/-

(iib) P = Q (R-V) - FC

= 87,000 (0.90-0.70) – 9,200

=\$ 8,200/-

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a. What volume per month is required in order to break even?

b. What profit would be realized on a monthly volume of 61,000 units? 87,000 units?

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(iii) $$Q = \frac{P + FC}{R - v}$$

$$Q = \frac{16{,}000 + 9{,}200}{0.9 - 0.7}$$

$Q = 25{,}200/0.2$ = **126,000 units**

In order to make a profit of \$16,000/- per month, 126,000 units must be sold.

Sample Practice#3

A producer of felt-tip pens has received a forecast of demand of 30,000 pens for the coming month from its marketing department. Fixed costs of $25,000 per month are allocated to the felt-tip operation, and variable costs are 37 cents per pen.

a. Find the break-even quantity if pens sell for $1 each.

b. At what price must pens be sold to obtain a monthly profit of $15,000, assuming that estimated demand materializes?

Sample Practice#3 (Contd.)

A producer of felt-tip pens has received a forecast of demand of 30,000 pens for the coming month from its marketing department. Fixed costs of $25,000 per month are allocated to the felt-tip operation, and variable costs are 37 cents per pen.

a. Find the break-even quantity if pens sell for $1 each.

b. At what price must pens be sold to obtain a monthly profit of $15,000, assuming that estimated demand materializes?

(i) For break even, R=C

Q_{BEP} = FC/R-V

= 25000/1 – 0.37

= 39,683 pens

(ii) Given, Q=30000 units and Profit, P= $15,000/-

P = Q (R – v) – FC

15,000=30,000(R -0.37) – 25,000

15,000= 30000R – 11,100 – 25,000

30,000R= 15,000+36,100

R= 51,100/30000 **R= $1.71**

To sell 30,000 pens, the company needs to sell at $1.71/- to make a profit of $15,000/-.

Sample Practice#4

Haripur Power Plant procures electricity.

Design capacity= 360 MW

Effective Capacity= 340 MW

Actual Output= 330 MW

Compute Efficiency and Utilization.

$$\text{Efficiency} = \frac{Actual\ Output}{Effective\ Capacity} = \frac{330}{340} \times 100\% = 97.06\%$$

$$\text{Utilization} = \frac{Actual\ Output}{Design\ Capacity} = \frac{330}{360} \times 100\% = 91.67\%$$

Sample Practice#5

A company produces 5 different types of product.

Product: A **Annual demand:** 400 units **Processing time per unit**: 3 hours

Product: B **Annual demand:** 370 units **Processing time per unit**: 2 hours

Product: C **Annual demand:** 430 units **Processing time per unit**: 8 hours

Product: D **Annual demand:** 200 units **Processing time per unit**: 5 hours

Product: E **Annual demand:** 600 units **Processing time per unit**: 10 hours

Machine annual capacity is 3500 hrs.

How many Machines/ equipment will be needed to meet the annual demand for these 5 products?

Sample Practice#5 (Contd.)

<u>Solution:</u>

Total processing time for Product A: 400 × 3= 1200 hours

Total processing time for Product B: 370 × 2= 740 hours

Total processing time for Product C: 430 × 8= 3440 hours

Total processing time for Product D: 200 × 5= 1000 hours

Total processing time for Product E: 600 × 10= 6000 hours

No of machines required=

$$\frac{Total\ Processing\ time}{Annual\ Capacity\ of\ the\ machine}$$

$$= \frac{1200+740+3440+1000+6000}{3500} = 3.54 = 4 \text{ machines}$$

END OF THE CHAPTER…