

# Course Title

## Engineering Economic Analysis

### Chapter 5

#### Replacement Analysis

#### Lecture 9 (Week 9)

### Approach for comparing defender and challenger, economic service life, replacement analysis under infinite and finite planning horizon

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#### **Learning Objective**

From studying this chapter the students will be able to understand on the topics:

- Approach for comparing defender and challenger
- Economic service life of a defender and challenger
- Replacement analysis under the infinite planning horizon
- Replacement analysis under the finite planning horizon

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## 5.7 Approach for Comparing Defender and Challenger

In previous lecture we have discussed about the basic concept of replacement analysis including the reasons for investment as well as the terminologies associated with it. We are going to learn about the remaining topics regarding the replacement analysis under this lecture. Replacement analysis is the economic comparison between the existing asset (defender) and the new asset (challenger). The decision in the replacement analysis is to make whether the existing equipment should be retained or replaced by the new equipment?

The first step in the replacement analysis is to identify the participants (defender and challenger). Challenger is chosen from a mutually exclusive set of challengers. Best challenger should be chosen based on challengers minimum cost life. Economic comparison is made between defender and chosen challenger to decide whether to continue with defender or replace it by new challenger.

Two basic approaches are considered for the analysis of replacement decision.

### (a) Cash Flow approach

### (b) Opportunity Cost approach

The analysis is made where the defender and the challenger have the same useful life. Presumably the defender has been around for a while before this time, and the required service period for the defender is relatively short. [1]

### (a) Cash Flow approach

In a cash flow approach, proceeding from the sale of the old machine is treated as down payment towards purchasing the new machine. This approach is meaningful when both the defender and challenger have same useful life. Net present worth method and annual equivalent worth method is used for the comparison.

### (b) Opportunity Cost approach

In an opportunity cost approach, proceedings from the sale of old machine is treated as the investment required to keep the old machine. Also known as the 'outsider viewpoint' because it represent the view of an impartial third party to establish the fair market value of used asset. [2] If the current market value of the defender is assigned to the defender then it cannot also be assigned as a benefit in regard to the challenger. This approach is more commonly practiced in replacement analysis.

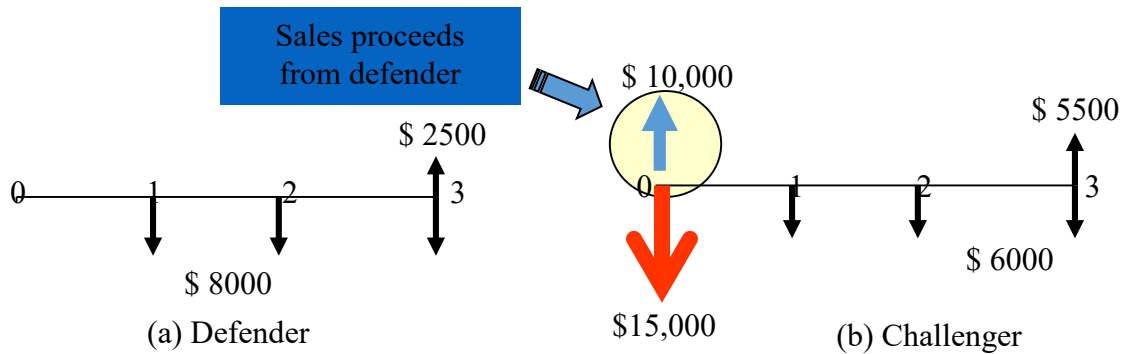
### Example 5.1 [1]

Decide whether replacement is justified for using cash flow and opportunity cost approach.

Defender	Challenger
Market Price = \$ 10,000	Initial Cost = \$15,000

Remaining Useful life = 3 years	Useful Life = 3 Years
Salvage Value = \$ 2500	Salvage Value = \$ 5,500
Operation and Maintenance cost = \$ 8000	Operation and Maintenance = \$ 6,000
MARR = 12%	

(a) From Cash Flow Approach



**Fig 5.1: Cash Flow Approach [1]**

Defender:

$$\begin{aligned} PW (12\%)_D &= \$ 2,500 (P/F, 12\%, 3) - \$ 8,000 (P/A, 12\%, 3) \\ &= - \$ 17,434.90 \end{aligned}$$

$$\begin{aligned} AW (12\%)_D &= PW (12\%)_D (A/P, 12\%, 3) \\ &= -\$7,259.10 \end{aligned}$$

Challenger:

$$\begin{aligned} PW (12\%)_C &= \$ 5,500 (P/F, 12\%, 3) - \$ 5,000 - \$ 6,000 (P/A, 12\%, 3) \\ &= - \$ 15,495.90 \end{aligned}$$

$$\begin{aligned} AW (12\%)_C &= PW (12\%)_C (A/P, 12\%, 3) \\ &= - \$ 6,451.79 \end{aligned}$$

**Here AW of Challenger is greater than Defender, replace the defender.**

(b) From Opportunity Cost Approach

Defender:

$$\begin{aligned} PW (12\%)_D &= - \$ 10,000 - \$ 8,000(P/A, 12\%, 3) + \$ 2,500(P/F, 12\%, 3) \\ &= - \$ 27,434.90 \end{aligned}$$

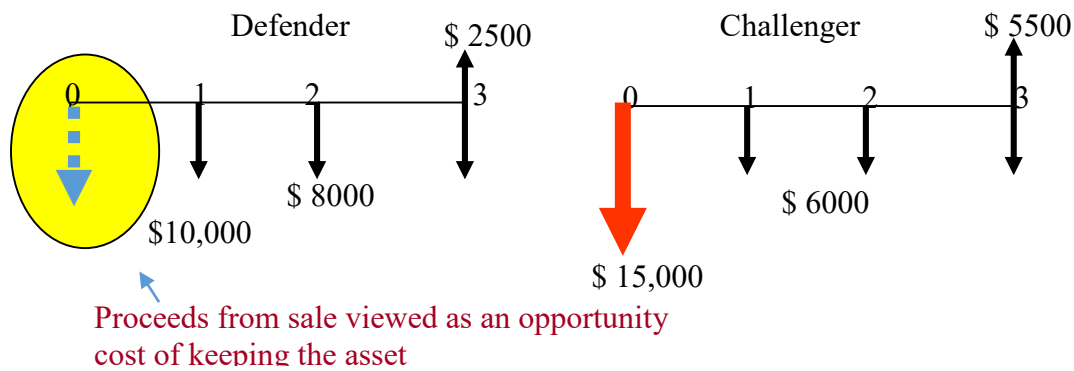
$$\begin{aligned} AW (12\%) D &= PW (12\%) D (A/P, 12\%, 3) \\ &= - \$ 11, 422.64 \end{aligned}$$

Challenger:

$$\begin{aligned} PW (12\%) C &= - \$ 15, 000 - \$ 6, 000(P/A, 12\%, 3) + \$ 5, 500(P/F, 12\%, 3) \\ &= - \$ 25, 495.90 \end{aligned}$$

$$\begin{aligned} AW (12\%) C &= PW (12\%) C (A/P, 12\%, 3) \\ &= - \$ 10, 615.33 \end{aligned}$$

**Here AW of Challenger < AW of Defender, replace the defender now.**



**Fig 5.2: Opportunity Cost Approach [1]**

## 5.8 Economic service Life (ESL)

Economic life is the expected period of time during which an asset remains useful to the average owner. When an asset is no longer useful to its owner, then it is said to be past its economic life. [3] An asset should be retained for a time period that minimizes its cost to the owner. We need to consider how long an asset should be held once it is placed in service.

In engineering economic analysis, an asset's operating and maintenance (O&M) costs increase with age, we are more interested in knowing the asset's practical service life, rather than its remaining physical life. [1] The economic service life (ESL) is the number of year  $n$  at which the equivalent uniform annual worth (AW) of costs (EUAC) is the minimum, considering the most current cost estimates over all possible years that the asset may provide a needed service. The smallest total AW of costs identifies the ESL value. [4]

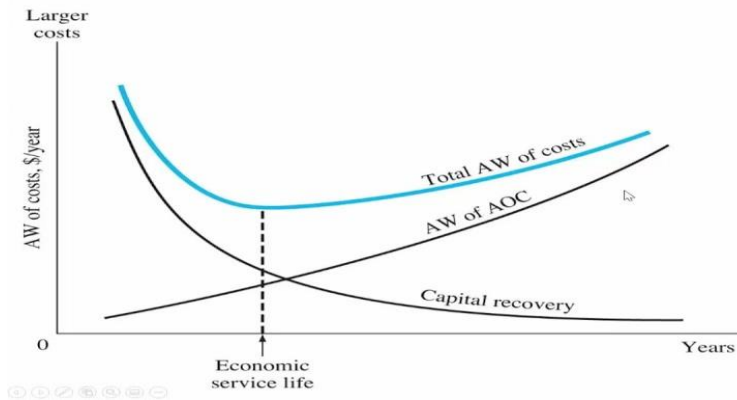
The "economic service life" is the useful life of a defender, or a challenger, that results in the minimum uniform equivalent annual cost (EUAC) of owning & operating the asset. Any defender & challenger comparison should be based on their respective economic service lives.

**Total AW of costs is the sum of the asset's annual capital recovery and AW of annual operating cost as shown in figure 5.3.**

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$$\begin{aligned} \text{Total AW} &= (-) \text{ Capital recovery} - \text{Aw of annual operating costs} \\ &= (-) \text{ CR} - \text{AW of AOC} \end{aligned}$$

### Annual Worth Curves For Determining Economic Service Life



**Fig 5.3: Economic Service Life [4]**

In figure, the curve of total AW of costs is represented by the concave shape. The capital recovery cost (CR) decreases as the time is elapsing and the annual operating cost (AOC) increases. At any year 'n' the capital recovery cost (CR) and annual operating cost (AOC) is calculated as:

$$(\text{CR})_n = -I (A/P, i\%, n) + S (A/F, i\%, n)$$

$$\text{AW of (AOC)}_n = \{AOC_1 (P/F, i\%, 1) + AOC_2 (P/F, i\%, 1) \dots\dots + AOC_n (P/F, i\%, n)\} (A/P, i\%, n)$$

#### Minimum Cost life of an asset

Minimum cost life of any new (existing) asset is the number of years at which the equivalent uniform annual cost (EUAC) of the ownership is minimized. That is we need to identify the year in which the total EUAC is minimized. The minimum cost life is normally shorter than the useful life of the asset because of increasing operating and maintenance cost in the later years of asset life.

#### Example 5.2

A piece of machinery costs \$7500 and has no salvage value after it is installed. No maintenance or repair is required in the first year. The second year, the maintenance cost will be \$900 and will increase on a \$900 arithmetic gradient in the subsequent years. The first year operating expense will be \$500 and will increase on a \$400 arithmetic gradient in the following years. If interest is 8%, compute the useful life of the machinery that will result in a minimum EUAC (Find its minimum cost life).

Year	EUAC of Capital Recovery \$ 7500 (A/P,8%,n)	EUAC of Maintenance and Repair Cost \$ 900 (A/G, 8%,n)	EUAC of Operating Costs \$ 500 + \$ 400 (A/G,8%,n)	Total EUAC (\$)
1	8100	0	500	8600
2	4205.77	432.69	692.31	5330.77
3	2910.25	853.87	879.50	4643.62
<b>4</b>	<b>2264.41</b>	<b>1263.56</b>	<b>1061.58</b>	<b>4589.55</b>
5	1878.42	1661.82	1238.59	4778.84
6	1622.37	2048.71	1410.54	5081.62
7	1440.54	2424.30	1577.47	5442.31
8	1305.11	2788.67	1739.41	5883.19
9	1200.60	3141.93	1896.41	6238.94
10	1117.72	3484.18	2048.53	6650.43
11	1050.57	3815.55	2195.80	7061.93
12	995.21	4136.17	2338.30	7469.68
13	948.91	4446.19	2476.08	7871.18
14	909.73	4745.75	2609.22	8264.69
15	876.22	5035.01	2737.78	8649.02

The minimum cost life of the machinery is 4 years, with minimum EUAC of \$ 4589 for each of those 4 years.

## 5.9 Performing replacement study

While performing replacement analysis, the analysis period (planning horizon) could be long i.e. infinite and finite. Economic Service life is used to determine when is the right time to replace the defender? If now is not the right time, when is the optimal time to replace the defender? For answering the above question the following three assumptions are made. [1]

- Planning horizon (study period)
- Technology
- Relevant cash flow information

### Planning horizon

By planning horizon it is mean that the service period required by the defender and a sequence of future challenger. [1]

- *Infinite planning horizon:* It is used when we are unable to predict when the activity under consideration will be terminated.

- *Finite planning horizon:* When the project has a definite and predictable duration, replacement policy should be formulated more realistically based on a finite planning horizon.

## Technology

A number of possibilities exist in predicting purchase cost, salvage value and operating cost dictated by the efficiency of machine over the life of an asset. If we assume that all future machines will be same as those now in service, there is no technological progress in the area will occur. We may recognize the possibility of future machine that will be significantly more efficient, reliable or productive than those currently on the market.

## Relevant cash flow information

Many varieties of cash flow can occur while estimating the revenues, costs and salvage value during the life of an asset. Sometimes revenue is constant, but costs increase, while salvage value does not, over the life of the machine. In other situations, a decline in revenue over equipment life can be expected. The specific situation will determine whether replacement analysis is directed toward cost minimization (with constant revenue) or profit maximization (with varying revenue).

[1]

### 5.9.1 Replacement analysis under infinite planning horizon

Under the infinite planning horizon, the service is required for a very long time. Either we continue to use the defender to provide the service or we replace the defender with the best available challenger for the same service requirement.

#### Procedure for replacement analysis (infinite planning horizon)

- Compute the economic service life of the both defender and challenger. Use  $N_D^*$  (economic service life of defender) and  $N_C^*$  (economic service life of Challenger) respectively. The annual equivalent cost for the defender and challenger at their economic lives are indicated by  $AE_D^*$  and  $AE_C^*$ .
- Compare  $AE_D^*$  and  $AE_C^*$ . If  $AE_D^*$  is bigger than  $AE_C^*$ , we know that it is more costly to keep the defender than to replace it with the challenger. Thus the challenger should replace the defender now.
- If the defender should not be replaced now, when should it be replaced? First, we need to continue to use until its economic service life is over. Then we should calculate the cost of running the defender for one more year after its economic life. If this cost is greater than  $AE_C^*$ , the defender should be replaced at the end of its economic life. This process should be continued until we find the optimal replacement time. This approach is called the *marginal analysis*, i.e. to calculate the incremental cost of operating the defender for just one more year.

Marginal cost analysis is the process of breaking down a decision into a series of 'yes or no' decisions. Marginal costs are year by year estimates of the cost to own and operate an asset for

that year. More formally, it is an examination of the additional benefits of an activity compared to the additional costs incurred by that same activity. [5]

### 5.9.2 Procedure for replacement analysis (finite planning horizon)

If the planning period is finite, comparison based on the annual equivalent cost (AEC) method over a defender's economic service life does not generally apply. [1] The procedure for solving such a problem with a finite planning horizon is to establish all 'reasonable' replacement patterns and then use the equivalent worth value for the planning period to select the most economical pattern.

#### Example 5.3

An existing machine has a market value of \$ 50,000 and can be used for six years after repair. The machine will require an immediate \$ 12000 overhaul to restore it to operable condition. The opportunity costs are estimated \$ 20,000 during first year and expected to increase by \$ 15,000 per year thereafter. Book value of the machine is expected to decline by 25% each year over the previous year's value.

New machine can be bought at \$1, 00,000 and will have operating cost of \$ 22,000 in the first year and increases by 20% per year thereafter. Salvage value will be \$ 60,000 after one year and will decline 15% each year. This new machine will last for eight years. Find the economic service life of both the alternatives and determine the best replacement strategy if a firm has a contract to perform a given service for next eight years. MARR =15%

If the existing machine (defender) is retained, total cost will be equal to \$ 50,000 + \$ 12,000 = \$ 62, 000 i.e. \$ 50,000 as opportunity cost and \$ 12,000 as overhaul cost. Operating costs and book values can be calculated as following:

Year	O&M (increasing by \$ 15,000 per year)	Book Values
1	20,000	75% of 50,000 = 37,500
2	35,000	75% of 37,500 = 28,130
3	50,000	75% of 28,130 = 21,090
4	65,000	75% of 21,090 = 15,820
5	80,000	75% of 15,820 = 11870
6	95,000	75% of 11870 = 8,900

#### AEC for N=1

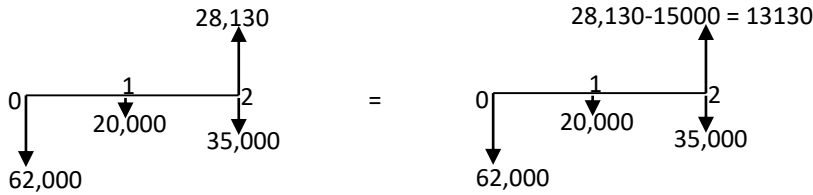
$$62,000 * 1.15 + 20,000 - 37,500 = \$ 53,800$$



AEC for N=2

$$60,000 (A/P, 15\%, 2) + 20,000 - 13,130 (A/F, 15\%, 2)$$

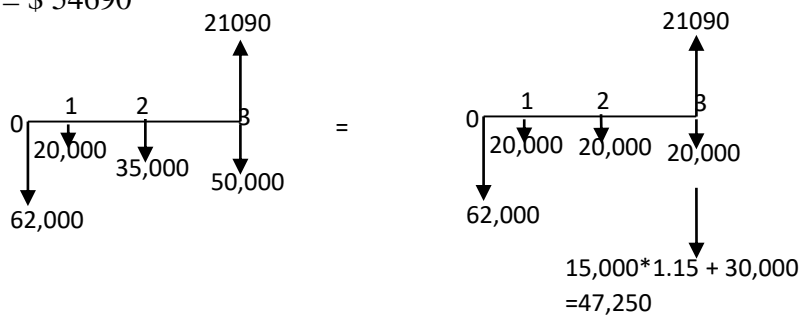
$$= \$ 52,030$$



AEC for N=3

$$62,000 (A/P, 15\%, 3) + 20,000 + \{ 15,000 * 1.15 + 30,000 - 21,090 \} (A/F, 15\%, 3)$$

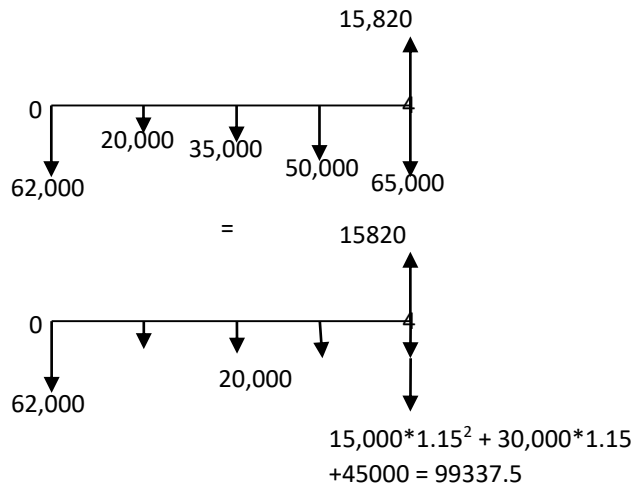
$$= \$ 54,690$$



AEC for N=4

$$62,000 (A/P, 15\%, 4) + 20,000 + \{ 15,000 * 1.15^2 + 30,000 * 1.15 + 45,000 - 15,820 \} (A/F, 15\%, 4)$$

$$= \$ 58,440$$



Similarly, for N= 5 years, AEC = \$ 62,580

for N = 6 years, AEC = \$ 66,820

**AEC is minimum i.e. \$ 52030 when N =2 years. Thus, the defender's economic service life is 2 years.**

In similar fashion, Economic service life (ESL) is calculated for the challenger.

For Challenger,

For n = 1 years, AEC = \$ 53,800

n = 2 years, AEC = \$ 61,840

n = 3 years, AEC = \$ 57,560

n = 4 years, AEC = \$ 56,250

n = 5 years, AEC = \$ 56,310

n = 6 years, AEC = \$ 57,210

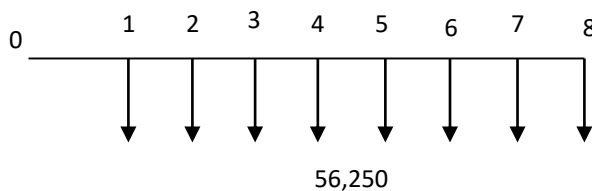
n = 7 years, AEC = \$ 58,690

n = 8 years, AEC = \$ 60,660

**Minimum AEC of Challenger is \$ 56,250 when N = 4 years. Thus, the challenger's economic service life is 4 years.**

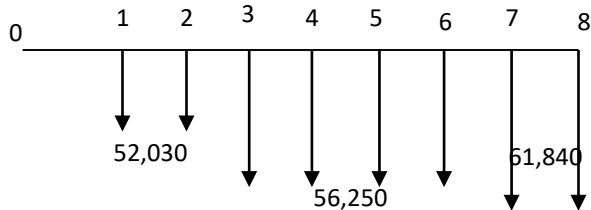
Many replacement scenario options would fulfill an eight year planning horizon as below.

Option 1: Use Challenger for eight years (4C + 4C years)



$$PW = 56,250 (P/A, 15\%, 8) = \$ 2, 52, 410$$

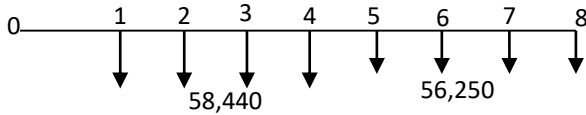
Option 2: Use defender for 2 years, challenger for next four years and challenger for two more years again (2D + 4C + 2C)



$$PW = 52,030 (P/A, 15\%, 2) + 56,250 (P/A, 15\%, 4) * \{P/F, 15\%, 2\} + 61,840 (P/A, 15\%, 2) * \{P/F, 15\%, 6\}$$

$$= \$ 2, 49, 480$$

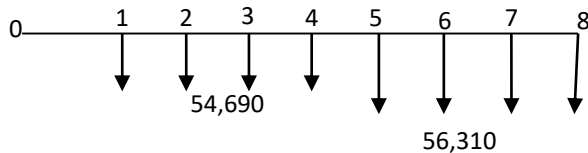
Option 3: Using defender for four years and challenger for remaining four years (4D + 4C)



$$PW = 58,440 (P/A, 15\%, 4) + 56,250 (P/A, 15\%, 4) * \{P/F, 15\%, 4\}$$

$$= \$ 2, 58,660$$

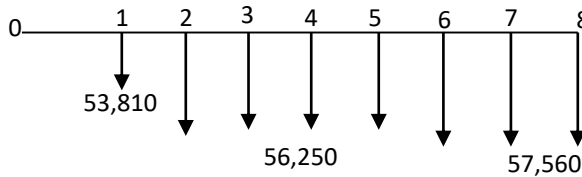
Option 4: Using defender for three years and challenger for remaining five years (3D + 5C)



$$PW = 54,690 (P/A, 15\%, 3) + 56,310 (P/A, 15\%, 5) * \{P/F, 15\%, 3\}$$

$$= \$ 2, 48,980 \text{ (minimum)}$$

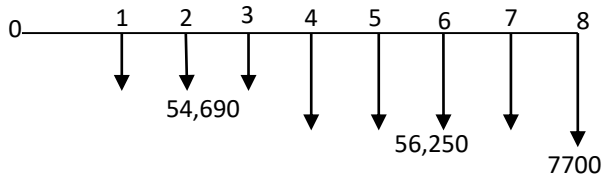
Option 5: Using defender for only one years and challenger for 7 years (1D+7C)



$$PW = 53,800 (P/A, 15\%, 1) + 56,250 (P/A, 15\%, 4) * \{P/F, 15\%, 1\} + 57560 (P/A, 15\%, 4) \{P/F, 15\%, 5\}$$

$$= \$ 2, 51,770$$

Option 6: Using defender for three years and challenger for 5 years (3D+5C)



$$PW = 54,690 (P/A, 15\%, 3) + 56,250 (P/A, 15\%, 4) * \{P/F, 15\%, 3\} + 77000 \{P/F, 15\%, 8\}$$

$$= 2, 55,630$$

From above calculations, least cost solution among six decision options considered appear to be option 4 with present worth equivalent of \$ 2,48,980. So, retain the defender for three years, purchase the challenger and keep it for five years.

References:

[1] *Contemporary Engineering Economics*, Chan S. Park, Second Edition, Addison-Wesley Publishing Company, 1997.

[2] *Engineering Economy*: William G. Sullivan, James A. Bontadelli & Elin M. Wicks, Eleventh Edition, Pearson Educations, Inc. 2000 .

[3] <https://www.investopedia.com/terms/e/economic-life.asp> (Viewed October 2022)

[4] *Basics of Engineering Economy*: Leland Blank and Anthony Tarquin, Indian Edition, Tata McGraw Hill Education Private Limited, New Delhi, India, 2013.

[5] <https://pressbooks.bccampus.ca/uvicecon103/chapter/1-3-marginal-analysis/> (Viewed October 2022)