

# Case Studies in Engineering Economics for Electrical Engineering Students

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**Abstract** – Undergraduate students are often faced with the challenge of trying to relate the theories and concepts presented in the classroom to real world situations. It is evident that when such a connection is made that the student becomes self motivated to master the concepts at hand. This paper presents two comprehensive case studies that can be used to demonstrate the relevant course concepts, and are specifically designed to peak the interest of electrical engineering students. The paper provides an introduction to each case along with an overview of the necessary economic theory and concepts. Then for each case study the paper outlines the suggested student activities, project assignment alternatives, along with detailed mathematical solutions.

*Keywords: Engineering economics, Case studies.*

## INTRODUCTION

All junior undergraduate electrical engineering students at The Citadel are required to complete a one semester course in Engineering Administration as part of their degree requirements. This two credit hour course presents the basic principles of engineering economy as applied to the analysis of the costs of construction of various engineering works. This course is typically taught outside the electrical engineering department and tends to focus on construction projects. This paper is focused on providing the relevant course concepts through two case studies specifically of interest to electrical engineers.

The first case study covers the general topic of present worth analysis and is intended to be used in the first half of the course. This case requires the students to compare computer networking equipment alternatives through analysis of the various life-cycle costs including the financing, acquisition phase, and operational phase. The second case study covers cost benefit analysis and is intended to be used in the second half of the course.

## CASE 1 PRESENT WORTH ANALYSIS

### Background Theory

Present Worth (PW) analysis is a popular analytical method for comparing two alternatives because it converts all future cash flows into equivalent present dollars. This single net present value is easily understood and makes for simple economic comparisons. The method requires that the PW of each alternative be evaluated at the Minimum Acceptable Rate of Return (MARR). The alternative with the numerically larger PW is selected as the best choice.[1]

PW analysis makes use of the single payment present worth factor (P/F factor) that provides a conversion of a given future amount (F) to a present value (P) based on the interest rate (i) and the number of compound periods (n). The P/F factor is tabulated and can be computed from [1]

$$P/F = [1/(1 + i)^n] . \text{ Eq. (1)}$$

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The uniform series present worth factor (P/A) transforms a uniform series of cash flows to a single present worth value. The P/A factor is also tabulated for a given interest rate (i) and number of compounding periods (n) and it can be computed as [1]

$$P/F = [(1 + i)^n - 1 / i (1 + i)^n] . \text{ Eq. (2)}$$

Both Eq. (1) and (2) are used to translate all cash flows for a given alternative to the present. The PW method requires that the alternatives are evaluated over equal time periods. However, in many cases the alternatives have different life-cycles or service lives. One technique is to compute the PW of the alternatives using the least common multiple of the service lives. A second technique is to compare the alternatives using a fixed length of time called the study period. It is possible that different conclusions will result from each of these techniques, and therefore realistic assumptions will dictate which technique is used to solve a particular problem. [2]

### Case 1 Problem Statement

A project engineer is assigned to provide computer networking and internet access to an office building. After research various equipment suppliers' two alternatives are detailed for further economic analysis. Alternative A is a wireless network with lower acquisition costs but higher operational costs. Alternative B is a wired network with low operational costs but higher equipment and installation costs. The costs associated with each of two alternatives are outlined below.

#### Alternative A Wireless Network

Design	\$1,000
Equipment	\$1,000
Installation	\$ 500
Upgrades	\$500 per year
M & O*	\$500 per year
Salvage	\$200
Service Life	6 years

#### Alternative B Wired Network

Design	\$2,000
Equipment	\$2,000
Installation	\$2,000
Upgrades	\$0
M & O*	\$100 per year
Salvage	\$100
Service Life	9 years

\* Maintenance and Operation

Using the information provided above, determine which alternative to recommend using PW analysis. Conduct the analysis twice, once for the least common multiple of the service lives and once using a five year study period. Assume a 10% interest rate.

### Solution

Table 1 provides a summary of the economic data. The acquisition costs include all activities prior to delivery including design, products and installation. The operational costs include expenditures on equipment upgrades, maintenance, and operations.

	Alternative A	Alternative B
Acquisition Phase	-2,500	-6,000
Operational Phase	-1,000	-100
Salvage Value	200	100
Service Years	6	9

Table 1: Case 1 costs

### Solution Steps for the LCM method

The least common multiple of the service lives is 18 years. This requires three complete cycles of the Alternative A costs, and two cycles of the Alternative B costs. Using Eq. (1) and (2) for each alternative leads to the following analysis.

#### Alternative A

$$PW_A = -2500 - 2500 (P/F, 10\%, 6\text{yrs}) - 2500 (P/F, 10\%, 12\text{yrs}) + 200 (P/F, 10\%, 6\text{yrs}) + 200 (P/F, 10\%, 12\text{yrs}) \\ + 200 (P/F, 10\%, 18\text{yrs}) - 1000 (P/A, 10\%, 18\text{yrs})$$

Combining similar terms yields:

$$PW_A = -2500 - 2300 (P/F, 10\%, 6\text{yrs}) - 2300 (P/F, 10\%, 12\text{yrs}) + 200 (P/F, 10\%, 18\text{yrs}) - 1000 (P/A, 10\%, 18\text{yrs})$$

$$PW_A = -2500 - 1298.5 - 732.8 + 36.0 - 820.1 = \$-12,696$$

#### Alternative B

$$PW_B = -6000 - 6000 (P/F, 10\%, 9\text{yrs}) + 100 (P/F, 10\%, 9\text{yrs}) + 100 (P/F, 10\%, 18\text{yrs}) - 100 (P/A, 10\%, 18\text{yrs})$$

$$PW_B = -6000 - 2544 + 42.4 + 18.0 - 820.1 = \$ - 9,303$$

The least cost alternative is B. Choose Alternative B.

### Solution Steps for the five year study period

Using Eq. (1) and (2) leads to the following analysis.

#### Alternative A

$$PW_A = -2500 - 1000 (P/A, 10\%, 5\text{yrs}) + 200 (P/F, 10\%, 5\text{yrs})$$

$$PW_A = -2500 - 3791 + 124.2 = \$-6,167$$

#### Alternative B

$$PW_B = -6000 - 100 (P/A, 10\%, 5\text{yrs}) + 100 (P/F, 10\%, 5\text{yrs})$$

$$PW_B = -6000 - 379.1 + 62.09 = \$ - 6,317$$

The least cost alternative is A. Choose Alternative A.

## Comments and Additional Activities

Clearly, the added service life associated with alternative B makes all the difference in the analysis. If it is anticipated that the service life will be truncated for any reason then alternative A becomes more competitive.

Additional activities can be assigned by including the use of spreadsheet analysis. A software package such as Microsoft Excel makes this an easy matter for most students. The spreadsheet will permit quick solutions to a number of reasonable parameter changes, such as a change in interest rates, or a change in the length of the study period. For example, have the student repeat the analysis at interest rates of 5%, and 15%, and also at study periods of 3 and 6 years.

## CASE 2 COST BENEFIT ANALYSIS

### Background Theory

Cost benefit analysis using the benefit/cost ratio (B/C) was developed to reduce subjectivity and provide economic analysis of public sector projects. The B/C ratio as its name suggests is computed as the ratio of benefits to costs. However, it can be calculated in number of differing ways. Typically, the B/C ratio uses positive costs (costs are given a + sign). Disbenefits are subtracted from benefits and placed in the numerator of the ratio. The decision rule is to compare the B/C ratio to unity. If  $B/C \geq 1$  the project is economically acceptable, otherwise it is not. The conventional B/C ratio is computed as [1]

$$B/C = (\text{benefits} - \text{disbenefits})/\text{costs} = (B - D) / C. \quad \text{Eq. (3)}$$

The B/C ratio can also be formulated to include maintenance and operational costs in the numerator, thus treating these costs as disbenefits. This leaves only the initial investment (minus salvage value) as costs in the denominator. This modified B/C ratio changes the magnitude of the ratio but not the threshold decision. The modified B/C is given by [1]

$$B/C = (\text{benefits} - \text{disbenefits} - \text{M\&O costs})/\text{initial investment}. \quad \text{Eq. (4)}$$

Sometimes it is simplest to compute the benefit and cost difference instead of a ratio. If the total benefit worth exceeds the costs which include the disbenefits the project is accepted. The B/C difference test is therefore [1]

$$B - C \geq 0. \quad \text{Eq. (5)}$$

When comparing two mutually exclusive alternatives the incremental B/C analysis method is used. This analysis uses the conventional B/C ratio on the incremental cost ( $\Delta C$ ) and incremental benefit ( $\Delta B$ ) to justify or eliminate the higher cost alternative. When using incremental analysis one must be sure that each alternative is only compared with another alternative for which the incremental cost is already justified. [2]

### Case 2 Problem Statement

Two mutually exclusive proposals for improvements to an electrical distribution utility station are under consideration. One proposal is to upgrade the existing facility at a much lower cost and lower overall benefit. The second more costly proposal and potentially more beneficial alternative is to build an entirely new facility. The new facility will incorporate many cost savings including more efficient machinery, economy of scale, and automation to reduce manpower. The disbenefits associated with the new facility include use of additional public land, the need for more roads, and the disruption of traffic and transportation. The costs and benefits are outlined in Table 2.

Using the information provided in Table 2, determine which alternative to recommend using B/C analysis using the conventional, modified, and incremental B/C analysis methods. Assume a 6% interest rate.

	Alternative A (x \$1000)	Alternative B (x \$1000)
Initial Construction Costs	40,000	4,000
Annual Maintenance Costs	1,500	150
Annual Public Benefit	6,500	650
Annual Public Disbenefit	1,500	0
Service Years	30	12

**Table 2: Case 2 benefits and costs**

### Solution Steps using conventional B/C analysis

The B/C may be computed using present values, future values or uniform series annual worth values (AW). It is straight forward to transform the presents value construction cost to an annual worth using the tabulated A/P factor. Applying Eq. 3 to the values shown in Table 2 results in the following calculations.

#### Alternative A

$$\text{Cost } AW_A = 40M (A/P, 6\%, 30 \text{ yrs}) + 1.5M = 40M (0.07265) + 1.5M = 2.906M + 1.5M = \$4.406M$$

Applying Eq. 3 yields:

$$B/C_A = (B - D) / C = (6.5M - 1.5M) / 4.406M = 1.14 > 1. \text{ Alternative A is justified.}$$

#### Alternative B

$$\text{Cost } AW_B = 4M (A/P, 6\%, 12 \text{ yrs}) + 0.15M = 4M (0.11928) + 0.15M = 0.447M + 0.15M = \$0.627M$$

Applying Eq. 3 yields:

$$B/C_B = (B - D) / C = (0.65M - 0) / 0.627M = 1.04 > 1. \text{ Alternative B is justified.}$$

Thus both alternatives are justified with A having a slight B/C advantage.

### Solution Steps using modified B/C analysis

Once again using AW values, and applying Eq. 4 provides the following calculations.

#### Alternative A

$$\text{Modified } B/C_A = (B - D - C) / \text{initial cost} = (6.5M - 1.5M - 1.5M) / 2.906M = 1.2 > 1. \text{ Alternative A is justified.}$$

#### Alternative B

$$\text{Modified } B/C_B = (B - D - C) / \text{initial cost} = (0.65M - 0 - 0.15M) / 0.447M = 1.1 > 1. \text{ Alternative B is justified.}$$

Which again demonstrates both alternatives are justified with A having a slight B/C advantage.

### Solution Steps using incremental B/C analysis

Applying incremental B/C analysis results in the following calculations.

$$\Delta C = AW_A - AW_B = 4.406M - 0.627M = \$3.78M$$

$$\Delta B = (B - D)_A - (B - D)_B = (6.5M - 1.5M) - (0.65M - 0) = \$4.35M$$

$B/C_{\Delta} = \Delta B / \Delta C = 4.35M / 3.78M = 1.15 > 1$ . The higher cost alternative is justified.

All three methods provide the same conclusion.

### **Comments and Additional Activities**

The assignment of benefit and disbenefit costs can be a highly subjective and sometimes political endeavor. Small changes in the evaluation of these costs can change the decision especially when the B/C ratio is very close to the threshold.

One additional student project activity would be to perform a sensitivity analysis on the various costs and benefits. Using a spreadsheet to aid in computations, small perturbations such as a 5-10% reduction in perceived benefits, or increase in disbenefits can be analyzed. A second activity would be to evaluate the effect of changing the assumptions about each alternative's service life. For example, shorting the service life of the more expensive alternative or increasing the service life of the lower cost alternative could alter the results of the incremental analysis.

### **SUMMARY**

This paper discussed two student project case studies in engineering economics. The case studies were developed to make them particularly interesting to undergraduate electrical engineering students taking a first course in engineering economics. Each case study was presented along with its solution steps. Ideas for additional student activities, and alternate assignments were also provided.

### **REFERENCES**

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After serving for 20 years as a naval officer in the United States submarine fleet, Robert J. Barsanti received his Ph.D. in Electrical Engineering from the Naval Postgraduate School in 2001. He joined the faculty of The Citadel Department of Electrical and Computer Engineering in 2001. His main areas of interest include control systems, and signal processing.