

Annual Equivalent-Worth Analysis

Thermally Activated Technologies: Absorption Chillers for Buildings¹

Absorption chillers provide cooling to buildings by using heat. This seemingly paradoxical, but highly efficient, technology is most cost effective in large facilities with significant heat loads. Not only do absorption chillers use less energy than conventional equipment does, but they also cool buildings without the use of ozone-depleting chlorofluorocarbons (CFCs). Unlike conventional electric chillers, which use mechanical energy in a vapor compression process to provide refrigeration, absorption chillers primarily use heat energy, with limited mechanical energy for pumping. Absorption chillers can be powered by natural gas, steam, or waste heat.

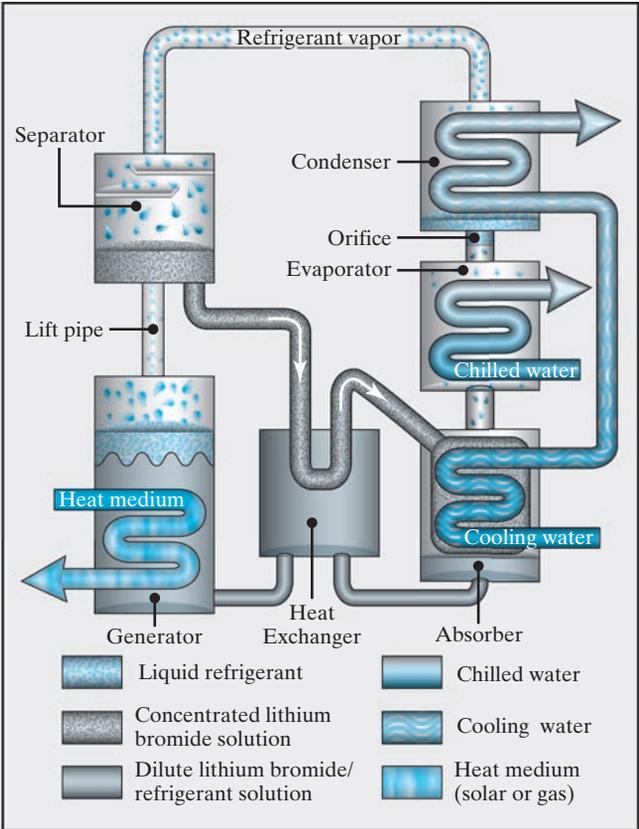
- The most promising markets for absorption chillers are in commercial buildings, government facilities, college campuses, hospital complexes, industrial parks, and municipalities.
- Absorption chillers generally become economically attractive when there is a source of inexpensive thermal energy at temperatures between 212°F and 392°F.

An absorption chiller transfers thermal energy from the heat source to the heat sink through an absorbent fluid and a refrigerant. The absorption chiller accomplishes its refrigerative effect by absorbing and then releasing water vapor into and out of a lithium bromide solution. Absorption chiller systems are classified by single-, double-, or triple-stage effects, which indicate the number of generators in the given system. The greater the number of stages, the higher is the overall efficiency of the system. Double-effect absorption chillers typically have a higher first cost, but a significantly lower energy cost, than single-effect chillers, resulting in a lower net present worth.

¹ Tech Brief, Office of Power Technology, U.S. Department of Energy, Washington, DC.



Single-Effect Absorption Chiller



Some of the known economic benefits of the absorption chiller over the conventional mechanical chiller are as follows:²

- In a plant where low-pressure steam is currently being vented to the atmosphere, a mechanical chiller with a Coefficient of Performance (COP) of 4.0 is used 4,000 hours a year to produce an average of 300 tons of refrigeration.
- The plant's cost of electricity is \$0.05 a kilowatt-hour. An absorption unit requiring 5,400 lb/hr of 15-psig steam could replace the mechanical chiller, providing the following annual electrical cost savings:

$$\text{Annual Savings} = 300 \text{ tons} \times (12,000 \text{ Btu/ton}/4.0) \times 4,000 \text{ hrs/yr} \\ \times \$0.05/\text{kWh} \times \text{kWh}/3,413 \text{ Btu} = \$52,740.$$

² Source: EcoGeneration Solutions™, LLC, Companies, 12615 Jones Rd., Suite 209, Houston, Texas 77070 (http://www.cogeneration.net/Absorption_Chillers.htm).

Suppose you plan to install the chiller and expect to operate it continuously for 10 years. How would you calculate the operating cost per hour? Suppose you are considering buying a new car. If you expect to drive 12,000 miles per year, can you figure out how much the car costs per mile? You would have good reason to want to know the cost if you were being reimbursed by your employer on a per mile basis for the business use of your car. Or consider a real-estate developer who is planning to build a 500,000-square-foot shopping center. What would be the minimum annual rental fee per square foot required to recover the initial investment?

Annual equivalence analysis is the method by which these and other unit costs (or profits) are calculated. Along with present-worth analysis, annual equivalence analysis is the second major equivalence technique for putting alternatives on a common basis of comparison. In this chapter, we develop the annual equivalent-worth criterion and demonstrate a number of situations in which annual equivalence analysis is preferable to other methods of comparison.

CHAPTER LEARNING OBJECTIVES

After completing this chapter, you should understand the following concepts:

- How to determine the equivalent annual worth (cost) for a given project.
- Why the annual equivalent approach facilitates the comparison of unequal service life problems.
- How to determine the capital cost (or ownership cost) when you purchase an asset.
- How to determine the unit cost or unit profit.
- How to conduct a life-cycle cost analysis.
- How to optimize design parameters in engineering design.

6.1 Annual Equivalent-Worth Criterion

In this section, we set forth a fundamental decision rule based on annual equivalent worth by considering both revenue and cost streams of a project. If revenue streams are irrelevant, then we make a decision solely on the basis of cost. This leads to a popular decision tool known as “life-cycle cost analysis,” which we will discuss in Section 6.4.

6.1.1 Fundamental Decision Rule

The **annual equivalent worth (AE)** criterion provides a basis for measuring the worth of an investment by determining equal payments on an annual basis. Knowing that any lump-sum cash amount can be converted into a series of equal annual payments, we may first find the net present worth (NPW) of the original series and then multiply this amount by the capital recovery factor:

$$AE(i) = PW(i)(A/P, i, N). \quad (6.1)$$

- **Single-project evaluation:** The accept–reject selection rule for a single *revenue* project is as follows:

If $AE(i) > 0$, accept the investment.

If $AE(i) = 0$, remain indifferent to the investment.

If $AE(i) < 0$, reject the investment.

Notice that the factor $(A/P, i, N)$ in Eq. (6.1) is positive for $-1 < i < \infty$, which indicates that the value of $AE(i)$ will be positive if, and only if, $PW(i)$ is positive. In other words, accepting a project that has a positive $AE(i)$ is equivalent to accepting a project that has a positive $PW(i)$. Therefore, the AE criterion for evaluating a project is consistent with the NPW criterion.

- **Comparing mutually exclusive alternatives:** As with present-worth analysis, when you compare mutually exclusive *service* projects whose revenues are the same, you may compare them on a *cost*-only basis. In this situation, the alternative with the minimum *annual equivalent cost* (or least negative annual equivalent worth) is selected.

Example 6.1 illustrates how to find the equivalent annual worth for a proposed energy-savings project. As you will see, you first calculate the net present worth of the project and then convert this present worth into an equivalent annual basis.

EXAMPLE 6.1 Annual Equivalent Worth: A Single-Project Evaluation

A utility company is considering adding a second feedwater heater to its existing system unit to increase the efficiency of the system and thereby reduce fuel costs. The 150-MW unit will cost \$1,650,000 and has a service life of 25 years. The expected salvage value of the unit is considered negligible. With the second unit installed, the efficiency of the system will improve from 55% to 56%. The fuel cost to run the feedwater is estimated at \$0.05 kWh. The system unit will have a load factor of 85%, meaning that the system will run 85% of the year.

- Determine the equivalent annual worth of adding the second unit with an interest rate of 12%.
- If the fuel cost increases at the annual rate of 4% after first year, what is the equivalent annual worth of having the second feedwater unit at $i = 12\%$?

DISCUSSION: Whenever we compare machines with different efficiency ratings, we need to determine the input powers required to operate the machines. Since the percent efficiency is equal to the ratio of the output power to the input power, we can determine the input power by dividing the output power by the motor's percent efficiency:

$$\text{Input power} = \frac{\text{output power}}{\text{percent efficiency}}.$$

A feedwater heater is a power-plant component used to preheat water delivered to a boiler. Preheating the feedwater reduces the amount of energy needed to make steam and thus reduces plant operation costs.

For example, a 30-HP motor with 90% efficiency will require an input power of

$$\begin{aligned}\text{Input power} &= \frac{(30 \text{ HP} \times 0.746 \text{ kW/HP})}{0.90} \\ &= 24.87 \text{ kW}.\end{aligned}$$

Therefore, energy consumption with and without the second unit can be calculated as follows:

- Before adding the second unit, $\frac{150,000 \text{ kW}}{0.55} = 272,727 \text{ kW}$
- After adding the second unit, $\frac{150,000 \text{ kW}}{0.56} = 267,857 \text{ kW}$

So the reduction in energy consumption is 4,871 kW.

Since the system unit will operate only 85% of the year, the total annual operating hours are calculated as follows:

$$\text{Annual operating hours} = (365)(24)(0.85) = 7,446 \text{ hours/year}.$$

SOLUTION

Given: $I = \$1,650,000$, $N = 25$ years, $S = 0$, annual fuel savings, and $i = 12\%$.
Find: AE of fuel savings due to improved efficiency.

- (a) With the assumption of constant fuel cost over the service life of the second heater,

$$\begin{aligned}A_{\text{fuel savings}} &= (\text{reduction in fuel requirement}) \times (\text{fuel cost}) \\ &\quad \times (\text{operating hours per year}) \\ &= \left(\frac{150,000 \text{ kW}}{0.55} - \frac{150,000 \text{ kW}}{0.56} \right) \times (\$0.05/\text{kWh}) \\ &\quad \times ((8,760)(0.85) \text{ hours/year}) \\ &= (4,871 \text{ kW}) \times (\$0.05/\text{kWh}) \times (7,446 \text{ hours/year}) \\ &= \$1,813,473/\text{year};\end{aligned}$$

$$\begin{aligned}\text{PW}(12\%) &= -\$1,650,000 + \$1,813,473(P/A, 12\%, 25) \\ &= \$12,573,321;\end{aligned}$$

$$\begin{aligned}\text{AE}(12\%) &= \$12,573,321(A/P, 12\%, 25) \\ &= \$1,603,098.\end{aligned}$$

- (b) With the assumption of escalating energy cost at the annual rate of 4%, since the first year's fuel savings is already calculated in (a), we use it as A_1 in the geometric-gradient-series present-worth factor ($P/A_1, g, i, N$):

$$\begin{aligned}
 A_1 &= \$1,813,473 \\
 PW(12\%) &= -\$1,650,000 + \$1,813,473(P/A_1, 4\%, 12\%, 25) \\
 &= \$17,463,697 \\
 AE(12\%) &= \$17,463,697(A/P, 12\%, 25) \\
 &= \$2,226,621
 \end{aligned}$$

Clearly, either situation generates enough fuel savings to justify adding the second unit of the feedwater. Figure 6.1 illustrates the cash flow series associated with the required investment and fuel savings over the heater's service life of 25 years.

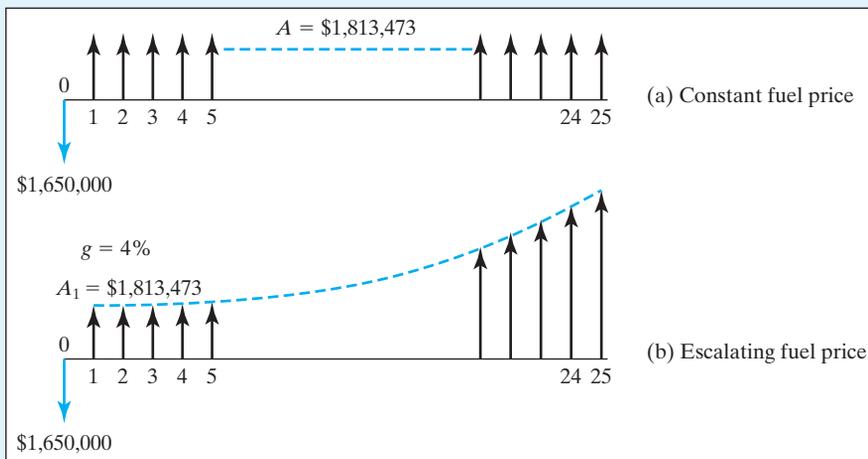


Figure 6.1 Cash flow diagram (Example 6.1).

6.1.2 Annual-Worth Calculation with Repeating Cash Flow Cycles

In some situations, a **cyclic cash flow pattern** may be observed over the life of the project. Unlike the situation in Example 6.1, where we first computed the NPW of the entire cash flow and then calculated the AE, we can compute the AE by examining the first cash flow cycle. Then we can calculate the NPW for the first cash flow cycle and derive the AE over that cycle. This shortcut method gives the same solution when the NPW of the entire project is calculated, and then the AE can be computed from this NPW.

EXAMPLE 6.2 Annual Equivalent Worth: Repeating Cash Flow Cycles

SOLEX Company is producing electricity directly from a solar source by using a large array of solar cells and selling the power to the local utility company. SOLEX decided to use amorphous silicon cells because of their low initial cost, but these cells degrade over time, thereby resulting in lower conversion efficiency and power output. The cells must be replaced every four years, which results in a particular cash flow pattern that repeats itself as shown in Figure 6.2. Determine the annual equivalent cash flows at $i = 12\%$.

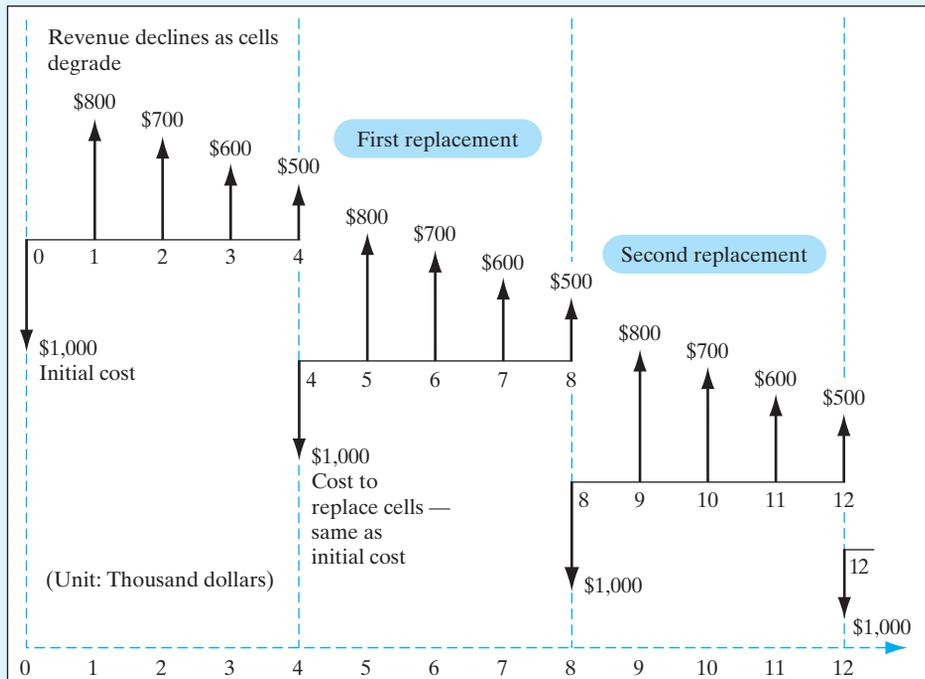


Figure 6.2 Conversion of repeating cash flow cycles into an equivalent annual payment (Example 6.2).

SOLUTION

Given: Cash flows in Figure 6.2 and $i = 12\%$.

Find: Annual equivalent benefit.

To calculate the AE, we need only consider one cycle over the four-year replacement period of the cells. For $i = 12\%$, we first obtain the NPW for the first cycle as follows:

$$\begin{aligned} \text{PW}(12\%) &= -\$1,000,000 \\ &\quad + [(\$800,000 - \$100,000(A/G, 12\%, 4))](P/A, 12\%, 4) \end{aligned}$$

$$\begin{aligned}
 &= -\$1,000,000 + \$2,017,150. \\
 &= \$1,017,150.
 \end{aligned}$$

Then we calculate the AE over the four-year life cycle:

$$\begin{aligned}
 AE(12\%) &= \$1,017,150(A/P, 12\%, 4) \\
 &= \$334,880.
 \end{aligned}$$

We can now say that the two cash flow series are equivalent:

Original Cash Flows		Annual Equivalent Flows	
n	A_n	n	A_n
0	-\$1,000,000	0	0
1	800,000	1	\$334,880
2	700,000	2	334,880
3	600,000	3	334,880
4	500,000	4	334,880

We can extend this equivalency over the remaining cycles of the cash flow. The reasoning is that each similar set of five values (one disbursement and four receipts) is equivalent to four annual receipts of \$334,880 each. In other words, the \$1 million investment in the solar project will recover the entire investment and generate equivalent annual savings of \$334,880 over a four-year life cycle.

6.1.3 Comparing Mutually Exclusive Alternatives

In this section, we consider a situation in which two or more mutually exclusive alternatives need to be compared on the basis of annual equivalent worth. In Section 5.5, we discussed the general principles that should be applied when mutually exclusive alternatives with unequal service lives were compared. The same general principles should be applied in comparing mutually exclusive alternatives on the basis of annual equivalent worth: Mutually exclusive alternatives in equal time spans must be compared. Therefore, we must give careful consideration to the period covered by the analysis: the **analysis period**. We will consider two situations: (1) The analysis period equals project lives and (2) the analysis period differs from project lives.

With situation (1), we compute AE for each project and select the project that has the least negative AE for service projects (or the largest AE for revenue projects). With situation (2), we need to consider the issue of unequal project lives. As we saw in Chapter 5, comparing projects with unequal service lives is complicated by the need to determine the lowest common multiple life. For the special situation of an indefinite service period and replacement with identical projects, we can avoid this complication by the use of AE analysis, provided that the following criteria are met:

1. The service of the selected alternative is required on a continuous basis.
2. Each alternative will be replaced by an *identical* asset that has the same costs and performance.

When these two criteria are met, we may solve for the AE of each project on the basis of its initial life span, rather than on that of the lowest common multiple of the projects' lives. Example 6.3 illustrates the process of comparing unequal service projects.

EXAMPLE 6.3 Annual Equivalent Cost Comparison: Unequal Project Lives

Consider again Example 5.14, in which we compared two types of equipment with unequal service lives. Apply the annual equivalent approach to select the most economical equipment.

SOLUTION

Given: Cost cash flows shown in Figure 6.3 and $i = 15\%$ per year.

Find: AE cost and which alternative is the preferred one.

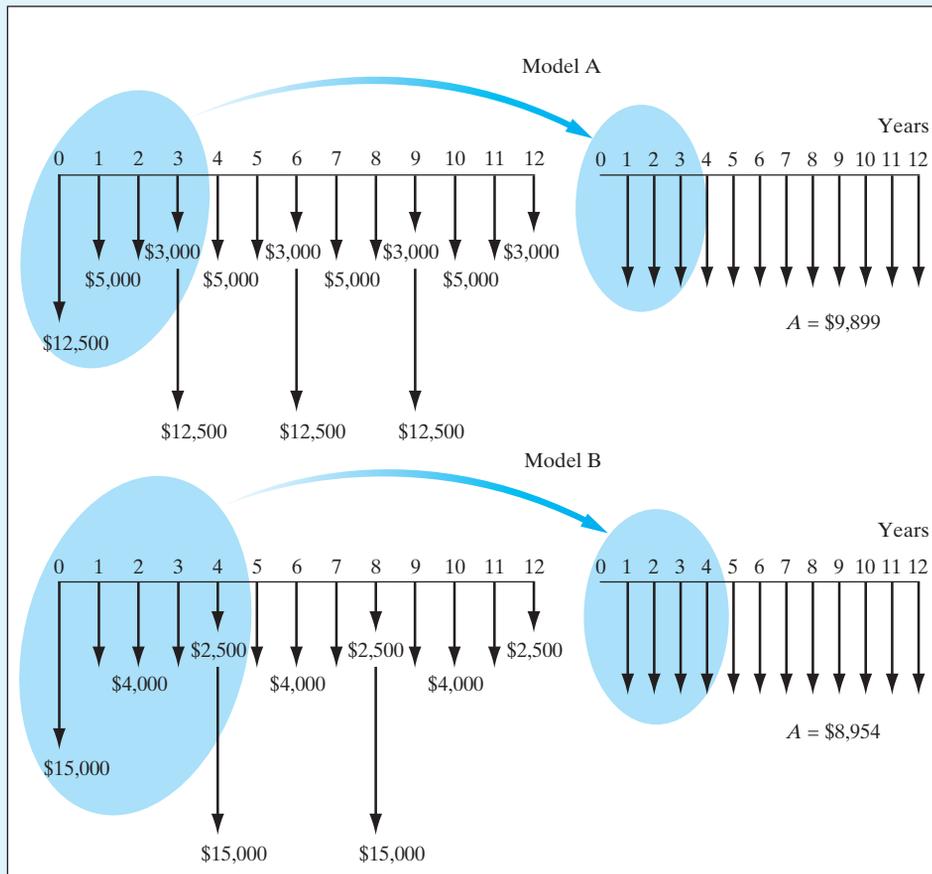


Figure 6.3 Comparison of projects with unequal lives and an indefinite analysis period using the annual equivalent-worth criterion (Example 6.3).

An alternative procedure for solving Example 5.14 is to compute the annual equivalent cost of an outlay of \$12,500 for model A every 3 years and the annual equivalent cost of an outlay of \$15,000 for model B every 4 years. Notice that the AE of each 12-year cash flow is the same as that of the corresponding 3- or 4-year cash flow (Figure 6.3). From Example 5.14, we calculate

- **Model A:** For a 3-year life,

$$\begin{aligned} \text{PW}(15\%) &= \$22,601 \\ \text{AE}(15\%) &= 22,601(A/P, 15\%, 3) \\ &= \$9,899. \end{aligned}$$

For a 12-year period (the entire analysis period),

$$\begin{aligned} \text{PW}(15\%) &= \$53,657 \\ \text{AE}(15\%) &= 53,657(A/P, 15\%, 12) \\ &= \$9,899. \end{aligned}$$

- **Model B:** For a 4-year life,

$$\begin{aligned} \text{PW}(15\%) &= \$25,562 \\ \text{AE}(15\%) &= 25,562(A/P, 15\%, 4) \\ &= \$8,954. \end{aligned}$$

For a 12-year period (the entire analysis period),

$$\begin{aligned} \text{PW}(15\%) &= \$48,534 \\ \text{AE}(15\%) &= 48,534(A/P, 15\%, 12) \\ &= \$8,954. \end{aligned}$$

Notice that the annual equivalent values that were calculated on the basis of the common service period are the same as those which were obtained over their initial life spans. Thus, for alternatives with unequal lives, we will obtain the same selection by comparing the NPW over a common service period using repeated projects or by comparing the AE for initial lives.

6.2 Capital Costs versus Operating Costs

When only costs are involved, the AE method is sometimes called the **annual equivalent cost (AEC)** method. In this case, revenues must cover two kinds of costs: **operating costs** and **capital costs**. Operating costs are incurred through the operation of physical plant or equipment needed to provide service; examples include items such as labor and

Capital cost: the amount of net investment.

raw materials. Capital costs are incurred by purchasing assets to be used in production and service. Normally, capital costs are nonrecurring (i.e., one-time) costs, whereas operating costs recur for as long as an asset is owned.

Because operating costs recur over the life of a project, they tend to be estimated on an annual basis anyway, so, for the purposes of annual equivalent cost analysis, no special calculation is required. However, because capital costs tend to be one-time costs, in conducting an annual equivalent cost analysis we must translate this one-time cost into its annual equivalent over the life of the project. The annual equivalent of a capital cost is given a special name: **capital recovery cost**, designated $CR(i)$.

Capital recovery cost: The annual payment that will repay the cost of a fixed asset over the useful life of the asset and will provide an economic rate of return on the investment.

Two general monetary transactions are associated with the purchase and eventual retirement of a capital asset: its initial cost (I) and its salvage value (S). Taking into account these sums, we calculate the capital recovery factor as follows:

$$CR(i) = I(A/P, i, N) - S(A/F, i, N). \quad (6.2)$$

Now, recall algebraic relationships between factors in Table 3.4, and notice that the factor $(A/F, i, N)$ can be expressed as

$$(A/F, i, N) = (A/P, i, N) - i.$$

Then we may rewrite $CR(i)$ as

$$\begin{aligned} CR(i) &= I(A/P, i, N) - S[(A/P, i, N) - i] \\ &= (I - S)(A/P, i, N) + iS. \end{aligned} \quad (6.3)$$

Since we are calculating the equivalent annual costs, we treat cost items with a positive sign. Then the salvage value is treated as having a negative sign in Eq. (6.3). We may interpret this situation thus: To obtain the machine, one borrows a total of I dollars, S dollars of which are returned at the end of the N th year. The first term, $(I - S)(A/P, i, N)$, implies that the balance $(I - S)$ will be paid back in equal installments over the N -year period at a rate of i . The second term, iS , implies that simple interest in the amount iS is paid on S until it is repaid (Figure 6.4). Thus, the amount to be financed is $I - S(P/F, i, N)$, and the installments of this loan over the N -year period are

$$\begin{aligned} AE(i) &= [I - S(P/F, i, N)](A/P, i, N) \\ &= I(A/P, i, N) - S(P/F, i, N)(A/P, i, N) \\ &= [I(A/P, i, N) - S(A/F, i, N)] \\ &= CR(i). \end{aligned} \quad (6.4)$$

Therefore, $CR(i)$ tells us what the bank would charge each year. Many auto leases are based on this arrangement, in that most require a guarantee of S dollars in salvage. From an industry viewpoint, $CR(i)$ is the annual cost to the firm of owning the asset.

With this information, the amount of annual savings required to recover the capital and operating costs associated with a project can be determined, as Example 6.4 illustrates.

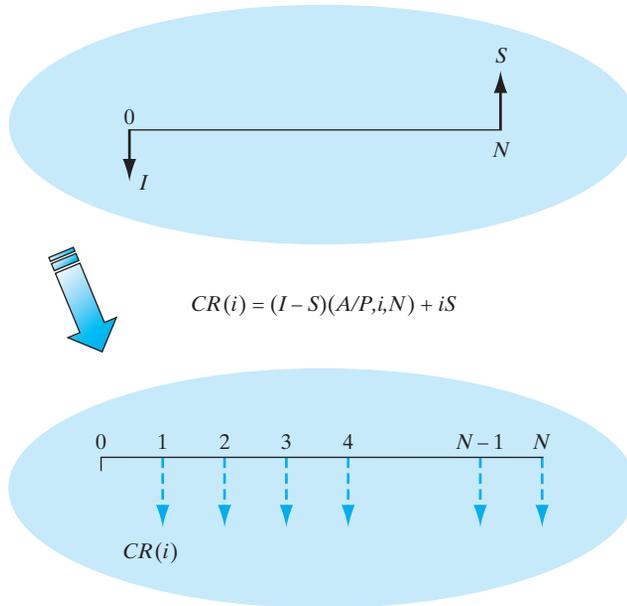


Figure 6.4 Capital recovery (ownership) cost calculation.

EXAMPLE 6.4 Capital Recovery Cost

Consider a machine that costs \$20,000 and has a five-year useful life. At the end of the five years, it can be sold for \$4,000 after tax adjustment. The annual operating and maintenance (O&M) costs are about \$500. If the firm could earn an after-tax revenue of \$5,000 per year with this machine, should it be purchased at an interest rate of 10%? (All benefits and costs associated with the machine are accounted for in these figures.)

SOLUTION

Given: $I = \$20,000$, $S = \$4,000$, $O\&M = \$500$, $A = \$5,000$, $N = 5$ years, and $i = 10\%$ per year.

Find: AE, and determine whether to purchase the machine.

The first task is to separate cash flows associated with acquisition and disposal of the asset from the normal operating cash flows. Since the operating cash flows—the \$5,000 yearly revenue—are already given in equivalent annual flows, we need to convert only the cash flows associated with acquisition and disposal of the asset into equivalent annual flows (Figure 6.5). Using Eq. (6.3), we obtain

$$\begin{aligned} CR(i) &= (I - S)(A/P, i, N) + iS \\ &= (\$20,000 - \$4,000)(A/P, 10\%, 5) + (0.10) \$4,000 \\ &= \$4,620.76, \end{aligned}$$

$$O\&M(i) = \$500,$$

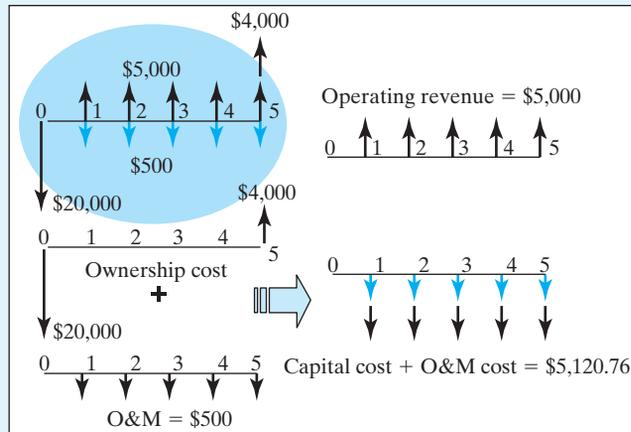


Figure 6.5 Separating ownership cost (capital cost) and operating cost from operating revenue, which must exceed the annual equivalent cost to make the project acceptable.

$$\begin{aligned}
 AEC(10\%) &= CR(10\%) + O\&M(10\%) \\
 &= \$4,620.76 + \$500 \\
 &= \$5,120.76,
 \end{aligned}$$

$$\begin{aligned}
 AE(10\%) &= \$5,000 - \$5,120.76 \\
 &= -\$120.76.
 \end{aligned}$$

This negative AE value indicates that the machine does not generate sufficient revenue to recover the original investment, so we must reject the project. In fact, there will be an equivalent loss of \$120.76 per year over the life of the machine.

COMMENTS: We may interpret the value found for the annual equivalent cost as asserting that the annual operating revenues must be at least \$5,120.76 in order to recover the cost of owning and operating the asset. However, the annual operating revenues actually amount to only \$5,000, resulting in a loss of \$120.76 per year. Therefore, the project is not worth undertaking.

6.3 Applying Annual-Worth Analysis

In general, most engineering economic analysis problems can be solved by the present-worth methods that were introduced in Chapter 5. However, some economic analysis problems can be solved more efficiently by annual-worth analysis. In this section, we introduce several applications that call for such an analysis.

6.3.1 Benefits of AE Analysis

Example 6.1 should look familiar to you: It is exactly the situation we encountered in Chapter 4 when we converted a mixed cash flow into a single present value and then into a series of equivalent cash flows. In the case of Example 6.1, you may wonder why we bother to convert NPW to AE at all, since we already know that the project is acceptable from NPW analysis. In fact, the example was mainly an exercise to familiarize you with the AE calculation.

However, in the real world, a number of situations can occur in which AE analysis is preferred, or even demanded, over NPW analysis. For example, corporations issue annual reports and develop yearly budgets. For these purposes, a company may find it more useful to present the annual cost or benefit of an ongoing project, rather than its overall cost or benefit. Following are some additional situations in which AE analysis is preferred:

1. **Consistency of report formats.** Financial managers commonly work with annual rather than overall costs in any number of internal and external reports. Engineering managers may be required to submit project analyses on an annual basis for consistency and ease of use by other members of the corporation and stockholders.
2. **Need for unit costs or profits.** In many situations, projects must be broken into unit costs (or profits) for ease of comparison with alternatives. Make-or-buy and reimbursement analyses are key examples, and these will be discussed in the chapter.
3. **Life-cycle cost analysis.** When there is no need for estimating the revenue stream for a proposed project, we can consider only the cost streams of the project. In that case, it is common to convert this life-cycle cost (LCC) into an equivalent annual cost for purposes of comparison. Industry has used the LCC to help determine which project will cost less over the life of a product. LCC analysis has had a long tradition in the Department of Defense, having been applied to virtually every new weapon system proposed or under development.

6.3.2 Unit Profit or Cost Calculation

In many situations, we need to know the unit profit (or cost) of operating an asset. To obtain this quantity, we may proceed as follows:

- Determine the number of units to be produced (or serviced) each year over the life of the asset.
- Identify the cash flow series associated with production or service over the life of the asset.
- Calculate the net present worth of the project cash flow series at a given interest rate, and then determine the equivalent annual worth.
- Divide the equivalent annual worth by the number of units to be produced or serviced during each year. When the number of units varies each year, you may need to convert them into equivalent annual units.

To illustrate the procedure, Example 6.5 uses the annual equivalent concept in estimating the savings per machine hour for the proposed acquisition of a machine.

EXAMPLE 6.5 Unit Profit per Machine Hour When Annual Operating Hours Remain Constant

Consider the investment in the metal-cutting machine of Example 5.5. Recall that this three-year investment was expected to generate an NPW of \$3,553. Suppose that the machine will be operated for 2,000 hours per year. Compute the equivalent savings per machine hour at $i = 15\%$.

SOLUTION

Given: NPW = \$3,553, $N = 3$ years, $i = 15\%$ per year, and 2,000 machine hours per year.

Find: Equivalent savings per machine hour.

We first compute the annual equivalent savings from the use of the machine. Since we already know the NPW of the project, we obtain the AE by the formula

$$AE(15\%) = \$3,553(A/P, 15\%, 3) = \$1,556.$$

With an annual usage of 2,000 hours, the equivalent savings per machine hour would be

$$\text{Savings per machine hour} = \$1,556/2,000 \text{ hours} = \$0.78/\text{hour}.$$

COMMENTS: Note that we cannot simply divide the NPW (\$3,553) by the total number of machine hours over the three-year period (6,000 hours) to obtain \$0.59/hour. This \$0.59 figure represents the instant savings in present worth for each hourly use of the equipment, but does not consider the time over which the savings occur. Once we have the annual equivalent worth, we can divide by the desired time unit if the compounding period is one year. If the compounding period is shorter, then the equivalent worth should be calculated for the compounding period.

EXAMPLE 6.6 Unit Profit per Machine Hour When Annual Operating Hours Fluctuate

Consider again Example 6.5, and suppose that the metal-cutting machine will be operated according to varying hours: 1,500 hours the first year, 2,500 hours the second year, and 2,000 hours the third year. The total operating hours still remain at 6,000 over three years. Compute the equivalent savings per machine hour at $i = 15\%$.

SOLUTION

Given: NPW = \$3,553, $N = 3$ years, $i = 15\%$ per year, and operating hours of 1,500 the first year, 2,500 the second year, and 2,000 the third year.

Find: Equivalent savings per machine hour.

As calculated in Example 6.5, the annual equivalent savings is \$1,556. Let C denote the equivalent annual savings per machine hour, which we need to determine. Now, with varying annual usages of the machine, we can set up the equivalent annual savings as a function of C :

$$\begin{aligned} \text{Equivalent annual savings} &= [C(1,500)(P/F, 15\%, 1) \\ &\quad + C(2,500)(P/F, 15\%, 2) \\ &\quad + C(2,000)(P/F, 15\%, 3)](A/P, 15\%, 3) \\ &= 1,975.16C. \end{aligned}$$

We can equate this amount to the \$1,556 we calculated in Example 6.5 and solve for C . This gives us

$$C = \$1,556/1,975.16 = \$0.79/\text{hour},$$

which is about a penny more than the \$0.78 we found in Example 6.5.

6.3.3 Make-or-Buy Decision

Make-or-buy problems are among the most common of business decisions. At any given time, a firm may have the option of either buying an item or producing it. Unlike the make-or-buy situation we will consider in Chapter 8, *if either the “make” or the “buy” alternative requires the acquisition of machinery or equipment, then it becomes an investment decision.* Since the cost of an outside service (the “buy” alternative) is usually quoted in terms of dollars per unit, it is easier to compare the two alternatives if the differential costs of the “make” alternative are also given in dollars per unit. This unit cost comparison requires the use of annual-worth analysis. The specific procedure is as follows:

- Step 1.** Determine the time span (planning horizon) for which the part (or product) will be needed.
- Step 2.** Determine the annual quantity of the part (or product).
- Step 3.** Obtain the unit cost of purchasing the part (or product) from the outside firm.
- Step 4.** Determine the equipment, manpower, and all other resources required to make the part (or product) in-house.
- Step 5.** Estimate the net cash flows associated with the “make” option over the planning horizon.
- Step 6.** Compute the annual equivalent cost of producing the part (or product).
- Step 7.** Compute the unit cost of making the part (or product) by dividing the annual equivalent cost by the required annual volume.
- Step 8.** Choose the option with the minimum unit cost.

EXAMPLE 6.7 Equivalent Worth: Outsourcing the Manufacture of Cassettes and Tapes

Ampex Corporation currently produces both videocassette cases and metal particle magnetic tape for commercial use. An increased demand for metal particle tapes is projected, and Ampex is deciding between increasing the internal production of empty cassette cases and magnetic tape or purchasing empty cassette cases from an outside vendor. If Ampex purchases the cases from a vendor, the company must also buy specialized equipment to load the magnetic tapes, since its current loading machine is not compatible with the cassette cases produced by the vendor under consideration. The projected production rate of cassettes is 79,815 units per week for 48 weeks of operation per year. The planning horizon is seven years. After considering the effects of income taxes, the accounting department has itemized the annual costs associated with each option as follows:

- **Make option (annual costs):**

Labor	\$1,445,633
Materials	\$2,048,511
Incremental overhead	<u>\$1,088,110</u>
Total annual cost	\$4,582,254

- **Buy option:**

Capital expenditure	
Acquisition of a new loading machine	\$ 405,000
Salvage value at end of seven years	\$ 45,000
Annual Operating Costs	
Labor	\$ 251,956
Purchasing empty cassette (\$0.85/unit)	\$3,256,452
Incremental overhead	<u>\$ 822,719</u>
Total annual operating costs	\$4,331,127

(Note the conventional assumption that cash flows occur in discrete lumps at the ends of years, as shown in Figure 6.6.) Assuming that Ampex's MARR is 14%, calculate the unit cost under each option.

SOLUTION

Given: Cash flows for two options and $i = 14\%$.

Find: Unit cost for each option and which option is preferred.

The required annual production volume is

$$79,815 \text{ units/week} \times 48 \text{ weeks} = 3,831,120 \text{ units per year.}$$

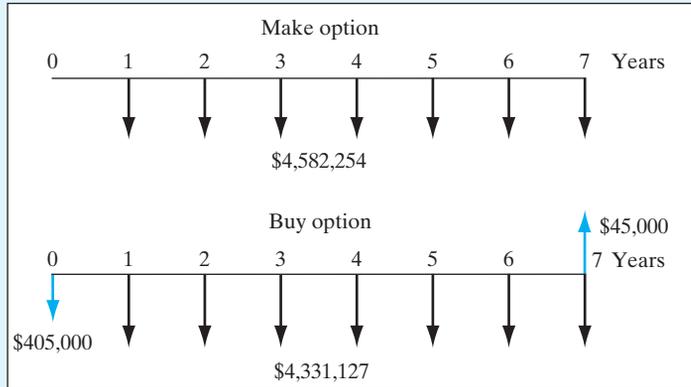


Figure 6.6 Make-or-buy analysis.

We now need to calculate the annual equivalent cost under each option:

- **Make option.** Since the “make option” is already given on an annual basis, the equivalent annual cost will be

$$AEC(14\%)_{\text{Make}} = \$4,582,254.$$

- **Buy option.** The two cost components are capital cost and operating cost.
Capital cost:

$$\begin{aligned} CR(14\%) &= (\$405,000 - \$45,000)(A/P, 14\%, 7) \\ &\quad + (0.14)(\$45,000) \\ &= \$90,249 \\ AEC(14\%)_1 &= CR(14\%) = \$90,249. \end{aligned}$$

Operating cost:

$$AEC(14\%)_2 = \$4,331,127.$$

Total annual equivalent cost:

$$AEC(14\%)_{\text{Buy}} = AEC(14\%)_1 + AEC(14\%)_2 = \$4,421,376.$$

Obviously, this annual equivalent calculation indicates that Ampex would be better off buying cassette cases from the outside vendor. However, Ampex wants to know the unit costs in order to set a price for the product. In such a situation, we need to calculate the unit cost of producing the cassette tapes under each option. We do this by dividing the magnitude of the annual equivalent cost for each option by the annual quantity required:

- **Make option:**

$$\text{Unit cost} = \$4,582,254/3,831,120 = \$1.20/\text{unit}.$$

- **Buy option:**

$$\text{Unit cost} = \$4,421,376/3,831,120 = \$1.15/\text{unit}.$$

Buying the empty cassette cases from the outside vendor and loading the tape in-house will save Ampex 5 cents per cassette before any consideration of taxes.

COMMENTS: Two important noneconomic factors should also be considered. The first is the question of whether the quality of the supplier's component is better than, equal to, or worse than the component the firm is presently manufacturing. The second is the reliability of the supplier in terms of providing the needed quantities of the cassette cases on a timely basis. A reduction in quality or reliability should virtually always rule out buying.

6.3.4 Pricing the Use of an Asset

Companies often need to calculate the cost of equipment that corresponds to a **unit of use** of that equipment. For example, if you own an asset such as a building, you would be interested in knowing the cost per square foot of owning and operating the asset. This information will be the basis for determining the rental fee for the asset. A familiar example is an employer's reimbursement of costs for the use of an employee's personal car for business purposes. If an employee's job depends on obtaining and using a personal vehicle on the employer's behalf, reimbursement on the basis of the employee's overall costs per mile seems fair.

EXAMPLE 6.8 Pricing an Apartment Rental Fee

Sunbelt Corporation, an investment company, is considering building a 50-unit apartment complex in a growing area near Tucson, Arizona. Since the long-term growth potential of the town is excellent, it is believed that the company could average 85% full occupancy for the complex each year. If the following financial data are reasonably accurate estimates, determine the minimum monthly rent that should be charged if a 15% rate of return is desired:

- Land investment cost = \$1,000,000
- Building investment cost = \$2,500,000
- Annual upkeep cost = \$150,000
- Property taxes and insurance = 5% of total initial investment
- Study period = 25 years
- Salvage value = Only land cost can be recovered in full.

SOLUTION

Given: Preceding financial data, study period = 25 years, and $i = 15\%$.

Find: Minimum monthly rental charge.

First we need to determine the capital cost associated with ownership of the property:

$$\text{Total investment required} = \text{land cost} + \text{building cost} = \$3,500,000,$$

$$\text{Salvage value} = \$1,000,000 \text{ at the end of 25 years,}$$

$$\begin{aligned} \text{CR}(15\%) &= (\$3,500,000 - \$1,000,000)(A/P, 15\%, 25) \\ &\quad + (\$1,000,000)(0.15) \\ &= \$536,749. \end{aligned}$$

Second, the annual operating cost has two elements: (1) property taxes and insurance and (2) annual upkeep cost. Thus,

$$\begin{aligned} \text{O\&M cost} &= (0.05)(\$3,500,000) + \$150,000 \\ &= \$325,000. \end{aligned}$$

So the total annual equivalent cost is

$$\begin{aligned} \text{AEC}(15\%) &= \$536,749 + \$325,000 \\ &= \$861,749, \end{aligned}$$

which is the minimum annual rental required to achieve a 15% rate of return. Therefore, with annual compounding, the monthly rental amount is

$$\begin{aligned} \text{Required monthly charge} &= \frac{\$861,749}{(12 \times 50)(0.85)} \\ &= \$1,690. \end{aligned}$$

COMMENTS: The rental charge that is exactly equal to the cost of owning and operating the building is known as the **break-even point**.

6.4 Life-Cycle Cost Analysis

Because 80% of the total life-cycle cost of a system occurs after the system has entered service, the best long-term system acquisition and support decisions are based on a full understanding of the total cost of acquiring, operating, and supporting the system (Figure 6.7). **Life-cycle cost analysis** (LCCA) enables the analyst to make sure that the selection of a design alternative is not based solely on the lowest initial costs, but also takes into account all the future costs over the project's usable life. Some of the unique features of LCCA are as follows:

- LCCA is used appropriately only to select from among design alternatives that would yield the same level of performance or benefits to the project's users during normal operations. If benefits vary among the design alternatives, then the alternatives cannot be compared solely on the basis of cost. Rather, the analyst would need to employ present-worth analysis or benefit–cost analysis (BCA), which measures the monetary value of life-cycle benefits as well as costs. BCA is discussed in Chapter 16.
- LCCA is a way to predict the most cost-effective solution; it does not guarantee a particular result, but allows the plant designer or manager to make a reasonable comparison among alternative solutions within the limits of the available data.
- To make a fair comparison, the plant designer or manager might need to consider the measure used. For example, the same process output volume should be considered, and if the two items being examined cannot give the same output volume, it may be appropriate to express the figures in cost per unit of output (e.g., \$/ton, or euro/kg), which requires a calculation of annual equivalent dollars generated. This calculation is based on the annual output.

Life-cycle cost analysis is useful when project alternatives that fulfill the same performance requirements, but differ with respect to initial costs and operating costs.

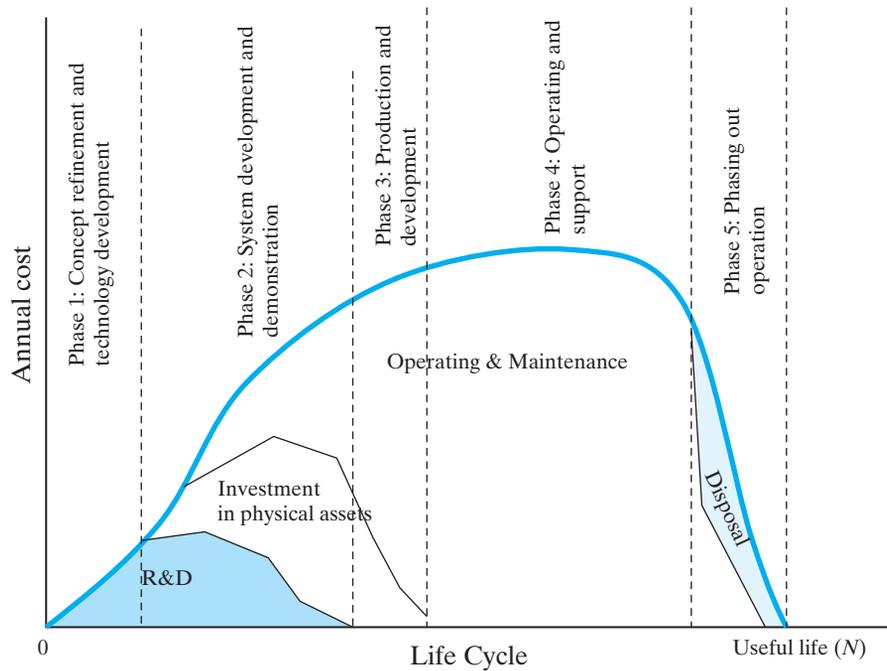


Figure 6.7 Stages of life-cycle cost. These include the concept refinement and technology development phase, the system development and demonstration phase, the production and deployment phase, the operating phase, and the disposal phase.

In many situations, we need to compare a set of different design alternatives, each of which would produce the same number of units (constant revenues), but would require different amounts of investment and operating costs (because of different degrees of mechanization). Example 6.9 illustrates the use of the annual equivalent-cost concept to compare the cost of operating an existing pumping system with that of an improved system.

EXAMPLE 6.9 Pumping System with a Problem Valve³

Consider a single-pump circuit that transports a process fluid containing some solids from a storage tank to a pressurized tank. A heat exchanger heats the fluid, and a control valve regulates the rate of flow into the pressurized tank to 80 cubic meters per hour (m^3/h), or 350 gallons per minute (gpm). The process is depicted in Figure 6.8.

The plant engineer is experiencing problems with a fluid control valve (FCV) that fails due to erosion caused by cavitations. The valve fails every 10 to 12 months at a cost of \$4,000 per repair. A change in the control valve is being considered: Replace the existing valve with one that can resist cavitations. Before the control valve

³ *Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems*. DOE/GO-102001-1190. December 2000, Office of Industrial Technologies, U.S. Department of Energy and Hydraulic Institute.

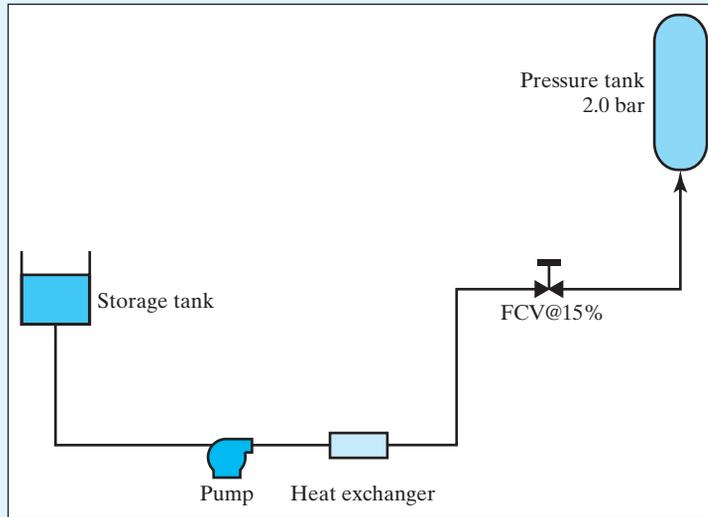


Figure 6.8 Sketch of a pumping system in which the control valve fails.

is repaired again, the project engineer wants to look at other options and perform an LCCA on alternative solutions.

Engineering Solution Alternatives

The first step is to determine how the system is currently operating and why the control valve fails. Then the engineer can see what can be done to correct the problem. The control valve currently operates between 15 and 20% open and with considerable cavitation noise from the valve. It appears that the valve was not sized properly for the application. After reviewing the original design calculations, it was discovered that the pump was oversized: $110 \text{ m}^3/\text{h}$ (485 gpm) instead of $80 \text{ m}^3/\text{h}$ (350 gpm). This resulted in a larger pressure drop across the control valve than was originally intended.

As a result of the large differential pressure at the operating rate of flow, and because the valve is showing cavitation damage at regular intervals, the engineer determines that the control valve is not suitable for this process.

The following four options are suggested:

- **Option A.** A new control valve can be installed to accommodate the high pressure differential.
- **Option B.** The pump impeller can be trimmed so that the pump does not develop as much head, resulting in a lower pressure drop across the current valve.
- **Option C.** A variable-frequency drive (VFD) can be installed and the flow control valve removed. The VFD can vary the pump speed and thus achieve the desired process flow.
- **Option D.** The system can be left as it is, with a yearly repair of the flow control valve to be expected.

Cost Summary:

Pumping systems often have a life span of 15 to 20 years. Some cost elements will be incurred at the outset, and others will be incurred at different times throughout the lives of the different solutions evaluated. Therefore, you need to calculate a present value of the LCC to accurately assess the different solutions.

Some of the major LCC elements related to a typical pumping system are summarized as follows:

$$\text{LCC} = C_{ic} + C_{in} + C_e + C_o + C_m + C_s + C_{env} + C_d$$

LCC = life-cycle cost

C_{ic} = initial costs, purchase price (costs of pump, system, pipe, auxiliary services)

C_{in} = installation and commissioning cost (including cost of training)

C_e = energy costs (predicted cost for system operation, including costs of pump driver, controls, and any auxiliary services)

C_o = operation cost (labor cost of normal system supervision)

C_m = maintenance and repair costs (costs of routine and predicted repairs)

C_s = downtime costs (cost of loss of production)

C_{env} = environmental costs (costs due to contamination from pumped liquid and auxiliary equipment)

C_d = decommissioning and disposal costs (including the cost of restoration of the local environment and disposal of auxiliary services)

For each option, the major cost elements identified are as follows:

- **Option A.** The cost of a new control valve that is properly sized is \$5,000. The cost of modifying the pump's performance by reducing the diameter of the impeller is \$2,250. The process operates at 80 m³/h for 6,000 h/year. The energy cost is \$0.08 per kWh and the motor efficiency is 90%.
- **Option B.** By trimming the impeller to 375 mm, the pump's total head is reduced to 42.0 m (138 ft) at 80 m³/h. This drop in pressure reduces the differential pressure across the control valve to less than 10 m (33 ft), which better matches the valve's original design intent. The resulting annual energy cost with the smaller impeller is \$6,720 per year. It costs \$2,250 to trim the impeller. This cost includes the machining cost as well as the cost to disassemble and reassemble the pump.
- **Option C.** A 30-kW VFD costs \$20,000 and an additional \$1,500 to install. The VFD will cost \$500 to maintain each year. It is assumed that it will not need any repairs over the project's eight-year life.
- **Option D.** The option to leave the system unchanged will result in a yearly cost of \$4,000 for repairs to the cavitating flow control valve.

Table 6.1 summarizes financial as well as technical data related to the various options.

TABLE 6.1 Cost Comparison for Options A through D in the System with a Failing Control Valve

Cost	Change Control Valve (A)	Trim Impeller (B)	VFD (C)	Repair Control Valve (D)
Pump Cost Data				
Impeller diameter	430 mm	375 mm	430 mm	430 mm
Pump head	71.7 m (235 ft)	42.0 m (138 ft)	34.5 m (113 ft)	71.7 m (235 ft)
Pump efficiency	75.1%	72.1%	77%	75.1%
Rate of flow	80 m ³ /h (350 gpm)			
Power consumed	23.1 kW	14.0 kW	11.6 kW	23.1 kW
Energy cost/year	\$11,088	\$6,720	\$ 5,568	\$11,088
New valve	\$ 5,000	0	0	0
Modify impeller	0	\$2,250	0	0
VFD	0	0	\$20,000	0
Installation of VFD	0	0	\$ 1,500	0
Valve repair/year	0	0	0	\$ 4,000

SOLUTION

Given: Financial data as summarized in Table 6.1.

Find: Which design option to choose.

Assumptions:

- The current energy price is \$0.08/kWh.
- The process is operated for 6,000 hours/year.
- The company has a cost of \$500 per year for routine maintenance of pumps of this size, with a repair cost of \$2,500 every second year.
- There is no decommissioning cost or environmental disposal cost associated with this project.
- The project has an eight-year life.
- The interest rate for new capital projects is 8%, and an inflation rate of 4% is expected.

A sample LCC calculation for Option A is shown in Table 6.2. Note that the energy cost and other cost data are escalated at the annual rate of 4%. For example, the current estimate of energy cost is \$11,088. To find the cost at the end of year 1, we

TABLE 6.3 Comparison of LCC for Options A through D

	Option A Change Control Valve	Option B Trim Impeller	Option C VFD and Remove Control Valve	Option D Repair Control Valve
Input				
Initial investment cost:	\$5,000	\$2,250	\$21,500	0
Energy price (present) per kWh:	0.080	0.080	0.080	0.080
Weighted average power of equipment in kW:	23.1	14.0	11.6	23.1
Average operating hours/year:	6,000	6,000	6,000	6,000
Energy cost/year (calculated) + energy price × weighted average power × average operating hours/year:	11,088	6,720	5,568	11,088
Maintenance cost (routine maintenance/year:	500	500	1,000	500
Repair every second year:	2,500	2,500	2,500	2,500
Other yearly costs:	0	0	0	4,000
Downtime cost/year:	0	0	0	0
Environmental cost:	0	0	0	0
Decommissioning/disposal (salvage) cost:	0	0	0	0
Lifetime in years:	8	8	8	8
Interest rate (%):	8.0%	8.0%	8.0%	8.0%
Inflation rate (%):	4.0%	4.0%	4.0%	4.0%
Output				
Present LCC value:	\$91,827	\$59,481	\$74,313	\$113,930
Cost per operating hour	\$2.66	\$1.73	\$2.16	\$3.30

multiply \$11,088 by $(1 + 0.04)$, yielding \$11,532. For year 2, we multiply \$11,532 by $(1 + 0.04)$ to obtain \$11,993. Once we calculate the LCC in present worth (\$91,827), we find the equivalent annual value (\$15,979) at 8% interest. Finally, to calculate the cost per hour, we divide \$15,979 by 6,000 hours, resulting in \$2.66. We can calculate the unit costs for other options in a similar fashion. (See Table 6.3.)

Option B, trimming the impeller, has the lowest life-cycle cost (\$1.73 per hour) and is the preferred option for this example.

6.5 Design Economics

Engineers are frequently involved in making design decisions that provide the required functional quality at the lowest cost. Another valuable extension of AE analysis is minimum-cost analysis, which is used to determine optimal engineering designs. The AE analysis method is useful when two or more cost components are affected differently by the same design element (i.e., for a single design variable, some costs may increase while others decrease). When the equivalent annual total cost of a design variable is a function of increasing and decreasing cost components, we can usually find the optimal value that will minimize the cost of the design with the formula

$$AEC(i) = a + bx + \frac{c}{x}, \quad (6.5)$$

where x is a common design variable and a , b , and c are constants.

To find the value of the common design variable that minimizes $AEC(i)$, we need to take the first derivative, equate the result to zero, and solve for x :

$$\begin{aligned} \frac{dAEC(i)}{dx} &= b - \frac{c}{x^2} \\ &= 0 \\ x = x^* &= \sqrt{\frac{c}{b}}. \end{aligned} \quad (6.6)$$

(It is common engineering practice to denote the optimal solution with an asterisk.)

The logic of the first-order requirement is that an activity should, if possible, be carried to a point where its **marginal yield** $dAEC(i)/dx$ is zero. However, to be sure whether we have found a maximum or a minimum when we have located a point whose marginal yield is zero, we must examine it in terms of what are called the **second-order conditions**. Second-order conditions are equivalent to the usual requirements that the second derivative be negative in the case of a maximum and positive for a minimum. In our situation,

$$\frac{d^2AEC(i)}{dx^2} = \frac{2C}{x^3}.$$

As long as $C > 0$, the second derivative will be positive, indicating that the value x^* is the minimum-cost point for the design alternative. To illustrate the optimization concept, two examples are given, the first having to do with designing the optimal cross-sectional area of a conductor and the second dealing with selecting an optimal size for a pipe.

EXAMPLE 6.10 Optimal Cross-Sectional Area

A constant electric current of 5,000 amps is to be transmitted a distance of 1,000 feet from a power plant to a substation for 24 hours a day, 365 days a year. A copper conductor can be installed for \$8.25 per pound. The conductor will have an estimated life of 25 years and a salvage value of \$0.75 per pound. The power loss from a conductor is inversely proportional to the cross-sectional area A of the conductor.

It is known that the resistance of the conductor sought is 0.8145×10^{-5} ohm for 1 square inch per foot of cross section. The cost of energy is \$0.05 per kilowatt-hour, the interest rate is 9%, and the density of copper is 555 lb/ft³. For the given data, calculate the optimum cross-sectional area A of the conductor.

DISCUSSION: The resistance of the conductor is the most important cause of power loss in a transmission line. The resistance of an electrical conductor varies directly with its length and inversely with its cross-sectional area according to the equation

$$R = \rho \left(\frac{L}{A} \right), \quad (6.7)$$

where R is the resistance of the conductor, L is the length of the conductor, A is the cross-sectional area of the conductor, and ρ is the resistivity of the conductor material.

Any consistent set of units may be used. In power work in the United States, L is usually given in feet, A in circular mils (cmil), and ρ in ohm-circular mils per foot.

A circular mil is the area of a circle that has a diameter of 1 mil, equal to 1×10^{-3} in. The cross-sectional area of a wire in square inches equals its area in circular mils multiplied by 0.7854×10^{-6} . More specifically, one unit relates to another as follows:

$$\begin{aligned} 1 \text{ linear mil} &= 0.001 \text{ in.} \\ &= 0.0254 \text{ millimeter.} \\ 1 \text{ circular mil} &= \text{area of circle 1 linear mil in diameter} \\ &= (0.5)^2 \pi \text{ mil}^2 \\ &= 0.7854 \times 10^{-6} \text{ in.}^2 \\ 1 \text{ in.}^2 &= 1/(0.7854 \times 10^{-6}) \\ &= 1.27324 \times 10^6 \text{ cmil.} \end{aligned}$$

In SI units (the official designation for the *Système International d'Unités*), L is in meters, A in square meters, and ρ in ohm-meters. In terms of SI units, the copper conductor has a ρ value of 1.7241×10^{-8} Ω -meter. We can easily convert this value into units of Ω -in.² per foot. From Eq. (6.7), solving for ρ yields

$$\begin{aligned} \rho &= RA/L = 1.7241 \times 10^{-8} \Omega (1 \text{ meter})^2 / 1 \text{ meter} \\ &= 1.7241 \times 10^{-8} \Omega (39.37 \text{ in.})^2 / 3.2808 \text{ ft} \\ &= 0.8145421 \times 10^{-5} \Omega \text{ in.}^2 / \text{ft.} \end{aligned}$$

When current flows through a circuit, power is used to overcome resistance. The unit of electrical work is the kilowatt hour (kWh), which is equal to the power in kilowatts, multiplied by the hours during which work is performed. If the current I is

steady, then the charge passing through the wire in time T is equivalent to the power that is converted to heat (known as energy loss) and is equal to

$$\text{Power} = I^2 \frac{RT}{1,000 \text{ kWh}}, \quad (6.8)$$

where I is the current in amperes, R is the resistance in ohms, and T is the duration, in hours, during which work is performed.

SOLUTION

Given: Cost components as a function of cross-sectional area (A), $N = 25$ years, and $i = 9\%$.

Find: Optimal value of A .

Step 1: This classic minimum-cost example, the design of the cross-sectional area of an electrical conductor, involves increasing and decreasing cost components. Since the resistance of a conductor is inversely proportional to the size of the conductor, energy loss will decrease as the size of the conductor increases. More specifically, the energy loss in kilowatt-hours (kWh) in a conductor due to resistance is equal to

$$\begin{aligned} \text{Energy loss in kilowatt-hours} &= \frac{I^2 R}{1,000 A} T \\ &= \frac{(5,000^2)(0.008145)}{1,000 A} (24 \times 365) \\ &= \frac{1,783,755}{A} \text{ kWh.} \end{aligned}$$

Step 2: Again, since the electrical resistance is inversely proportional to the cross-sectional area A of the conductor, the total energy loss in dollars per year for a specified conductor material is

$$\begin{aligned} \text{Cost of energy loss} &= \frac{1,783,755}{A} (\phi) \\ &= \frac{1,783,755}{A} (\$0.05) \\ &= \frac{\$89,188}{A}, \end{aligned}$$

where ϕ is the cost of energy in dollars per kWh.

Step 3: As we increase the size of the conductor, however, it costs more to build. First, we need to calculate the total amount of conductor material in pounds.

Since the cross-sectional area is given in square inches, we need to convert the total length in feet to inches before finding the weight of the material:

$$\begin{aligned}\text{Weight of material in pounds} &= \frac{(1,000)(12)(555)A}{12^3} \\ &= 3,854(A) \\ \text{Total material cost} &= 3,854(A)(\$8.25) \\ &= \$31,797(A).\end{aligned}$$

Here, we are looking for the trade-off between the cost of installation and the cost of energy loss.

Step 4: Since, at the end of 25 years, the copper material will be salvaged at the rate of \$0.75 per pound, we can compute the capital recovery cost as

$$\begin{aligned}\text{CR}(9\%) &= [31,797A - 0.75(3,854A)](A/P, 9\%, 25) + 0.75(3,854A)(0.09) \\ &= 2,943A + 260A \\ &= 3,203A.\end{aligned}$$

Step 5: Using Eq. (6.5), we express the total annual equivalent cost as a function of the design variable A :

$$\text{AEC}(9\%) = \underbrace{3,203A}_{\text{Capital cost}} + \underbrace{\frac{89,188}{A}}_{\text{Operating cost}}.$$

To find the minimum annual equivalent cost, we use Eq. (6.6):

$$\begin{aligned}\frac{d\text{AEC}(9\%)}{dA} &= 3,203 - \frac{89,188}{A^2} = 0, \\ A^* &= \sqrt{\frac{89,188}{3,203}} \\ &= 5.276 \text{ in.}^2.\end{aligned}$$

The minimum annual equivalent total cost is

$$\begin{aligned}\text{AEC}(9\%) &= 3,203(5.276) + \frac{89,188}{5.276} \\ &= \$33,802.\end{aligned}$$

Figure 6.9 illustrates the nature of this design trade-off problem.

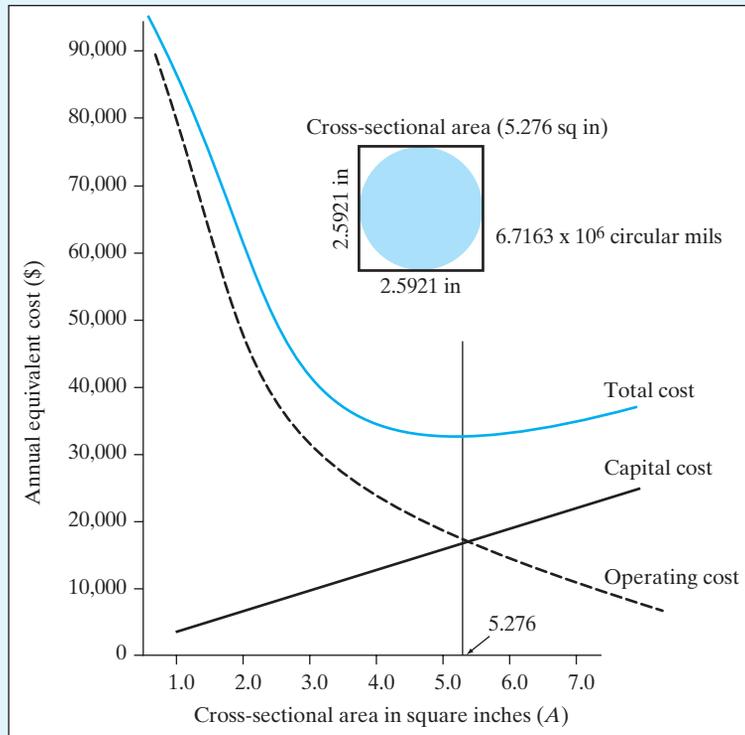


Figure 6.9 Optimal cross-sectional areas for a copper conductor. Note that the minimum point almost coincides with the crossing point of the capital-cost and operating-cost lines. This is not always true. Since the cost components can have a variety of cost patterns, the minimum point does not in general occur at the crossing point (Example 6.10).

EXAMPLE 6.11 Economical Pipe Size

As a result of the 1990 conflict in the Persian Gulf, Kuwait is studying the feasibility of running a steel pipeline across the Arabian Peninsula to the Red Sea. The pipeline will be designed to handle 3 million barrels of crude oil per day under optimum conditions. The length of the line will be 600 miles. Calculate the optimum pipeline diameter that will be used for 20 years for the following data at $i = 10\%$:

$$\text{Pumping power} = \frac{1.333Q\Delta P}{1,980,000} \text{ HP}$$

$$Q = \text{volume flow rate, ft}^3/\text{hour}$$

$$\Delta P = \frac{128Q\mu L}{g\pi D^4}, \text{ pressure drop, lb/ft}^2$$

$$L = \text{pipe length, ft}$$

D = inside pipe diameter, ft
 $t = 0.01D$, pipeline wall thickness, ft
 $\mu = 8,500$ lb/hour ft, oil viscosity
 $g = 32.3 \times 12,960,000$ ft/hour²
 Power cost, \$0.015 per HP hour
 Oil cost, \$50 per barrel
 Pipeline cost, \$1.00 per pound of steel
 Pump and motor costs, \$195 per HP

The salvage value of the steel after 20 years is assumed to be zero because removal costs exhaust scrap profits from steel. (See Figure 6.10 for the relationship between D and t .)

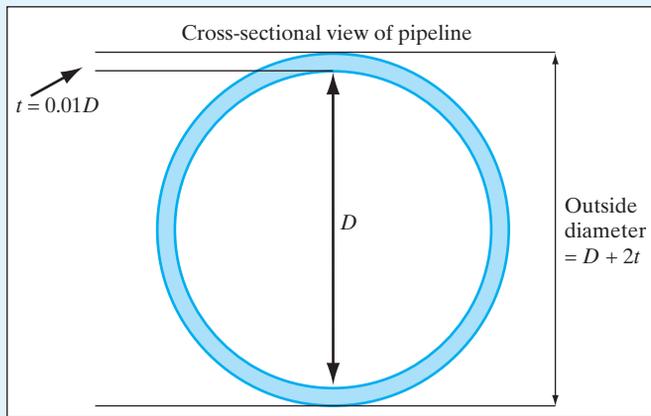


Figure 6.10 Designing economical pipe size to handle 3 million barrels of crude oil per day (Example 6.11).

DISCUSSION: In general, when a progressively larger size of pipe is used to carry a given fluid at a given volume flow rate, the energy required to move the fluid will progressively decrease. However, as we increase the pipe size, the cost of its construction will increase. In practice, to obtain the best pipe size for a particular situation, you may choose a reasonable, but small, starting size. Compute the energy cost of pumping fluid through this size of pipe and the total construction cost, and then compare the difference in energy cost with the difference in construction cost. When the savings in energy cost exceeds the added construction cost, the process may be repeated with progressively larger pipe sizes until the added construction cost exceeds the savings in energy cost. As soon as this happens, the best pipe size to use in the particular application is identified. However, this search process can be simplified by using the minimum-cost concept encompassed by Eqs. (6.5) and (6.6).

SOLUTION

Given: Cost components as a function of pipe diameter (D), $N = 20$ years, and $i = 10\%$.

Find: Optimal pipe size (D).

Step 1: Several different units are introduced; however, we need to work with common units. We will assume the following conversions:

$$\begin{aligned} 1 \text{ mile} &= 5,280 \text{ ft} \\ 600 \text{ miles} &= 600 \times 5,280 = 3,168,000 \text{ ft} \\ 1 \text{ barrel} &= 42 \text{ U.S. gallons} \\ 1 \text{ barrel} &= 42 \text{ gallons} \times 231 \text{ in.}^3/\text{gallon} = 9,702 \text{ in.}^3 \\ 1 \text{ barrel} &= 9,702 \text{ in.}^3/12^3 = 5.6146 \text{ ft}^3 \\ \text{Density of steel} &= 490.75 \text{ lb/ft}^3 \end{aligned}$$

Step 2: Power required to pump oil:

It is well known that, for any given set of operating conditions involving the flow of a noncompressible fluid, such as oil, through a pipe of constant diameter, a small-diameter pipe will have a high fluid velocity and a high fluid pressure drop through the pipe. This will require a pump that will deliver a high discharge pressure and a motor with large energy consumption. To determine the pumping power required to boost the pressure drop, we need to determine both the volume flow rate and the amount of pressure drop. Then we can calculate the cost of the power required to pump oil.

- Volume flow rate per hour:

$$\begin{aligned} Q &= 3,000,000 \text{ barrels/day} \times 5.6146 \text{ ft}^3/\text{barrel} \\ &= 16,843,800 \text{ ft}^3/\text{day} \\ &= 701,825 \text{ ft}^3/\text{hour}. \end{aligned}$$

- Pressure drop:

$$\begin{aligned} \Delta P &= \frac{128Q\mu L}{g\pi D^4} \\ &= \frac{128 \times 701,825 \times 8,500 \times 3,168,000}{32.3 \times 12,960,000 \times 3.14159 D^4} \\ &= \frac{1,845,153,595}{D^4} \text{ lb/ft}^2. \end{aligned}$$

- Pumping power required to boost the pressure drop:

$$\begin{aligned} \text{Power} &= \frac{1.333Q\Delta P}{1,980,000} \\ &= \frac{1.333 \times 701,825 \times \frac{1,845,153,595}{D^4}}{1,980,000} \\ &= \frac{871,818,975}{D^4} \text{ HP}. \end{aligned}$$

- Power cost to pump oil:

$$\begin{aligned}\text{Power cost} &= \frac{871,818,975}{D^4} \text{HP} \times \$0.015/\text{HP} \cdot \text{hour} \\ &\quad \times 24 \text{ hours/day} \times 365 \text{ days/year} \\ &= \frac{\$114,557,013,315}{D^4} / \text{year}.\end{aligned}$$

Step 3: Pump and motor cost calculation:

Once we determine the required pumping power, we can find the size of the pump and the motor costs. This is because the capacity of the pump and motor is proportional to the required pumping power. Thus,

$$\begin{aligned}\text{Pump and motor cost} &= \frac{871,818,975}{D^4} \times \$195/\text{HP} \\ &= \frac{\$170,004,700,125}{D^4}.\end{aligned}$$

Step 4: Required amount and cost of steel:

The pumping cost will be counterbalanced by the lower costs for the smaller pipe, valves, and fittings. If the pipe diameter is made larger, the fluid velocity drops markedly and the pumping costs become substantially lower. Conversely, the capital cost for the larger pipe, fittings, and valves becomes greater. For a given cross-sectional area of the pipe, we can determine the total volume of the pipe as well as the weight. Once the total weight of the pipe is determined, we can easily convert it into the required investment cost. The calculations are as follows:

$$\begin{aligned}\text{Cross-sectional area} &= 3.14159[(0.51D)^2 - (0.50D)^2] \\ &= 0.032D^2 \text{ ft}^2,\end{aligned}$$

$$\begin{aligned}\text{Total volume of pipe} &= 0.032D^2 \text{ ft}^2 \times 3,168,000 \text{ ft} \\ &= 101,376D^2 \text{ ft}^3,\end{aligned}$$

$$\begin{aligned}\text{Total weight of steel} &= 101,376D^2 \text{ ft}^3 \times 490.75 \text{ lb/ft}^3 \\ &= 49,750,272D^2 \text{ lb},\end{aligned}$$

$$\begin{aligned}\text{Total pipeline cost} &= \$1.00/\text{lb} \times 49,750,272D^2 \text{ lb} \\ &= \$49,750,272D^2.\end{aligned}$$

Step 5: Annual equivalent cost calculation:

For a given total pipeline cost and its salvage value at the end of 20 years of service life, we can find the equivalent annual capital cost by using the formula for the capital recovery factor with return:

$$\begin{aligned}\text{Capital cost} &= \left(\$49,750,272D^2 + \frac{\$170,004,700,125}{D^4} \right) (A/P, 10\%, 20) \\ &= 5,843,648D^2 + \frac{19,968,752,076}{D^4}\end{aligned}$$

$$\text{Annual power cost} = \frac{\$114,557,013,315}{D^4}.$$

Step 6: Economical pipe size:

Now that we have determined the annual pumping and motor costs and the equivalent annual capital cost, we can express the total equivalent annual cost as a fraction of the pipe diameter (D):

$$\text{AEC}(10\%) = 5,843,648D^2 + \frac{19,968,752,076}{D^4} + \frac{114,557,013,315}{D^4}.$$

To find the optimal pipe size (D) that results in the minimum annual equivalent cost, we take the first derivative of $\text{AEC}(10\%)$ with respect to D , equate the result to zero, and solve for D :

$$\begin{aligned}\frac{d\text{AEC}(10\%)}{dD} &= 11,687,297D - \frac{538,103,061,567}{D^5} \\ &= 0; \\ 11,687,297D^6 &= 538,103,061,567, \\ D^6 &= 46,041.70, \\ D^* &= 5.9868 \text{ ft.}\end{aligned}$$

Note that, ideally, the velocity in a pipe should be no more than approximately 10 ft/sec, because friction wears the pipe. To check whether the preceding answer is reasonable, we may compute

$$\begin{aligned}Q &= \text{velocity} \times \text{pipe inner area}, \\ 701,825 \text{ ft}^3/\text{hr} \times \frac{1}{3,600} \text{ hr/sec} &= V \frac{3.14159(5.9868)^2}{4}, \\ V &= 6.93 \text{ ft/sec},\end{aligned}$$

which is less than 10 ft/sec. Therefore, the optimal answer as calculated is practical.

Step 7: Equivalent annual cost at optimal pipe size:

$$\begin{aligned}\text{Capital cost} &= \left[\$49,750,272(5.9868)^2 + \frac{\$170,004,700,125}{5.9868^4} \right] (A/P, 10\%, 20) \\ &= 5,843,648(5.9868)^2 + \frac{19,968,752,076}{5.9868^4} \\ &= \$224,991,039;\end{aligned}$$

$$\begin{aligned}\text{Annual power cost} &= \frac{114,557,013,315}{5.9868^4} \\ &= \$89,174,911;\end{aligned}$$

$$\begin{aligned}\text{Total annual cost} &= \$224,991,039 + \$89,174,911 \\ &= \$314,165,950.\end{aligned}$$

Step 8: Total annual oil revenue:

$$\begin{aligned}\text{Annual oil revenue} &= \$50/\text{bbl} \times 3,000,000 \text{ bbl/day} \\ &= \times 365 \text{ day/year} \\ &= \$54,750,000,000/\text{year}.\end{aligned}$$

Enough revenues are available to offset the capital cost as well as the operating cost.

COMMENTS: A number of other criteria exist for choosing the pipe size for a particular fluid transfer application. For example, low velocity may be required when erosion or corrosion concerns must be considered. Alternatively, higher velocities may be desirable for slurries when settling is a concern. Ease of construction may also weigh significantly in choosing a pipe size. On the one hand, a small pipe size may not accommodate the head and flow requirements efficiently; on the other, space limitations may prohibit the selection of large pipe sizes.

SUMMARY

- Annual equivalent worth analysis, or AE, is—along with present-worth analysis—one of the two main analysis techniques based on the concept of equivalence. The equation for AE is

$$AE(i) = PW(i)(A/P, i, N).$$

AE analysis yields the same decision result as PW analysis.

- The capital recovery cost factor, or $CR(i)$, is one of the most important applications of AE analysis, in that it allows managers to calculate an annual equivalent cost of capital for ease of itemization with annual operating costs. The equation for $CR(i)$ is

$$CR(i) = (I - S)(A/P, i, N) + iS,$$

where I = initial cost and S = salvage value.

- AE analysis is recommended over NPW analysis in many key real-world situations for the following reasons:
 1. In many financial reports, an annual equivalent value is preferred to a present-worth value.
 2. Unit costs often must be calculated to determine reasonable pricing for items that are on sale.
 3. The cost per unit of use of an item must be calculated in order to reimburse employees for the business use of personal cars.
 4. Make-or-buy decisions usually require the development of unit costs for the various alternatives.
 5. Minimum-cost analysis is easy to do when it is based on annual equivalent cost.
- LCCA is a way to predict the most cost-effective solution by allowing engineers to make a reasonable comparison among alternatives within the limit of the available data.

PROBLEMS

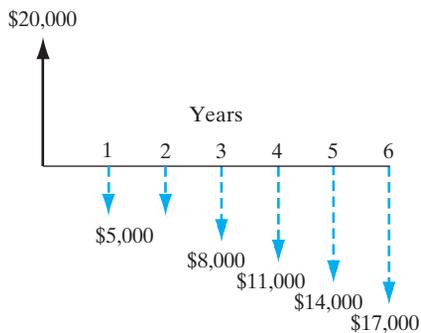
Note: Unless otherwise stated, all cash flows given in the problems that follow represent after-tax cash flows.

Annual Equivalent-Worth Calculation

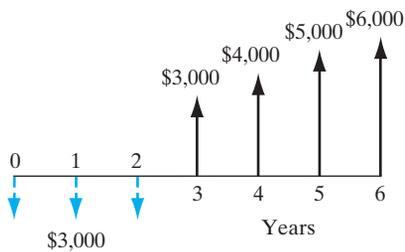
- 6.1 Consider the following cash flows and compute the equivalent annual worth at $i = 10\%$:

n	A_n	
	Investment	Revenue
0	-\$5,000	
1		\$2,000
2		2,000
3		3,000
4		3,000
5		1,000
6	2,000	500

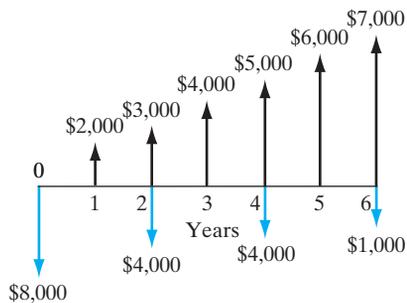
- 6.2 Consider the accompanying cash flow diagram. Compute the equivalent annual worth at $i = 12\%$.



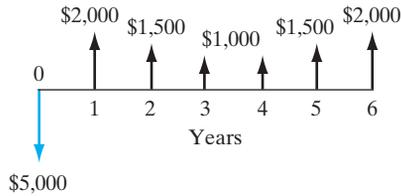
- 6.3 Consider the accompanying cash flow diagram. Compute the equivalent annual worth at $i = 10\%$.



- 6.4 Consider the accompanying cash flow diagram. Compute the equivalent annual worth at $i = 13\%$.



- 6.5 Consider the accompanying cash flow diagram. Compute the equivalent annual worth at $i = 8\%$.



- 6.6 Consider the following sets of investment projects:

Project's Cash Flow (\$)				
n	A	B	C	D
0	-\$2,500	-\$4,500	-\$8,000	-\$12,000
1	400	3,000	-2,000	2,000
2	500	2,000	6,000	4,000
3	600	1,000	2,000	8,000
4	700	500	4,000	8,000
5	800	500	2,000	4,000

Compute the equivalent annual worth of each project at $i = 10\%$, and determine the acceptability of each project.

- 6.7 Sun-Devil Company is producing electricity directly from a solar source by using a large array of solar cells and selling the power to the local utility company. Because these cells degrade over time, thereby resulting in lower conversion efficiency and power output, the cells must be replaced every four years, which results in a particular cash flow pattern that repeats itself as follows: $n = 0$, $-\$500,000$; $n = 1$, $\$600,000$; $n = 2$, $\$400,000$; $n = 3$, $\$300,000$, and $n = 4$, $\$200,000$. Determine the annual equivalent cash flows at $i = 12\%$.
- 6.8 Consider the following sets of investment projects:

Project's Cash Flow				
n	A	B	C	D
0	-\$7,500	-\$4,000	-\$5,000	-\$6,600
1	0	1,500	4,000	3,800
2	0	1,800	3,000	3,800
3	15,500	2,100	2,000	3,800

Compute the equivalent annual worth of each project at $i = 13\%$, and determine the acceptability of each project.

6.9 The cash flows for a certain project are as follows:

n	Net Cash Flow		
	Investment	Operating Income	
0	−\$800		1st cycle
1		\$900	
2		700	2nd cycle
3	−800	500	
4		900	
5		700	3rd cycle
6	−800	500	
7		900	
8		700	
9		500	

Find the equivalent annual worth for this project at $i = 10\%$, and determine the acceptability of the project.

- 6.10 Beginning next year, a foundation will support an annual seminar on campus by the earnings of a \$100,000 gift it received this year. It is felt that 8% interest will be realized for the first 10 years, but that plans should be made to anticipate an interest rate of 6% after that time. What amount should be added to the foundation now to fund the seminar at the \$10,000 level into infinity?

Capital (Recovery) Cost/Annual Equivalent Cost

- 6.11 The owner of a business is considering investing \$55,000 in new equipment. He estimates that the net cash flows will be \$5,000 during the first year, but will increase by \$2,500 per year the next year and each year thereafter. The equipment is estimated to have a 10-year service life and a net salvage value of \$6,000 at that time. The firm's interest rate is 12%.
- Determine the annual capital cost (ownership cost) for the equipment.
 - Determine the equivalent annual savings (revenues).
 - Determine whether this is a wise investment.
- 6.12 You are considering purchasing a dump truck. The truck will cost \$45,000 and have an operating and maintenance cost that starts at \$15,000 the first year and increases by \$2,000 per year. Assume that the salvage value at the end of five years is \$9,000 and interest rate is 12%. What is the equivalent annual cost of owning and operating the truck?
- 6.13 Emerson Electronics Company just purchased a soldering machine to be used in its assembly cell for flexible disk drives. The soldering machine cost \$250,000. Because of the specialized function it performs, its useful life is estimated to be five years. It is also estimated that at that time its salvage value will be \$40,000. What is the capital cost for this investment if the firm's interest rate is 18%?

6.14 The present price (year 0) of kerosene is \$1.80 per gallon, and its cost is expected to increase by \$.15 per year. (At the end of year 1, kerosene will cost \$1.95 per gallon.) Mr. Garcia uses about 800 gallons of kerosene for space heating during a winter season. He has an opportunity to buy a storage tank for \$600, and at the end of four years he can sell the storage tank for \$100. The tank has a capacity to supply four years of Mr. Garcia's heating needs, so he can buy four years' worth of kerosene at its present price (\$1.80), or he can invest his money elsewhere at 8%. Should he purchase the storage tank? Assume that kerosene purchased on a pay-as-you-go basis is paid for at the end of the year. (However, kerosene purchased for the storage tank is purchased now.)

6.15 Consider the following advertisement, which appeared in a local paper.

Pools-Spas-Hot Tubs—Pure Water without Toxic Chemicals: The comparative costs between the conventional chemical system (chlorine) and the IONETICS systems are as follows:

Item	Conventional System	IONETICS System
Annual costs		
Chemical	\$471	
IONETICS		\$ 85
Pump (\$0.667/kWh)	\$576	\$ 100
Capital investment		\$1,200

Note that the IONETICS system pays for itself in less than 2 years.

Assume that the IONETICS system has a 12-year service life and the interest rate is 6%. What is the equivalent annual cost of operating the IONETICS system?

6.16 The cash flows for two investment projects are as follows:

<i>n</i>	Project's Cash Flow	
	A	B
0	−\$4,000	\$5,500
1	1,000	−1,400
2	X	−1,400
3	1,000	−1,400
4	1,000	−1,400

(a) For project A, find the value of X that makes the equivalent annual receipts equal the equivalent annual disbursement at $i = 13\%$.

(b) Would you accept project B at $i = 15\%$, based on an AE criterion?

6.17 An industrial firm can purchase a special machine for \$50,000. A down payment of \$5,000 is required, and the unpaid balance can be paid off in five equal year-end

- installments at 7% interest. As an alternative, the machine can be purchased for \$46,000 in cash. If the firm's MARR is 10%, use the annual equivalent method to determine which alternative should be accepted.
- 6.18 An industrial firm is considering purchasing several programmable controllers and automating the company's manufacturing operations. It is estimated that the equipment will initially cost \$100,000 and the labor to install it will cost \$35,000. A service contract to maintain the equipment will cost \$5,000 per year. Trained service personnel will have to be hired at an annual salary of \$30,000. Also estimated is an approximate \$10,000 annual income-tax savings (cash inflow). How much will this investment in equipment and services have to increase the annual revenues after taxes in order to break even? The equipment is estimated to have an operating life of 10 years, with no salvage value because of obsolescence. The firm's MARR is 10%.
- 6.19 A construction firm is considering establishing an engineering computing center. The center will be equipped with three engineering workstations that cost \$35,000 each, and each has a service life of five years. The expected salvage value of each workstation is \$2,000. The annual operating and maintenance cost would be \$15,000 for each workstation. At a MARR of 15%, determine the equivalent annual cost for operating the engineering center.

Unit-Cost Profit Calculation

- 6.20 You have purchased a machine costing \$20,000. The machine will be used for two years, at the end of which time its salvage value is expected to be \$10,000. The machine will be used 6,000 hours during the first year and 8,000 hours during the second year. The expected annual net savings will be \$30,000 during the first year and \$40,000 during the second year. If your interest rate is 10%, what would be the equivalent net savings per machine hour?
- 6.21 The engineering department of a large firm is overly crowded. In many cases, several engineers share one office. It is evident that the distraction caused by the crowded conditions reduces the productive capacity of the engineers considerably. Management is considering the possibility of providing new facilities for the department, which could result in fewer engineers per office and a private office for some. For an office presently occupied by five engineers, what minimum individual increase in effectiveness must result to warrant the assignment of only three engineers to an office if the following data apply?
- The office size is 16×20 feet.
 - The average annual salary of each engineer is \$80,000.
 - The cost of the building is \$110 per square foot.
 - The estimated life of the building is 25 years.
 - The estimated salvage value of the building is 10% of the initial cost.
 - The annual taxes, insurance, and maintenance are 6% of the initial cost.
 - The cost of janitorial service, heating, and illumination is \$5.00 per square foot per year.
 - The interest rate is 12%.

Assume that engineers reassigned to other office space will maintain their present productive capability as a minimum.

- 6.22 Sam Tucker is a sales engineer at Buford Chemical Engineering Company. Sam owns two vehicles, and one of them is entirely dedicated to business use. His business car is a used small pickup truck, which he purchased with \$11,000 of personal savings. On the basis of his own records and with data compiled by the U.S. Department of Transportation, Sam has estimated the costs of owning and operating his business vehicle for the first three years as follows:

	First Year	Second Year	Third Year
Depreciation	\$2,879	\$1,776	\$1,545
Scheduled maintenance	100	153	220
Insurance	635	635	635
Registration and taxes	<u>78</u>	<u>57</u>	<u>50</u>
Total ownership cost	\$3,692	\$2,621	\$2,450
Nonscheduled repairs	35	85	200
Replacement tires	35	30	27
Accessories	15	13	12
Gasoline and taxes	688	650	522
Oil	80	100	100
Parking and tolls	<u>135</u>	<u>125</u>	<u>110</u>
Total operating costs	<u>\$988</u>	<u>\$1,003</u>	<u>\$971</u>
Total of all costs	\$4,680	\$3,624	\$3,421
Expected miles driven	14,500	13,000	11,500

- If his interest rate is 6%, what should be Sam's reimbursement rate per mile so that he can break even?
- 6.23 Two 150-horsepower (HP) motors are being considered for installation at a municipal sewage-treatment plant. The first costs \$4,500 and has an operating efficiency of 83%. The second costs \$3,600 and has an efficiency of 80%. Both motors are projected to have zero salvage value after a life of 10 years. If all the annual charges, such as insurance, maintenance, etc., amount to a total of 15% of the original cost of each motor, and if power costs are a flat 5 cents per kilowatt-hour, how many minimum hours of full-load operation per year are necessary to justify purchasing the more expensive motor at $i = 6\%$? (A conversion factor you might find useful is $1 \text{ HP} = 746 \text{ watts} = 0.746 \text{ kilowatts}$.)
- 6.24 Danford Company, a manufacturer of farm equipment, currently produces 20,000 units of gas filters per year for use in its lawn-mower production. The costs, based on the previous year's production, are reported in Table P6.24.
- It is anticipated that gas-filter production will last five years. If the company continues to produce the product in-house, annual direct material costs will increase at the rate of 5%. (For example, annual material costs during the first production

TABLE P6.24 Production costs

Item	Expense (\$)
Direct materials	\$ 60,000
Direct labor	180,000
Variable overhead (power and water)	135,000
Fixed overhead (light and heat)	70,000
Total cost	\$445,000

year will be \$63,000.) Direct labor will also increase at the rate of 6% per year. However, variable overhead costs will increase at the rate of 3%, but the fixed overhead will remain at its current level over the next five years. John Holland Company has offered to sell Danford 20,000 units of gas filters for \$25 per unit. If Danford accepts the offer, some of the manufacturing facilities currently used to manufacture the filter could be rented to a third party for \$35,000 per year. In addition, \$3.5 per unit of the fixed overhead applied to the production of gas filters would be eliminated. The firm's interest rate is known to be 15%. What is the unit cost of buying the gas filter from the outside source? Should Danford accept John Holland's offer, and why?

- 6.25 Southern Environmental Consulting (SEC), Inc., designs plans and specifications for asbestos abatement (removal) projects in public, private, and governmental buildings. Currently, SEC must conduct an air test before allowing the reoccupancy of a building from which asbestos has been removed. SEC subcontracts air-test samples to a laboratory for analysis by transmission electron microscopy (TEM). To offset the cost of TEM analysis, SEC charges its clients \$100 more than the subcontractor's fee. The only expenses in this system are the costs of shipping the air-test samples to the subcontractor and the labor involved in shipping the samples. With the growth of the business, SEC is having to consider either continuing to subcontract the TEM analysis to outside companies or developing its own TEM laboratory. Because of the passage of the Asbestos Hazard Emergency Response Act (AHERA) by the U.S. Congress, SEC expects about 1,000 air-sample testings per year over eight years. The firm's MARR is known to be 15%.
- **Subcontract option.** The client is charged \$400 per sample, which is \$100 above the subcontracting fee of \$300. Labor expenses are \$1,500 per year, and shipping expenses are estimated to be \$0.50 per sample.
 - **TEM purchase option.** The purchase and installation cost for the TEM is \$415,000. The equipment would last for eight years, at which time it should have no salvage value. The design and renovation cost is estimated to be \$9,500. The client is charged \$300 per sample, based on the current market price. One full-time manager and two part-time technicians are needed to operate the laboratory. Their combined annual salaries will be \$50,000. Material required to operate the lab includes carbon rods, copper grids, filter equipment, and acetone. The costs of these materials are estimated at \$6,000 per year. Utility costs, operating and maintenance

costs, and the indirect labor needed to maintain the lab are estimated at \$18,000 per year. The extra income-tax expenses would be \$20,000.

- (a) Determine the cost of an air-sample test by the TEM (in-house).
- (b) What is the required number of air samples per year to make the two options equivalent?
- 6.26 A company is currently paying its employees \$0.38 per mile to drive their own cars on company business. The company is considering supplying employees with cars, which would involve purchasing at \$25,000, with an estimated three-year life, a net salvage value of \$8,000, taxes and insurance at a cost of \$900 per year, and operating and maintenance expenses of \$0.22 per mile. If the interest rate is 10% and the company anticipates an employee's annual travel to be 22,000 miles, what is the equivalent cost per mile (neglecting income taxes)?
- 6.27 An automobile that runs on electricity can be purchased for \$25,000. The automobile is estimated to have a life of 12 years with annual travel of 20,000 miles. Every 3 years, a new set of batteries will have to be purchased at a cost of \$3,000. Annual maintenance of the vehicle is estimated to cost \$700. The cost of recharging the batteries is estimated at \$0.015 per mile. The salvage value of the batteries and the vehicle at the end of 12 years is estimated to be \$2,000. Suppose the MARR is 7%. What is the cost per mile to own and operate this vehicle, based on the preceding estimates? The \$3,000 cost of the batteries is a net value, with the old batteries traded in for the new ones.
- 6.28 The estimated cost of a completely installed and ready-to-operate 40-kilowatt generator is \$30,000. Its annual maintenance costs are estimated at \$500. The energy that can be generated annually at full load is estimated to be 100,000 kilowatt-hours. If the value of the energy generated is \$0.08 per kilowatt-hour, how long will it take before this machine becomes profitable? Take the MARR to be 9% and the salvage value of the machine to be \$2,000 at the end of its estimated life of 15 years.
- 6.29 A large land-grant university that is currently facing severe parking problems on its campus is considering constructing parking decks off campus. A shuttle service could pick up students at the off-campus parking deck and transport them to various locations on campus. The university would charge a small fee for each shuttle ride, and the students could be quickly and economically transported to their classes. The funds raised by the shuttle would be used to pay for trolleys, which cost about \$150,000 each. Each trolley has a 12-year service life, with an estimated salvage value of \$3,000. To operate each trolley, the following additional expenses will be incurred:

Item	Annual Expenses (\$)
Driver	\$50,000
Maintenance	10,000
Insurance	3,000

If students pay 10 cents for each ride, determine the annual ridership per trolley (number of shuttle rides per year) required to justify the shuttle project, assuming an interest rate of 6%.

- 6.30 Eradicator Food Prep, Inc., has invested \$7 million to construct a food irradiation plant. This technology destroys organisms that cause spoilage and disease, thus

- extending the shelf life of fresh foods and the distances over which they can be shipped. The plant can handle about 200,000 pounds of produce in an hour, and it will be operated for 3,600 hours a year. The net expected operating and maintenance costs (taking into account income-tax effects) would be \$4 million per year. The plant is expected to have a useful life of 15 years, with a net salvage value of \$700,000. The firm's interest rate is 15%.
- (a) If investors in the company want to recover the plant investment within 6 years of operation (rather than 15 years), what would be the equivalent after-tax annual revenues that must be generated?
- (b) To generate annual revenues determined in part (a), what minimum processing fee per pound should the company charge to its producers?
- 6.31 The local government of Santa Catalina Island, off the coast of Long Beach, California, is completing plans to build a desalination plant to help ease a critical drought on the island. The drought has combined with new construction on Catalina to leave the island with an urgent need for a new water source. A modern desalination plant could produce fresh water from seawater for \$1,000 an acre-foot (326,000 gallons), or enough to supply two households for 1 year. On Catalina, the cost of acquiring water from natural sources is about the same as that for desalting. The \$3 million plant, with a daily desalting capacity of 0.4 acre-foot, can produce 132,000 gallons of fresh water a day (enough to supply 295 households daily), more than a quarter of the island's total needs. The desalination plant has an estimated service life of 20 years, with no appreciable salvage value. The annual operating and maintenance costs would be about \$250,000. Assuming an interest rate of 10%, what should be the minimum monthly water bill for each household?
- 6.32 A California utility firm is considering building a 50-megawatt geothermal plant that generates electricity from naturally occurring underground heat. The binary geothermal system will cost \$85 million to build and \$6 million (including any income-tax effect) to operate per year. (Virtually no fuel costs will accrue compared with fuel costs related to a conventional fossil-fuel plant.) The geothermal plant is to last for 25 years. At that time, its expected salvage value will be about the same as the cost to remove the plant. The plant will be in operation for 70% (plant utilization factor) of the year (or 70% of 8,760 hours per year). If the firm's MARR is 14% per year, determine the cost per kilowatt-hour of generating electricity.
- 6.33 A corporate executive jet with a seating capacity of 20 has the following cost factors:

Item	Cost
Initial cost	\$12,000,000
Service life	15 years
Salvage value	\$2,000,000
Crew costs per year	\$225,000
Fuel cost per mile	\$1.10
Landing fee	\$250
Maintenance per year	\$237,500
Insurance cost per year	\$166,000
Catering per passenger trip	\$75

The company flies three round trips from Boston to London per week, a distance of 3,280 miles one way. How many passengers must be carried on an average trip in order to justify the use of the jet if the first-class round-trip fare is \$3,400? The firm's MARR is 15%. (Ignore income-tax consequences.)

Comparing Mutually Exclusive Alternatives by the AE Method

- 6.34 The following cash flows represent the potential annual savings associated with two different types of production processes, each of which requires an investment of \$12,000:

<i>n</i>	Process A	Process B
0	−\$12,000	−\$12,000
1	9,120	6,350
2	6,840	6,350
3	4,560	6,350
4	2,280	6,350

Assuming an interest rate of 15%,

- Determine the equivalent annual savings for each process.
 - Determine the hourly savings for each process if it is in operation 2,000 hours per year.
 - Which process should be selected?
- 6.35 Birmingham Steel, Inc., is considering replacing 20 conventional 25-HP, 230-V, 60-Hz, 1800-rpm induction motors in its plant with modern premium efficiency (PE) motors. Both types of motors have a power output of 18.650 kW per motor ($25 \text{ HP} \times 0.746 \text{ kW/HP}$). Conventional motors have a published efficiency of 89.5%, while the PE motors are 93% efficient. The initial cost of the conventional motors is \$13,000, whereas the initial cost of the proposed PE motors is \$15,600. The motors are operated 12 hours per day, five days per week, 52 weeks per year, with a local utility cost of \$0.07 per kilowatt-hour (kWh). The motors are to be operated at 75% load, and the life cycle of both the conventional and PE motor is 20 years, with no appreciable salvage value.
- At an interest rate of 13%, what are the savings per kWh achieved by switching from the conventional motors to the PE motors?
 - At what operating hours are the two motors equally economical?
- 6.36 A certain factory building has an old lighting system, and lighting the building costs, on average, \$20,000 a year. A lighting consultant tells the factory supervisor that the lighting bill can be reduced to \$8,000 a year if \$50,000 were invested in relighting the building. If the new lighting system is installed, an incremental maintenance cost of \$3,000 per year must be taken into account. The new lighting system has zero salvage value at the end of its life. If the old lighting system also has zero salvage value, and the new lighting system is estimated to have a life of 20 years, what is the net annual benefit for this investment in new lighting? Take the MARR to be 12%.

6.37 Travis Wenzel has \$2,000 to invest. Usually, he would deposit the money in his savings account, which earns 6% interest compounded monthly. However, he is considering three alternative investment opportunities:

- **Option 1.** Purchasing a bond for \$2,000. The bond has a face value of \$2,000 and pays \$100 every six months for three years, after which time the bond matures.
- **Option 2.** Buying and holding a stock that grows 11% per year for three years.
- **Option 3.** Making a personal loan of \$2,000 to a friend and receiving \$150 per year for three years.

Determine the equivalent annual cash flows for each option, and select the best option.

6.38 A chemical company is considering two types of incinerators to burn solid waste generated by a chemical operation. Both incinerators have a burning capacity of 20 tons per day. The following data have been compiled for comparison:

	Incinerator A	Incinerator B
Installed cost	\$1,200,000	\$750,000
Annual O&M costs	\$ 50,000	\$ 80,000
Service life	20 years	10 years
Salvage value	\$ 60,000	\$ 30,000
Income taxes	\$ 40,000	\$ 30,000

If the firm's MARR is known to be 13%, determine the processing cost per ton of solid waste incurred by each incinerator. Assume that incinerator B will be available in the future at the same cost.

6.39 Consider the cash flows for the following investment projects (MARR = 15%):

<i>n</i>	Project's Cash Flow		
	A	B	C
0	−\$2,500	−\$4,000	−\$5,000
1	1,000	1,600	1,800
2	1,800	1,500	1,800
3	1,000	1,500	2,000
4	400	1,500	2,000

- (a) Suppose that projects A and B are mutually exclusive. Which project would you select, based on the AE criterion?
- (b) Assume that projects B and C are mutually exclusive. Which project would you select, based on the AE criterion?

Life-Cycle Cost Analysis

- 6.40 An airline is considering two types of engine systems for use in its planes. Each has the same life and the same maintenance and repair record.
- **System A** costs \$100,000 and uses 40,000 gallons per 1,000 hours of operation at the average load encountered in passenger service.
 - **System B** costs \$200,000 and uses 32,000 gallons per 1,000 hours of operation at the same level.
- Both engine systems have three-year lives before any major overhaul is required. On the basis of the initial investment, the systems have 10% salvage values. If jet fuel currently costs \$2.10 a gallon and fuel consumption is expected to increase at the rate of 6% per year because of degrading engine efficiency, which engine system should the firm install? Assume 2,000 hours of operation per year and a MARR of 10%. Use the AE criterion. What is the equivalent operating cost per hour for each engine?
- 6.41 Mustang Auto-Parts, Inc., is considering one of two forklift trucks for its assembly plant. Truck A costs \$15,000 and requires \$3,000 annually in operating expenses. It will have a \$5,000 salvage value at the end of its three-year service life. Truck B costs \$20,000, but requires only \$2,000 annually in operating expenses; its service life is four years, at which time its expected salvage value will be \$8,000. The firm's MARR is 12%. Assuming that the trucks are needed for 12 years and that no significant changes are expected in the future price and functional capacity of each truck, select the most economical truck, on the basis of AE analysis.
- 6.42 A small manufacturing firm is considering purchasing a new machine to modernize one of its current production lines. Two types of machines are available on the market. The lives of machine A and machine B are four years and six years, respectively, but the firm does not expect to need the service of either machine for more than five years. The machines have the following expected receipts and disbursements:

Item	Machine A	Machine B
First cost	\$6,500	\$8,500
Service life	4 years	6 years
Estimated salvage value	\$600	\$1,000
Annual O&M costs	\$800	\$520
Change oil filter every other year	\$100	None
Engine overhaul	\$200 (every 3 years)	\$280 (every 4 years)

The firm always has another option: leasing a machine at \$3,000 per year, fully maintained by the leasing company. After four years of use, the salvage value for machine B will remain at \$1,000.

- How many decision alternatives are there?
- Which decision appears to be the best at $i = 10\%$?

6.43 A plastic-manufacturing company owns and operates a polypropylene production facility that converts the propylene from one of its cracking facilities to polypropylene plastics for outside sale. The polypropylene production facility is currently forced to operate at less than capacity due to an insufficiency of propylene production capacity in its hydrocarbon cracking facility. The chemical engineers are considering alternatives for supplying additional propylene to the polypropylene production facility. Two feasible alternatives are to build a pipeline to the nearest outside supply source and to provide additional propylene by truck from an outside source. The engineers also gathered the following projected cost estimates:

- Future costs for purchased propylene excluding delivery: \$0.215 per lb.
- Cost of pipeline construction: \$200,000 per pipeline mile.
- Estimated length of pipeline: 180 miles.
- Transportation costs by tank truck: \$0.05 per lb, utilizing a common carrier.
- Pipeline operating costs: \$0.005 per lb, excluding capital costs.
- Projected additional propylene needs: 180 million lb per year.
- Projected project life: 20 years.
- Estimated salvage value of the pipeline: 8% of the installed costs.

Determine the propylene cost per pound under each option if the firm's MARR is 18%. Which option is more economical?

6.44 The City of Prattville is comparing two plans for supplying water to a newly developed subdivision:

- **Plan A** will take care of requirements for the next 15 years, at the end of which time the initial cost of \$400,000 will have to be duplicated to meet the requirements of subsequent years. The facilities installed at dates 0 and 15 may be considered permanent; however, certain supporting equipment will have to be replaced every 30 years from the installation dates, at a cost of \$75,000. Operating costs are \$31,000 a year for the first 15 years and \$62,000 thereafter, although they are expected to increase by \$1,000 a year beginning in the 21st year.
- **Plan B** will supply all requirements for water indefinitely into the future, although it will be operated only at half capacity for the first 15 years. Annual costs over this period will be \$35,000 and will increase to \$55,000 beginning in the 16th year. The initial cost of Plan B is \$550,000; the facilities can be considered permanent, although it will be necessary to replace \$150,000 worth of equipment every 30 years after the initial installation.

The city will charge the subdivision for the use of water on the basis of the equivalent annual cost. At an interest rate of 10%, determine the equivalent annual cost for each plan, and make a recommendation to the city.

Minimum-Cost Analysis

6.45 A continuous electric current of 2,000 amps is to be transmitted from a generator to a transformer located 200 feet away. A copper conductor can be installed for \$6 per pound, will have an estimated life of 25 years, and can be salvaged for \$1 per pound. Power loss from the conductor will be inversely proportional to the cross-sectional area of the conductor and may be expressed as $6.516/A$ kilowatt, where

A is in square inches. The cost of energy is \$0.0825 per kilowatt-hour, the interest rate is 11%, and the density of copper is 555 pounds per cubic foot.

- Calculate the optimum cross-sectional area of the conductor.
- Calculate the annual equivalent total cost for the value you obtained in part (a).
- Graph the two individual cost factors (capital cost and power-loss cost) and the total cost as a function of the cross-sectional area A , and discuss the impact of increasing energy cost on the optimum obtained in part (a).

Short Case Studies

ST6.1 Automotive engineers at Ford are considering the laser blank welding (LBW) technique to produce a windshield frame rail blank. The engineers believe that, compared with the conventional sheet metal blanks, LBW would result in a significant savings as follows:

- Scrap reduction through more efficient blank nesting on coil.
- Scrap reclamation (weld scrap offal into a larger usable blank).

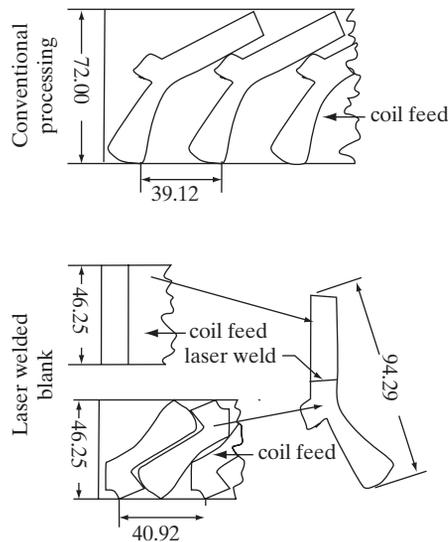
The use of a laser welded blank provides a reduction in engineered scrap for the production of a window frame rail blank.

On the basis of an annual volume of 3,000 blanks, Ford engineers have estimated the following financial data:

Description	Blanking Method	
	Conventional	Laser Blank Welding
Weight per blank (lb/part)	63.764	34.870
Steel cost/part	\$ 14.98	\$ 8.19
Transportation/part	\$ 0.67	\$ 0.42
Blanking/part	\$ 0.50	\$ 0.40
Die investment	\$106,480	\$83,000

The LBW technique appears to achieve significant savings, so Ford's engineers are leaning toward adopting it. Since the engineers have had no previous experience with LBW, they are not sure whether producing the windshield frames in-house at this time is a good strategy. For this windshield frame, it may be cheaper to use the services of a supplier that has both the experience with, and the machinery for, laser blanking. Ford's lack of skill in laser blanking may mean that it will take six months to get up to the required production volume. If, however, Ford relies on a supplier, it can only assume that supplier labor problems will not halt the production of Ford's parts. The make-or-buy decision depends on two factors: the amount of new investment that is required in laser welding and whether additional machinery will be required for future products. Assuming a lifetime of 10 years and an interest rate of 16%, recommend the best course of action. Assume also that

the salvage value at the end of 10 years is estimated to be insignificant for either system. If Ford considers the subcontracting option, what would be the acceptable range of contract bid (unit cost per part)?



ST6.2 The proliferation of computers into all aspects of business has created an ever-increasing need for data capture systems that are fast, reliable, and cost effective. One technology that has been adopted by many manufacturers, distributors, and retailers is a bar-coding system. Hermes Electronics, a leading manufacturer of underwater surveillance equipment, evaluated the economic benefits of installing an automated data acquisition system into its plant. The company could use the system on a limited scale, such as for tracking parts and assemblies for inventory management, or it could opt for a broader implementation by recording information that is useful for quality control, operator efficiency, attendance, and other functions. All these aspects are currently monitored, but although computers are used to manage the information, the recording is conducted primarily manually. The advantages of an automated data collection system, which include faster and more accurate data capture, quicker analysis of and response to production changes, and savings due to tighter control over operations, could easily outweigh the cost of the new system. Two alternative systems from competing suppliers are under consideration:

- **System 1** relies on handheld bar-code scanners that transmit radio frequencies. The hub of this wireless network can then be connected to the company's existing LAN and integrated with its current MRP II system and other management software.
- **System 2** consists primarily of specialized data terminals installed at every collection point, with connected bar-code scanners where required. This system is configured in such a way as to facilitate phasing in the components over two stages or installing the system all at once. The former would allow Hermes to defer some of the capital investment, while becoming thoroughly familiar with the functions introduced in the first stage.

Either of these systems would satisfy Hermes's data collection needs. They each have some unique elements, and the company needs to compare the relative benefits of the features offered by each system. From the point of view of engineering economics, the two systems have different capital costs, and their operating and maintenance costs are not identical. One system may also be rated to last longer than the other before replacement is required, particularly if the option of acquiring System 2 in phases is selected. Discuss many issues to be considered before making the best choice of those types of technology in manufacturing.

ST6.3 A Veterans Administration (VA) hospital is to decide which type of boiler fuel system will most efficiently provide the required steam energy output for heating, laundry, and sterilization purposes. The current boilers were installed in the early 1950s and are now obsolete. Much of the auxiliary equipment is also old and in need of repair. Because of these general conditions, an engineering recommendation was made to replace the entire plant with a new boiler plant building that would house modern equipment. The cost of demolishing the old boiler plant would be almost a complete loss, as the salvage value of the scrap steel and used brick was estimated to be only about \$1,000. The VA hospital's engineer finally selected two alternative proposals as being worthy of more intensive analysis. The hospital's annual energy requirement, measured in terms of steam output, is approximately 145,000,000 pounds of steam. As a rule of thumb for analysis, 1 pound of steam is approximately 1,000 Btu, and 1 cubic foot of natural gas is also approximately 1,000 Btu. The two alternatives are as follows:

- **Proposal 1.** Replace the old plant with a new coal-fired boiler plant that costs \$1,770,300. To meet the requirements for particulate emission as set by the Environmental Protection Agency, this coal-fired boiler, even if it burned low-sulfur coal, would need an electrostatic precipitator, which would cost approximately \$100,000. The plant would last for 20 years. One pound of dry coal yields about 14,300 Btu. To convert the 145,000,000 pounds of steam energy to the common denominator of Btu, it is necessary to multiply by 1,000. To find the Btu input requirements, it is necessary to divide by the relative boiler efficiency for the type of fuel. The boiler efficiency for coal is 0.75. The price of coal is estimated to be \$55.50 per ton.
 - **Proposal 2.** Build a gas-fired boiler plant with No. 2 fuel oil, and use the new plant as a standby. This system would cost \$889,200 and have an expected service life of 20 years. Since small household or commercial gas users that are entirely dependent on gas have priority, large plants must have an oil switchover capability. It has been estimated that 6% of 145,000,000 pounds of steam energy (or 8,700,000 pounds) would come about as a result of the switch to oil. The boiler efficiency with each fuel would be 0.78 for gas and 0.81 for oil, respectively. The heat value of natural gas is approximately 1,000,000 Btu/MCF (thousand cubic feet), and for No. 2 fuel oil it is 139,400 Btu/gal. The estimated gas price is \$9.50/MCF, and the price of No. 2 fuel oil is \$1.35 per gallon.
- (a) Calculate the annual fuel costs for each proposal.
 - (b) Determine the unit cost per steam pound for each proposal. Assume that $i = 10\%$.
 - (c) Which proposal is the more economical?

ST6.4 The following is a letter that I received from a local city engineer:

Dear Professor Park:

Thank you for taking the time to assist with this problem. I'm really embarrassed at not being able to solve it myself, since it seems rather straightforward. The situation is as follows:

A citizen of Opelika paid for concrete drainage pipe approximately 20 years ago to be installed on his property. (We have a policy that if drainage trouble exists on private property and the owner agrees to pay for the material, city crews will install it.) That was the case in this problem. Therefore, we are dealing with only material costs, disregarding labor.

However, this past year, we removed the pipe purchased by the citizen, due to a larger area drainage project. He thinks, and we agree, that he is due some refund for salvage value of the pipe due to its remaining life.

Problem:

- Known: 80' of 48" pipe purchased 20 years ago. Current quoted price of 48" pipe = \$52.60/foot, times 80 feet = \$4,208 total cost in today's dollars.
- Unknown: Original purchase price.
- Assumptions: 50-year life; therefore, assume 30 years of life remaining at removal after 20 years. A 4% price increase per year, average, over 20 years.

Thus, we wish to calculate the cost of the pipe 20 years ago. Then we will calculate, in today's dollars, the present salvage value after 20 years, use with 30 years of life remaining. Thank you again for your help. We look forward to your reply.

Charlie Thomas, P.E.

Director of Engineering

City of Opelika

After reading this letter, recommend a reasonable amount of compensation to the citizen for the replaced drainage pipe.