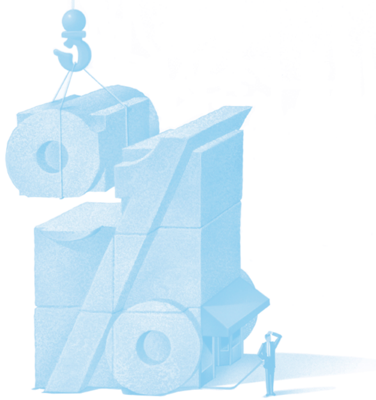
PART

5



Special Topics in Engineering Economics

CHAPTER FOURTEEN

Replacement Decisions

Options for Replacing Alaskan Viaduct[1] The Alaskan Way Viaduct in Seattle, Washington, will be either rebuilt or replaced with a tunnel, the Washington State Department of Transportation (WSDOT) said. The urgency to replace the bridge, which carries 110,000 cars a day, came after the February 2001 Nisqually quake, which caused major damage to the viaduct. The road was built in 1953 to carry 64,000 cars a day.

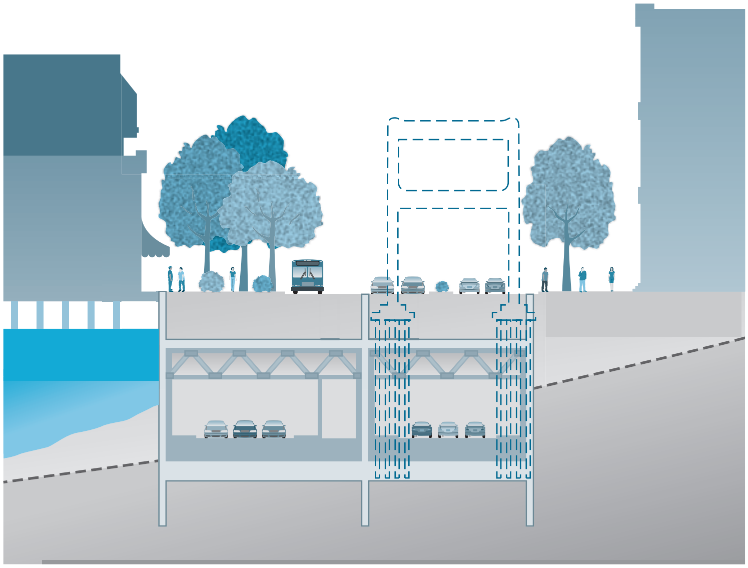
Rebuilding the viaduct and replacing it with a tunnel are the most likely options for replacing the bridge and seem to be the most popular among those who responded to an environmental-impact statement produced for the project.

Option 1: Build a Tunnel This plan, supported by arts organizations and the Greater Seattle Chamber of Commerce, would replace the viaduct with a tunnel along the central waterfront carrying three lanes in each direction. This is the most expensive option, with cost estimates of $3.6 billion to $4.1 billion. It would take from seven to nine years to build.

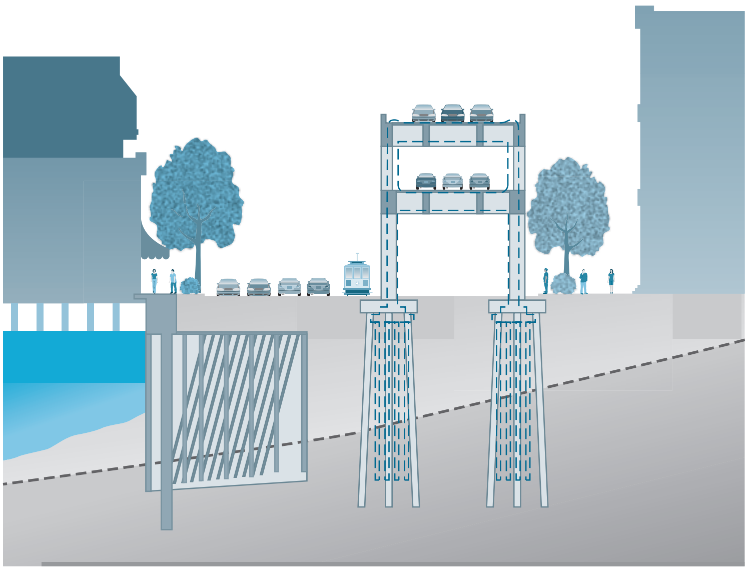
Option 2: Rebuild the Viaduct This alternative, backed by a group of Magnolia residents, would replace the viaduct in its existing location with a structure similar to what is there now, including ramps into downtown at Seneca and Columbia Streets. Unlike the existing structure, this new viaduct would be designed to current earthquake standards. It would cost $2.7–$3.1 billion and take six to seven years.

[1] *SR 99—Alaskan Way Viaduct and Seawall Replacement*, Washington State Department of Transportation, http://www.wsdot.wa.gov/Projects/Viaduct/default.htm, and "Options for replacing viaduct down to two," *The Seattle Times*, September 8, 2004.

Option 1



Option 2



Currently, there is no money to replace the viaduct, other than $177 million as part of the nickel-a-gallon gas-tax increase approved by the legislature. The state is envisioning that it would contribute $2 billion to the project, and the rest would come from other sources, such as the Army Corps of Engineers, possible federal funds dedicated to megaprojects, the city, the Port of Seattle, and a possible voter-approved regional-transportation package. However, the WSDOT has to decide soon whether the state should replace the damaged viaduct with a tunnel or rebuild the viaduct in its current existing structure.

In Chapters 7 through 9, we presented methods that helped us choose the best of a number of investment alternatives. The problems we examined in those chapters concerned primarily profit-adding projects. However, economic analysis is also frequently performed on projects with existing facilities or profit-maintaining projects—those projects whose primary purpose is not to increase sales, but rather, simply to maintain ongoing operations. In practice, profit-maintaining projects less frequently involve the comparison of new machines; instead, the problem often facing management is whether to buy new and more efficient equipment or to continue to use existing equipment. This class of decision problems is known as the **replacement problem**. In this chapter, we examine the basic concepts and techniques related to replacement analysis.

CHAPTER LEARNING OBJECTIVES

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

- What makes the replacement decision problems differ from the other capital investment decisions.
- What types of financial information should be collected to conduct a typical replacement decision problem.
- How to compare a defender with a challenger on the basis of opportunity cost concept.
- How to determine the economic service life for any given asset.
- How to determine the optimal time to replace a defender.
- How to consider the tax effects in replacement analysis.

14.1 Replacement Analysis Fundamentals

In this section and the next two, we examine three aspects of the replacement problem: (1) approaches to comparing defender and challenger, (2) the determination of economic service life, and (3) replacement analysis when the required service period is long. The impact of income tax regulations will be ignored; in Section 14.4, we revisit these replacement problems, taking income taxes into account.

14.1.1 Basic Concepts and Terminology

Replacement projects are decision problems involving the replacement of existing obsolete or worn-out assets. The continuation of operations is dependent on these assets. The failure to make an appropriate decision results in a slowdown or shutdown of the operations. The question is when existing equipment should be replaced with more efficient equipment.

This situation has given rise to the use of the terms **defender** and **challenger**, terms commonly used in the boxing world. In every boxing class, the current defending champion is constantly faced with a new challenger. In replacement analysis, the defender is the existing machine (or system), and the challenger is the best available replacement equipment.

An existing piece of equipment will be removed at some future time, either when the task it performs is no longer necessary or when the task can be performed more efficiently by newer and better equipment. The question is not *whether* the existing piece of equipment will be removed, but *when* it will be removed. A variation of this question is why we should replace existing equipment at the current time, rather than postponing replacement of the equipment by repairing or overhauling it. Another aspect of the defender–challenger comparison concerns deciding exactly which equipment is the best challenger. If the defender is to be replaced by the challenger, we would generally want to install the very best of the possible alternatives.

Current Market Value

The most common problem encountered in considering the replacement of existing equipment is the determination of what financial information is actually relevant to the analysis. Often, a tendency to include irrelevant information in the analysis is apparent. To illustrate this type of decision problem, let us consider Example 14.1.

EXAMPLE 14.1 Information Relevant to Replacement Analysis

Macintosh Printing, Inc., purchased a $20,000 printing machine two years ago. The company expected this machine to have a five-year life and a salvage value of $5,000. The company spent $5,000 last year on repairs, and current operating costs are running at the rate of $8,000 per year. Furthermore, the anticipated salvage value of the machine has been reduced to $2,500 at the end of the its remaining useful life. In addition, the company has found that the current machine has a market value of $10,000 today. The equipment vendor will allow the company this full amount as a trade-in on a new machine. What values for the defender are relevant to our analysis?

SOLUTION

In this example, three different dollar amounts relating to the defender are presented:

1. **Original cost.** The printing machine was purchased for $20,000.
2. **Market value.** The company estimates the old machine's market value at $10,000.
3. **Trade-in allowance.** This is the same as the market value. (In other problems, however, it could be different from the market value.)

COMMENTS: In this example and in all defender analyses, the relevant cost is the **current market value** of the equipment. The original cost, repair cost, and trade-in value are irrelevant. A common misconception is that the trade-in value is the same as the current market value of the equipment and thus could be used to assign a suitable current value to the equipment. This is not always true, however. For example, a car dealer typically offers a trade-in value on a customer's old car to reduce the price of a new car. Would the dealer offer the same value on the old car if he or she were not also selling the new one? The answer is, Not generally. In many instances, the trade-in allowance is inflated to make the deal look good, and the price of the new car is also inflated to compensate for the dealer's trade-in cost. In this type of situation, the trade-in value does not represent the true value of the item, so we should not use it in economic analysis.[2]

Sunk Costs

Sunk costs are costs that have already been incurred and which cannot be recovered to any significant degree.

As mentioned in Section 3.4.3, a **sunk cost** is any past cost that is unaffected by any future investment decision. In Example 14.1, the company spent $20,000 to buy the machine two years ago. Last year, $5,000 more was spent on the machine. The total accumulated expenditure is $25,000. If the machine were sold today, the company could get only $10,000 back (Figure 14.1). It is tempting to think that the company would lose $15,000 in addition to the cost of the new machine if the old machine were to be sold and replaced with a new one. This is an incorrect way of doing economic analysis, however. In a proper engineering economic analysis, only future costs should be considered; past or sunk costs should be ignored. Thus, the value of the defender that should be used in a replacement analysis should be its current market value, not what it cost when it was originally purchased and not the cost of repairs that have already been made to the machine.

Sunk costs are money that is gone, and no present action can recover them. They represent past actions—the results of decisions made in the past. In making economic decisions at the present time, one should consider only the possible outcomes of the various decisions and pick the one with the best possible future results. Using sunk costs in arguing one option over the other would only lead to more bad decisions.

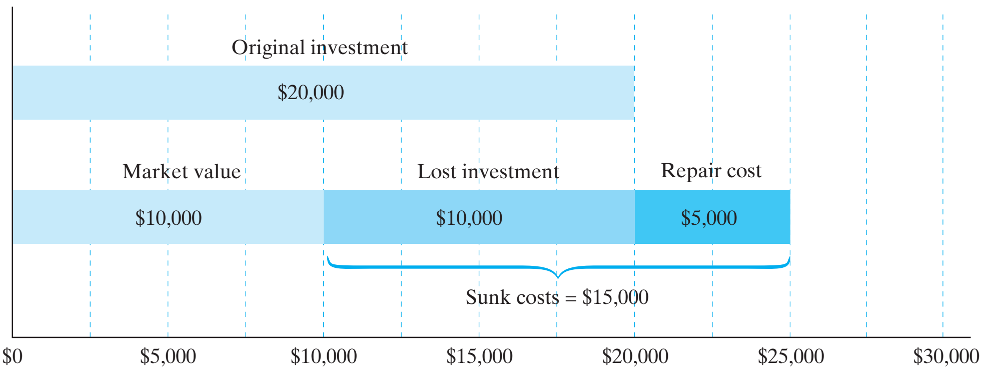


Figure 14.1 Sunk cost associated with an asset's disposal as described in Example 14.1.

[2] If we do make the trade, however, the actual net cash flow at the time of the trade, properly used, is certainly relevant.

Operating Costs

The driving force for replacing existing equipment is that it becomes more expensive to operate with time. The total cost of operating a piece of equipment may include repair and maintenance costs, wages for the operators, energy consumption costs, and costs of materials. Increases in any one or a combination of these cost items over a period of time may impel us to find a replacement for the existing asset. The challenger is usually newer than the defender and often incorporates improvements in design and newer technology. As a result, some or all of the cost items for the challenger are likely to be less expensive than those for the defender.

We will call the sum of the various cost items related to the operation of an asset the **operating costs**. As is illustrated in the sections that follow, keeping the defender involves a lower initial cost than purchasing the challenger, but higher annual operating costs. Usually, operating costs increase over time for both the defender and the challenger. In many instances, the labor costs, material costs, and energy costs are the same for the defender and the challenger and do not change with time. It is the repair and maintenance costs that increase and cause the operating costs to increase each year as an asset ages.

When repair and maintenance costs are the only cost items that differ between the defender and the challenger on a year-by-year basis, we need to include only those costs in the operating costs used in the analysis. Regardless of which cost items we choose to include in the operating costs, it is essential that the same items be included for both the defender and the challenger. For example, if energy costs are included in the operating costs of the defender, they should also be included in the operating costs of the challenger. A more comprehensive discussion of the various types of costs incurred in a complex manufacturing facility was provided in Chapter 8.

14.1.2 Opportunity Cost Approach to Comparing Defender and Challenger

Although replacement projects are a subcategory of the mutually exclusive categories of project decisions we studied in Chapter 5, they do possess unique characteristics that allow us to use specialized concepts and analysis techniques in their evaluation. We consider a basic approach to analyzing replacement problems commonly known as the **opportunity cost approach**.

The basic issue is how to treat the proceeds from the sale of the old equipment. In fact, if you decide to keep the old machine, this potential sales receipt is forgone. The opportunity cost approach views the net proceeds from sale as the opportunity cost of keeping the defender. In other words, we consider the salvage value as a cash outflow for the defender (or an investment required in order to keep the defender).

EXAMPLE 14.2 Replacement Analysis Using the Opportunity Cost Approach

Consider again Example 14.1. The company has been offered a chance to purchase another printing machine for $15,000. Over its three-year useful life, the machine will reduce the usage of labor and raw materials sufficiently to cut operating costs from $8,000 to $6,000. It is estimated that the new machine can be sold for $5,500 at the end of year 3. If the new machine were purchased, the old machine would be sold to another company, rather than traded in for the new machine.

Suppose that the firm will need either machine (old or new) for only three years and that it does not expect a new, superior machine to become available on the market during this required service period. Assuming that the firm's interest rate is 12%, decide whether replacement is justified now.

SOLUTION

- **Option 1: Keep the defender.**
If the decision is to keep the defender, the opportunity cost approach treats the $10,000 current salvage value of the defender as an incurred cost. The annual operating cost for the next three years will be $8,000 per year, and the defender's salvage value three years from today will be $2,500. The cash flow diagram for the defender is shown in Figure 14.2(a).

Opportunity cost approach views the net proceeds from the sale of the old machine as an investment required to keep the old asset.

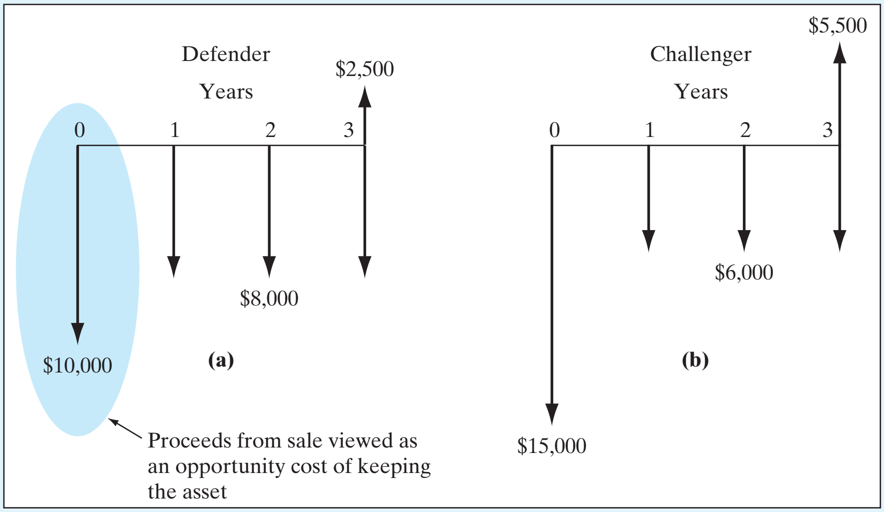


Figure 14.2 Comparison of defender and challenger based on the opportunity cost approach (Example 14.2).

- **Option 2: Replace the defender with the challenger.**
The new machine costs $15,000. The annual operating cost of the challenger is $6,000. The salvage value of the challenger three years later will be $5,500. The actual cash flow diagram for this option is shown in Figure 14.2(b). We calculate the net present worth and annual equivalent cost for each of the two options as follows:

$$\begin{aligned}\text{PW}(12\%)_D &= \$10{,}000 + \$8{,}000(P/A, 12\%, 3) \\ &\quad - \$2{,}500(P/F, 12\%, 3) \\ &= \$27{,}435,\end{aligned}$$

$$\text{AEC}(12\%)_D = \text{PW}(12\%)_D\,(A/P, 12\%, 3)$$
$$= \$11{,}423,$$

$$\text{PW}(12\%)_C = \$15{,}000 + \$6{,}000(P/A, 12\%, 3) - \$5{,}500(P/F, 12\%, 3)$$
$$= \$25{,}496,$$

$$\text{AEC}(12\%)_C = \text{PW}(12\%)_C\,(A/P, 12\%, 3)$$
$$= \$10{,}615.$$

Because of the annual difference of \$808 in favor of the challenger, the replacement should be made now.

COMMENTS: If our analysis showed instead that the defender should not be replaced now, we still need to address the question of whether the defender should be kept for one or two years and then replaced with the challenger. This is a valid question that requires more data on market values over time. We address the situation later, in Section 14.3. Recall that we assumed the same service life for both the defender and the challenger in Examples 14.1 and 14.2. In general, however, old equipment has a relatively short remaining life compared with new equipment, so this assumption is overly simplistic. In the next section, we discuss how to find the economic service life of equipment.

14.2 Economic Service Life

Perhaps you have seen a 50-year-old automobile that is still in service. Provided that it receives the proper repair and maintenance, almost anything can be kept operating for an extended period of time. If it's possible to keep a car operating for an almost indefinite period, why aren't more old cars spotted on the streets? Two reasons are that some people may get tired of driving the same old car, and other people may want to keep a car as long as it will last, but they realize that repair and maintenance costs will become excessive.

Economic service life is the remaining useful life of an asset that results in the minimum annual equivalent cost.

In general, we need to consider economically how long an asset should be held once it is placed in service. For instance, a truck-rental firm that frequently purchases fleets of identical trucks may wish to arrive at a policy decision on how long to keep each vehicle before replacing it. If an appropriate life span is computed, a firm could stagger a schedule of truck purchases and replacements to smooth out annual capital expenditures for its overall truck purchases.

The costs of owning and operating an asset can be divided into two categories: **capital costs** and **operating costs**. Capital costs have two components: the initial investment and the salvage value at the time of disposal of the asset. The initial investment for the challenger is simply its purchase price. For the defender, we should treat the opportunity cost as its initial investment. We will use N to represent the length of time in years the asset will be kept, I to denote the initial investment, and S_N to designate the salvage value at the end of the ownership period of N years.

The annual equivalent of capital costs, which is called the capital recovery cost (see Section 8.2), over the period of N years can be calculated with the following equation:

$$\text{CR}(i) = I(A/P, i, N) - S_N(A/F, i, N). \tag{14.1}$$

Generally speaking, as an asset becomes older, its salvage value becomes smaller. As long as the salvage value is less than the initial cost, the capital recovery cost is a decreasing function of N. In other words, the longer we keep an asset, the lower the capital recovery cost becomes. If the salvage value is equal to the initial cost no matter how long the asset is kept, the capital recovery cost is constant.

As described earlier, the operating costs of an asset include operating and maintenance (O&M) costs, labor costs, material costs, and energy consumption costs. Labor costs, material costs, and energy costs are often constant for the same equipment from year to year if the usage of the equipment remains constant. However, O&M costs tend to increase as a function of the age of the asset. Because of the increasing trend of the O&M costs, the total operating costs of an asset usually increase as well as the asset ages. We use OC_n to represent the total operating costs in year n of the ownership period and OC(i) to represent the annual equivalent of the operating costs over a life span of N years. Then OC(i) can be expressed as

$$\text{OC}(i) = \left(\sum_{n=1}^{N} \text{OC}_n\,(P/F, i, n) \right)(A/P, i, N). \tag{14.2}$$

As long as the annual operating costs increase with the age of the equipment, OC(i) is an increasing function of the life of the asset. If the annual operating costs are the same from year to year, OC(i) is constant and equal to the annual operating costs, no matter how long the asset is kept.

The total annual equivalent costs of owning and operating an asset (AEC(i)) are a summation of the capital recovery costs and the annual equivalent of operating costs of the asset:

$$\text{AEC}(i) = \text{CR}(i) + \text{OC}(i). \tag{14.3}$$

The economic service life of an asset is defined to be the period of useful life that minimizes the annual equivalent costs of owning and operating the asset. On the basis of the foregoing discussions, we need to find the value of N that minimizes AE as expressed in Eq. (14.3). If CR(i) is a decreasing function of N and OC(i) is an increasing function of N, as is often the case, AE will be a convex function of N with a unique minimum point. (See Figure 14.3.) In this book, we assume that AE has a unique minimum point. If the salvage value of the asset is constant and equal to the initial cost, and if the annual operating cost increases with time, then AE is an increasing function of N and attains its minimum at $N = 1$. In this case, we should try to replace the asset as soon as possible. If, however, the annual operating cost is constant and the salvage value is less than the initial cost and decreases with time, then AE is a decreasing function of N. In this case, we would try to delay the replacement of the asset as much as possible. Finally, if the salvage value is

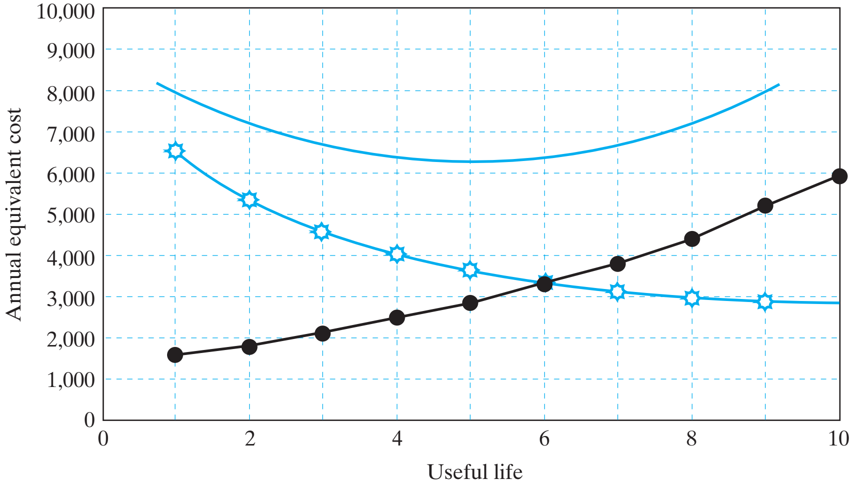


Figure 14.3 A schematic illustrating the trends of capital recovery cost (ownership cost), annual operating cost, and total annual equivalent cost.

constant and equal to the initial cost and the annual operating costs are constant, then AE will also be constant. In this case, when to replace the asset does not make any economic difference.

If a new asset is purchased and operated for the length of its economic life, the annual equivalent cost is minimized. If we further assume that a new asset of identical price and features can be purchased repeatedly over an indefinite period, we would always replace this kind of asset at the end of its economic life. By replacing perpetually according to an asset's economic life, we obtain the minimum AE cost stream over an indefinite period. However, if the identical-replacement assumption cannot be made, we will have to use the methods to be covered in Section 14.3 to carry out a replacement analysis. The next example explains the computational procedure for determining an asset's economic service life.

EXAMPLE 14.3 Economic Service Life of a Lift Truck

Suppose a company has a forklift, but is considering purchasing a new electric-lift truck that would cost \$18,000, have operating costs of \$1,000 in the first year, and have a salvage value of \$10,000 at the end of the first year. For the remaining years, operating costs increase each year by 15% over the previous year's operating costs. Similarly, the salvage value declines each year by 25% from the previous year's salvage value. The lift truck has a maximum life of seven years. An overhaul costing \$3,000 and \$4,500 will be required during the fifth and seventh years of service, respectively. The firm's required rate of return is 15%. Find the economic service life of this new machine.

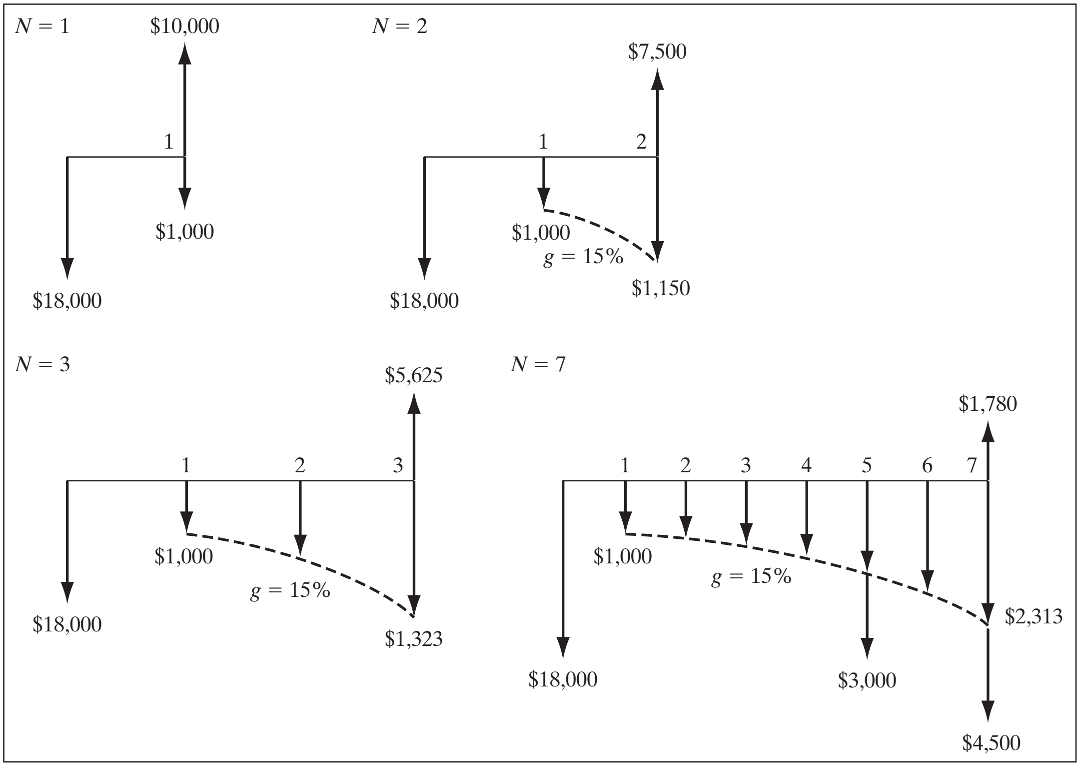


Figure 14.4 Cash flow diagrams for the options of keeping the asset for one year, two years, three years, and seven years (Example 14.3).

DISCUSSION: For an asset whose revenues are either unknown or irrelevant, we compute its economic life on the basis of the costs for the asset and its year-by-year salvage values. To determine an asset's economic service life, we need to compare the options of keeping the asset for one year, two years, three years, and so forth. The option that results in the lowest annual equivalent cost (AEC) gives the economic service life of the asset.

- $N = 1$**: One-year replacement cycle.** In this case, the machine is bought, used for one year, and sold at the end of year 1. The cash flow diagram for this option is shown in Figure 14.4. The annual equivalent cost for this option is

$$\begin{aligned}\text{AEC}(15\%) &= \$18{,}000(A/P, 15\%, 1) + \$1{,}000 - \$10{,}000 \\ &= \$11{,}700.\end{aligned}$$

Note that $(A/P, 15\%, 1) = (F/P, 15\%, 1)$ and the annual equivalent cost is the equivalent cost at the end of year 1, since $N = 1$. Because we are calculating the annual equivalent cost in the computation of AEC(15%), we have treated cost items with a positive sign, while the salvage value has a negative sign.

- ***N* = 2: Two-year replacement cycle.** In this case, the truck will be used for two years and disposed of at the end of year 2. The operating cost in year 2 is 15% higher than that in year 1, and the salvage value at the end of year 2 is 25% lower than that at the end of year 1. The cash flow diagram for this option is also shown in Figure 14.4. The annual equivalent cost over the two-year period is

$$\begin{aligned} \text{AEC}(15\%) &= [\$18{,}000 + \$1{,}000(P/A_1\ 15\%, 15\%, 2)](A/P, 15\%, 2) \\ &\quad -\$7{,}500(A/F, 15\%, 2) \\ &= \$8{,}653. \end{aligned}$$

- ***N* = 3: Three-year replacement cycle.** In this case, the truck will be used for three years and sold at the end of year 3. The salvage value at the end of year 3 is 25% lower than that at the end of year 2; that is, $7,500(1 − 25%) = $5,625. The operating cost per year increases at a rate of 15%. The cash flow diagram for this option is also shown in Figure 14.4. The annual equivalent cost over the three-year period is

$$\begin{aligned} \text{AEC}(15\%) &= [\$18{,}000 + \$1{,}000(P/A_1\ 15\%, 15\%, 3)](A/P, 15\%, 3) \\ &\quad - \$5{,}625(A/F, 15\%, 3) \\ &= \$7{,}406. \end{aligned}$$

- Similarly, we can find the annual equivalent costs for the options of keeping the asset for four, five, six, and seven years. One has to note that there is an additional cost of overhaul in year 5. The cash flow diagram when $N = 7$ is shown in Figure 14.4. The computed annual equivalent costs for each of these options are

$$N = 4, \text{AEC}(15\%) = \$6{,}678,$$
$$N = 5, \text{AEC}(15\%) = \$6{,}642,$$
$$N = 6, \text{AEC}(15\%) = \$6{,}258,$$
$$N = 7, \text{AEC}(15\%) = \$6{,}394.$$

From the preceding calculated AEC values for $N = 1, \ldots, 7$, we find that AEC(15%) is smallest when $N = 6$. If the truck were to be sold after six years, it would have an annual cost of $6,258 per year. If it were to be used for a period other than six years, the annual equivalent costs would be higher than $6,258. Thus, a life span of six years for this truck results in the lowest annual cost. We conclude that the economic service life of the truck is six years. By replacing the assets perpetually according to

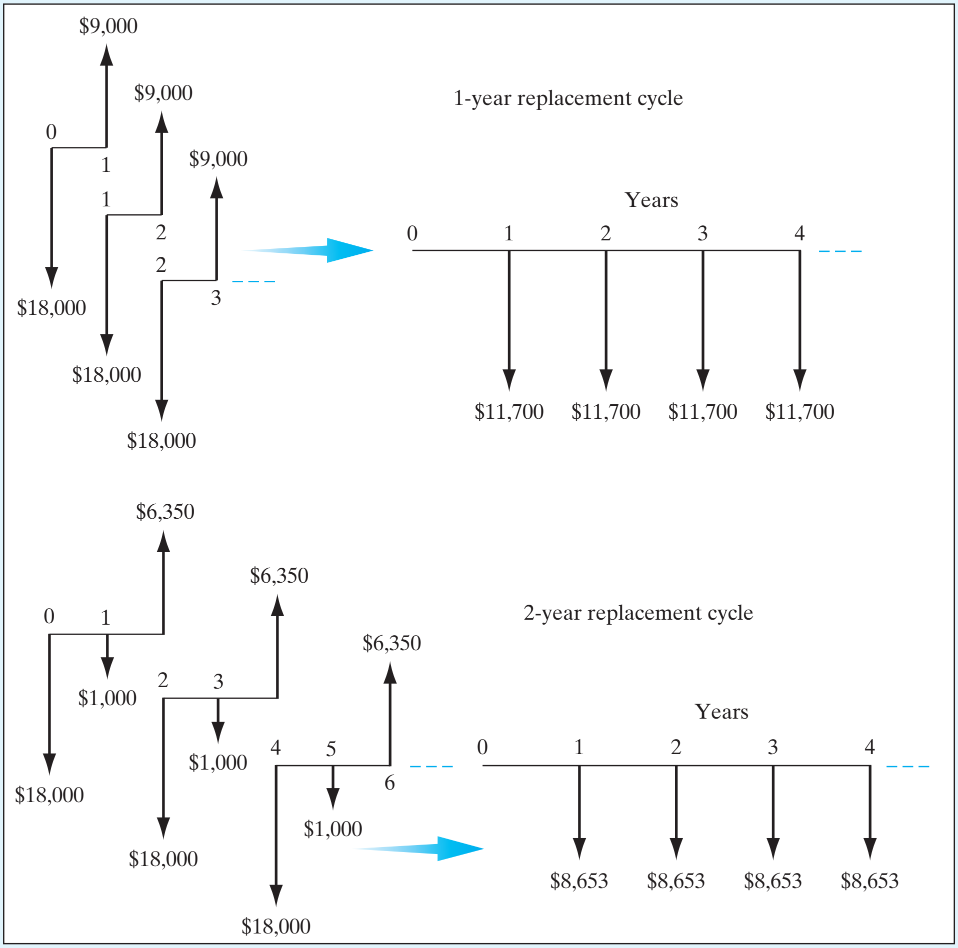


Figure 14.5 Conversion of an infinite number of replacement cycles to infinite AE cost streams (Example 14.3).

an economic life of six years, we obtain the minimum annual equivalent cost stream. Figure 14.5 illustrates this concept. Of course, we should envision a long period of required service for this kind of asset.

14.3 Replacement Analysis when the Required Service Is Long

Now that we understand how the economic service life of an asset is determined, the next question is how to use these pieces of information to decide whether now is the time to replace the defender. If now is not the right time, when *is* the optimal time to replace the defender? Before presenting an analytical approach to answer this question, we consider several important assumptions.

14.3.1 Required Assumptions and Decision Frameworks

In deciding whether now is the time to replace the defender, we need to consider the following three factors:

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

Planning Horizon (Study Period)

By the planning horizon, we simply mean the service period required by the defender and a sequence of future challengers. The infinite planning horizon is used when we are simply unable to predict when the activity under consideration will be terminated. In other situations, it may be clear that the project will have a definite and predictable duration. In these cases, replacement policy should be formulated more realistically on the basis of a finite planning horizon.

Technology

Predictions of technological patterns over the planning horizon refer to the development of types of challengers that may replace those under study. A number of possibilities exist in predicting purchase cost, salvage value, and operating cost that are dictated by the efficiency of a new machine over the life of an existing asset. If we assume that all future machines will be the same as those now in service, we are implicitly saying that no technological progress in the area will occur. In other cases, we may explicitly recognize the possibility of machines becoming available in the future that will be significantly more efficient, reliable, or productive than those currently on the market. (Personal computers are a good example.) This situation leads to the recognition of technological change and obsolescence. Clearly, if the best available machine gets better and better over time, we should certainly investigate the possibility of delaying an asset's replacement for a couple of years—a viewpoint that contrasts with the situation in which technological change is unlikely.

Revenue and Cost Patterns over the Life of an Asset

Many varieties of predictions can be used to estimate the patterns of revenue, cost, and salvage value over the life of an asset. Sometimes revenue is constant, but costs increase, while salvage value decreases, over the life of a machine. In other situations, a decline in revenue over the life of a piece of equipment can be expected. The specific situation will determine whether replacement analysis is directed toward cost minimization (with constant revenue) or profit maximization (with varying revenue). We formulate a replacement policy for an asset whose salvage value does not increase with age.

Decision Frameworks

To illustrate how a decision framework is developed, we indicate a replacement sequence of assets by the notation $(j_0, n_0), (j_1, n_1), (j_2, n_2), \ldots, (j_K, n_K)$. Each pair of numbers (j, n) indicates a type of asset and the lifetime over which that asset will be retained. The defender, asset 0, is listed first; if the defender is replaced now, $n_0 = 0$. A sequence of pairs may cover a finite period or an infinite period. For example, the sequence $(j_0, 2), (j_1, 5), (j_2, 3)$ indicates retaining the defender for two years, then replacing the defender with an asset of type j_1 and using it for five years, and then replacing j_1 with an asset of type j_2 and using it for three years. In this situation, the total planning horizon

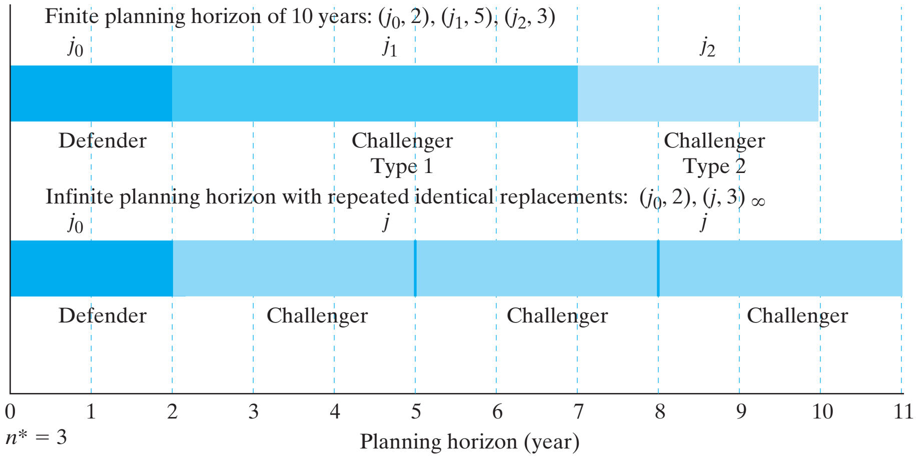


Figure 14.6 Types of typical replacement decision frameworks.

covers 10 years $(2 + 5 + 3)$. The special case of keeping the defender for n_0 periods, followed by infinitely repeated purchases and the use of an asset of type j for n^* years, is represented by $(j_0, n_0), (j, n^*)_\infty$. This sequence covers an infinite period, and the relationship is illustrated in Figure 14.6.

Decision Criterion

Although the economic life of the defender is defined as the additional number of years of service which minimizes the annual equivalent cost (or maximizes the annual equivalent revenue), that is *not* necessarily the *optimal* time to replace the defender. The correct replacement time depends on data on the challenger, as well as on data on the defender.

As a decision criterion, the AE method provides a more direct solution when the planning horizon is infinite. When the planning horizon is finite, the PW method is more convenient to use. We will develop the replacement decision procedure for both situations. We begin by analyzing an infinite planning horizon without technological change. Even though a simplified situation such as this is not likely to occur in real life, the analysis of this replacement situation introduces methods that will be useful in analyzing infinite-horizon replacement problems with technological change.

14.3.2 Replacement Strategies under the Infinite Planning Horizon

Consider a situation in which a firm has a machine that is in use in a process which is expected to continue for an indefinite period. Presently, a new machine will be on the market that is, in some ways, more effective for the application than the defender is. The problem is when, if at all, the defender should be replaced with the challenger.

Under the infinite planning horizon, the service is required for a very long time. Either we continue to use the defender to provide the service, or we replace the defender with the best available challenger for the same service requirement. In this case, we may apply the following procedure in replacement analysis:

1. Compute the economic lives of both the defender and the challenger. Let's use N_D* and N_C* to indicate the economic lives of the defender and the challenger, respectively. The annual equivalent costs for the defender and the challenger at their respective economic lives are indicated by AEC_D* and AEC_C*.
2. Compare AEC_D* and AEC_C*. If AEC_D* is bigger than AEC_C*, it is more costly to keep the defender than to replace it with the challenger. Thus, the challenger should replace the defender now. If AEC_D* is smaller than AEC_C*, it costs less to keep the defender than to replace it with the challenger. Thus, the defender should *not* be replaced now. The defender should continue to be used at least for the duration of its economic life if there are no technological changes over that life.
3. If the defender should not be replaced now, when should it be replaced? First we need to continue to use it until its economic life is over. Then we should calculate the cost of running the defender for one more year after its economic life. If this cost is greater than AEC_C*, the defender should be replaced at the end of its economic life. Otherwise, we should calculate the cost of running the defender for the second year after its economic life. If this cost is bigger than AEC_C*, the defender should be replaced one year after its economic life. The process should be continued until we find the optimal replacement time. This approach is called **marginal analysis**; that is, we calculate the incremental cost of operating the defender for just one more year. In other words, we want to see whether the cost of extending the use of the defender for an additional year exceeds the savings resulting from delaying the purchase of the challenger. Here, we have assumed that the best available challenger does not change.

Note that this procedure might be applied dynamically. For example, it may be performed annually for replacement analysis. Whenever there are updated data on the costs of the defender or new challengers available on the market, the new data should be used in the procedure. Example 14.4 illustrates the procedure.

EXAMPLE 14.4 Replacement Analysis under an Infinite Planning Horizon

Advanced Electrical Insulator Company is considering replacing a broken inspection machine, which has been used to test the mechanical strength of electrical insulators, with a newer and more efficient one.

- If repaired, the old machine can be used for another five years, although the firm does not expect to realize any salvage value from scrapping it at that time. However, the firm can sell it now to another firm in the industry for $5,000. If the machine is kept, it will require an immediate $1,200 overhaul to restore it to operable condition. The overhaul will neither extend the service life originally estimated nor increase the value of the inspection machine. The operating costs are estimated at $2,000 during the first year, and these are expected to increase by $1,500 per year thereafter. Future market values are expected to decline by $1,000 per year.

- The new machine costs \$10,000 and will have operating costs of \$2,000 in the first year, increasing by \$800 per year thereafter. The expected salvage value is \$6,000 after one year and will decline 15% each year. The company requires a rate of return of 15%. Find the economic life for each option, *and* determine when the defender should be replaced.

SOLUTION

1. Economic service life:

- **Defender.** If the company retains the inspection machine, it is in effect deciding to overhaul the machine and invest the machine's current market value in that alternative. The opportunity cost of the machine is \$5,000. Because an overhaul costing \$1,200 is also needed to make the machine operational, the total initial investment in the machine is \$5,000 + \$1,200 = \$6,200. Other data for the defender are summarized as follows:

n	Overhaul	Forecasted Operating Cost	Market Value if Disposed of
0	\$1,200		\$5,000
1	0	\$2,000	\$4,000
2	0	\$3,500	\$3,000
3	0	\$5,000	\$2,000
4	0	\$6,500	\$1,000
5	0	\$8,000	0

We can calculate the annual equivalent costs if the defender is to be kept for one year, two years, three years, and so forth. For example, the cash flow diagram for $N = 4$ years is shown in Figure 14.7. The annual equivalent costs for four years are as follows:

$$\begin{aligned} N = 4 \text{ years: AEC}(15\%) &= \$6{,}200(A/P, 15\%, 4) + \$2{,}000 \\ &\quad + \$1{,}500(A/G, 15\%, 4) - \$1{,}000(A/F, 15\%, 4) \\ &= \$5{,}961. \end{aligned}$$

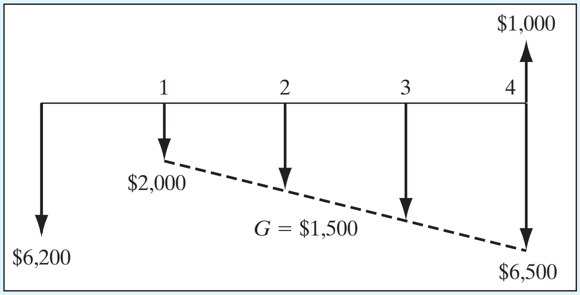


Figure 14.7 Cash flow diagram for defender when $N = 4$ years (Example 14.4).

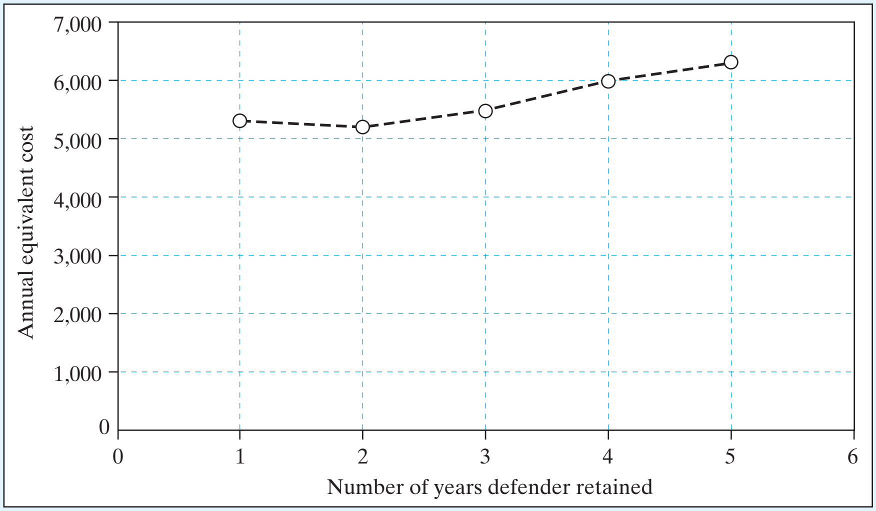


Figure 14.8 AEC as a function of the life of the defender (Example 14.4).

The other AE cost figures can be calculated with the following equation:

$$\text{AEC}(15\%)_N = \$6{,}200(A/P, 15\%, N) + \$2{,}000 + \$1{,}500(A/G, 15\%, N) - \$1{,}000(5 - N)(A/F, 15\%, N) \text{ for } N = 1, 2, 3, 4, 5;$$

$$N = 1: \text{AEC}(15\%) = \$5{,}130,$$
$$N = 2: \text{AEC}(15\%) = \$5{,}116,$$
$$N = 3: \text{AEC}(15\%) = \$5{,}500,$$
$$N = 4: \text{AEC}(15\%) = \$5{,}961,$$
$$N = 5: \text{AEC}(15\%) = \$6{,}434.$$

When $N = 2$ years, we get the lowest AEC value. Thus, the defender's economic life is two years. Using the notation we defined in the procedure, we have

$$N_D{}^* = 2 \text{ years},$$
$$\text{AEC}_D{}^* = \$5{,}116.$$

The AEC values as a function of N are plotted in Figure 14.8. Actually, after computing AEC for $N = 1, 2,$ and 3, we can stop right there. There is no need to compute AEC for $N = 4$ and $N = 5$, because AEC is increasing when $N > 2$ and we have assumed that AEC has a unique minimum point.

- **Challenger.** The economic life of the challenger can be determined with the same procedure we used in this example for the defender and in Example 14.3. A summary of the general equation for calculating AEC for the challenger follows. You don't have to summarize such an equation when you need to determine the economic life of an asset, as long as you follow the procedure illustrated in Example 14.3. The equation is

$$\begin{aligned}\text{AEC}(15\%)_N = {} & \$10{,}000(A/P, 15\%, N) + \$2{,}000 \\ & + \$800(A/G, 15\%, N) \\ & - \$6{,}000(1 - 15\%)^{N-1}(A/F, 15\%, N).\end{aligned}$$

The results of "plugging in" the values and solving are as follows:

$$\begin{aligned} N &= 1 \text{ year: AEC}(15\%) = \$7{,}500, \\ N &= 2 \text{ years: AEC}(15\%) = \$6{,}151, \\ N &= 3 \text{ years: AEC}(15\%) = \$5{,}857, \\ N &= 4 \text{ years: AEC}(15\%) = \$5{,}826, \\ N &= 5 \text{ years: AEC}(15\%) = \$5{,}897. \end{aligned}$$

The economic life of the challenger is four years; that is,

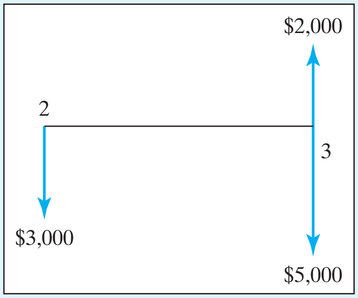
$$N_C{}^* = 4 \text{ years}.$$

Thus,

$$\text{AEC}_C{}^* = \$5{,}826.$$

2. **Should the defender be replaced now?**
Since $\text{AEC}_D{}^* = \$5{,}116 < \text{AEC}_C{}^* = \$5{,}826$, the defender should not be replaced now. If there are no technological advances in the next few years, the defender should be used for at least $N_D{}^* = 2$ more years. However, it is not necessarily best to replace the defender right at the high point of its economic life.
3. **When should the defender be replaced?**
If we need to find the answer to this question today, we have to calculate the cost of keeping and using the defender for the third year from today. That is, what is the cost of not selling the defender at the end of year 2, using it for the third year, and replacing it at the end of year 3? The following cash flows are related to this question:
   (a) Opportunity cost at the end of year 2: equal to the market value then, or \$3,000.
   (b) Operating cost for the third year: \$5,000.
   (c) Salvage value of the defender at the end of year 3: \$2,000.

   The following diagram represents these cash flows:



The cost of using the defender for one more year from the end of its economic life is

$$\$3{,}000 \times 1.15 + \$5{,}000 - \$2{,}000 = \$6{,}450.$$

Now compare this cost with the $AEC_C^* = \$5,826$ of the challenger. It is greater than AEC_C^*. Thus, it is more expensive to keep the defender for the third year than to replace it with the challenger. Accordingly, we conclude that we should replace the defender at the end of year 2. If this one-year cost is still smaller than AEC_C^*, we need to calculate the cost of using the defender for the fourth year and then compare that cost with the AEC_C^* of the challenger.

In replacement analysis, it is common for a defender and its challenger to have different economic service lives. The annual-equivalent approach is frequently used, but it is important to know that we use the AEC method in replacement analysis, not because we have to deal with the problem of unequal service lives, but rather because the AEC approach provides some computational advantage for a special class of replacement problems.

In Chapter 5, we discussed the general principle for comparing alternatives with unequal service lives. In particular, we pointed out that use of the AEC method relies on the concept of repeatability of projects and one of two assumptions: an infinite planning horizon or a common service period. In defender–challenger situations, however, repeatability of the defender cannot be assumed. In fact, by virtue of our definition of the problem, we are not repeating the defender, but replacing it with its challenger, an asset that in some way constitutes an improvement over the current equipment. Thus, the assumptions we made for using an annual cash flow analysis with unequal service life alternatives are not valid in the usual defender–challenger situation.

The complication—the unequal-life problem—can be resolved if we recall that the replacement problem at hand is not *whether* to replace the defender, but *when* to do so. When the defender is replaced, it will always be by the challenger—the best available equipment. An identical challenger can then replace the challenger repeatedly. In fact, we really are comparing the following two options in replacement analysis:

1. **Replace the defender now.** The cash flows of the challenger will be used from today and will be repeated because an identical challenger will be used if replacement becomes necessary again in the future. This stream of cash flows is equivalent to a cash flow of AEC_C^* each year for an infinite number of years.
2. **Replace the defender, say, x years later.** The cash flows of the defender will be used in the first x years. Starting in year $x + 1$, the cash flows of the challenger will be used indefinitely.

The annual-equivalent cash flows for the years beyond year x are the same for these two options. We need only to compare the annual-equivalent cash flows for the first x years to determine which option is better. This is why we can compare AEC_D^* with AEC_C^* to determine whether now is the time to replace the defender.

14.3.3 Replacement Strategies under the Finite Planning Horizon

If the planning period is finite (for example, eight years), a comparison based on the AE method over a defender's economic service life does not generally apply. The procedure for solving such a problem with a finite planning horizon is to establish all "reasonable" replacement patterns and then use the PW value for the planning period to select the most economical pattern. To illustrate this procedure, consider Example 14.5.

EXAMPLE 14.5 Replacement Analysis under the Finite Planning Horizon (PW Approach)

Consider again the defender and the challenger in Example 14.4. Suppose that the firm has a contract to perform a given service, using the current defender or the challenger for the next eight years. After the contract work, neither the defender nor the challenger will be retained. What is the best replacement strategy?

SOLUTION

Recall again the annual equivalent costs for the defender and challenger under the assumed holding periods (a boxed number denotes the minimum AEC value at $N_D{}^* = 2$ and $N_C{}^* = 4$, respectively):

Annual Equivalent Cost ($)		
n	Defender	Challenger
1	5,130	7,500
2	[5,116]	6,151
3	5,500	5,857
4	5,961	[5,826]
5	6,434	5,897

Many ownership options would fulfill an eight-year planning horizon, as shown in Figure 14.9. Of these options, six appear to be the most likely by inspection. These options are listed, and the present equivalent cost for each option is calculated, as follows:

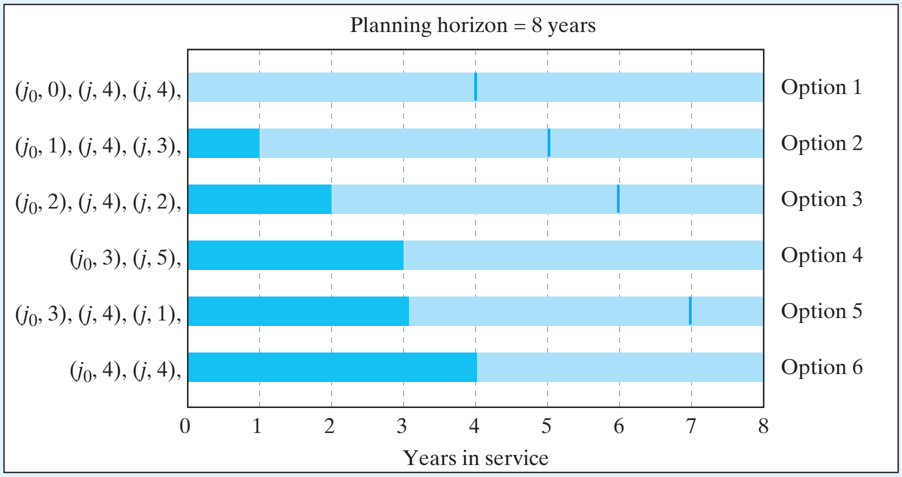


Figure 14.9 Some likely replacement patterns under a finite planning horizon of eight years (Example 14.5).

- **Option 1:** $(j_0, 0), (j, 4), (j, 4)$

$$\begin{aligned} PW(15\%)_1 &= \$5{,}826(P/A, 15\%, 8) \\ &= \$26{,}143. \end{aligned}$$

- **Option 2:** $(j_0, 1), (j, 4), (j, 3)$

$$\begin{aligned} PW(15\%)_2 &= \$5{,}130(P/F, 15\%, 1) \\ &\quad + \$5{,}826(P/A, 15\%, 4)(P/F, 15\%, 1) \\ &\quad + \$5{,}857(P/A, 15\%, 3)(P/F, 15\%, 5) \\ &= \$25{,}573. \end{aligned}$$

- **Option 3:** $(j_0, 2), (j, 4), (j, 2)$

$$\begin{aligned} PW(15\%)_3 &= \$5{,}116(P/A, 15\%, 2) \\ &\quad + \$5{,}826(P/A, 15\%, 4)(P/F, 15\%, 2) \\ &\quad + \$6{,}151(P/A, 15\%, 2)(P/F, 15\%, 6) \\ &= \$25{,}217 \leftarrow \text{minimum cost}. \end{aligned}$$

- **Option 4:** $(j_0, 3), (j, 5)$

$$\begin{aligned} PW(15\%)_4 &= \$5{,}500(P/A, 15\%, 3) \\ &\quad + \$5{,}897(P/A, 15\%, 5)(P/F, 15\%, 3) \\ &= \$25{,}555. \end{aligned}$$

- **Option 5:** $(j_0, 3), (j, 4), (j, 1)$

$$\begin{aligned} PW(15\%)_5 &= \$5{,}500(P/A, 15\%, 3) \\ &\quad + \$5{,}826(P/A, 15\%, 4)(P/F, 15\%, 3) \\ &\quad + \$7{,}500(P/F, 15\%, 8) \\ &= \$25{,}946. \end{aligned}$$

- **Option 6:** $(j_0, 4), (j, 4)$

$$\begin{aligned} PW(15\%)_6 &= \$5{,}961(P/A, 15\%, 4) \\ &\quad + \$5{,}826(P/A, 15\%, 4)(P/F, 15\%, 4) \\ &= \$26{,}529. \end{aligned}$$

An examination of the present equivalent cost of a planning horizon of eight years indicates that the least-cost solution appears to be Option 3: Retain the defender for two years, purchase the challenger and keep it for four years, and purchase another challenger and keep it for two years.

COMMENTS: In this example, we examined only six decision options that were likely to lead to the best solution, but it is important to note that several other possibilities

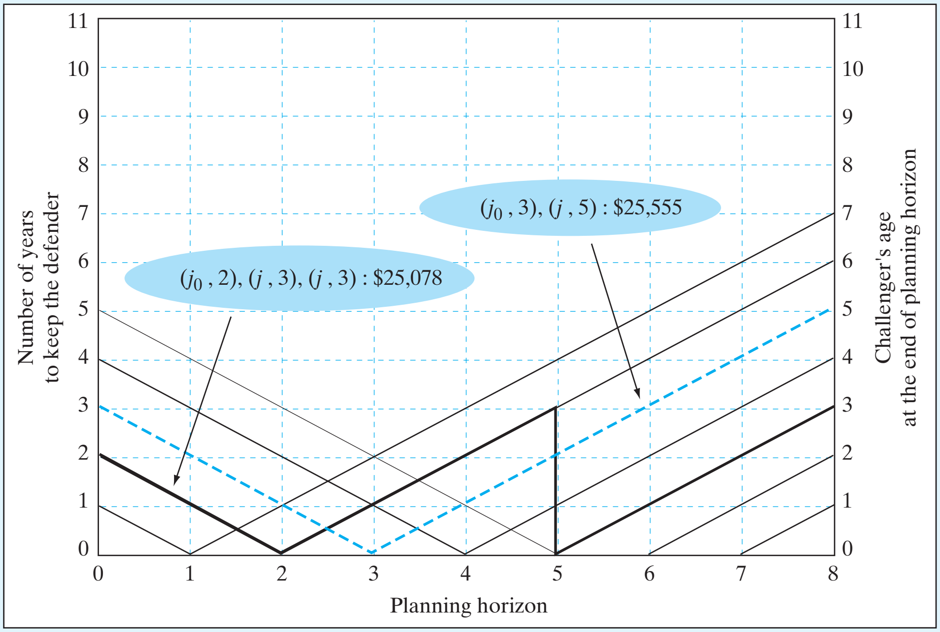


Figure 14.10 Graphical representations of replacement strategies under a finite planning horizon (Example 14.5).

have not been looked at. To explain, consider Figure 14.10, which shows a graphical representation of various replacement strategies under a finite planning horizon. For example, the replacement strategy $[(j_0, 2), (j, 3), (j, 3)]$ (shown as a solid line in the figure) is certainly feasible, but we did not include it in the previous computation. Naturally, as we extend the planning horizon, the number of possible decision options can easily multiply. To make sure that we indeed find the optimal solution for such a problem, an optimization technique such as dynamic programming can be used.[3]

14.3.4 Consideration of Technological Change

Thus far, we have defined the challenger simply as the best available replacement for the defender. It is more realistic to recognize that the replacement decision often involves an asset now in use versus a candidate for replacement—that is, in some way, an improvement on the current asset. This, of course, reflects technological progress that is ongoing continually. Future models of a machine are likely to be more effective than a current model. In most areas, technological change appears as a combination of gradual advances in effectiveness; the occasional technological breakthrough, however, can revolutionize the character of a machine.

The prospect of improved future challengers makes a current challenger a less desirable alternative. By retaining the defender, we may have an opportunity to acquire an improved challenger later. If this is the case, the prospect of improved future challengers may affect a current decision between a defender and its challenger. It is difficult to forecast future technological trends in any precise fashion. However, in developing a long-term replacement policy, we need to take technological change into consideration.

[3] F. S. Hillier and G. S. Lieberman, *Introduction to Operations Research*, 8th ed. (New York: McGraw-Hill, 2005).

14.4 Replacement Analysis with Tax Considerations

Up to this point, we have covered various concepts and techniques that are useful in replacement analysis in general. In this section, we illustrate how to use those concepts and techniques to conduct replacement analysis on an after-tax basis.

To apply the concepts and methods covered in Sections 14.1 through 14.3 in an after-tax comparison of defender and challenger, we have to incorporate the tax effects (gains or losses) whenever an asset is disposed of. Whether the defender is kept or the challenger is purchased, we also need to incorporate the tax effects of depreciation allowances into our analysis.

Replacement studies require a knowledge of the depreciation schedule and of taxable gains or losses at disposal of the asset. Note that the depreciation schedule is determined at the time the asset is acquired, whereas the relevant tax law determines the gains tax effects at the time of disposal. In this section, we will use the same examples (Example 14.1 through 14.4) to illustrate how to do the following analyses on an after-tax basis:

1. Calculate the net proceeds due to disposal of the defender (Example 14.6).
2. Use the opportunity cost approach in comparing defender and challenger (Example 14.7).
3. Calculate the economic life of the defender or the challenger (Example 14.8).
4. Conduct replacement analysis under the infinite planning horizon (Example 14.9).

EXAMPLE 14.6 Net Proceeds from the Disposal of an Old Machine

Suppose that, in Example 14.1, the $20,000 capital expenditure was set up to be depreciated on a seven-year MACRS (allowed annual depreciation: $2,858, $4,898, $3,498, $2,498, $1,786, $1,784, $1,786, and $892). If the firm's marginal income tax rate is 40%, determine the taxable gains (or losses) and the net proceeds from disposal of the old printing machine.

SOLUTION

First we need to find the current book value of the old printing machine. The original cost minus the accumulated depreciation, calculated with the half-year convention (if the machine sold now), is

$$\$20{,}000 - (\$2{,}858 + \$4{,}898/2) = \$14{,}693,$$

so we compute the following:

Allowed book value	=	$14,693
Current market value	=	$10,000
Losses	=	$4,693
Tax savings = $4,693(0.40)	=	$1,877
Net proceeds from the sale	=	$10,000 + $1,877
	=	$11,877

This calculation is illustrated in Figure 14.11.

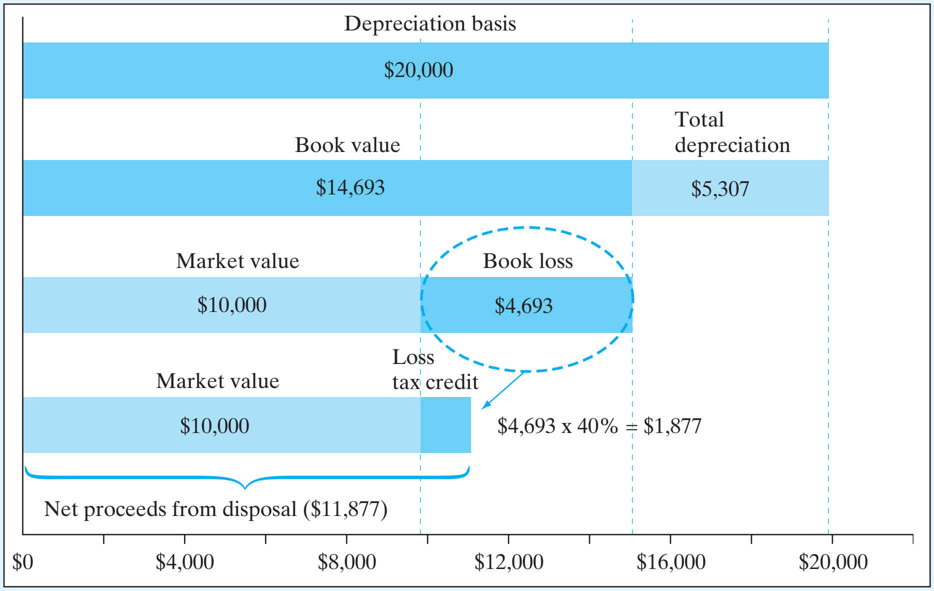


Figure 14.11 Net proceeds from the sale of the old printing machine—defender (Example 14.6).

EXAMPLE 14.7 Replacement Analysis Using the Opportunity Cost Approach

Suppose, in Example 14.2, that the new machine would fall into the same seven-year MACRS class as the old machine. The firm's after-tax interest rate (MARR) is 12%, and the marginal income tax rate is 40%. Use the opportunity cost approach to decide whether replacement of the old machine is justified now.

SOLUTION

Tables 14.1 and 14.2 show the worksheet formats the company uses to analyze a typical replacement project with the generalized cash flow approach. Each line is numbered, and a line-by-line description of the table follows:

- **Option 1: Keep the defender.**

  Lines 1–4: If the old machine is kept, the depreciation schedule would be ($3,498, $2,498, and $1,786). Following the half-year convention, it is assumed that the asset will be retired at the end of three years; thus, the depreciation for year 3 is $(0.5)(\$1{,}786) = \$893$. This results in total depreciation in the amount of $14,645 and a remaining book value of $\$20{,}000 - \$14{,}645 = \$5{,}355$.

  Lines 5–6: Repair costs in the amount of $5,000 were already incurred before the replacement decision. This is a sunk cost and should not be considered in the analysis. If a repair in the amount of $5,000 is required to keep the defender in serviceable condition, it will show as an expense in year 0. If the old machine is

TABLE 14.1 **Replacement Worksheet: Option 1—Keep the Defender (Example 14.6)**

n	−2	−1	0	1	2	3
Financial data (cost information):						
(1) Depreciation		$2,858	$ 4,898	$3,498	$2,498	$ 893
(2) Book value	$20,000	$17,142	$12,244	$8,746	$6,248	$5,355
(3) Salvage value						$2,500
(4) Loss from sale						−$2,855
(5) Repair cost		$5,000				
(6) O&M costs				$8,000	$8,000	$8,000
Cash flow statement:						
(7) Opportunity cost			−$11,877			
(8) Net proceeds from sale						$3,642
(9) −O&M cost × (0.6)				−$4,800	−$4,800	−$4,800
(10) +Depreciation × (0.4)				$1,399	$ 999	$ 357
(11) Net cash flow			−$11,877	−$3,401	−$3,801	−$ 801

Note: The highlighted data represent sunk costs.

TABLE 14.2 **Replacement Worksheet: Option 2—Replace the Defender (Example 14.6)**

n	−2	−1	0	1	2	3
Financial data (cost information):						
(1) Cost of new printer			$15,000			
(2) Depreciation				$ 2,144	$3,674	$1,312
(3) Book value				$12,856	$9,182	$7,870
(4) Salvage value						$5,500
(5) Loss from sale						−$2,370
(6) O&M costs				$6,000	$6,000	$6,000
Cash flow statement:						
(7) Investment cost			−$15,000			
(8) Net proceeds from sale						$6,448
(9) −O&M cost × (0.6)				−$3,600	−$3,600	−$3,600
(10) +Depreciation × (0.4)				$858	$1,470	$525
(11) Net cash flow			−$15,000	−$2,742	−$2,130	$3,373

retained for the next three years, the before-tax annual O&M costs are as shown in Line 6.

Lines 7–11: Recall that the depreciation allowances result in a tax reduction equal to the depreciation amount multiplied by the tax rate. The operating expenses are multiplied by the factor of (1 − the tax rate) to obtain the after-tax O&M. For a situation in which the asset is retained for one year, Table 14.1 summarizes the cash flows obtained by using the generalized cash flow approach.

- **Option 2: Replace the defender.**

Line 1: The purchase price of the new machine, including installation and freight charges, is listed in Table 14.2.

Line 2: The depreciation schedule, along with the book values for the new machine (seven-year MACRS), is shown. The depreciation amount of $1,312 in year 3 reflects the half-year convention.

Line 5: With the salvage value estimated at $5,500, we expect a loss ($2,370 = $7,878 − $5,500) on the sale of the new machine at the end of year 3.

Line 6: The O&M costs for the new machine are listed.

If the decision to keep the defender had been made, the opportunity cost approach would treat the $11,877 current salvage value of the defender as an incurred cost. Figure 14.12 illustrates the cash flows related to these decision options.

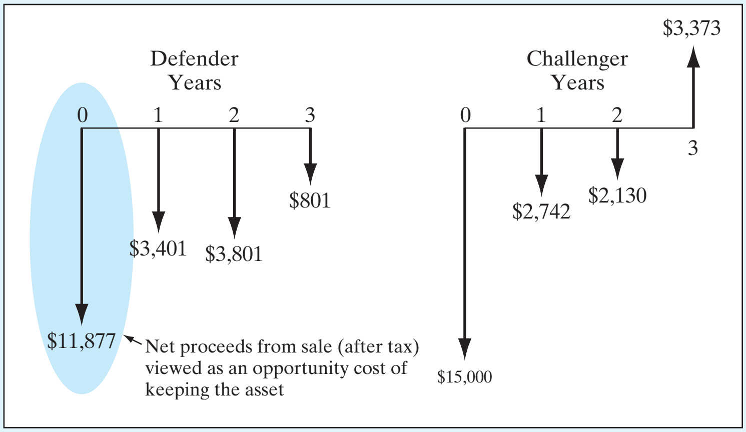


Figure 14.12 Comparison of defender and challenger on the basis of the opportunity cost approach (Example 14.7).

Since the lifetimes of the defender and challenger are the same, we can use either PW or AE analysis as follows:

$$\begin{aligned}\text{PW}(12\%)_{\text{Old}} &= \$11{,}877 + \$3{,}401(P/F, 12\%, 1) + \$3{,}801(P/F, 12\%, 2) \\ &\quad + \$801(P/F, 12\%, 3) \\ &= \$18{,}514; \\ \text{AEC}(12\%)_{\text{Old}} &= \$18{,}514(A/P, 12\%, 3) \\ &= \$7{,}708;\end{aligned}$$

$$\begin{aligned} PW(12\%)_{New} &= \$15{,}000 + \$2{,}742(P/F, 12\%, 1) \\ &\quad + \$2{,}130(P/F, 12\%, 2) - \$3{,}373(P/F, 12\%, 3) \\ &= \$16{,}745; \\ AEC(12\%)_{New} &= \$16{,}745(A/P, 12\%, 3) \\ &= \$6{,}972. \end{aligned}$$

Because of the annual difference of $736 in favor of the challenger, the replacement should be made now.

COMMENTS: Recall that we assumed the same service life for both the defender and the challenger. In general, however, old equipment has a relatively short remaining life compared with new equipment, so that assumption is too simplistic. When the defender and challenger have unequal lifetimes, we must make an assumption in order to obtain a common analysis period. A typical assumption is that, after the initial decision, we make **perpetual replacements** with assets similar to the challenger. Certainly, we can still use PW analysis with actual cash flows, but that would require evaluating *infinite* cash flow streams.

EXAMPLE 14.8 Economic Service Life of a Lift Truck

Consider again Example 14.3, but with the following additional data: The asset belongs to a five-year MACRS property class with the following annual depreciation allowances: 20%, 32%, 19.20%, 11.52%, 11.52%, and 5.76%. The firm's marginal tax rate is 40%, and its after-tax MARR is 15%. Find the economic service life of this new machine.

DISCUSSION: To determine an asset's economic service life, we first list the gains or losses that will be realized if the truck were to be disposed of at the end of each operating year. In doing so, we need to compute the book values at the end of each operating year, assuming that the asset would be disposed of at that time. Recall that, with the half-year convention, the book value (for the MACRS property) at the end of the year is based on its disposal during the year. As summarized in Table 14.3, these values provide a basis for identifying the relevant after-tax cash flows at the end of an assumed operating period.

SOLUTION

Two approaches may be used to find the economic life of an asset: (a) the generalized cash flow approach and (b) the tabular approach.

(a) Generalized cash flow approach:
Since we have only a few cash flow elements (O&M, depreciation, and salvage value), an efficient way to obtain the after-tax cash flow is to use the generalized cash flow approach discussed in Section 9.4. Table 14.4 summarizes the cash flows for two-year ownership obtained by using the generalized cash flow approach.

If we use the expected operating costs and the salvage values from Table 14.3, we can continue to generate yearly after-tax entries for the asset's remaining

TABLE 14.3 **Forecasted Operating Costs and Net Proceeds from Sale as a Function of Holding Period (Example 14.8)**

Holding Period	O&M	Permitted Annual Depreciation Amount over the Holding Period							Total Depreciation	Book Value	Expected Market Value	Taxable Gains	Gains Tax	Net A/T Salvage Value
		1	2	3	4	5	6	7						
1	$1,000	$3,600							$3,600	$14,400	$10,000	$(4,400)	$(1,760)	$11,760
2	1,150	3,600	$2,880						6,480	11,520	7,500	(4,020)	(1,608)	9,108
3	1,323	3,600	5,760	$1,728					11,088	6,912	5,625	(1,287)	(515)	6,140
4	1,521	3,600	5,760	3,456	$1,037				13,853	4,147	4,219	72	29	4,190
5	4,749	3,600	5,760	3,456	2,074	$1,037			15,927	2,073	3,164	1,091	436	2,728
6	2,011	3,600	5,760	3,456	2,074	2,074	$1,036	$0	18,000	0	2,373	2,373	949	1,424
7	6,813	3,600	5,760	3,456	2,074	2,074	1,036	$0	18,000	0	1,780	1,780	712	1,068

Note: Asset price of $18,000, depreciated under MACRS for five-year property with the half-year convention; in year 5, normal operating expense ($1,749) + overhaul ($3,000); in year 7, normal operating expense ($2,313) + another engine overhaul ($4,500).

TABLE 14.4 **After-Tax Cash Flow Calculation for Owning and Operating the Asset for Two Years (Example 14.10)**

n	0	1	2
Financial data (cost information):			
(1) Cost of new printer	\$18,000		
(2) Depreciation		\$3,600	\$2,880
(3) Book value		\$14,400	\$11,520
(4) Salvage value			\$7,500
(5) Gain (loss) from sale			−\$4,020
(6) O&M costs		\$1,000	\$1,150
Cash flow statement:			
(7) Investment cost	−\$18,000		
(8) Net proceeds from sale			\$9,108
(9) −O&M cost × (0.6)		−\$600	−\$690
(10) +Depreciation × (0.4)		\$1,440	\$1,152
(11) Net cash flow	−\$18,000	\$840	\$9,570

physical life. For the first two operating years, we compute the equivalent annual costs of owning and operating the asset as follows:

- $n = 1$, *one-year replacement cycle:*

$$\begin{aligned} AEC(15\%) &= \left\{ \$18{,}000 + \begin{bmatrix} (0.6)(\$1{,}000) - (0.4)(\$3{,}600) \\ -\$11{,}760 \end{bmatrix} (P/F, 15\%, 1) \right\} (A/P, 15\%, 1) \\ &= \$7{,}043(1.15) \\ &= \$8{,}100. \end{aligned}$$

- $n = 2$, *two-year replacement cycle:*

$$\begin{aligned} AEC(15\%) &= \left\{ \begin{matrix} \$18{,}000 + [0.6(\$1{,}000) - 0.4(\$3{,}600)(P/F, 15\%, 1)] \\ + [0.6(\$1{,}150) - 0.4(\$2{,}880) + \$9{,}108](P/F, 15\%, 2) \end{matrix} \right\} \\ &\quad (A/P, 15\%, 2) \\ &= \$10{,}033(0.6151) \\ &= \$6{,}171. \end{aligned}$$

Similarly, the annual equivalent costs for the subsequent years can be computed as shown in Table 14.5 (column 12). If the truck were to be sold after six years, it would have a minimum annual cost of \$4,344 per year, and this is the life that is most favorable for comparison purposes. That is, by replacing the asset perpetually according to an economic life of six years, we obtain the minimum infinite AE cost stream. Figure 14.13 illustrates this concept. Of course, we should envision a long period of required service for the asset, its life no

TABLE 14.5 Tabular Calculation of Economic Service Life (Example 14.8)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Holding Period		Before-Tax Operating Expenses				After-Tax Cash Flow if the Asset Is Kept for *N* More Years			Equivalent Annual Cost		
N	*n*	O&M	Depreciation	A/T O&M	Depreciation Credit	Net Operating Cost	Investment and Net Salvage	Net A/T Cash Flow	Capital Cost	Operating Cost	Total Cost
	0	–		–	–	–	$(18,000)	(18,000)			
1	1	$1,000	$3,600	$ (600)	$1,440	$ 840	11,760	12,600	$(8,940)	$ 840	$(8,100)
	0	–		–	–	–	(18,000)	(18,000)			
	1	1,000	3,600	(600)	1,440	840		840			
2	2	1,150	2,880	(690)	1,152	462	9,108	9,570	(6,835)	664	(6,171)
	0	–		–	–	–	(18,000)	(18,000)			
	1	1,000	3,600	(600)	1,440	840		840			
	2	1,150	5,760	(690)	2,304	1,614		1,614			
3	3	1,323	1,728	(794)	691	(103)	6,140	6,037	(6,115)	825	(5,291)
	0	–		–	–	–	(18,000)	(18,000)			
	1	1,000	3,600	(600)	1,440	840		840			
	2	1,150	5,760	(690)	2,304	1,614		1,614			
	3	1,323	3,456	(794)	1,382	589		589			
4	4	1,521	1,037	(913)	415	(498)	4,190	3,692	(5,466)	719	(4,746)
	0	–		–	–	–	(18,000)	(18,000)			
	1	1,000	3,600	(600)	1,440	840		840			
	2	1,150	5,760	(690)	2,304	1,614		1,614			
	3	1,323	3,456	(794)	1,382	589		589			
	4	1,521	2,074	(913)	830	(83)		(83)			
5	5	4,749	1,037	(2,849)	415	(2,435)	2,728	293	(4,965)	322	(4,643)
	0	–					(18,000)	(18,000)			
	1	1,000	3,600	(600)	1,440	840		840			
	2	1,150	5,760	(690)	2,304	1,614		1,614			
	3	1,323	3,456	(794)	1,382	589		589			
	4	1,521	2,074	(913)	830	(83)		(83)			
	5	4,749	2,074	(2,849)	830	(2,020)		(2,020)			
6	6	2,011	1,037	(1,207)	415	(792)	1,424	632	(4,594)	249	(4,344)
	0	–					(18,000)	(18,000)			
	1	1,000	3,600	(600)	1,440	840		840			
	2	1,150	5,760	(690)	2,304	1,614		1,614			
	3	1,323	3,456	(794)	1,382	589		589			
	4	1,521	2,074	(913)	830	(83)		(83)			
	5	4,749	2,074	(2,849)	830	(2,020)		(2,020)			
	6	2,011	1,037	(1,207)	415	(792)		(792)			
7	7	6,813	–	(4,088)	–	(4,088)	1,068	(3,020)	(4,230)	(143)	(4,372)

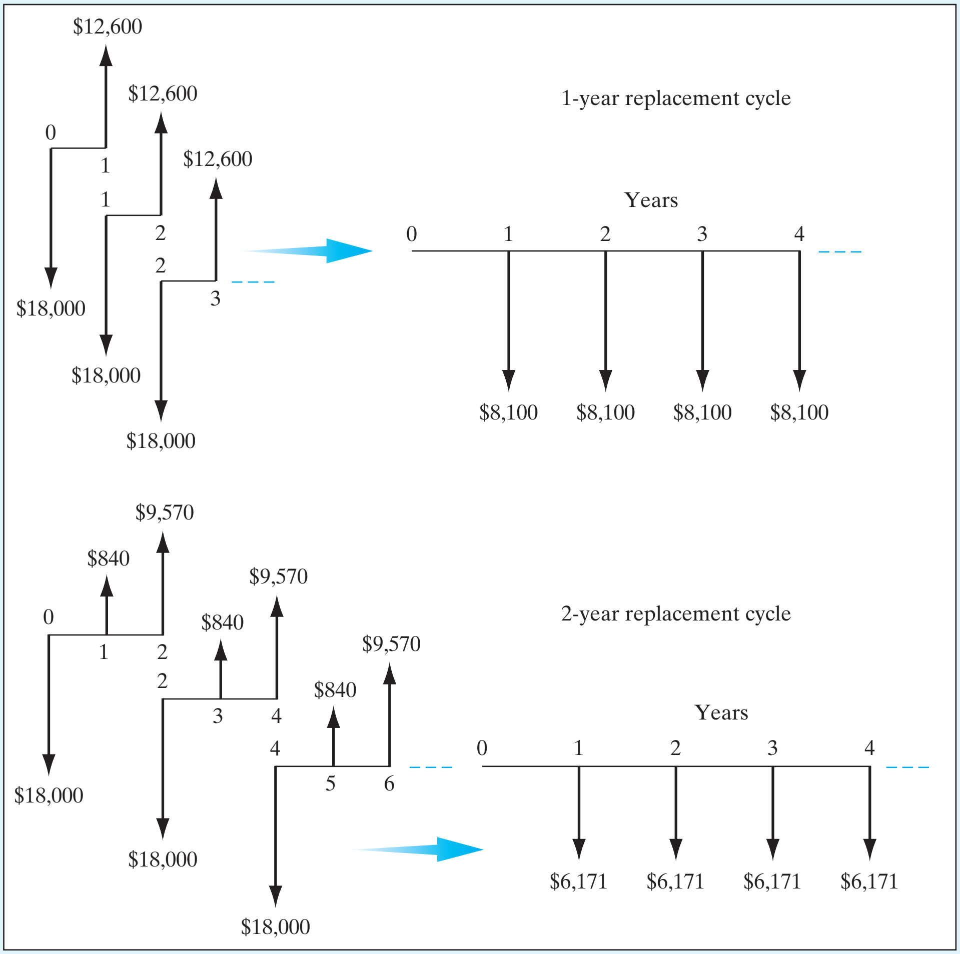


Figure 14.13 Conversion of an infinite number of replacement cycles to infinite AE cost streams (Example 14.8).

doubt being heavily influenced by market values, O&M costs, and depreciation credits.

(b) Tabular approach:
The tabular approach separates the annual cost elements into two parts, one associated with the capital recovery of the asset and the other associated with operating the asset. In computing the capital recovery cost, we need to determine the after-tax salvage values at the end of each holding period, as calculated previously in Table 14.3. Then, we compute the total annual equivalent cost of the asset for any given year's operation using Eq. (14.3).

If we examine the equivalent annual costs itemized in Table 14.5 (columns 10 and 11), we see that, as the asset ages, the equivalent annual O&M cost savings decrease. At the same time, capital recovery costs decrease with prolonged use of the asset. The combination of decreasing capital recovery costs and increasing annual O&M costs

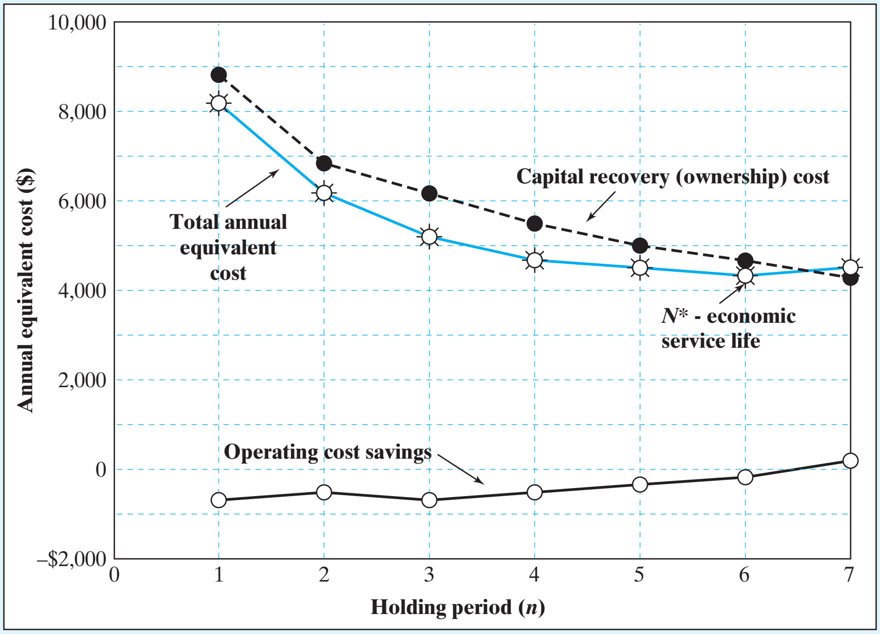


Figure 14.14 Economic service life obtained by finding the minimum AEC (Example 14.8). Note that we treat the cost items with a positive sign.

results in the total annual equivalent cost taking on a form similar to that depicted in Figure 14.14. Even though an expensive overhaul is required during the fifth year of service, it is more economical to keep the equipment over a six-year life.

EXAMPLE 14.9 Replacement Analysis under the Infinite Planning Horizon

Recall Example 14.4, in which Advanced Electrical Insulator Company is considering replacing a broken inspection machine. Let's assume the following additional data:

- The old machine has been fully depreciated, so it has zero book value. The machine could be used for another five years, but the firm does not expect to realize any salvage value from scrapping it in five years.
- The new machine falls into the five-year MACRS property class and will be depreciated accordingly.

The marginal income tax rate is 40%, and the after-tax MARR is 15%. Find the useful life for each option presented in Example 14.4, *and* decide whether the defender should be replaced now or later.

SOLUTION

1. Economic service life:

- **Defender.** The defender is fully depreciated, so that all salvage values can be treated as ordinary gains and taxed at 40%. The after-tax salvage values are thus as follows:

n	Current Market Value	After-Tax Salvage Value
0	\$5,000	\$5,000(1 − 0.40) = \$3,000
1	4,000	4,000(1 − 0.40) = 2,400
2	3,000	3,000(1 − 0.40) = 1,800
3	2,000	2,000(1 − 0.40) = 1,200
4	1,000	1,000(1 − 0.40) = 600
5	0	0
6	0	0
⋮	⋮	⋮

If the company retains the inspection machine, it is in effect deciding to overhaul the machine and invest the machine's current market value (after taxes) in that alternative. Although the company will make no physical cash flow transaction, it is withholding the market value of the inspection machine (the opportunity cost) from the investment. The after-tax O&M costs are as follows:

n	Overhaul	Forecasted O&M Cost	After-Tax O&M Cost
0	\$1,200		\$1,200(1 − 0.40) = \$720
1	0	\$2,000	2,000(1 − 0.40) = 1,200
2	0	3,500	3,500(1 − 0.40) = 2,100
3	0	5,000	5,000(1 − 0.40) = 3,000
4	0	6,500	6,500(1 − 0.40) = 3,900
5	0	8,000	8,000(1 − 0.40) = 4,800

Using the current year's market value as the investment required to retain the defender, we obtain the data in Table 14.6, indicating that the remaining useful life of the defender is two years, *in the absence of future challengers*. The overhaul (repair) cost of \$1,200 in year 0 can be treated as a deductible operating expense for tax purposes, as long as it does not add value to the property. (Any repair or improvement expenses that increase the value of the property must be capitalized by depreciating them over the estimated service life.)

- **Challenger.** Because the challenger will be depreciated over its tax life, we must determine the book value of the asset at the end of each period to compute the after-tax salvage value. This is done in Table 14.7. With the after-tax salvage values computed in that table, we are now ready to find the economic service life of the challenger by generating AEC value entries. These calculations are summarized in Table 14.8. The economic life of the challenger is four years, with an AEC(15%) value of \$4,065.

2. **Optimal time to replace the defender:** Since the AEC value for the defender's remaining useful life (two years) is \$3,070, which is less than \$4,065, the decision will be to keep the defender for now. Of course, the defender's remaining

TABLE 14.6 Economics of Retaining the Defender for *N* More Years (Example 14.9)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Holding Period		Before-Tax Operating Expenses			After-Tax Cash Flow if the Asset Is Kept for *N* More Years				Equivalent Annual Cost		
N	*n*	O&M	Depreciation	A/T O&M	Depreciation Credit	Net Operating Cost	Investment and Net Salvage	Net A/T Cash Flow	Capital Cost	Operating Cost	Total Cost
	0	$1,200		$ (720)		$ (720)	$(3,000)	$(3,720)			
1	1	2,000		(1,200)		(1,200)	2,400	1,200	$(1,050)	$(2,028)	$(3,078)
	0	1,200		(720)		(720)	(3,000)	(3,720)			
	1	2,000		(1,200)		(1,200)		(1,200)			
2	2	3,500		(2,100)		(2,100)	1,800	(300)	(1,008)	(2,061)	(3,070)
	0	1,200		(720)		(720)	(3,000)	(3,720)			
	1	2,000		(1,200)		(1,200)		(1,200)			
	2	3,500		(2,100)		(2,100)		(2,100)			
3	3	5,000		(3,000)		(3,000)	1,200	(1,800)	(968)	(2,332)	(3,300)
	0	1,200		(720)		(720)	(3,000)	(3,720)			
	1	2,000		(1,200)		(1,200)		(1,200)			
	2	3,500		(2,100)		(2,100)		(2,100)			
	3	5,000		(3,000)		(3,000)		(3,000)			
4	4	6,500		(3,900)		(3,900)	600	(3,300)	(931)	(2,646)	(3,576)
	0	1,200		(720)		(720)	(3,000)	(3,720)			
	1	2,000		(1,200)		(1,200)		(1,200)			
	2	3,500		(2,100)		(2,100)		(2,100)			
	3	5,000		(3,000)		(3,000)		(3,000)			
	4	6,500		(3,900)		(3,900)		(3,900)			
5	5	8,000		(4,800)		(4,800)	–	(4,800)	(895)	(2,965)	(3,860)

TABLE 14.7 **Forecasted Operating Costs and Net Proceeds from Sale as a Function of Holding Period—Challenger (Example 14.9)**

Holding Period	O&M	Permitted Annual Depreciation Amount over the Holding Period: 1	2	3	4	5	6	7	Expected Total Depreciation	Book Value	Market Value	Net A/T Taxable Gains	Gains Tax	Salvage Value
1	$2,000	$2,000							$2,000	$8,000	$6,000	$(2,000)	$ (800)	$6,800
2	3,000	2,000	$1,600						3,600	6,400	5,100	(1,300)	(520)	5,620
3	4,000	2,000	3,200	$ 960					6,160	3,840	4,335	495	198	4,137
4	5,000	2,000	3,200	1,920	$ 576				7,696	2,304	3,685	1,381	552	3,133
5	6,000	2,000	3,200	1,920	1,152	$ 576			8,848	1,152	3,132	1,980	792	2,340
6	7,000	2,000	3,200	1,920	1,152	1,152	$ 576	$ 0	10,000	0	2,662	2,662	1,065	1,597
7	8,000	2,000	3,200	1,920	1,152	1,152	576	0	10,000	0	2,263	2,263	905	1,358

Note: Asset price of $10,000, depreciated under MACRS for five-year property with the half-year convention.

TABLE 14.8 Economics of Owning and Operating the Challenger for *N* More Years (Example 14.9)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Holding Period		Before-Tax Operating Expenses				After-Tax Cash Flow if the Asset Is Kept for *N* More Years			Equivalent Annual Cost		
N	*n*	O&M	Depreciation	A/T O&M	Depreciation Credit	Net Operating Cost	Investment and Net Salvage	Net A/T Cash Flow	Capital Cost	Operating Cost	Total
	0						$(10,000)	$(10,000)			
1	1	$2,000	$2,000	$(1,200)	$ 800	$(400)	6,800	6,400	$(4,700)	$(400)	$(5,100)
	0						(10,000)	(10,000)			
	1	2,000	2,000	(1,200)	800	(400)	(400)				
2	2	3,000	1,600	(1,800)	640	(1,160)	5,620	4,460	(3,536)	(753)	(4,290)
	0						(10,000)	(10,000)			
	1	2,000	2,000	(1,200)	800	(400)		(400)			
	2	3,000	3,200	(1,800)	1,280	(520)		(520)			
3	3	4,000	960	(2,400)	384	(2,016)	4,137	2,121	(3,188)	(905)	(4,094)
	0						(10,000)	(10,000)			
	1	2,000	2,000	(1,200)	800	(400)		(400)			
	2	3,000	3,200	(1,800)	1,280	(520)		(520)			
	3	4,000	1,920	(2,400)	768	(1,632)		(1,632)			
4	4	5,000	576	(3,000)	230	(2,770)	3,133	363	(2,875)	(1,190)	(4,065)
	0						(10,000)	(10,000)			
	1	2,000	2,000	(1,200)	800	(400)		(400)			
	2	3,000	3,200	(1,800)	1,280	(520)		(520)			
	3	4,000	1,920	(2,400)	768	(1,632)		(1,632)			
	4	5,000	1,152	(3,000)	461	(2,539)		(2,539)			
5	5	6,000	576	(3,600)	230	(3,370)	2,340	(1,030)	(2,636)	(1,474)	(4,110)

useful life of two years does not imply that the defender should actually be kept for two years before the company switches to the challenger. The reason for this is that the defender's remaining useful life of two years was calculated without considering what type of challenger would be available in the future. When a challenger's financial data are available, we need to enumerate all replacement timing possibilities. Since the defender can be used for another five years, six replacement strategies exist:

- Replace the defender with the challenger now.
- Replace the defender with the challenger in year 1.
- Replace the defender with the challenger in year 2.
- Replace the defender with the challenger in year 3.
- Replace the defender with the challenger in year 4.
- Replace the defender with the challenger in year 5.

The possible replacement cash patterns associated with each of these alternatives are shown in Figure 14.15, assuming that the costs and efficiency of the current challenger remain unchanged in future years. From the figure, we observe that, on an annual basis, the cash flows after the remaining physical life of the defender are the same.

Before we evaluate the economics of various replacement-decision options, recall the AEC values for the defender and the challenger under the assumed service lives (a boxed figure denotes the minimum AEC value at $n_0 = 2$ and $n^* = 4$):

	Annual Equivalent Cost	
n	**Defender**	**Challenger**
1	$3,078	$5,100
2	[3,070]	4,290
3	3,300	4,094
4	3,576	[4,065]
5	3,860	4,110
6		4,189
7		4,287

Instead of using the marginal analysis in Example 14.4, we will use PW analysis, which requires an evaluation of infinite cash flow streams. (The result is the same under both analyses.) Immediate replacement of the defender by the challenger is equivalent to computing the PW for an infinite cash flow stream of −$4,065. If we use the capitalized equivalent-worth approach of Chapter 6 $(CE(i) = A/i)$, we obtain

- $n = 0$:

$$\begin{aligned} PW(15\%)_{n_0=0} &= (1/0.15)(\$4{,}065) \\ &= \$27{,}100. \end{aligned}$$

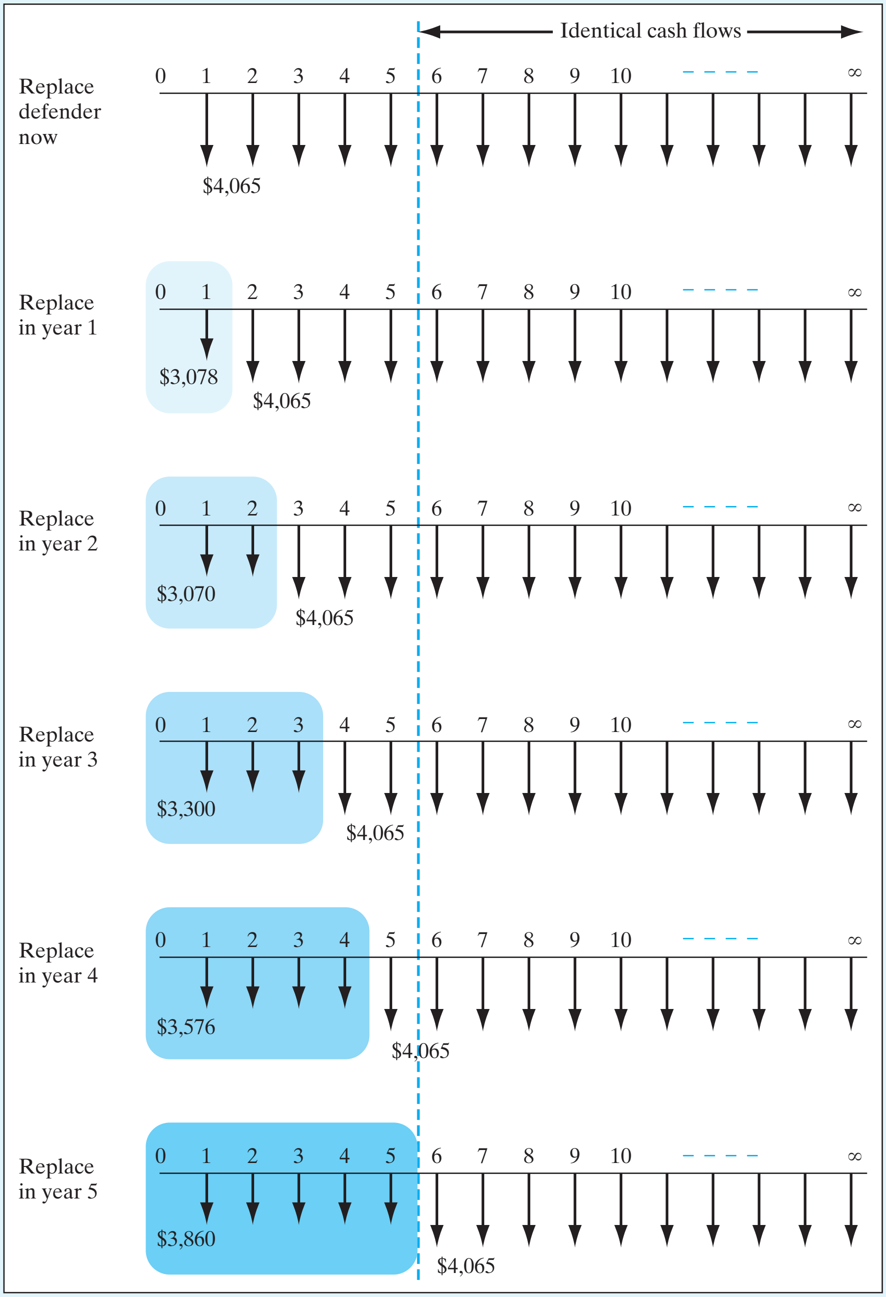


Figure 14.15 Equivalent annual cash flow streams when the defender is kept for n years followed by infinitely repeated purchases of the challenger every four years (Example 14.9).

Suppose we retain the old machine n more years and then replace it with the new one. Now we will compute $\text{PW}(i)_{n_0=n}$:

- $n = 1$:

$$\text{PW}(15\%)_{n_0=1} = \$3{,}078(P/A, 15\%, 1) + \$27{,}100(P/F, 15\%, 1) = \$26{,}242.$$

- $n = 2$:

$$\text{PW}(15\%)_{n_0=2} = \$3{,}070(P/A, 15\%, 2) + \$27{,}100(P/F, 15\%, 2) = \$25{,}482.$$

- $n = 3$:

$$\text{PW}(15\%)_{n_0=3} = \$3{,}300(P/A, 15\%, 3) + \$27{,}100(P/F, 15\%, 3) = \boxed{\$25{,}353.}$$

- $n = 4$:

$$\text{PW}(15\%)_{n_0=4} = \$3{,}576(P/A, 15\%, 4) + \$27{,}100(P/F, 15\%, 4) = \$25{,}704.$$

- $n = 5$:

$$\text{PW}(15\%)_{n_0=5} = \$3{,}860(P/A, 15\%, 5) + \$27{,}100(P/F, 15\%, 5) = \$26{,}413.$$

This leads us to conclude that the defender should be kept for three more years. The present worth of $25,353 represents the net cost associated with retaining the defender for three years, replacing it with the challenger, and then replacing the challenger every four years for an indefinite period.

SUMMARY

- In replacement analysis, the **defender** is an existing asset; the **challenger** is the best available replacement candidate.
- The **current market value** is the value to use in preparing a defender's economic analysis. **Sunk costs**—past costs that cannot be changed by any future investment decision—should not be considered in a defender's economic analysis.
- The basic approach to analyzing replacement problems is the **opportunity cost approach**. The opportunity cost approach views the net proceeds from the sale of the defender as an opportunity cost of keeping the defender. That is, instead of deducting the salvage value from the purchase cost of the challenger, we consider the net proceeds as an investment required to keep the asset.
- The **economic service life** is the remaining useful life of a defender *or* a challenger that results in the minimum equivalent annual cost or maximum annual equivalent revenue. We should use the respective economic service lives of the defender and the challenger when conducting a replacement analysis.

- Ultimately, in replacement analysis, the question is not *whether* to replace the defender, but *when* to do so. The AE method provides a marginal basis on which to make a year-by-year decision about the best time to replace the defender. As a general decision criterion, the PW method provides a more direct solution to a variety of replacement problems, with either an infinite or a finite planning horizon, or a technological change in a future challenger.
- The role of **technological change** in improving assets should be evaluated in making long-term replacement plans: If a particular item is undergoing rapid, substantial technological improvements, it may be prudent to delay replacement (to the extent where the loss in production does not exceed any savings from improvements in future challengers) until a desired future model is available.

PROBLEMS

Sunk Costs, Opportunity Costs, and Cash Flows

14.1 Columbus Electronics Company is considering replacing a 1,000-pound-capacity forklift truck that was purchased three years ago at a cost of $15,000. The diesel-operated forklift was originally expected to have a useful life of eight years and a zero estimated salvage value at the end of that period. The truck has not been dependable and is frequently out of service while awaiting repairs. The maintenance expenses of the truck have been rising steadily and currently amount to about $3,000 per year. The truck could be sold for $6,000. If retained, the truck will require an immediate $1,500 overhaul to keep it in operating condition. This overhaul will neither extend the originally estimated service life nor increase the value of the truck. The updated annual operating costs, engine overhaul cost, and market values over the next five years are estimated as follows:

n	O&M	Depreciation	Engine Overhaul	Market Value
−3				
−2		$3,000		
−1		4,800		
0		2,880	$1,500	$6,000
1	$3,000	1,728		4,000
2	3,500	1,728		3,000
3	3,800	864		1,500
4	4,500	0		1,000
5	4,800	0	5,000	0

A drastic increase in O&M costs during the fifth year is expected due to another overhaul, which will again be required to keep the truck in operating condition. The firm's MARR is 15%.

(a) If the truck is to be sold now, what will be its sunk cost?

(b) What is the opportunity cost of not replacing the truck now?

(c) What is the equivalent annual cost of owning and operating the truck for two more years?

(d) What is the equivalent annual cost of owning and operating the truck for five years?

14.2 Komatsu Cutting Technologies is considering replacing one of its CNC machines with one that is newer and more efficient. The firm purchased the CNC machine 10 years ago at a cost of $135,000. The machine had an expected economic life of 12 years at the time of purchase and an expected salvage value of $12,000 at the end of the 12 years. The original salvage estimate is still good, and the machine has a remaining useful life of 2 years. The firm can sell this old machine now to another firm in the industry for $30,000. The new machine can be purchased for $165,000, including installation costs. It has an estimated useful (economic) life of 8 years. The new machine is expected to reduce cash operating expenses by $30,000 per year over its 8-year life, at the end of which the machine is estimated to be worth only $5,000. The company has a MARR of 12%.

(a) If you decided to retain the old machine, what is the opportunity (investment) cost of retaining the old asset?

(b) Compute the cash flows associated with retaining the old machine in years 1 to 2.

(c) Compute the cash flows associated with purchasing the new machine in years 1 to 8. (Use the opportunity cost concept.)

(d) If the firm needs the service of these machines for an indefinite period and no technology improvement is expected in future machines, what will be your decision?

14.3 Air Links, a commuter airline company, is considering replacing one of its baggage-handling machines with a newer and more efficient one. The current book value of the old machine is $50,000, and it has a remaining useful life of five years. The salvage value expected from scrapping the old machine at the end of five years is zero, but the company can sell the machine now to another firm in the industry for $10,000. The new baggage-handling machine has a purchase price of $120,000 and an estimated useful life of seven years. It has an estimated salvage value of $30,000 and is expected to realize economic savings on electric power usage, labor, and repair costs and also to reduce the amount of damaged luggage. In total, an annual savings of $50,000 will be realized if the new machine is installed. The firm uses a 15% MARR. Using the opportunity cost approach,

(a) What is the initial cash outlay required for the new machine?

(b) What are the cash flows for the defender in years 0 to 5?

(c) Should the airline purchase the new machine?

14.4 Duluth Medico purchased a digital image-processing machine three years ago at a cost of $50,000. The machine had an expected life of eight years at the time of purchase and an expected salvage value of $5,000 at the end of the eight years. The old machine has been slow at handling the increased business volume, so management is considering replacing the machine. A new machine can be purchased for $75,000, including installation costs. Over its five-year life, the machine will reduce cash operating expenses by $30,000 per year. Sales are not expected to change. At the end of its useful life, the machine is estimated to be worthless. The old machine can be sold today for $10,000. The firm's interest rate for project justification is known to be 15%. The firm does not expect a better machine (other than the current challenger) to be available for the next five years. Assuming that the economic service life of the new machine, as well as the remaining useful life of the old machine, is five years,

(a) Determine the cash flows associated with each option (keeping the defender versus purchasing the challenger).

(b) Should the company replace the defender now?

14.5 The Northwest Manufacturing Company is currently manufacturing one of its products on a hydraulic stamping press machine. The unit cost of the product is $12, and 3,000 units were produced and sold for $19 each during the past year. It is expected that both the future demand of the product and the unit price will remain steady at 3,000 units per year and $19 per unit. The old machine has a remaining useful life of three years. The old machine could be sold on the open market now for $5,500. Three years from now, the old machine is expected to have a salvage value of $1,200. The new machine would cost $36,500, and the unit manufacturing cost on the new machine is projected to be $11. The new machine has an expected economic life of five years and an expected salvage value of $6,300. The appropriate MARR is 12%. The firm does not expect a significant improvement in technology, and it needs the service of either machine for an indefinite period.

(a) Compute the cash flows over the remaining useful life of the old machine if the firm decides to retain it.

(b) Compute the cash flows over the economic service life if the firm decides to purchase the machine.

(c) Should the machine be acquired now?

Economic Service Life

14.6 A firm is considering replacing a machine that has been used to make a certain kind of packaging material. The new, improved machine will cost $31,000 installed and will have an estimated economic life of 10 years, with a salvage value of $2,500. Operating costs are expected to be $1,000 per year throughout the service life of the machine. The old machine (still in use) had an original cost of $25,000 four years ago, and at the time it was purchased, its service life (physical life) was estimated to be seven years, with a salvage value of $5,000. The old machine has a current market value of $7,700. If the firm retains the old machine, its updated market values and operating costs for the next four years will be as follows:

Year-End	Market Value	Book Value	Operating Costs
0	$7,700	$7,889	
1	4,300	5,578	$3,200
2	3,300	3,347	3,700
3	1,100	1,116	4,800
4	0	0	5,850

The firm's MARR is 12%.

(a) Working with the updated estimates of market values and operating costs over the next four years, determine the remaining useful life of the old machine.

(b) Determine whether it is economical to make the replacement now.

(c) If the firm's decision is to replace the old machine, when should it do so?

14.7 The University Resume Service has just invested $8,000 in a new desktop publishing system. From past experience, the owner of the company estimates its after-tax cash returns as

$$A_n = \$8{,}000 - \$4{,}000(1 + 0.15)^{n-1},$$
$$S_n = \$6{,}000(1 - 0.3)^n,$$

where A_n stands for the net after-tax cash flows from operation of the system during period n and S_n stands for the after-tax salvage value at the end of period n.

(a) If the company's MARR is 12%, compute the economic service life of the system.

(b) Explain how the economic service life varies with the interest rate.

14.8 A special-purpose machine is to be purchased at a cost of $15,000. The following table shows the expected annual operating and maintenance cost and the salvage values for each year of the machine's service:

Year of Service	O&M Costs	Market Value
1	$2,500	$12,800
2	3,200	8,100
3	5,300	5,200
4	6,500	3,500
5	7,800	0

(a) If the interest rate is 10%, what is the economic service life for this machine?

(b) Repeat (a), using $i = 15\%$.

Replacement Decisions with an Infinite Planning Horizon and No Technological Change

14.9 A special-purpose turnkey stamping machine was purchased four years ago for $20,000. It was estimated at that time that this machine would have a life of 10 years and a salvage value of $3,000, with a removal cost of $1,500. These estimates are still good. The machine has annual operating costs of $2,000. A new machine that is more efficient will reduce the operating costs to $1,000, but it will require an investment of $20,000, plus $1,000 for installation. The life of the new machine is estimated to be 12 years, with a salvage of $2,000 and a removal cost of $1,500. An offer of $6,000 has been made for the old machine, and the purchaser is willing to pay for removal of the machine. Find the economic advantage of replacing or of continuing with the present machine. State any assumptions that you make. (Assume that MARR = 8%).

14.10 A five-year-old defender has a current market value of $4,000 and expected O&M costs of $3,000 this year, increasing by $1,500 per year. Future market values are expected to decline by $1,000 per year. The machine can be used for another three years. The challenger costs $6,000 and has O&M costs of $2,000 per year, increasing by $1,000 per year. The machine will be needed for only three years, and the salvage value at the end of that time is expected to be $2,000. The MARR is 15%.

(a) Determine the annual cash flows for retaining the old machine for three years.

(b) Determine whether now is the time to replace the old machine. First show the annual cash flows for the challenger.

14.11 Greenleaf Company is considering purchasing a new set of air-electric quill units to replace an obsolete one. The machine currently being used for the operation has a market value of zero: however, it is in good working order, and it will last for at least an additional five years. The new quill units will perform the operation with so much more efficiency that the firm's engineers estimate that labor, material, and other direct costs will be reduced $3,000 a year if the units are installed. The new set of quill units costs $10,000, delivered and installed, and its economic life is estimated to be five years with zero salvage value. The firm's MARR is 10%.

(a) What investment is required to keep the old machine?

(b) Compute the cash flow to use in the analysis for each option.

(c) If the firm uses the internal-rate-of-return criterion, should the firm buy the new machine on that basis?

14.12 Wu Lighting Company is considering replacing an old, relatively inefficient vertical drill machine that was purchased 7 years ago at a cost of $10,000. The machine had an original expected life of 12 years and a zero estimated salvage value at the end of that period. The divisional manager reports that a new machine can be bought and installed for $12,000. Further, over its 5-year life, the machine will expand sales from $10,000 to $11,500 a year and will reduce the usage of labor and raw materials sufficiently to cut annual operating costs from $7,000 to $5,000. The new machine has an estimated salvage value of $2,000 at the end of its 5-year life. The old machine's current market value is $1,000; the firm's MARR is 15%.

(a) Should the new machine be purchased now?

(b) What current market value of the old machine would make the two options equal?

14.13 Advanced Robotics Company is faced with the prospect of replacing its old call-switching system, which has been used in the company's headquarters for 10 years. This particular system was installed at a cost of $100,000, and it was assumed that it would have a 15-year life with no appreciable salvage value. The current annual operating costs for the old system are $20,000, and these costs would be the same for the rest of its life. A sales representative from North Central Bell is trying to sell the company a computerized switching system that would require an investment of $200,000 for installation. The economic life of this computerized system is estimated to be 10 years, with a salvage value of $18,000, and the system will reduce annual operating costs to $5,000. No detailed agreement has been made with the sales representative about the disposal of the old system. Determine the ranges of resale value associated with the old system that would justify installation of the new system at a MARR of 14%.

14.14 A company is currently producing chemical compounds by a process that was installed 10 years ago at a cost of $100,000. It was assumed that the process would have a 20-year life with a zero salvage value. The current market value of the process however, is \$60,000, and the initial estimate of its economic life is still good. The annual operating costs associated with the process are \$18,000. A sales representative from U.S. Instrument Company is trying to sell a new chemical-compound-making process to the company. This new process will cost \$200,000, have a service life of 10 years and a salvage value of \$20,000, and reduce annual operating costs to \$4,000. Assuming that the company desires a return of 12% on all investments, should it invest in the new process?

14.15 Eight years ago, a lathe was purchased for \$45,000. Its operating expenses were \$8,700 per year. An equipment vendor offers a new machine for \$53,500 whose operating costs are \$5,700 per year. An allowance of \$8,500 would be made for the old machine when the new one is purchased. The old machine is expected to be scrapped at the end of five years. The new machine's economic service life is five years with a salvage value of \$12,000. The new machine's O&M cost is estimated to be \$4,200 for the first year, increasing at an annual rate of \$500 thereafter. The firm's MARR is 12%. What option would you recommend?

14.16 The New York Taxi Cab Company has just purchased a new fleet of models for the year 2000. Each brand-new cab cost \$20,000. From past experience, the company estimates after-tax cash returns for each cab as

$$A_n = \$65{,}800 - 30{,}250(1 + 0.15)^{n-1},$$
$$S_n = \$20{,}000(1 - 0.15)^n,$$

where, again, A_n stands for net after-tax cash flows from the cab's operation during period n and S_n stands for the after-tax salvage value of the cab at the end of period n. The management views the replacement process as a constant and infinite chain.

(a) If the firm's MARR is 10% and it expects no major technological and functional change in future models, what is the optimal period (constant replacement cycle) to replace its cabs? (Ignore inflation.)

(b) What is the internal rate of return for a cab if it is retired at the end of its economic service life? What is the internal rate of return for a sequence of identical cabs if each cab in the sequence is replaced at the optimal time?

14.17 Four years ago, an industrial batch oven was purchased for \$23,000. It has been depreciated over a 10-year life and has a \$1,000 salvage value. If sold now, the machine will bring \$2,000. If sold at the end of the year, it will bring \$1,500. Annual operating costs for subsequent years are \$3,800. A new machine will cost \$50,000 with a 12-year life and have a \$3,000 salvage value. The operating cost will be \$3,000 as of the end of each year, with the \$6,000-per-year savings due to better quality control. If the firm's MARR is 10%, should the machine be purchased now?

14.18 Georgia Ceramic Company has an automatic glaze sprayer that has been used for the past 10 years. The sprayer can be used for another 10 years and will have a zero salvage value at that time. The annual operating and maintenance costs for the sprayer amount to \$15,000 per year. Due to an increase in business, a new sprayer must be purchased. Georgia Ceramic is faced with two options:

- **Option 1.** If the old sprayer is retained, a new smaller capacity sprayer will be purchased at a cost of \$48,000, and it will have a \$5,000 salvage value in 10 years. This new sprayer will have annual operating and maintenance costs of \$12,000. The old sprayer has a current market value of \$6,000.

- **Option 2.** If the old sprayer is sold, a new sprayer of larger capacity will be purchased for $84,000. This sprayer will have a $9,000 salvage value in 10 years and will have annual operating and maintenance costs of $24,000.

Which option should be selected at MARR = 12%?

Replacement Problem with a Finite Planning Horizon

14.19 The annual equivalent after-tax costs of retaining a defender machine over 4 years (physical life) or operating its challenger over 6 years (physical life) are as follows:

n	Defender	Challenger
1	$3,200	$5,800
2	2,500	4,230
3	2,650	3,200
4	3,300	3,500
5		4,000
6		5,500

If you need the service of either machine for only the next 10 years, what is the best replacement strategy? Assume a MARR of 12% and no improvements in technology in future challengers.

14.20 The after-tax annual equivalent worth of retaining a defender over four years (physical life) or operating its challenger over six years (physical life) are as follows:

n	Defender	Challenger
1	$13,400	$12,300
2	13,500	13,000
3	13,800	13,600
4	13,200	13,400
5		13,000
6		12,500

If you need the service of either machine for only the next eight years, what is the best replacement strategy? Assume a MARR of 12% and no improvements in technology in future challengers.

14.21 An existing asset that cost $16,000 two years ago has a market value of $12,000 today, an expected salvage value of $2,000 at the end of its remaining useful life of six more years, and annual operating costs of $4,000. A new asset under consideration as a replacement has an initial cost of $10,000, an expected salvage value of $4,000 at the end of its economic life of three years, and annual operating costs of $2,000. It is assumed that this new asset could be replaced by another one identical in every respect after three years at a salvage value of $4,000, if desired. Use a MARR of 11%, a six-year study period, and PW calculations to decide whether the existing asset should be replaced by the new one.

14.22 Repeat Problem 14.21, using the AE criterion.

Replacement Analysis with Tax Considerations

14.23 Redo Problem 14.1, but with the following additional information: The asset is classified as a five-year MACRS property and has a book value of $5,760 if disposed of now. The firm's marginal tax rate is 40% and its after-tax MARR is 15%.

14.24 Redo Problem 14.2, but with the following additional information: The asset is classified as a seven-year MACRS. The firm's marginal tax rate is 40%, and its after-tax MARR is 12%.

14.25 Redo Problem 14.3, but with the following additional information:

- The current book value of the old machine is $50,000. The old machine is being depreciated toward a zero salvage value by means of conventional straight-line methods, or by $10,000 per year.
- The new machine will be depreciated under a seven-year MACRS class.
- The company's marginal tax rate is 40%, and the firm uses a 15% after-tax MARR.

14.26 Redo Problem 14.4, but with the following additional information:

- The old machine has been depreciated under a five-year MACRS property class.
- The new machine will be depreciated under a five-year MACRS class.
- The marginal tax rate is 35%, and the firm's after-tax MARR is 15%.

14.27 Redo Problem 14.5, but with the following additional information:

- The old stamping machine has been fully depreciated.
- For tax purposes, the entire cost of $36,500 can be depreciated according to a five-year MACRS property class.
- The firm's marginal tax rate is 40%, and the after-tax MARR is 12%.

14.28 Redo Problem 14.6, but with the following additional information:

- The current book value of the old machine is $7,889. The anticipated book value for the next four years are as follows: Year 1: $5,578; Year 2: $3,347; Year 3: $1,116; and Year 4: $0. The new machine will be depreciated under a seven-year MACRS class.
- The company's marginal tax rate is 35%, and the firm uses a 12% after-tax MARR.

14.29 A machine has a first cost of $10,000. End-of-year book values, salvage values, and annual O&M costs are provided over its useful life as follows:

Year End	Book Value	Salvage Value	Operating Costs
1	$8,000	$5,300	$1,500
2	4,800	3,900	2,100
3	2,880	2,800	2,700
4	1,728	1,800	3,400
5	1,728	1,400	4,200
6	576	600	4,900

(a) Determine the economic life of the machine if the MARR is 15% and the marginal tax rate is 40%.

(b) Determine the economic life of the machine if the MARR is 10% and the marginal tax rate remains at 40%.

14.30 Given the data

$$
\begin{aligned}
I &= \$20{,}000, \\
S_n &= 12{,}000 - 2{,}000n, \\
B_n &= 20{,}000 - 2{,}500n, \\
\text{O\&M}_n &= 3{,}000 + 1{,}000(n - 1), \text{ and} \\
t_m &= 0.40, \\
\text{where } I &= \text{Asset purchase price}, \\
S_n &= \text{Market value at the end of year } n, \\
B_n &= \text{Book value at the end of year } n, \\
\text{O\&M}_n &= \text{O\&M cost during year } n, \text{ and} \\
t_m &= \text{Marginal tax rate},
\end{aligned}
$$

(a) Determine the economic service life of the asset if $i = 10\%$.

(b) Determine the economic service life of the asset if $i = 25\%$.

(c) Assume that $i = 0$ and determine the economic service life of the asset mathematically (i.e., use the calculus technique for finding the minimum point, as described in Chapter 8).

14.31 Redo Problem 14.8, but with the following additional information:

- For tax purposes, the entire cost of $15,000 can be depreciated according to a five-year MACRS property class.
- The firm's marginal tax rate is 40%.

14.32 Quintana Electronic Company is considering purchasing new robot-welding equipment to perform operations currently being performed by less efficient equipment. The new machine's purchase price is $150,000, delivered and installed. A Quintana industrial engineer estimates that the new equipment will produce savings of $30,000 in labor and other direct costs annually, compared with the current equipment. He estimates the proposed equipment's economic life at 10 years, with a zero salvage value. The current equipment is in good working order and will last, physically, for at least 10 more years. Quintana Company expects to pay income taxes of 40%, and any gains will also be taxed at 40%. Quintana uses a 10% discount rate for analysis performed on an after-tax basis. Depreciation of the new equipment for tax purposes is computed on the basis of a seven-year MACRS property class.

(a) Assuming that the current equipment has zero book value and zero salvage value, should the company buy the proposed equipment?

(b) Assuming that the current equipment is being depreciated at a straight-line rate of 10%, has a book value of $72,000 (cost, $120,000; accumulated depreciation, $48,000), and zero net salvage value today, should the company buy the proposed equipment?

(c) Assuming that the current equipment has a book value of $72,000 and a salvage value today of $45,000 and that, if the current equipment is retained for 10 more years, its salvage value will be zero, should the company buy the proposed equipment?

(d) Assume that the new equipment will save only $15,000 a year, but that its economic life is expected to be 12 years. If other conditions are as described in part (a), should the company buy the proposed equipment?

14.33 Quintana Company decided to purchase the equipment described in Problem 14.32 (hereafter called "Model A" equipment). Two years later, even better equipment (called "Model B") came onto the market, making Model A obsolete, with no resale value. The Model B equipment costs $300,000 delivered and installed, but it is expected to result in annual savings of $75,000 over the cost of operating the Model A equipment. The economic life of Model B is estimated to be 10 years, with a zero salvage value. (Model B also is classified as a seven-year MACRS property.)

(a) What action should the company take?

(b) If the company decides to purchase the Model B equipment, a mistake must have been made, because good equipment, bought only two years previously, is being scrapped. How did this mistake come about?

14.34 Redo Problem 14.9, but with the following additional information:

- The current book value of the old machine is $6,248, and the old asset has been depreciated as a seven-year MACRS property.
- The new asset is also classified as a seven-year MACRS property.
- The company's marginal tax rate is 30%, and the firm uses an 8% after-tax MARR.

14.35 Redo Problem 14.10, but with the following additional information:

- The old machine has been fully depreciated.
- The new machine will be depreciated under a three-year MACRS class.
- The marginal tax rate is 40%, and the firm's after-tax MARR is 15%.

14.36 Redo Problem 14.11, but with the following additional information:

- The current book value of the old machine is $4,000, and the annual depreciation charge is $800 if the firm decides to keep the old machine for the additional five years.
- The new asset is classified as a seven-year MACRS property.
- The company's marginal tax rate is 40%, and the firm uses a 10% after-tax MARR.

14.37 Redo Problem 14.12, but with the following additional information:

- The old machine has been fully depreciated.
- The new machine will be depreciated under a seven-year MACRS class.
- The marginal tax rate is 40%, and the firm's after-tax MARR is 15%.

14.38 Redo Problem 14.13, with the following additional information:

- The old switching system has been fully depreciated.
- The new system falls into a five-year MACRS property class.
- The company's marginal tax rate is 40%, and the firm uses a 14% after-tax MARR.

14.39 Five years ago, a conveyor system was installed in a manufacturing plant at a cost of $35,000. It was estimated that the system, which is still in operating condition, would have a useful life of eight years, with a salvage value of $3,000. It was also estimated that if the firm continues to operate the system, its market values and operating costs for the next three years would be as follows:

Year-End	Market Value	Book Value	Operating Cost
0	$11,500	$15,000	
1	5,200	11,000	$4,500
2	3,500	7,000	5,300
3	1,200	3,000	6,100

A new system can be installed for $43,500; it would have an estimated economic life of 10 years, with a salvage value of $3,500. Operating costs are expected to be $1,500 per year throughout the service life of the system. The firm's MARR is 18%. The system belongs to the seven-year MACRS property class. The firm's marginal tax rate is 35%.

(a) Decide whether to replace the existing system now.

(b) If the decision is to replace the existing system, when should replacement occur?

14.40 Redo Problem 14.14, but with the following additional information:

- The old machine has been depreciated on a straight-line basis.
- The new machine will be depreciated under a seven-year MACRS class.
- The marginal tax rate is 40%, and the firm's after-tax MARR is 12%.

14.41 Redo Problem 14.15, but with the following additional information:
- The old machine has been fully depreciated.
- The new machine will be depreciated under a seven-year MACRS class.
- The marginal tax rate is 35%, and the firm's after-tax MARR is 12%.

14.42 Redo Problem 14.17, but with the following additional information:
- The old machine has been depreciated according to a seven-year MACRS.
- The new machine will also be depreciated under a seven-year MACRS class.
- The marginal tax rate is 40%, and the firm's after-tax MARR is 10%.

14.43 Redo Problem 14.18, but with the following additional information:
- **Option 1:** The old sprayer has been fully depreciated. The new sprayer is classified as having a seven-year MACRS recovery period.
- **Option 2:** The larger capacity sprayer is classified as a seven-year MACRS property.
- The company's marginal tax rate is 40%, and the firm uses a 12% after-tax MARR.

14.44 A six-year-old computer numerical control (CNC) machine that originally cost $8,000 has been fully depreciated, and its current market value is $1,500. If the machine is kept in service for the next five years, its O&M costs and salvage value are estimated as follows:

End of Year	O&M Costs: Operation and Repairs	O&M Costs: Delays Due to Breakdowns	Salvage Value
1	$1,300	$600	$1,200
2	1,500	800	1,000
3	1,700	1,000	500
4	1,900	1,200	0
5	2,000	1,400	0

It is suggested that the machine be replaced by a new CNC machine of improved design at a cost of $6,000. It is believed that this purchase will completely eliminate breakdowns and the resulting cost of delays and that operation and repair costs will be reduced $200 a year from what they would be with the old machine. Assume a five-year life for the challenger and a $1,000 terminal salvage value. The new machine falls into a five-year MACRS property class. The firm's MARR is 12%, and its marginal tax rate is 30%. Should the old machine be replaced now?

14.45 Redo Problem 14.21, but with the following additional information:
- The old asset has been depreciated according to a five-year MACRS.
- The new asset will also be depreciated under a five-year MACRS class.
- The marginal tax rate is 30%, and the firm's after-tax MARR is 11%.

Short Case Studies

ST14.1 Chevron Overseas Petroleum, Inc., entered into a 1993 joint venture with the Republic of Kazakhstan, a former republic of the old Soviet Union, to develop the huge Tengiz oil field.[4] Unfortunately, the climate in the region is harsh, making it difficult to keep oil flowing. The untreated oil comes out of the ground at 114°F. Even though the pipelines are insulated, as the oil gets further from the well on its way to be processed, hydrate salts begin to precipitate out of the liquid phase as the oil cools. These hydrate salts create a dangerous condition by forming plugs in the line.

The method for preventing this trap pressure condition is to inject methanol (MeOH) into the oil stream. This keeps the oil flowing and prevents hydrate salts from precipitating out of the liquid phase. The present methanol loading and storage facility is a completely manual controlled system, with no fire protection and with a rapidly deteriorating tank that causes leaks. The scope of repairs and upgrades is extensive. The storage tanks are rusting and are leaking at their riveted joints. The manual control system causes frequent tank overfills. There is no fire protection system, as water is not available at the site.

The present storage facility has been in service for 5 years. Permit requirements mandate upgrades to achieve minimum acceptable Kazakhstan standards. Upgrades in the amount of $104,000 will extend the life of the current facility to about 10 years. However, upgrades will not completely stop the leaks. The expected spill and leak losses will amount to $5,000 a year. The annual operating costs are expected to be $36,000.

As an alternative to the old facility, a new methanol storage facility can be designed on the basis of minimum acceptable international oil industry practices. The new facility, which would cost $325,000, would last about 12 years before a major upgrade would be required. However, it is believed that oil transfer technology will be such that methanol will not be necessary in 10 years. The pipeline heating and insulation systems will make methanol storage and use systems obsolete. With a lower risk of leaks, spills, and evaporation loss and a more closely monitored system, the expected annual operating cost would be $12,000.

(a) Assume that the storage tanks (the new ones as well as the upgraded ones) will have no salvage value at the end of their useful lives (after considering the removal costs) and that the tanks will be depreciated by the straight-line method according to the Kazakhstan's tax law. If Chevron's interest rate is 20% for foreign projects, which option is a better choice?

(b) How would the decision change as you consider the risk of spills (resulting in cleanup costs) and the evaporation of the product having an environmental impact?

[4] This example was provided by Mr. Joel M. Height of the Chevron Oil Company.

ST14.2 National Woodwork Company, a manufacturer of window frames, is considering replacing a conventional manufacturing system with a flexible manufacturing system (FMS). The company cannot produce rapidly enough to meet demand. One manufacturing problem that has been identified is that the present system is expected to be useful for another 5 years, but will require an estimated $105,000 per year in maintenance, which will increase $10,000 each year as parts become more scarce. The current market value of the existing system is $140,000, and the machine has been fully depreciated.

The proposed system will reduce or entirely eliminate setup times, and each window can be made as it is ordered by the customer, who phones the order into the head office, where details are fed into the company's main computer. These manufacturing details are then dispatched to computers on the manufacturing floor, which are, in turn, connected to a computer that controls the proposed FMS. This system eliminates the warehouse space and material-handling time that are needed when the conventional system is used.

Before the FMS is installed, the old equipment will be removed from the job shop floor at an estimated cost of $100,000. This cost includes needed electrical work on the new system. The proposed FMS will cost $1,200,000. The economic life of the machine is expected to be 10 years, and the salvage value is expected to be $120,000. The change in window styles has been minimal in the past few decades and is expected to continue to remain stable in the future. The proposed equipment falls into the 7-year MACRS category. The total annual savings will be $664,243: $12,000 attributed to a reduction in the number of defective windows, $511,043 from the elimination of 13 workers, $100,200 from the increase in productivity, and $41,000 from the near elimination of warehouse space and material handling. The O&M costs will be only $45,000, increasing by $2,000 per year. The National Woodwork's MARR is about 15%, and the expected marginal tax rate over the project years is 40%.

(a) What assumptions are required to compare the conventional system with the FMS?

(b) With the assumptions defined in (a), should the FMS be installed now?

ST14.3 In 2 × 4 and 2 × 6 lumber production, significant amounts of wood are present in sideboards produced after the initial cutting of logs. Instead of processing the sideboards into wood chips for the paper mill, Union Camp Company uses an "edger" to reclaim additional lumber, resulting in savings for the company. An edger is capable of reclaiming lumber by any of the following three methods: (1) removing rough edges, (2) splitting large sideboards, and (3) salvaging 2 × 4 lumber from low-quality 4 × 4 boards. Union Camp Company's engineers have discovered that a significant reduction in production costs could be achieved simply by replacing the original edger with a newer, laser-controlled model.

The old edger was placed in service 12 years ago and is fully depreciated. Any machine scrap value would offset the removal cost of the equipment. No market exists for this obsolete equipment. The old edger needs two operators. During the cutting operation, the operator makes edger settings, using his or her judgment. The operator has no means of determining exactly what dimension of lumber could be recovered from a given sideboard and must guess at the proper setting to recover the highest grade of lumber. Furthermore, the old edger is not capable of salvaging good-quality 2 × 4's from poor-quality 4 × 4's. The defender can continue in service for another 5 years with proper maintenance. Following are the financial data for the old edger:

Current market value	$0
Current book value	$0
Annual maintenance cost	$2,500 in year 1, increasing at a rate of 15% each year over the previous year's cost
Annual operating costs (labor and power)	$65,000

The new edger has numerous advantages over its defender, including laser beams that indicate where cuts should be made to obtain the maximum yield by the edger. The new edger requires a single operator, and labor savings will be reflected in lower operating and maintenance costs of $35,000 a year. The following gives the estimated costs and the depreciation methods associated with the new edger:

Estimated Cost	
Equipment	$ 35,700
Equipment installation	21,500
Building	47,200
Conveyor modification	14,500
Electrical (wiring)	16,500
Subtotal	$135,400
Engineering	7,000
Construction management	20,000
Contingency	16,200
Total	$178,600
Useful life of new edger	10 years
Salvage value	
Building (tear down)	$0
Equipment	10% of the original cost
Annual O&M costs	$35,000

Depreciation Methods	
Building	39-year MACRS
Equipment and installation	7-year MACRS

Twenty-five percent of the total mill volume passes through the edger. A 12% improvement in yield is expected to be realized with the new edger, resulting in an improvement of $(0.25)(0.12) = 3\%$ in the total mill volume. The annual savings due to the improvement in productivity is thus expected to be \$57,895.

(a) Should the defender be replaced now if the mill's MARR and marginal tax rate are 16% and 40%, respectively?

(b) If the defender will eventually be replaced by the current challenger, when is the optimal time to perform the replacement?

ST14.4 Rivera Industries, a manufacturer of home heating appliances, is considering purchasing an Amada Turret Punch Press, a more advanced piece of machinery, to replace its present system that uses four old presses. Currently, the four smaller presses are used (in varying sequences, depending on the product) to produce one component of a product until a scheduled time when all machines must retool to set up for a different component. Because the setup cost is high, production runs of individual components take a long time and result in large inventory buildups of one component. These buildups are necessary to prevent extended backlogging while other products are being manufactured.

The four presses in use now were purchased six years ago at a price of \$100,000. The manufacturing engineer expects that these machines can be used for eight more years, but they will have no market value after that. The presses have been depreciated by the MACRS method (seven-year property). Their current book value is \$13,387, and their present market value is estimated to be \$40,000. The average setup cost, which is determined by the number of labor hours required times the labor rate for the old presses, is \$80 per hour, and the number of setups per year expected by the production control department is 200, yielding a yearly setup cost of \$16,000. The expected operating and maintenance cost for each year in the remaining life of the old system is estimated as follows:

Year	Setup Costs	O&M Costs
1	\$16,000	\$15,986
2	16,000	16,785
3	16,000	17,663
4	16,000	18,630
5	16,000	19,692
6	16,000	20,861
7	16,000	22,147
8	16,000	23,562

These costs, which were estimated by the manufacturing engineer, with the aid of data provided by the vendor, represent a reduction in efficiency and an increase in needed service and repair over time.

The price of the two-year-old Amada Turret Punch Press is $135,000 and would be paid for with cash from the company's capital fund. In addition, the company would incur installation costs totaling $1,200. An expenditure of $12,000 would be required to recondition the press to its original condition. The reconditioning would extend the Amada's economic service life to eight years, after which time the machine would have no salvage value. The Amada would be depreciated under the MACRS as a seven-year property with the half-year convention. The cash savings of the Amada over the present system are due to the reduced setup time. The average setup cost of the Amada is $15, and the machine would incur 1,000 setups per year, yielding a yearly setup cost of $15,000. The savings due to the reduced setup time occur because of the reduction in carrying costs associated with that level of inventory at which the production run and ordering quantity are reduced. The Accounting Department has estimated that at least $26,000, and probably $36,000, per year could be saved by shortening production runs. The operating and maintenance costs of the Amada, as estimated by the manufacturing engineer, are similar to, but somewhat less, than the O&M costs of the present system.

Year	Setup Costs	O&M Costs
1	$15,000	$11,500
2	15,000	11,950
3	15,000	12,445
4	15,000	12,990
5	15,000	13,590
6	15,000	14,245
7	15,000	14,950
8	15,000	15,745

The reduction in the O&M costs is caused by the age difference of the machines and the reduced power requirements of the Amada.

If Rivera Industries delays the replacement of the current four presses for another year, the secondhand Amada machine will no longer be available, and the company will have to buy a brand-new machine at a price of $200,450, installed. The expected setup costs would be the same as those for the secondhand machine, but the annual operating and maintenance costs would be about 10% lower than the estimated O&M costs for the secondhand machine. The expected economic service life of the brand-new press would be eight years, with no salvage value. The brand-new press also falls into a seven-year MACRS.

Rivera's MARR is 12% after taxes, and the marginal income tax rate is expected to be 40% over the life of the project.

(a) Assuming that the company would need the service of either press for an indefinite period, what would you recommend?

(b) Assuming that the company would need the press for only five more years, what would you recommend?

ST14.5 Tiger Construction Company purchased its current bulldozer (a Caterpillar D8H) and placed it in service six years ago. Since the purchase of the Caterpillar, new technology has produced changes in machines resulting in an increase in productivity of approximately 20%. The Caterpillar worked in a system with a fixed (required) production level to maintain overall system productivity. As the Caterpillar aged and logged more downtime, more hours had to be scheduled to maintain the required production. Tiger is considering purchasing a new bulldozer (a Komatsu K80A) to replace the Caterpillar. The following data have been collected by Tiger's civil engineer:

	Defender (Caterpillar D8H)	**Challenger (Komatsu K80A)**
Useful life	Not known	Not known
Purchase price		$400,000
Salvage value if kept for		
0 year	$75,000	$400,000
1 year	60,000	300,000
2 years	50,000	240,000
3 years	30,000	190,000
4 years	30,000	150,000
5 years	10,000	115,000
Fuel use (gallon/hour)	11.30	16
Maintenance costs:		
1	$46,800	$35,000
2	46,800	38,400
3	46,800	43,700
4	46,800	48,300
5	46,800	58,000

	Defender (Caterpillar D8H) (continued)	Challenger (Komatsu K80A) (continued)
Operating hours (hours/year):		
1	1,800	2,500
2	1,800	2,400
3	1,700	2,300
4	1,700	2,100
5	1,600	2,000
Productivity index	1.00	1.20
Other relevant information:		
Fuel cost ($/gallon)		$1.20
Operator's wages ($/hour)		$23.40
Market interest rate (MARR)		15%
Marginal tax rate		40%
Depreciation methods	Fully Depreciated	MACRS (5-year)

(a) A civil engineer notices that both machines have different working hours and hourly production capacities. To compare the different units of capacity, the engineer needs to devise a combined index that reflects the machine's productivity as well as actual operating hours. Develop such a combined productivity index for each period.

(b) Adjust the operating and maintenance costs by the index you have come up with.

(c) Compare the two alternatives. Should the defender be replaced now?

(d) If the following price index were forecasted for the next five project years, should the defender be replaced now?

Year	Forecasted Price Index			
	General Inflation	Fuel	Wage	Maintenance
0	100	100	100	100
1	108	110	115	108
2	116	120	125	116
3	126	130	130	124
4	136	140	135	126
5	147	150	140	128