4

PART

Special Topics in Engineering Economics

CHAPTER TWELVE

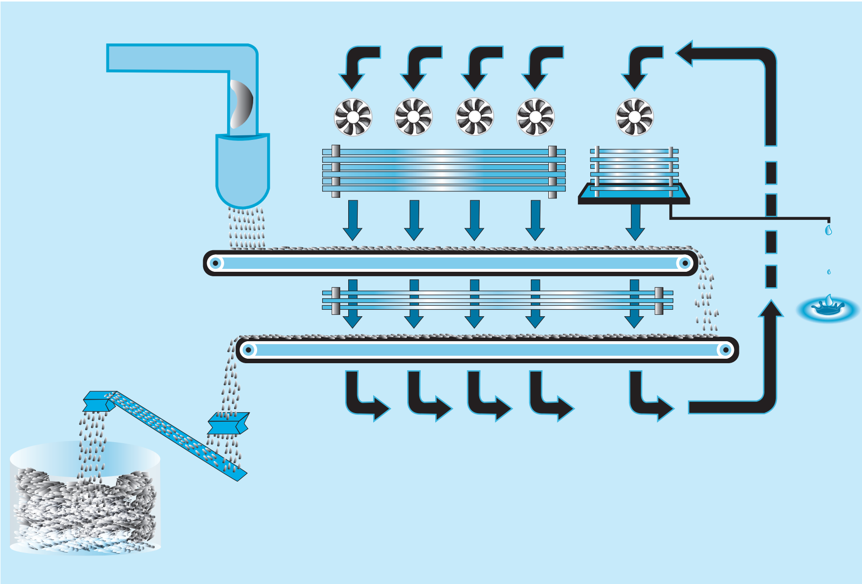
Replacement Decisions

As Milorganite factory ages, repair costs mount[1] The Milwaukee Organic Nitrogen factory in Milwaukee, Wisconsin located on Jones Island began its useful life in 1994. Processing raw sewage and biological sludge at a rate of 130 tons a day the factory is able to produce 43,800 tons of milorganite, an extremely effective non harmful, organic fertilizer. It is a profitable, green, worthy engineering endeavor and business model but there are considerable cost considerations. Equipment is requiring more and more maintenance as it ages and additional capital assets and operating budget need to be applied.

- A recent equipment failure (a broken auger) caused the sewer sludge conveyor system in the 22 year old factory to shutdown.
- The shutdown of the conveyor and the subsequent repair crippled the operation of the factory's sewer sludge dryers when only 6 of the 12 dryers could continue to operate.
- The resultant equipment failure cut process capacity by 50% leading to major financial losses and safety conditions were compromised in the facility due to the rapid accumulation of biosolids on the line.
- This occurrence forced the company to examine all their facility assets as well as their operational cost and maintenance plans in order to improve critical process stability.

Milwaukee Organic Nitrogen engineers and managers apply resources of equipment and man hours for maintenance on a continual basis to keep the factory operational. In 2016 and 2017 a total of $66.5 million in resources were budgeted, this was only a portion of the company's ten-year $100 million maintenance plan. On the outside, the huge expense or capital investment appears negative on margin but it is in fact critical to sustaining the project and the business as a whole.

[1] Don Behm, "As Milorganite Factory Ages, Repair Costs Mount," *Milwaukee Journal Sentinel*, July 30, 2016. (http://www.jsonline.com/story/news/local/milwaukee/2016/07/30/milorganite-factoryages-repair-costs-mount/87815204/).



A factory is a capital asset that the business depends on for its profitable existence. Unfortunately or fortunately from an accounting perspective, it's a depreciable asset. Equipment and structures degrade with time and use and need constant maintenance and upgrades. How is this captured when evaluating an investment and the economics behind that investment?

In Chapters 5 through 7, we presented methods to help us choose the best investment alternative. The problems we examined in those chapters primarily concern profit-adding projects. However, economic analysis is also frequently performed on projects with existing facilities or profit-maintaining projects. Profit-maintaining projects are 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—which we can classify as a **replacement problem**—often facing management is whether to buy new and more efficient equipment or to continue to use existing equipment. In this chapter, we examine the basic concepts and techniques related to replacement analysis.

12.1 Replacement-Analysis Fundamentals

In this section and the following two sections, we examine three aspects of the replacement problem: (1) approaches for comparing defender and challenger; (2) 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 these sections. In Section 12.4, we revisit these replacement problems and consider the effects of income taxes on them.

12.1.1 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. Failure to make an appropriate decision results in a slowdown or shutdown of the operations. The question is when the 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.

The question is not whether an existing piece of equipment will be removed but when it will be removed. 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, then, is why we should replace existing equipment at this 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, the inclusion of irrelevant information in the analysis is apparent. To illustrate this type of decision problem, let us consider Example 12.1.

EXAMPLE 12.1 Relevant Information for Replacement Analysis

Steve Hausmann, a production engineer at Euro Fashion-USA, a European-style furniture company, was considering replacing a 1,000 lb. capacity industrial forklift truck, which was purchased three years ago for $18,000. The truck was being used to move assembled furniture from the finishing department to the warehouse. Recently, the truck had not been dependable and had been frequently out of service while awaiting repairs, a situation that eventually cost the company $3,000. Maintenance expenses were rising steadily. When the truck was not available, the company had to rent one. In addition, the forklift truck was diesel operated, and workers in the plant were complaining about the air pollution. If retained, the truck would have required an immediate engine overhaul to keep it in operable condition. The overhaul would have neither extended the originally estimated service life nor increased the value of the truck. Steve has found that the current truck has a book value of $0 (fully depreciated) and a market value of $7,500 today.

Steve is considering an electric forklift truck as a replacement, which would eliminate the air-pollution problem entirely. The new electric lift truck is quoted at $20,000. The equipment dealer will allow Steve $8,000 as trade-in on a new truck. What value(s) for the defender is (are) relevant in our analysis?

DISSECTING THE PROBLEM

Given: Financial data and history of the defender.

Find: Identify all cost information relevant to making the best replacement decision.

METHODOLOGY

Use the process of elimination.

In all replacement analyses, the relevant cost is the **current market value** of the equipment. The original cost, repair cost, and trade-in value are irrelevant.[2]

SOLUTION

In this example, four different dollar figures relating to the defender are presented:

1. Original cost: $18,000.
2. Market value: $7,500.
3. Book value: $0.
4. Trade-in allowance: $8,000.
5. Operating and maintenance costs if the defender is kept.
6. Salvage value if the defender is kept.

A common misconception is that the trade-in value is always 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 the case. 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 to the customer? Not usually. In many instances, the trade-in allowance is inflated in order 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.[3]

Sunk Costs

A **sunk cost** is any past cost unaffected by any future investment decision. In Example 12.1, the company recently spent $3,000 to repair the truck. However, if the truck were sold today, the company could get only $7,500 back. It is tempting to think that the company could count the $3,000 repair cost, in addition to the cost of the new truck, if the old truck were to be sold and replaced with a new one, but this interpretation is incorrect. 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 the *current market* value, not the cost when defender was originally purchased and not the cost of repairs that have already been made on it.

Sunk cost refers to money that has already been spent; no present action can recover it. These costs are the results of decisions made in the past. In making economic

[2]The original cost and current book value are relevant when you calculate any gains or losses associated with the disposal of the equipment.

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

decisions, we must consider options with only future results in mind—hopefully with the best possible future results. Incorporating sunk costs into the decision-making process would lead only to more bad decisions.

Operating Costs

The driving force in the decision to replace existing equipment is that equipment becomes more and more expensive to operate over time. The total cost of operating a piece of equipment may include repair and maintenance costs, wages for operators, energy consumption costs, and costs of materials. Increases in any one or a combination of these cost items over time may lead us to want a replacement for the existing asset. Since the challenger is usually newer than the defender and often incorporates design improvements and more advanced technology, it likely will be cheaper to operate than the defender.

Whether these savings in operating costs offset the initial investment of buying the challenger thus becomes the focus of our analysis. It is important to focus on those operating costs that differ between the defender and challenger. In many cases, projected labor, energy, and material costs may be identical for each asset—whereas repair and maintenance costs will differ because older assets require more maintenance. Regardless of which cost items we choose to include in the operating costs for our analysis, it is essential that the same items are 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.

12.1.2 Approaches for Comparing Defender and Challenger

Although replacement projects are a subcategory of the mutually exclusive projects we studied in Chapters 5 and 6, they do possess unique characteristics that allow us to use specialized concepts and analysis techniques in their evaluation. We consider two basic approaches to analyzing replacement problems: the cash flow approach and the opportunity-cost approach. We start with a replacement problem where both the defender and the challenger have the same useful life.

Cash-Flow Approach

This approach can be used as long as *the analysis period is the same* for all replacement alternatives. In particular, with the actual cash flow approach, the salvage value of the defender is credited against the purchase price of the challenger. In other words, we explicitly consider the actual cash-flow consequences for each replacement alternative and compare them, using either PW or AE values.

EXAMPLE 12.2 Replacement Analysis Using the Cash-Flow Approach[4]

Adams Corporation is considering the purchase of equipment employing advanced technology to lower production costs in a product line. At the end of the third year, management will close down the line and liquidate the remaining assets.

[4]This problem statement is adapted from "Replacement Decision: Getting It Right," *Business Horizon,* 50 (2007): 231–237.

The project will require an investment of $500,000 in plant upgrade and equipment and an additional $30,000 in working capital, which will be recovered in full at the end of year 3.

Over its three-year useful life, the new equipment will reduce labor and raw materials usage sufficiently to cut operating costs from $9,000,000 to $8,850,000. It is estimated that the new equipment can be sold for $150,000 at the end of year 3. If the new equipment were purchased, the old machine would be sold to another company for $170,000 rather than be traded in for the new equipment. If the old equipment is kept for three more years, the salvage value would be reduced to $70,000. Adams management uses 10% to discount the cash flows. Decide whether replacement is justified now, ignoring any tax consideration.

DISSECTING THE PROBLEM

Given: Financial data for both defender and challenger, $N = 3$ years, $i = 10\%$ per year.
Find: Whether to replace the defender now.

METHODOLOGY

Use cash flow values to find the present worth of each option and then the annual-equivalent value for each.

SOLUTION

- **Option 1: Keep the old equipment.** If the old equipment is kept, there is no additional cash expenditure today. The machine is in good operational condition. The annual operating cost for the next three years will be $9,000,000 per year, and the equipment's salvage value three years from today will be $70,000. The cash-flow diagram for the defender is shown in Figure 12.1(a).

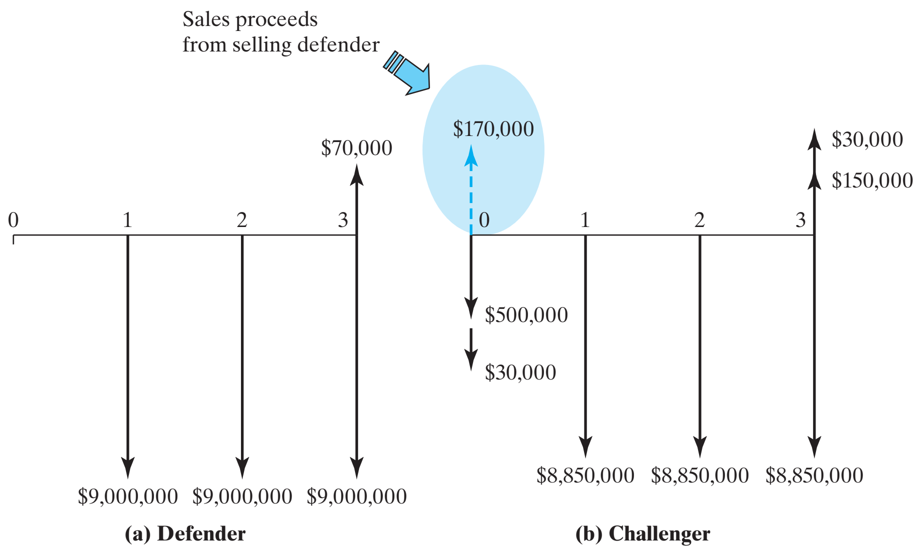


Figure 12.1 Comparison of defender and challenger based on the cash-flow approach.

- **Option 2: Sell the old equipment and buy new.** If this option is taken, the defender (designated as D) can be sold for \$170,000. The cost of the challenger (designated as C) is \$530,000. Thus, the initial combined cash flow for this option is $-\$530{,}000 + \$170{,}000 = -\$360{,}000$. The annual operating cost of the challenger is \$8,850,000. The salvage value of the challenger after three years will be \$150,000, and the \$30,000 working capital will be fully recovered as well. The cash-flow diagram for this option is shown in Figure 12.1(b).

We now use these cash flow values to find the present worth of each option and then use this value to find the annual-equivalent value for the option. For the defender, we have

$$\begin{aligned} \mathrm{PW}(10\%)_D &= -\$9{,}000{,}000(P/A,\ 10\%,\ 3) + \$70{,}000(P/F,\ 10\%,\ 3) \\ &= -\$22{,}329{,}076. \\ \mathrm{AEC}(10\%)_D &= \$22{,}329{,}076(A/P,\ 10\%,\ 3) \\ &= \$8{,}978{,}852. \end{aligned}$$

For the challenger, we have

$$\begin{aligned} \mathrm{PW}(10\%)_C &= -\$360{,}000 - \$8{,}850{,}000(P/A, 10\%,\ 3) \\ &\quad +\$180{,}000(P/F,\ 10\%,\ 3) \\ &= -\$22{,}233{,}402. \\ \mathrm{AEC}(10\%)_C &= \$22{,}233{,}402(A/P, 10\%,\ 3) \\ &= \$8{,}940{,}380. \end{aligned}$$

Because of the annual difference of \$38,472 in favor of the challenger, the replacement should be made now.

COMMENTS: Once again, the cash-flow approach works when both the defender and challenger have the *same service lives*. If not, we must make some adjustment to our analysis in calculating the AEC for the challenger. Suppose the challenger's life is six years, instead of three years, then the \$170,000 current salvage value of the defender should be spread over the three-year life of the challenger (not over the six-year life) as the remaining life of the defender is only three years. Otherwise, there is a distortion of the AEC figures.

Opportunity-Cost Approach

Another way to analyze such a problem is to charge the \$170,000 as an **opportunity cost** of keeping the asset.[5] That is, instead of deducting the salvage value from the purchase cost of the challenger, we consider the salvage value as a cash outflow for the defender (or investment required in keeping the defender). In replacement analysis, the opportunity-cost approach is more commonly used when the defender and challenger have *unequal lifetimes*.

[5] The opportunity-cost concept should not be confused with the outsider-viewpoint approach, which is commonly described in traditional engineering economics texts. The outsider-viewpoint method approaches a typical replacement problem from the standpoint of a person (an outsider) who has a need for the service that the defender or challenger can provide but owns neither. This view has some conceptual flaws, however. For example, the outsider purchases the defender at the seller's market price (or seller's tax rate) and assumes the seller's depreciation schedule. In practice, however, if you place a used asset in service, you will be able to depreciate it even though the asset may have been fully depreciated by the previous owner.

EXAMPLE 12.3 Replacement Analysis Using the Opportunity-Cost Approach

Rework Example 12.2 using the opportunity-cost approach.

DISSECTING THE PROBLEM

Recall that the cash-flow approach in Example 12.2 credited proceeds in the amount of \$170,000 from the sale of the defender toward the \$500,000 purchase price of the challenger, and no initial outlay would have been required had the decision been to keep the defender.

Given: Financial data for both defender and challenger, $N = 3$ years, $i = 10\%$ per year.

Find: Whether to replace the defender now.

METHODOLOGY

Use PW or AE analysis to determine the better option.

SOLUTION

If the decision to keep the defender had been made under the opportunity-cost approach, however, the \$170,000 current salvage value of the defender would have been treated as an incurred cost. Figure 12.2 illustrates the cash flows related to these decision options.

Since the lifetimes are the same, we can use either PW or AE analysis to find the better option. For the defender, we have

$$\begin{aligned} PW(10\%)_D &= -\$170{,}000 - \$9{,}000{,}000(P/A,\ 10\%,\ 3) \\ &\quad +\$70{,}000(P/F,\ 10\%,\ 3) \\ &= -\$22{,}499{,}076. \end{aligned}$$

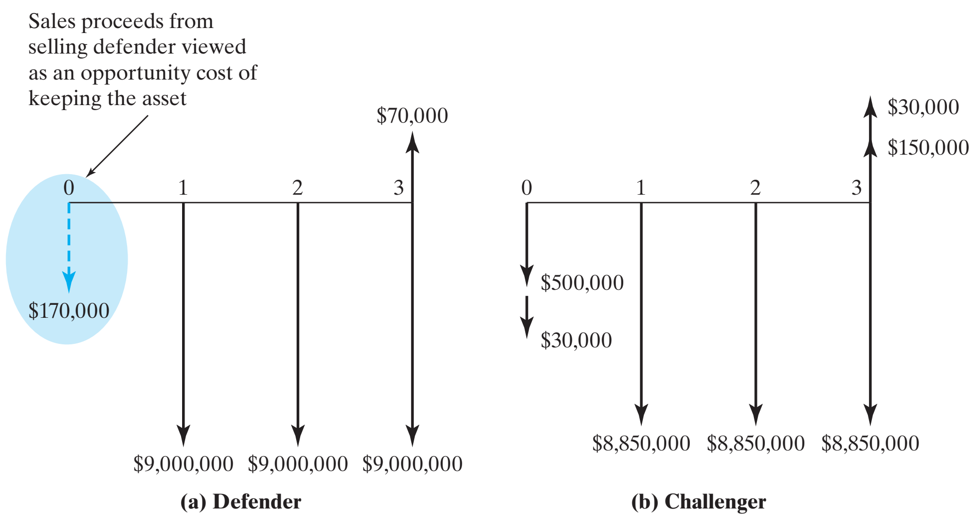


Figure 12.2 Comparison of defender and challenger based on the opportunity-cost approach.

$$\begin{aligned}\text{AEC}(10\%)_D &= \$22{,}499{,}076(A/P, 10\%, 3)\\ &= \$9{,}047{,}212.\end{aligned}$$

For the challenger, we have

$$\begin{aligned}\text{PW}(10\%)_C &= -\$530{,}000 - \$8{,}850{,}000(P/A, 10\%, 3)\\ &\quad + \$180{,}000(P/F, 10\%, 3)\\ &= -\$22{,}403{,}402.\\ \text{AEC}(10\%)_C &= \$22{,}403{,}402(A/P, 10\%, 3)\\ &= \$9{,}008{,}740.\end{aligned}$$

The decision outcome is the same as in Example 12.2; that is, the replacement should be made. Since both the challenger and defender cash flows were adjusted by the same amount $(-\$170{,}000)$ at time zero, this outcome should not be a surprise.

COMMENTS: Recall that we assumed the same service life for both the defender and the challenger in Examples 12.2 and 12.3. In general, however, old equipment has a relatively short remaining life compared with new equipment, so this assumption is overly simplistic. In Section 12.3.3, we will consider handling unequal service life problems in replacement analysis. In the next section, we discuss how to find the economic service life of equipment.

12.2 Economic Service Life

You have probably seen a 50-year-old automobile still in service—provided that it receives the proper repair and maintenance, almost anything can be kept operating for an extended period. If it is possible to keep a car operating for an almost indefinite period, why aren't there more old cars on the streets? There are several reasons. For example, some people get tired of driving the same old car. Others want to keep a car as long as it will last but realize that repair and maintenance costs will become excessive.

We need to consider explicitly 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 make a policy decision on how long to keep a vehicle before replacing it. If an appropriate life span is computed, the firm could stagger the schedule of truck purchases and replacements to smooth out annual capital expenditures for overall truck purchases. Recall that in Section 6.1.2, the costs of owning and operating an asset can be divided into two categories: **capital costs** and **operating costs**. The economic service life is found simply by examining the sum of these two costs as a function of holding period.

Capital (Ownership) Costs

Capital costs have two components: the initial investment and the salvage value at the time of disposal. The initial investment for the challenger is simply its purchase price. For the defender, we should treat the opportunity cost (current market value) as its initial investment. We will use N to represent the length of time in years that the asset will be kept, I to represent the initial investment, and S_N to represent the salvage value at the end of the ownership period of N years.

The annual equivalent of capital cost, which is called the capital-recovery (CR) cost (refer to Section 6.1.2), over the period of N years can be calculated with the following equation:

$$\begin{aligned} CR(i) &= I(A/P, i, N) - S_N(A/F, i, N) \\ &= (I - S_N)(A/P, i, N) + iS_N. \end{aligned} \tag{12.1}$$

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, then no matter how long the asset is kept, the capital-recovery cost is also constant.

Operating Costs

As described earlier, operating and maintenance (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 (OC) of an asset usually increase 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. $OC(i)$ can be expressed as

$$OC(i) = \left(\sum_{n=1}^{N} OC_n(P/F, i, n)\right)(A/P, i, N). \tag{12.2}$$

Economic Service Life

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

$$AEC(i) = CR(i) + OC(i). \tag{12.3}$$

The economic service life of an asset is the period of useful life that minimizes the annual-equivalent costs, in constant dollars, of owning and operating that asset. From the foregoing discussions, we need to find the value of N that minimizes AEC as expressed in Eq. (12.3). If $CR(i)$ is a decreasing function of N and $OC(i)$ is an increasing function of N, as is often the case, then AEC will be a convex function of N with a unique minimum point as shown in Figure 12.3. In this book, we assume that AEC has a unique minimum point. Here are some special cases that the economic service life can be determined easily.

- If the salvage value is constant and equal to the initial cost, and the annual operating cost increases with time, AEC 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 the annual operating cost is constant and the salvage value is less than the initial cost and decreases with time, AEC is a decreasing function of N. In this case, we would try to delay replacement of the asset as long as possible.
- If the salvage value is constant and equal to the initial cost and the annual operating costs are constant, AEC will also be constant. In this case, the time at which the asset is replaced 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

- Capital Cost:
  $\mathrm{CR}(i) = I(A/P, i, N) - S_N(A/F, i, N)$
- Operating Cost:
  $$\mathrm{OC}(i) = \left(\sum_{n=1}^{N} OC_n(P/F, i, n)\right)(A/P, i, N)$$
- Total Cost:
  $\mathrm{AEC}(i) = \mathrm{CR}(i) + \mathrm{OC}(i)$
- Objective: Find n^*
  that minimizes $\mathrm{AEC}(i)$

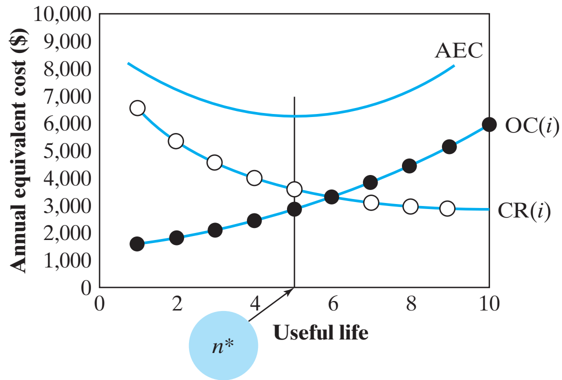


Figure 12.3 A schematic illustrating the trends of capital-recovery cost (ownership cost), annual operating cost, and total annual-equivalent cost, as a function of asset age.

asset's economic life, we obtain the minimum AEC stream in *constant dollars* 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 12.3 to perform replacement analysis. The next example explains the computational procedure for determining economic service life.[6]

EXAMPLE 12.4 Economic Service Life for a Forklift Truck

As a challenger to the forklift truck described in Example 12.1, consider a new electric forklift truck that would cost \$20,000, have operating costs of \$6,000 in the first year, and have a salvage value of \$14,000 at the end of the first year. For the remaining years, operating costs (including any loss of productivity due to maintenance) increase each year by 25% over the previous year's operating costs. Similarly, the salvage value declines each year by 30% from the previous year's salvage value. The truck has a maximum life of eight years without any major engine overhaul. The firm's required rate of return is 12%. Find the economic service life of this new machine without considering any income taxes.

DISSECTING THE PROBLEM

For an asset whose revenues are either unknown or irrelevant, we compute its economic life from the costs of the asset and its year-by-year market (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 AEC gives the economic service life of the asset.

Given: Changes in market values and O&M costs, physical eight years, $i = 12\%$ per year.
Find: Economic service life.

[6] Unless otherwise mentioned, or in the absence of income taxes, we are assuming that all cash flows are estimated in constant dollars. Therefore, the interest rate used in finding the economic service life represents the inflation-free (or real) interest rate.

METHODOLOGY

Create a cash-flow diagram for one-year, two-year, three-year, and eight-year replacement cycles.

SOLUTION

In this case, our examination proceeds as follows:

- **$N = 1$ (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 12.4. The annual-equivalent cost for this option is calculated as follows:

$$\begin{aligned}\text{AEC}(12\%) &= \overbrace{(\$20{,}000 - \$14{,}000)(A/P, 12\%, 1) + (0.12)(\$14{,}000)}^{\text{CR}(12\%)} \\ &\quad + \underbrace{\$6.000}_{\text{OC}(12\%)} \\ &= \$14{,}400.\end{aligned}$$

Note that $(A/P, 12\%, 1) = (F/P, 12\%, 1)$ and that the annual-equivalent cost is the equivalent cost at the end of year 1, since $N = 1$. Because we are calculating the annual-equivalent costs, we have treated cost items with a positive sign and the salvage value with 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 25% higher than in year 1, and the salvage value at the end of year 2 is 30% lower than at the end of year 1. The cash-flow

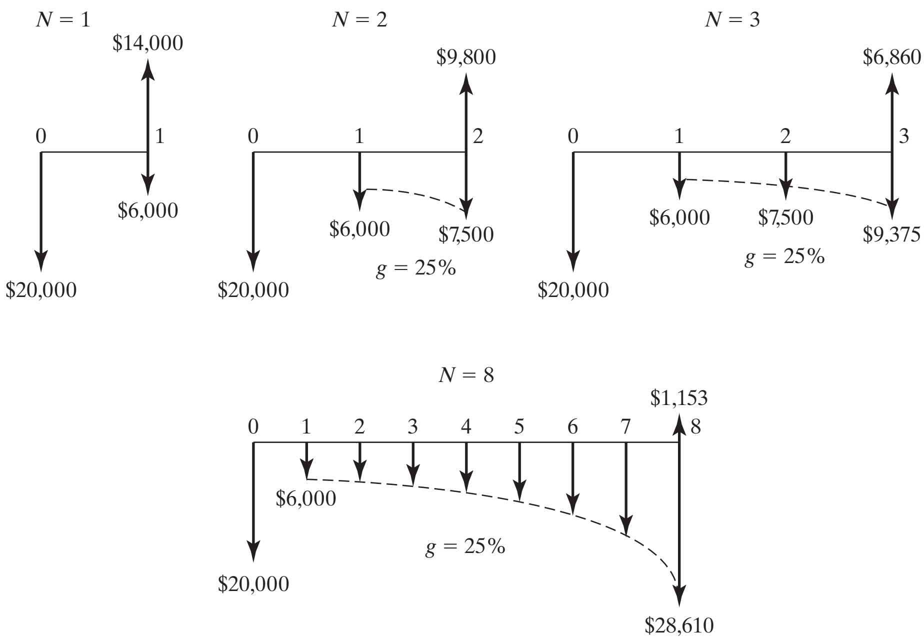


Figure 12.4 Cash-flow diagrams for the options of keeping the asset for one year, two years, three years, and eight years, where g represents a geometric gradient.

diagram for this option is also shown in Figure 12.4. The annual-equivalent cost over the two-year period is calculated as follows:

$$\begin{aligned}\text{AEC}(12\%) &= \overbrace{(\$20{,}000 - \$9{,}800)(A/P, 12\%, 2) + (0.12)(\$9{,}800)}^{\text{CR}(12\%)} \\ &\quad \underbrace{+\$6{,}000(P/A_1, 25\%, 12\%, 2)(A/P, 12\%, 2)}_{\text{OC}(12\%)} \\ &= \$13{,}919.\end{aligned}$$

- ***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 30% lower than at the end of year 2—that is, \$6,860. The operating cost per year increases at a rate of 25%. The cash-flow diagram for this option is also shown in Figure 12.4. For this case, the annual-equivalent cost is calculated as follows:

$$\begin{aligned}\text{AEC}(12\%) &= \overbrace{(\$20{,}000 - \$6{,}860)(A/P, 12\%, 3) + (0.12)(\$6{,}860)}^{\text{CR}(12\%)} \\ &\quad \underbrace{+\$6{,}000(P/A_1, 25\%, 12\%, 3)(A/P, 12\%, 3)}_{\text{OC}(12\%)} \\ &= \$13{,}792.\end{aligned}$$

- Similarly, we can find the annual-equivalent cost for the option of keeping the asset for each remaining year. The cash-flow diagram for $N = 8$ years is shown in Figure 12.4. The computed annual-equivalent costs over eight years are shown in Table 12.1.

From Table 12.1, we find that AEC (12%) is the smallest when $N = 3$. If the truck were to be replaced every three years, it would have an annual cost of \$13,792 per year. If it were to be used for a period other than three years, the annual-equivalent costs would be higher than \$13,792. Thus, a life span of three years for this truck results in the lowest annual cost. We conclude that the economic service life of the truck is three years. By replacing the assets perpetually, according to an economic life of three years, we obtain the minimum annual-equivalent cost stream. Figure 12.5 illustrates the concept of perpetual replacement for one- and two-year replacement cycles. Of course, we should envision a long period of required service for this kind of asset.

TABLE 12.1 **Economic Service Life Calculation for Electric Fork Lift Truck (Example 12.4)**

	A	B	C	D	E	F	G
1							
2		Annual changes in MV		-30%			
3		Annual increases in O&M		25%			
4		Interest rate		12%			
5							
6	*n*	Market Value	O&M Costs	CR(12%)	OC(12%)	AEC(12%)	
7							
8	0	$20,000					
9	1	$14,000	$6,000	$8,400	$6,000	$14,400	
10	2	$9,800	$7,500	$7,211	$6,708	$13,919	
11	3	$6,860	$9,375	$6,294	$7,498	$13,792	
12	4	$4,802	$11,719	$5,580	$8,381	$13,961	
13	5	$3,361	$14,648	$5,019	$9,368	$14,387	
14	6	$2,353	$18,311	$4,575	$10,470	$15,044	
15	7	$1,647	$22,888	$4,219	$11,701	$15,920	
16	8	$1,153	$28,610	$3,932	$13,075	$17,008	
17							
18							
19							
20							
21							
22							
23							
24							

=D16+E16

=-PMT($D$4,A16,NPV($D$4,$C$9:C16),0)

=B15*(1+$D$2)

=C15*(1+$D$3)

=-PMT($D$4,A16,$B$8,-B16)

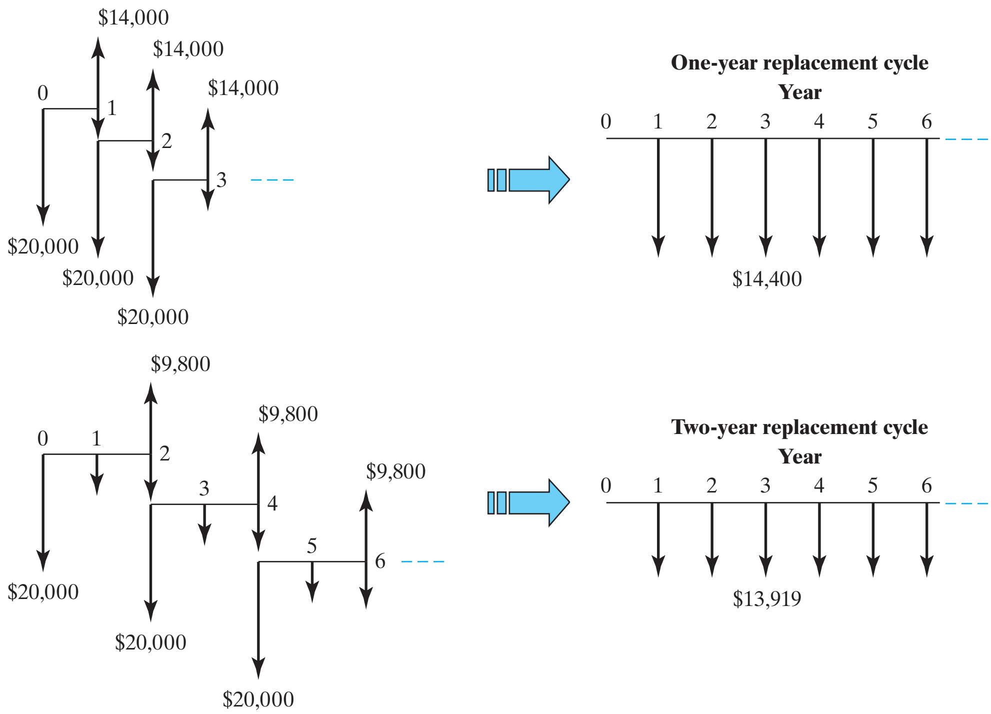


Figure 12.5 Conversion of an infinite number of replacement cycles to infinite AE cost streams.

12.3 Replacement Analysis When the Required Service Period Is Long

Now that we understand how the economic service life of an asset is determined, the next question is how we can use this 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.

12.3.1 Required Assumptions and Decision Frameworks

In deciding the replacement time for the defender, we need to consider the following three factors:

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

Planning Horizon (Study Period)

By "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 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, a 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 as dictated by the efficiency of the asset over its life. If we assume that all future assets 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 future technologies that will make new machines 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, or obsolescence, via alternatives (such as smart-phones virtually eliminate the needs of GPS devices). Clearly, if the best available machine gets better and better over time, we should certainly investigate the possibility of delaying replacement for several years; this scenario contrasts with situations where technological change is unlikely.

Relevant Cash-Flow Information

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 and salvage value decreases over the life of a machine. In other situations, a decline in revenue over equipment life can be expected. The specific situation will determine whether replacement analysis is directed toward cost minimization (with constant revenue) or profit maximization (with varying revenue). We formulate a replacement policy for an asset for which the salvage value does not increase with age.

Decision Criterion

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

As a decision criterion, the AEC 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 the infinite planning horizon. In case of a finite planning horizon, decision making requires some additional analysis techniques that are beyond the scope of this textbook; so we will not address them here. 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 useful for analyzing actual infinite-horizon replacement problems with technological change.

12.3.2 Handling Unequal Service Life Problems in Replacement Analysis

One important consideration in comparing defender and challenger is the question of how we can perform replacement analysis on assets with unequal lives. Recall from Chapter 6 that the use of AEC with unequal lives is justified in some special circumstances. We have here another special situation in which AE with unequal lives gives valid results but only when using the opportunity-cost approach.

The implicit assumption made in using AEC when the defender's remaining life is shorter than the challenger's life is that, after the initial decision, we make perpetual replacements with assets similar to those of the challenger. For example, let us consider a situation where you are comparing a defender (D) with an economic service life of three years and a challenger (C) with an economic service life of six years. This means that if we decide to keep the old machine (D) for three years, we will replace it at time 3 by an asset similar to the new machine. This asset will in turn be replaced six years later, at time 9, by another asset C. There are two implied infinite sequences in this scenario:

- Keep defender (D), buy a challenger (C) at time 3, buy another challenger (C) at time 9, buy another challenger (C) at time 15, and so on.
- Buy challenger (C) at time 0, buy a challenger (C) at time 6, buy a challenger (C) at time 12, and so on.

As shown in Figure 12.6, it is clear that the AEC approach for either sequence of assets is the same after the remaining life of the defender. Therefore, we can directly compare the AEC for the remaining life of the defender with the AEC for the challenger over its economic service life.

12.3.3 Replacement Strategies under the Infinite Planning Horizon

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

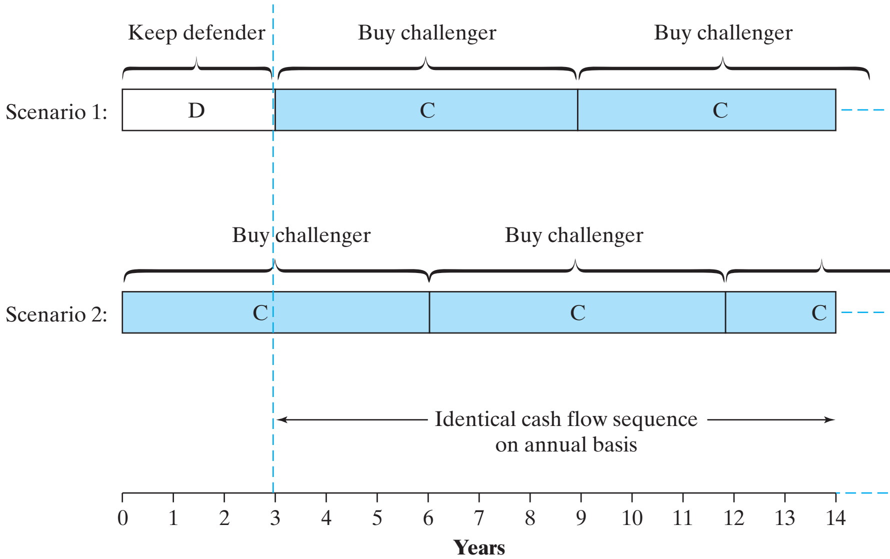


Figure 12.6 Implicit assumption made in AEC method when the defender's remaining life is shorter than the challenger's life.

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 such cases, the following procedure may be implemented in replacement analysis:

1. Compute the economic lives of both defender and challenger. Let us 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 for their respective economic lives are indicated by AEC_D^* and AEC_C^*, respectively.
2. Compare AEC_D^* and AEC_C^*.
   - If AEC_D^* is more than AEC_C^*, we know that it is more costly to keep the defender than to replace it with the challenger. Thus, the challenger should replace the defender now.
   - If AEC_D^* is less 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 as long as there are no technological changes over the economic life of the defender.
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 using the defender for one more year beyond its economic life. If this cost is higher 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 more than AEC_C^*, the defender should be replaced one year after its economic life. This 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

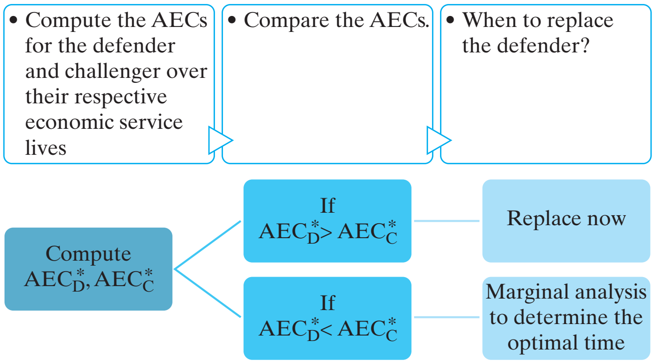


Figure 12.7 Logical steps for comparing the defender with the challenger under the infinite planning horizon.

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. The sequential steps for replacement decision are summarized in Figure 12.7.

It should be noted 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 data on new challengers available on the market, these new data should be used in the procedure. Example 12.5 illustrates this.

EXAMPLE 12.5 Replacement Analysis under the Infinite Planning Horizon

General Engineering Company (GEC) is considering replacing an old vertical cylinder honing machine that had been used for honing automobile and tractor cylinders after the boring process. GEC is considering two options:

- **Option 1:** Retain the old honing machine. If kept, the old machine can be used for another six years with proper maintenance. The firm does not expect to realize any salvage value from scrapping it in six years. The market value of the machine is expected to decline 25% annually over the previous year's market value. The operating costs are estimated at $3,500 during the first year and are expected to increase by $1,000 per year thereafter.
- **Option 2:** Alternatively, the firm can sell the machine to another firm in the industry now for $4,000 and buy a new honing machine. The new machine costs $12,000 and will have operating costs of $2,300 in the first year, increasing by 20% per year thereafter. The expected salvage value is $8,000 after one year and will decline 30% each year thereafter.

The company requires a rate of return of 12% before tax. Find the economic life for each option, and determine when the defender should be replaced. Do not consider any income-tax effects.

DISSECTING THE PROBLEM

Given: Financial data for both defender and challenger.
Find: (a) Economic service life for both defender and challenger and (b) the best time to replace the defender.

METHODOLOGY

Use Excel work sheets to determine the economic service life for each option and compare the options.

SOLUTION

(a) Economic service life:

- **Defender:** If the company retains the honing machine, it is, in effect, forgoing the opportunity to cash in on the machine's current market value, which is the opportunity cost of the machine, at $4,000. Other data for the defender are summarized as follows:

n	Forecasted Operating Cost	Market Value if Disposed of
0		$4,000
1	$3,500	$3,000
2	$4,500	$2,250
3	$5,500	$1,688
4	$6,500	$1,266
5	$7,500	$949
6	$8,500	$712

We can calculate the annual-equivalent costs if the defender is to be kept for one year, two years, three years, and so forth, respectively. In doing so, we may use the following expressions:

$$\text{AEC}(12\%)_N$$

$$= \overbrace{\$4{,}000\,(A/P, 12\%, N) - \$4{,}000\,(1-0.25)^N\,(A/F, 12\%, N)}^{\text{CR}\,(12\%)}$$

$$\underbrace{+\ \$3{,}500 + \$1{,}000\,(A/G, 12\%, N)}_{\text{OC}\,(12\%)}.$$

For example, the cash flow diagram for $N = 4$ years is shown in Figure 12.8.

For $N = 4$ years, we also calculate that

$$\begin{aligned}\text{AEC}(12\%) &= \$4{,}000\,(A/P, 12\%, 4) - \$1{,}266\,(A/F, 12\%, 4)\\ &\quad + \$3{,}500 + \$1{,}000\,(A/G,\ 12\%,\ 4)\\ &= \$5{,}911,\end{aligned}$$

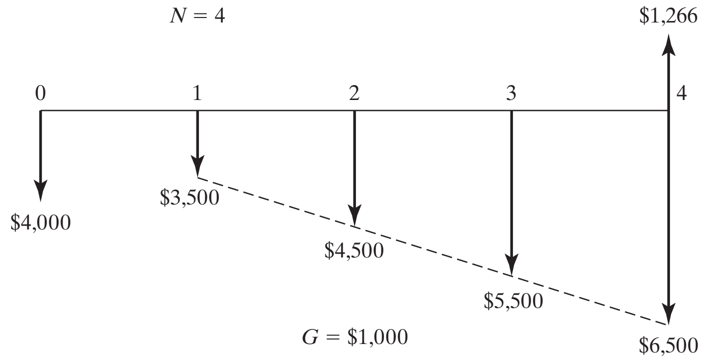


Figure 12.8 Cash flow transactions associated with keeping the defender for four years.

TABLE 12.2 Economic Service Life Calculation for Defender

	A	B	C	D	E	F	G
1							
2		Annual changes in MV		-25%			
3		Annual increases in O&M		$1,000			
4		Interest rate		12%			
5							
6	*n*	Market Value	O&M Costs	CR(12%)	OC(12%)	AEC(12%)	
7							
8	0	$4,000					
9	1	$3,000	$3,500	$1,480	$3,500	$4,980	
10	2	$2,250	$4,500	$1,305	$3,972	$5,277	
11	3	$1,688	$5,500	$1,165	$4,425	$5,590	
12	4	$1,266	$6,500	$1,052	$4,859	$5,911	
13	5	$949	$7,500	$960	$5,275	$6,235	
14	6	$712	$8,500	$885	$5,672	$6,557	
15							
16							
17							
18						=D14+E14	
19		=B13*(1+$D$2)					
20			=C13+$D$3				
21				=-PMT($D$4,A14,NPV($D$4,$C$9:C14)+$C$8,0)			
22							
23			=-PMT($D$4,A14,$B$8,-B14)				
24							

where G represents the gradient amount. When $N = 1$ year, we get the lowest AEC value. Thus, the defender's economic life is one year. Using the notation we have defined in the procedure, we have

$$N_D^* = 1 \text{ year}$$

and

$$\text{AEC}^*_D = \$4{,}980.$$

For $N = 1$ to 6, the results are shown in Table 12.2.

- **Challenger:** The economic life of the challenger can be determined by using the same procedure shown in this example for the defender and in Example 12.4. A summary of the general equation for AEC calculation for the challenger is as follows:

$$\text{AEC}(12\%)_N$$

$$= \overbrace{\$12{,}000\,(A/P, 12\%, \text{N}) - \$8{,}000\,(1-0.30)^{N-1}\,(A/F, 12\%, \text{N})}^{\text{CR }(12\%)}$$

$$\underbrace{+\ \$2{,}300\,(P/A_1, 20\%, 12\%, N)\,(A/P, 12\%, N)}_{\text{OC }(12\%)}.$$

You do not have to express the AEC equation in this format. What you need to do is just calculate two different cost components—ownership cost (capital cost), CR(12%), and the operating cost, OC(12%) year by year. The obtained results are as shown in Table 12.3.

TABLE 12.3 **Economic Service Life Calculation for Challenger**

	A	B	C	D	E	F	G
1							
2		Annual changes in MV		-30%			
3		Annual increases in O&M		20%			
4		Interest rate		12%			
5							
6	*n*	Market Value	O&M Costs	CR(12%)	OC(12%)	AEC(12%)	
7							
8	0	$12,000					
9	1	$8,000	$2,300	$5,440	$2,300	$7,740	
10	2	$5,600	$2,760	$4,459	$2,517	$6,976	
11	3	$3,920	$3,312	$3,834	$2,753	$6,587	
12	4	$2,744	$3,974	$3,377	$3,008	$6,385	
13	5	$1,921	$4,769	$3,027	$3,285	$6,312	
14	6	$1,345	$5,723	$2,753	$3,586	$6,339	
15	7	$941	$6,868	$2,536	$3,911	$6,447	
16	8	$659	$8,241	$2,362	$4,263	$6,625	
17							
18							
19							
20							
21							
22							
23							
24							

=B15*(1+$D$2)

=C15*(1+$D$3)

=-PMT($D$4,A16,$B$8,-B16)

=-PMT($D$4,A16,NPV($D$4,$C$9:C16),0)

=D16+E16

The economic life of the challenger is thus five years; that is,

$$N_{\mathrm{C}}^{*} = 5 \text{ years}$$

and

$$\mathrm{AEC}_{\mathrm{C}}^{*} = \$6{,}312.$$

(b) Should the defender be replaced now?

Since $\mathrm{AEC}_{\mathrm{D}}^{*} = \$4{,}980 < \mathrm{AEC}_{\mathrm{C}}^{*} = \$6{,}312$, the answer is not to replace the defender now. If there are no technological advances in the next few years, the defender should be used for at least *one* more year.

- **When should the defender be replaced?**
  Our question is, then whether we should replace the defender at the end of its economic service life. As we will see shortly, it is not necessarily best to replace the defender right at the end of its economic life.

  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 second year from today. That is, what is the cost of not selling the defender at the end of year 1, using it for the second year, and replacing it at the end of year 2? The following cash flows are related to this question:

  (1) Opportunity cost at the end of year 1, which is equal to the market value then: \$3,000
  (2) Operating cost for the second year: \$4,500
  (3) Market value of the defender at the end of year 2: \$2,250

The diagram in Figure 12.9 represents these cash flows.

As shown in Figure 12.9, the cost of using the defender for one year beyond its economic life is

$$\$3{,}000 \times 1.12 + \$4{,}500 - \$2{,}250 = \$5{,}610.$$

Now compare this cost with $\mathrm{AEC}_{\mathrm{C}}^{*} = \$6{,}312$. It is less than $\mathrm{AEC}_{\mathrm{C}}^{*}$. So, it is less expensive to keep the defender for the second year than to replace it with the challenger. Thus, the conclusion is to keep the defender beyond its economic service life.

Since this second-year cost is still less than $\mathrm{AEC}_{\mathrm{C}}^{*}$, we need to calculate the cost of using the defender for the third year and then compare it with $\mathrm{AEC}_{\mathrm{C}}^{*}$.

$$\$2{,}250 \times 1.12 + \$5{,}500 - \$1{,}688 = \$6{,}332.$$

For year 3, keeping the defender is more expensive than replacing the defender with the challenger. This means that we should replace the defender at the end of year 2.

- **Step 1**: Calculate the equivalent cost of retaining the defender one more year beyond its economic service life, say 1 to 2.

- **Step 2**: Compare this cost with $AEC_C^* = \$6{,}312$

- **Conclusion**: Since keeping the defender for the second year is less expensive than replacing it with the challenger, keep the defender beyond its economic service life.

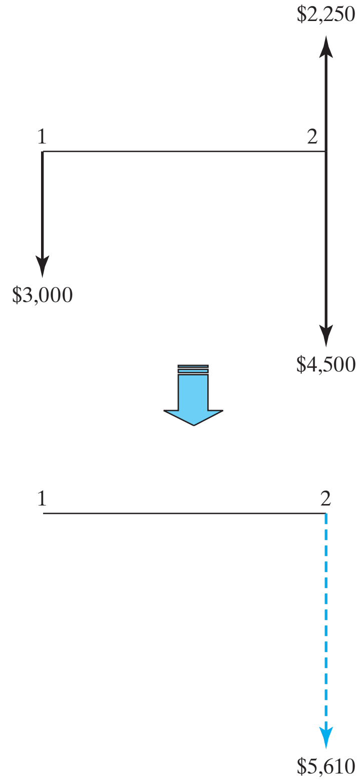


Figure 12.9 Illustration of marginal analysis to determine the optimal time for replacing the defender with the challenger.

12.4 Replacement Analysis with Tax Considerations

Up to this point, we have covered various concepts and techniques that are useful in replacement analysis. 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 12.1 through 12.3 to after-tax comparisons of the defender with the challenger, we have to incorporate the tax effects of 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 and operating costs in our analysis.

Performing replacement studies requires knowledge of the depreciation schedule and of taxable gains or losses at disposal. Note that the depreciation schedule is determined at the time of asset acquisition whereas the current tax law determines the tax effects of gains at the time of disposal. In this section, we will use Example 12.6 to illustrate how to do replacement analyses on an after-tax basis.

EXAMPLE 12.6 Replacement Analysis under an Infinite Planning Horizon

Recall Example 12.5, where General Engineering Company was considering replacing an old honing machine. Let us 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 six years, but the firm does not expect to realize any salvage value from scrapping it in six years.
- The new machine falls into a seven-year MACRS property class and will be depreciated accordingly.

The marginal income-tax rate is 25%, and the after-tax MARR is 10%. Find the useful life for each option, and decide whether the defender should be replaced now or later.

DISSECTING THE PROBLEM

Given: Financial data as given in Example 12.5, tax rate = 25%, and MARR = 10% after tax.
Find: (a) Economic service life for both defender and challenger and (b) optimal time to replace the defender.

METHODOLOGY

Use Excel to calculate the economic service lives for the defender and the challenger, and compare the results.

SOLUTION

(a) Economic service life:

- **Defender:** The defender is *fully depreciated*, so 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	\$4,000	\$4,000(1 − 0.25) = \$3,000
1	\$3,000	\$3,000(1 − 0.25) = \$2,250
2	\$2,250	\$2,250(1 − 0.25) = \$1,688
3	\$1,688	\$1,688(1 − 0.25) = \$1,266
4	\$1,266	\$1,266(1 − 0.25) = \$949
5	\$949	\$949(1 − 0.25) = \$712
6	\$712	\$712(1 − 0.25) = \$534

If the company retains the old honing machine, it is, in effect, deciding to invest the machine's current market value (after taxes) in that alternative. Although there is no actual cash flow, the firm is withholding from the investment the market value of the honing machine (opportunity cost). The after-tax O&M costs are as follows:

n	Forecasted O&M Cost	After-Tax O&M Cost
0		
1	\$3,500	\$3,500(1 − 0.25) = \$2,625
2	\$4,500	\$4,500(1 − 0.25) = \$3,375
3	\$5,500	\$5,500(1 − 0.25) = \$4,125
4	\$6,500	\$6,500(1 − 0.25) = \$4,875
5	\$7,500	\$7,500(1 − 0.25) = \$5,625
6	\$8,500	\$8,500(1 − 0.25) = \$6,375

Using the current year's market value as the investment required to retain the defender, we obtain the data in Table 12.4, which indicate that the remaining useful life of the defender is still one year *in the absence of future challengers*. Note that we also use a 10% discount rate (instead of 12%) to reflect the return desired after-tax.

TABLE 12.4 Economic Service Life Calculation for Defender with Income-Tax Consideration

	A	B	C	D	E	F	G
1							
2		Annual changes in MV		-25%			
3		Annual increases in A/T O&M		\$750			
4		Interest rate (After tax)		10%			
5							
6		After-Tax	After-Tax				
7	*n*	Market Value	O&M Costs	CR(10%)	OC(10%)	AEC(10%)	
8							
9	0	\$3,000					
10	1	\$2,250	\$2,625	\$1,050	\$2,625	\$3,675	
11	2	\$1,688	\$3,375	\$925	\$2,982	\$3,907	
12	3	\$1,266	\$4,125	\$824	\$3,327	\$4,151	
13	4	\$949	\$4,875	\$742	\$3,661	\$4,403	
14	5	\$712	\$5,625	\$675	\$3,983	\$4,657	
15	6	\$534	\$6,375	\$620	\$4,293	\$4,912	
16							
17							
18							
19							
20							
21							
22							
23							
24							

=C10+\$D\$3

=D10+E10

=B9*(1+\$D\$2)

=-PMT(\$D\$4,A10,NPV(\$D\$4,\$C\$10:C10)+\$C\$9,0)

=-PMT(\$D\$4,A10,\$B\$9,-B10)

You have an option to claim bonus depreciation for the challenger, then the depreciation and its tax shield calculation would be much simpler.

- **Challenger:** The economic service life with tax consideration can be calculated in several steps.
  - **Step 1:** Because the challenger will be depreciated over its tax life, we must determine the book value of the asset at the end of each holding period in order to compute the after-tax market value. This process is shown in rows 4 through 15 in Table 12.5. For example, if you keep the challenger for four years, the allowed MACRS depreciation amounts are as follows:

$$\begin{aligned}\text{Total depreciation} &= \$1{,}715 + \$2{,}939 + \$2{,}099 \\ &\quad + (1/2)(\$1{,}499) \\ &= \$7{,}503. \\ \text{Book value} &= \$12{,}000 - \$7{,}503 = \$4{,}497.\end{aligned}$$

  - **Step 2:** To determine the equivalent annual operating cost for each holding period, we need to consider two cash flow elements: (1) O&M cost and (2) depreciation tax shield. The process is illustrated in rows 17 through 28 in Table 12.5. For example, if you keep the challenger for four more years, the O&M cost each year will be as follows:

n	1	2	3	4
O&M Costs	\$2,300	\$2,760	\$3,312	\$3,974
A/T O&M	\$1,725	\$2,070	\$2,484	\$2,981
PW of A/T O&M	\$1,568	\$1,711	\$1,866	\$2,036

$$\begin{aligned}\text{Total PW of A/T O\&M Costs} &= \$1{,}568 + \$1{,}711 \\ &\quad + \$1{,}866 + \$2{,}036 \\ &= \$7{,}181.\end{aligned}$$

  This figure is shown in cell K24 in Table 12.5.

  - **Step 3:** With the book value as calculated in Step 1, we can determine the after-tax market values. With $N = 4$,

$$\begin{aligned}&\text{Taxable gains (losses)} = \$2{,}744 - \$4{,}497 = -\$1{,}753, \\ &\text{Gains taxes (loss credit)} = (\$1{,}753)(0.25) = -\$438, \text{ and} \\ &\text{Net A/T market value} = \$2{,}744 - (-\$438) = \$3{,}182.\end{aligned}$$

  - **Step 4:** We are now ready to find the economic service life of the challenger by generating AEC entries. These calculations are summarized in rows 30 through 41 in Table 12.5.
  - **Step 5:** The economic life of the challenger is five years with an AEC(10%) of \$4,822.

TABLE 12.5 Economics of Owning and Operating the Challenger for *N* More Years

	A	B	C	D	E	F	G	H	I	J	K
5	Period	Holding Period								Total	Book
6	(*N*)	1	2	3	4	5	6	7	8	Depreciation	Value
7	0										$12,000
8	1	$1,715								$1,715	$10,285
9	2	$1,715	$1,470							$3,185	$8,815
10	3	$1,715	$2,939	$1,050						$5,704	$6,296
11	4	$1,715	$2,939	$2,099	$750					$7,503	$4,497
12	5	$1,715	$2,939	$2,099	$1,499	$536				$8,788	$3,212
13	6	$1,715	$2,939	$2,099	$1,499	$1,072	$535			$9,859	$2,141
14	7	$1,715	$2,939	$2,099	$1,499	$1,072	$1,070	$536		$10,930	$1,070
15	8	$1,715	$2,939	$2,099	$1,499	$1,072	$1,070	$1,072	$534	$12,000	$0
16											
17	Holding	Annual O&M Costs over the Holding Period									Total PW
18	Period									Total PW of	of A/T
19	(*N*)	1	2	3	4	5	6	7	8	O&M Costs	O&M Costs
20	0										
21	1	$2,300								$2,091	$1,568
22	2	$2,300	$2,760							$4,372	$3,279
23	3	$2,300	$2,760	$3,312						$6,860	$5,145
24	4	$2,300	$2,760	$3,312	$3,974					$9,575	$7,181
25	5	$2,300	$2,760	$3,312	$3,974	$4,769				$12,536	$9,402
26	6	$2,300	$2,760	$3,312	$3,974	$4,769	$5,723			$15,766	$11,825
27	7	$2,300	$2,760	$3,312	$3,974	$4,769	$5,723	$6,868		$19,291	$14,468
28	8	$2,300	$2,760	$3,312	$3,974	$4,769	$5,723	$6,868	$8,241	$23,135	$17,351
29											
30	Holding	Expected			Net A/T	A/T Operating Costs (in PW)					Total
31	Period	Market	Taxable	Gains	Market	over the Holding Period			OC(10%)	CR(10%)	AEC(10%)
32	(*N*)	Value	Gains	Tax	Value	O&M Costs	Tax Shield	Total OC			
33	0										
34	1	$8,000	($2,285)	($571)	$8,571	$1,568	$390	$1,178	$1,296	$4,629	$5,925
35	2	$5,600	($3,215)	($804)	$6,404	$3,279	$693	$2,585	$1,490	$3,865	$5,355
36	3	$3,920	($2,376)	($594)	$4,514	$5,145	$1,194	$3,951	$1,589	$3,462	$5,050
37	4	$2,744	($1,753)	($438)	$3,182	$7,181	$1,519	$5,662	$1,786	$3,100	$4,886
38	5	$1,921	($1,291)	($323)	$2,244	$9,402	$1,730	$7,671	$2,024	$2,798	$4,822
39	6	$1,345	($796)	($199)	$1,544	$11,825	$1,889	$9,936	$2,281	$2,555	$4,836
40	7	$941	($129)	($32)	$973	$14,468	$2,033	$12,435	$2,554	$2,362	$4,916
41	8	$659	$659	$165	$494	$17,351	$2,164	$15,187	$2,847	$2,206	$5,053
42											
43	Sample cell formulas:										
44	cell K13:=$K$7-J13				cell D39:=C39*$B$2			cell G39:=NPV($B$3,B13:I13)*$B$2			
45	cell K26:==J26*(1-$B$2)				cell E39:=B39-D39			cell I39:=-PMT($B$3,A26,H39,0,0)			
46	cell C39:=B39-K13				cell F39:=K26			cell J39:=-PMT($B$3,A26,12000,-E39)			
47											

(b) Optimal time to replace the defender:

Since the AEC for the defender's remaining useful life (one year) is \$3,675, which is less than \$4,822, the best decision will be to keep the defender for now. Note, however, that the defender's remaining useful life of one year does not necessarily imply that the defender should be kept for only one year before it is switched for the challenger. The reason for this is that the defender's remaining useful life was calculated without considering for what type of challenger would be available in the future. When a challenger's financial data are available, we need to enumerate all timing possibilities for replacement. Since the defender can be used for another six years, seven replacement strategies exist:

- Replace now with the challenger.
- Replace in year 1 with the challenger.
- Replace in year 2 with the challenger.
- Replace in year 3 with the challenger.
- Replace in year 4 with the challenger.
- Replace in year 5 with the challenger.
- Replace in year 6 with the challenger.

If the costs and efficiency of the current challenger remain unchanged in the future years, the possible replacement cash patterns associated with each alternative are as shown in Figure 12.10. From the figure, we observe that, on an annual basis, the cash flows after six years are the same, regardless of how long the defender is kept.

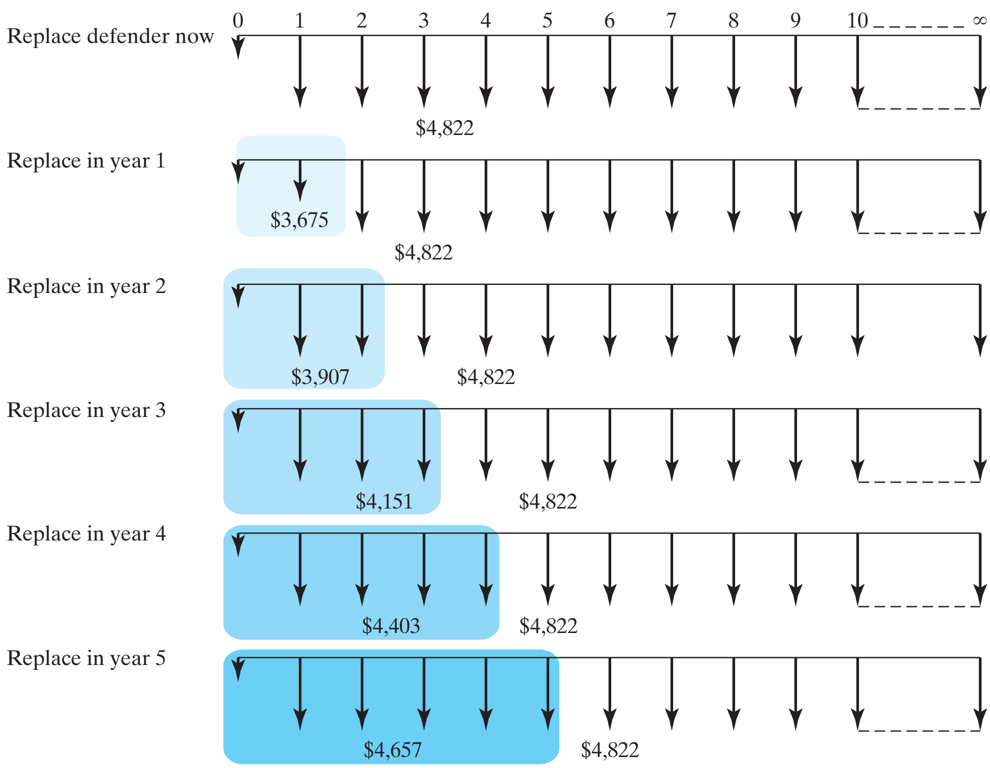


Figure 12.10 Equivalent annual cash flow streams when the defender is kept for n years followed by infinitely repeated purchases of the similar challenger every six years.

Before we evaluate the economics of various replacement-decision options, recall the AEC figures for the defender and the challenger under the assumed service lives as shown in the accompanying chart. (A figure in box denotes the minimum AEC at $N_D^* = 1$ and $N_C^* = 5$, respectively.)

Annual-Equivalent Cost ($)

n	Defender	Challenger
1	$\boxed{\$3,675}$	$5,925
2	$3,907	$5,355
3	$4,151	$5,050
4	$4,403	$4,886
5	$4,657	$\boxed{\$4,822}$
6	$4,912	$4,836
7		$4,916
8		$5,053

Instead of using the marginal analysis in Example 12.5, we will use the PW analysis, which requires evaluation of infinite cash-flow streams. (You will have the same result under marginal analysis.) Immediate replacement of the defender by the challenger is equivalent to computing the PW for an infinite cash flow stream of \$4,822. If we use the capitalized-equivalent-worth approach from Chapter 5 $(CE(i) = A/i)$, we obtain the following:

- $n = 0$:

$$\begin{aligned} PW(10\%)_{n=0} &= (1/0.10)(\$4,822) \\ &= \$48,220. \end{aligned}$$

Suppose we retain the old machine n more years and then replace it with the new one. Now we will compute $PW(i)_n$.

- $n = 1$:

$$\begin{aligned} PW(10\%)_{n=1} &= \$3,675(P/A, 10\%, 1) \\ &\quad + (1/0.10)(\$4,822)(P/F, 10\%, 1) \\ &= \$51,561. \end{aligned}$$

- $n = 2$:

$$\begin{aligned} PW(10\%)_{n=2} &= \$3,907(P/A, 10\%, 2) \\ &\quad + (1/0.10)(\$4,822)(P/F, 10\%, 2) \\ &= \$46,632. \end{aligned}$$

- $n = 3$:

$$\begin{aligned} PW(10\%)_{n=3} &= \$4,151(P/A, 10\%, 3) \\ &\quad + (1/0.10)(\$4,822)(P/F, 10\%, 3) \\ &= \boxed{\$46,551.} \end{aligned}$$

- $n = 4$:

$$\begin{aligned}\text{PW}(10\%)_{n=4} &= \$4{,}403(P/A,\ 10\%,\ 4) \\ &\quad + (1/0.10)(\$4{,}822)(P/F,\ 10\%,\ 4) \\ &= \$46{,}892.\end{aligned}$$

- $n = 5$:

$$\begin{aligned}\text{PW}(10\%)_{n=5} &= \$4{,}657(P/A,\ 10\%,\ 5) \\ &\quad + (1/0.10)(\$4{,}822)(P/F,\ 10\%,\ 5) \\ &= \$47{,}595.\end{aligned}$$

COMMENTS: This result leads us to conclude that the defender should be kept for three more years. The NPW of $46,551 represents the net PW cost associated with retaining the defender for three years, replacing it with the challenger, and then replacing the challenger every five 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 any economic analysis.
- Two basic approaches to analyzing replacement problems are the **cash-flow approach** and the **opportunity-cost approach**. The cash flow approach explicitly considers the actual cash-flow consequences for each replacement alternative as it occurs. Typically, the net proceeds from the sale of the defender are subtracted from the purchase price of the challenger. 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 salvage value an investment required in order to keep the asset.
- **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 the 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 asset improvement should be weighed in making long-term replacement plans: If a particular item is undergoing rapid, substantial technological improvements, it may be prudent to shorten or 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.

SELF-TEST QUESTIONS

Problem Statement for Questions (12s.1–12s.5)

Consider the following replacement decision problem:

- **Option 1:** Continue to use the old machine: A machine now in use, which was bought five years ago for $4,000, has been fully depreciated. It can be sold for $2,500 but could be used for three more years (remaining useful life), at the end of which time it would have no salvage value. The annual operating and maintenance costs for the old machine amount to $10,000.
- **Option 2:** Replace the old machine: A new machine can be purchased at an invoice price of $14,000 to replace the present equipment. Because of the nature of the manufactured product, the new machine has an expected economic life of three years, and it will have no salvage value at the end of that time. The new machine's expected operating and maintenance costs amount to $2,000 for the first year and $3,000 for each of the next two years. The income tax rate is 25%. Any gains will also be taxed at 25%. The allowed depreciation amounts for the new machine are $4,667 during the first year and $6,223 the second year and $1,037 third year, respectively. The firm's interest rate is 15%.

12s.1 If the old machine is to be sold now, what will be the gains tax?
(a) $800 (b) $625 (c) $900 (d) $950

12s.2 If you decide to retain the old machine for now, what will be the opportunity cost?
(a) $2,500 (b) $4,000 (c) $1,875 (d) $1,500

12s.3 If the old asset is to be sold now, what is its sunk cost?
(a) $2,500 (b) $4,000 (c) $1,650 (d) $1,500

12s.4 For depreciation purposes, the first cost of the new machine under the opportunity-cost approach will be
(a) $14,000 (b) $11,500 (c) $12,350 (d) $16,500

12s.5 What is the incremental annual after-tax benefit of replacing the old machine?
(a) $1,408 (b) $919 (c) $967 (d) $992

12s.6 A local delivery company has purchased a delivery truck for $15,000. The truck will be depreciated under MACRS as a five-year property. The truck's market value (or selling price) is expected to be $2,500 less each year. The O&M costs are expected to be $3,000 per year. The firm is in a 25% tax bracket, and its MARR is 15%. Compute the annual-equivalent cost for retaining the truck for a two-year period, which will be
(a) $5,527 (b) $5,175 (c) $5,784 (d) $5,014

12s.7 The following table summarizes the financial data for a proposed new asset. The issue is how long the asset should be kept. Assume an interest rate of 12% and determine the economic service life of the asset before taxes.

End of Year (n)	Investment Cost	O&M Cost	Salvage Value
0	$14,000		
1		$3,400	$8,000
2		$4,600	$6,000
3		$5,800	$4,000
4		$7,200	$2,000
5		$8,300	$0

(a) 2 years (b) 3 years (c) 4 years (d) 5 years

12s.8 The annual equivalent after-tax costs of retaining a defender over its three-year remaining life and the annual equivalent operating costs for its challenger over its four-year physical life are as follows:

	Annual Equivalent Cost	
Holding Period	**Defender**	**Challenger**
1	\$3,500	\$5,800
2	\$2,800	\$4,700
3	\$3,300	\$3,450
4		\$4,900

Assume an MARR of 10% and determine the optimal replacement time for the defender. Assume an infinite planning horizon and no technological change (cost) in the challenger. What would be your decision?

(a) Replace one year later (b) Replace two years later
(c) Replace three years later (d) Replace four years later

12s.9 Razorback Manufacturing is considering replacing a broken metal-cutting machine. Several options have been proposed. The broken machine can be sold today for \$2,800.

- **Option 1:** It can be overhauled completely for \$10,000, after which it will produce \$4,000 in annual cash flows over the next five years. The resale value of the asset at the end of five years is zero.
- **Option 2:** It can be replaced for \$22,500. The life of the replacement machine is five years, and it has an estimated salvage value of \$3,500 at the end of five years. The anticipated operating cash flows for each year will be \$6,200. If the firm's required rate of return is 13%, what should Razorback do? Use the cash flow approach.

12s.10 Consider a new electric forklift 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. Overhauls costing \$3,000 and \$4,500 will be required during the 6th and 10th years of service, respectively. With these two overhauls, the truck's service life can be extended for 13 years. The firm's required rate of return is 15%. Find the economic service life of this new machine.

(a) 4 years (b) 5 years (c) 6 years (d) 9 years

PROBLEMS

Replacement Basics without Considering Income-Tax Effects

12.1 Newnan Furniture owns and operates an industrial lift truck in its warehousing operation. The record indicates that the lift truck was purchased four years ago at \$12,000. The estimated salvage value is \$3,000 after four years of operation. First-year O&M expenses were \$2,500, but the O&M expenses have increased by \$500 each year for the first four years of operation. Using $i = 10\%$, compute the annual-equivalent costs of the lift truck for four years on a before-tax basis.

12.2 McCullum Traders purchased a $35,000 packing machine two years ago. The company expected this machine to have a seven-year life and a salvage value of $6,000. Unfortunately, the company spent $8,000 last year on repairs, and current operating costs are now running at the rate of $10,500 per year. Furthermore, the anticipated salvage value has now been reduced to $2,800 at the end of the machine's remaining useful life. In addition, the company has found that the current machine has a book value of $16,495 and a market value of $12,240 today. The equipment vendor will allow the company the full amount of the market value as a trade-in on a new machine. What value(s) for the defender is (are) relevant in our analysis?

12.3 Consider again the scenario in Problem 12.2. Suppose that the company has been offered the opportunity to purchase another packing machine for $18,000. Over its three-year useful life, the machine will reduce labor and raw-material usage sufficiently to cut operating costs from $10,500 to $8,000. This reduction in costs will allow after-tax profits to rise by $2,500 per year. It is estimated that the new machine can be sold for $6,800 at the end of year 3. If the new machine were purchased, the old machine would be sold to another company rather than be 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 the required service period. Assuming that the firm's interest rate is 10%, decide whether the replacement is justified now.

12.4 The Columbus Electronics Company is considering replacing a 1,200-pound capacity forklift truck that was purchased three years ago at a cost of $24,000. 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 $9,000. If retained, the truck will require an immediate $2,000 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 given in Table P12.4.

TABLE P12.4

n	O&M	Depreciation	Engine Overhaul	Market Value
−3	—	—	—	—
−2	—	$3,000	—	—
−1	—	$4,800	—	—
0	—	$2,880	$2,000	$9,000
1	$4,000	$1,728	—	$7,000
2	$4,800	$1,728	—	$5,000
3	$5,000	$864	—	$3,500
4	$5,500	$0	—	$1,500
5	$5,800	$0	$6,200	$0

A drastic increase in operating 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 18%.

(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?

12.5 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 $15,000 at the end of the 12 years. The original salvage estimate is still good, and the machine has a remaining useful life of two years. The firm can sell this old machine now to another firm in the industry for $42,000. The new machine can be purchased for $180,000, including installation costs. It has an estimated useful (economic) life of 10 years. The new machine is expected to reduce cash operating expenses by $35,000 per year over its 10-year life, at the end of which the machine is estimated to be worth only $10,000. The company has an MARR of 15%.

(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 one and two.

(c) Compute the cash flows associated with purchasing the new machine in years one through ten.

(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?

12.6 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 zero through five?

(c) Should the airline purchase the new machine?

12.7 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?

12.8 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 service 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 new machine.

(c) Should the new machine be acquired now?

Economic Service Life

12.9 A new asset is available for $200,000. O&M costs are $20,000 each year for the first five years, $22,000 in year six, $25,000 in year seven, and $28,000 in year eight. Salvage values are estimated to be $130,000 after one year and will decrease at the rate of 20% per year thereafter. At a MARR of 12%, determine the economic service life of the asset.

12.10 A special-purpose machine is to be purchased at a cost of $15,000. Table P12.10 shows the expected annual operating and maintenance cost and the salvage values for each year of the machine's service.

TABLE P12.10

Year of Service	O&M Cost	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 part (a) using $i = 15\%$.

12.11 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 given in Table P12.11.

TABLE P12.11

Year End	Market Value	Book Value	Operating Costs
0	$7,700	$7,810	
1	$4,300	$5,578	$3,200
2	$3,300	$3,347	$3,700
3	$1,100	$1,160	$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?

Replacement Decisions When Required Service Life Is Long

12.12 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. 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?

12.13 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 in five years. Alternatively, the firm can sell the machine to another firm in the industry now 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 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 following 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.

12.14 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, a salvage value of \$3,000, and 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, 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. The firm's interest rate is 12% for any project justification on a before-tax basis.

12.15 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.

12.16 The 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 13%.

(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?

12.17 The Wu Lighting Company is considering replacing an old, relatively inefficient vertical drill machine that was purchased seven 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. Furthermore, over its five-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 five-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 price of the new machine would make the two options equal?

12.18 The 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 an advanced digital 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%.

12.19 A company is currently producing chemical compounds by a process that was installed 10 years ago at a cost of $140,000. 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 $72,000, and the initial estimate of its economic life is still good. The annual operating costs associated with the process are $20,000. A sales representative from the Global Instrument Company is trying to sell a new chemical-compound-making process to the company. This new process will cost $240,000, have a service life of 10 years, a salvage value of $30,000, and reduce annual operating costs to $6,000. Assuming that the company desires a return of 14% on all investments, should it invest in the new process?

12.20 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 $6,000-per-year savings due to better quality control. If the firm's MARR is 14%, should the machine be purchased now?

12.21 The 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 = 15%?

Replacement Analysis with Tax Considerations

(Note: In all tax problems, no bonus depreciation is considered unless otherwise mentioned. You always have an option to claim bonus depreciation, instead of regular MACRS.)

12.22 Rework Problem 12.1, assuming the following additional information: The asset is classified as a five-year MACRS property. The firm's marginal tax rate is 25%, and its after-tax MARR is 8%.

12.23 Redo Problem 12.6 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 25%, and the firm uses a 12% after-tax MARR.

12.24 Redo Problem 12.7 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 25%, and the firm's after tax MARR is 12%.

Economic Service Life with Tax Considerations

12.25 Redo Problem 12.10 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 25%.
- The firm's after-tax MARR is 12%.

12.26 Redo Problem 12.11 with the following additional information.

- Recall that the current book value of the old machine is \$7,810. The new machine will be depreciated under a seven-year MACRS class.
- The company's marginal tax rate is 25%, and the firm uses a 10% after-tax MARR.

12.27 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 given in Table P12.27

TABLE P12.27

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	\$576	\$1,400	\$4,200
6	\$0	\$600	\$4,900

(a) Determine the economic life of the machine if the MARR is 15% and the marginal tax rate is 25%.

(b) Determine the economic life of the machine if the MARR is 10% and the marginal tax rate remains at 25%.

12.28 Given the following data:

$$\begin{aligned} I &= \$30{,}000 \\ S_n &= 22{,}000 - 2{,}000n \\ B_n &= 30{,}000 - 3{,}000n \\ \text{O\&M}_n &= 3{,}000 \times (1 + 0.15)^{n-1} \end{aligned}$$

and

$$t_m = 0.25.$$

where

I = Asset purchase price

S_n = Market value at the end of year n

B_n = Book value at the end of year n

O&M$_n$ = O&M cost during year n

t_m = Marginal tax rate

(a) Determine the economic service life of the asset if $i = 12\%$.

(b) Determine the economic service life of the asset if $i = 20\%$.

(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).

Replacement Decisions When the Required Service Period Is Long (with tax considerations)

12.29 Redo Problem 12.14 with the following additional information.

- The current book value of the old machine is \$5,623, 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 10% after-tax MARR.

12.30 Redo Problem 12.16 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 25%, and the firm uses a 10% after-tax MARR.

12.31 Redo Problem 12.18 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 25%, and the firm uses a 10% after-tax MARR.

12.32 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 Costs
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 25%.

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

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

12.33 Redo Problem 12.12 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 25%, and the firm's after tax MARR is 10%.

12.34 Redo Problem 12.21 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 25%, and the firm uses a 12% after-tax MARR.

12.35 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 given in Table P12.35

TABLE P12.35

	O & M Costs		
End of Year	Operation and Repairs	Delays due to Repairs	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?

Short Case Studies with Excel

12.36 Quintana Electronic Company is considering the purchase of 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 as compared with the present equipment. He estimates the proposed equipment's economic life at 10 years, with a zero salvage value. Depreciation of the new equipment for tax purposes is computed on the basis of the seven-year MACRS property class.
- The present equipment is in good working order and will last, physically, for at least 10 more years.

Quintana Company expects to pay income taxes of 25%, and any gains will also be taxed at 25%. Quintana uses a 10% discount rate for analysis performed on an after-tax basis.

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

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

(c) Assuming that the present equipment has a book value of $72,000 and a salvage value today of $45,000 and that, if the 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 all other conditions are as described in (a), should the company buy the proposed equipment?

(e) Assume that Quintana Company decided to purchase the new equipment (hereafter called "Model *A*"). Two years later, even better equipment (called "Model *B*") comes onto the market. This equipment makes Model *A* completely 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.) What action should the company take with respect to the potential replacement of Model *A* with Model *B*?

(f) In (e), 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?

12.37 Rivera Industries, a manufacturer of home-heating appliances, is considering the purchase of a used Amada turret punch press to replace its less advanced present system, which uses four old, small 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 in order to set up for a different component. Because setup cost is high, production runs of individual components are long. This factor results in large inventory buildups of one component, which 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. These presses have been depreciated by the MACRS method (seven-year property). The current book value is $13,387, and the present market value is estimated to be $40,000. The average setup cost, which is determined by the number of required labor hours 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. These conditions yield a yearly setup cost of $16,000. The expected operating and maintenance costs for each year in the remaining life of this system are 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. Also, an expenditure of $12,000 would be required in order to recondition the press to its original condition. The reconditioning would extend the Amada's economic service life to eight years. It would have no salvage value at the end of that time. The Amada would be depreciated under the MACRS with the half-year convention as a seven-year property. The average setup cost of the Amada is $15, and it would require 1,000 setups per year, yielding a yearly setup cost of $15,000. Rivera's accounting department has estimated that at least $26,000, and probably $36,000, per year could be saved by shortening production runs and thus, carrying costs. 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 for 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 an installed price of $200,450. Its expected setup costs would be the same as those for the secondhand machine, but the annual O&M costs of the new one 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 at the end of that period. The brand-new press also falls into a seven-year MACRS property class.

Rivera's MARR is 12% after taxes, and the marginal income-tax rate is expected to be 25% over the life of the project.

(a) Assuming that the company would need the service of either the Amada press or the current presses for an indefinite period, which option would you recommend?

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