LEVEL TWO

TOOLS FOR EVALUATING ALTERNATIVES

One or more engineering alternatives are formulated to solve a problem or provide specified results. In engineering economics, each alternative has cash flow estimates for the initial investment, periodic (usually annual) incomes and/or costs, and possibly a salvage value at the end of its estimated life. The chapters in this level develop the four different methods by which one or more alternatives can be evaluated economically using the factors and formulas learned in the previous Level One.

In professional practice, it is typical that the evaluation method and parameter estimates necessary for the economic study are not specified. The last chapter in this level begins with a focus on selecting the best evaluation method for the study. It continues by treating the fundamental question of what MARR to use and the historic dilemma of how to consider noneconomic factors when selecting an alternative.

Important note: If depreciation and/or after tax analysis is to be considered along with the evaluation methods in Chapters 5 through 9, Chapter 16 and/or Chapter 17 should be covered, preferably after Chapter 6.

CHAPTER 5

Present Worth Analysis

A future amount of money converted to its equivalent value now has a present worth (PW) that is always less than that of the actual cash flow, because for any interest rate greater than zero, all *P*/*F* factors have a value less than 1.0. For this reason, present worth values are often referred to as *discounted cash flows* (*DCF*). Similarly, the interest rate is referred to as the *discount rate*. Besides PW, two other terms frequently used are present value (PV) and net present value (NPV). Up to this point, present worth computations have been made for one project or alternative. In this chapter, techniques for comparing two or more mutually exclusive alternatives by the present worth method are treated.

Several extensions to PW analysis are covered here—future worth, capitalized cost, payback period, life-cycle costing, and bond analysis, these all use present worth relations to analyze alternatives.

In order to understand how to organize an economic analysis, this chapter begins with a description of independent and mutually exclusive projects, as well as revenue and service alternatives.

The case study examines the payback period and sensitivity for a public sector project.

LEARNING OBJECTIVES

Purpose: Compare mutually exclusive alternatives on a present worth basis, and apply extensions of the present worth method.

This chapter will help you:

Formulating alternatives	1. Identify mutually exclusive and independent projects, and define a service and a revenue alternative.
PW of equal-life alternatives	2. Select the best of equal-life alternatives using present worth analysis.
PW of different-life alternatives	3. Select the best of different-life alternatives using present worth analysis.
FW analysis	4. Select the best alternative using future worth analysis.
Capitalized cost (CC)	5. Select the best alternative using capitalized cost calculations.
Payback period	6. Determine the payback period at $i = 0\%$ and $i > 0\%$, and state the shortcomings of payback analysis.
Life-cycle cost (LCC)	7. Perform a life-cycle cost analysis for the acquisition and operations phases of a (system) alternative.
PW of bonds	8. Calculate the present worth of a bond investment.
Spreadsheets	9. Develop spreadsheets that use PW analysis and its extensions, including payback period.

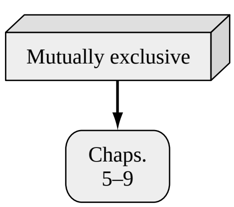
5.1 FORMULATING MUTUALLY EXCLUSIVE ALTERNATIVES

Section 1.3 explains that the economic evaluation of an alternative requires cash flow estimates over a stated time period and a criterion for selecting the best alternative. The alternatives are developed from project proposals to accomplish a stated purpose. This progression is depicted in Figure 5–1. Some projects are economically and technologically viable, and others are not. Once the viable projects are defined, it is possible to formulate the alternatives. For example, assume Med-supply.com, an internet-based medical supply provider, wants to challenge it storefront competitors by significantly shortening the time between order placement and delivery to the hospital or clinic. Three projects have been proposed: closer networking with UPS and FedEx for shortened delivery time; partnering with local medical supply houses in major cities to provide same-day delivery; and developing a 3-d fax-like machine to ship items not physically larger than the machine. Economically (and technologically) only the first two project proposals can be pursued at this time; they are the two alternatives to evaluate.

The description above correctly treats project proposals as precursors to economic alternatives. To help formulate alternatives, *categorize each project* as one of the following:

- **Mutually exclusive.** *Only one of the viable projects can be selected* by the economic analysis. Each viable project *is* an alternative.
- **Independent.** *More than one viable project may be selected* by the economic analysis. (There may be dependent projects requiring a particular project to be selected before another, and contingent projects where one project may be substituted for another.)

The *do-nothing* (*DN*) option is usually understood to be an alternative when the evaluation is performed. If it is absolutely required that one of the defined alternatives be selected, do nothing is not considered an option. (This may occur when a mandated function must be installed for safety, legal, or other purposes.) Selection of the DN alternative means that the current approach is maintained; nothing new is initiated. No new costs, revenues, or savings are generated by the DN alternative.



A mutually exclusive alternative selection takes place, for example, when an engineer must select the one best diesel-powered engine from several competing models. Mutually exclusive alternatives are, therefore, the same as the viable projects; each one is evaluated, and the one best alternative is chosen. Mutually exclusive alternatives *compete with one another* in the evaluation. All the analysis techniques through Chapter 9 are developed to compare mutually exclusive alternatives. Present worth is discussed in the remainder of this chapter. If no mutually exclusive alternative is considered economically acceptable, it is possible to reject all alternatives and (by default) accept the DN alternative. (This option is indicated in Figure 5–1 by lighter shading on the DN mutually exclusive alternative.)

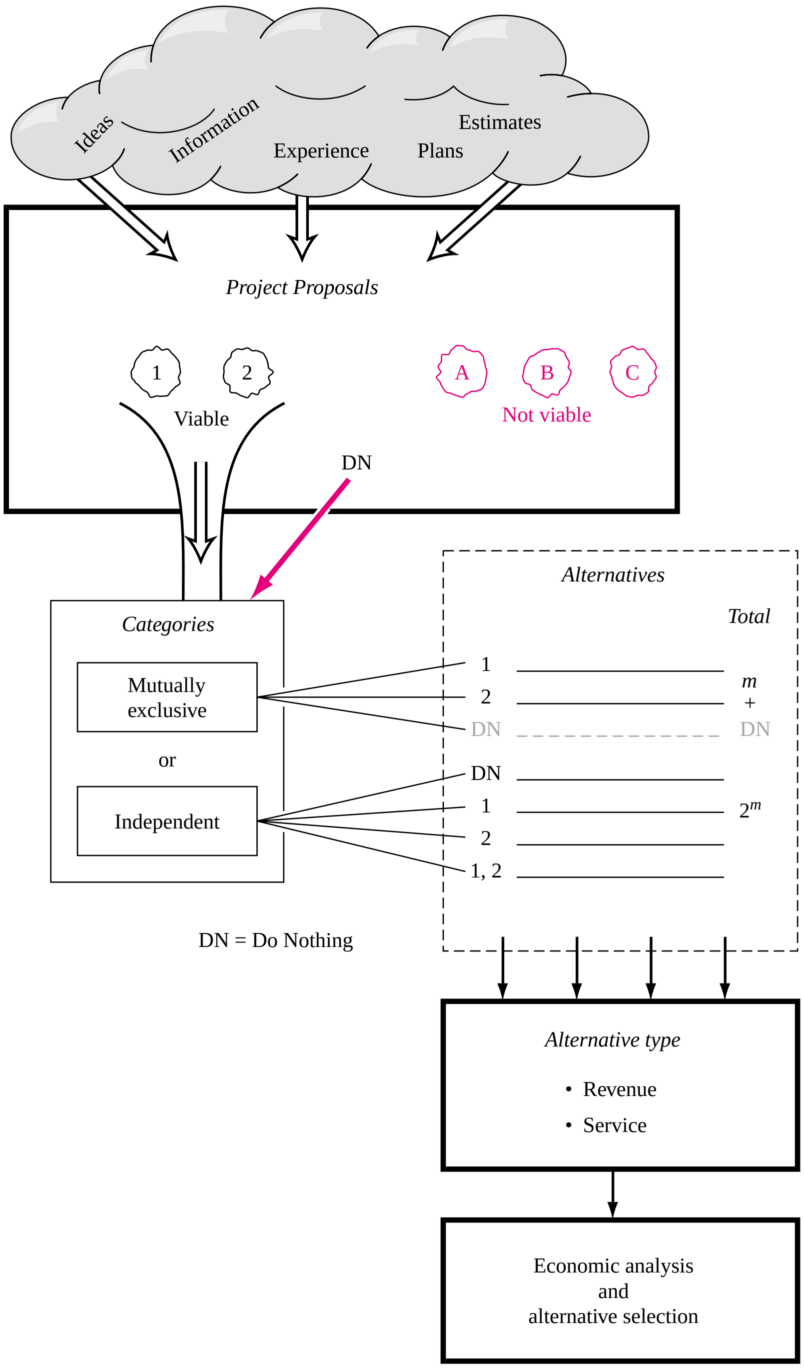
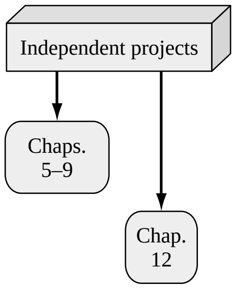


Figure 5–1
Progression from projects to alternatives to economic analysis.



Independent projects do not compete with one another in the evaluation. Each project is evaluated separately, and thus the *comparison is between one project at a time and the do-nothing alternative.* If there are *m* independent projects, zero, one, two, or more may be selected. Since each project may be in or out of the selected group of projects, there are a total of 2^m mutually exclusive alternatives. This number includes the DN alternative, as shown in Figure 5–1. For example, if the engineer has three diesel engine models (A, B, and C) and may select any number of them, there are $2^3 = 8$ alternatives: DN, A, B, C, AB, AC, BC, ABC. Commonly, in real-world applications, there are restrictions, such as an upper budgetary limit, that eliminate many of the 2^m alternatives. Independent project analysis without budget limits is discussed in this chapter and through Chapter 9. Chapter 12 treats independent projects with a budget limitation; this is called the capital budgeting problem.

Finally, it is important to recognize the *nature or type of alternatives* before starting an evaluation. The cash flows determine whether the alternatives are revenue-based or service-based. All the alternatives evaluated in one particular engineering economy study must be of the same type.

- **Revenue.** *Each alternative generates cost (or disbursement) and revenue (or receipt) cash flow estimates, and possibly savings.* Revenues are dependent upon which alternative is selected. These alternatives usually involve new systems, products, and the like that require capital investment to generate revenues and/or savings. Purchasing new equipment to increase productivity and sales is a revenue alternative.
- **Service.** *Each alternative has only cost cash flow estimates.* Revenues or savings are not dependent upon the alternative selected, so these cash flows are assumed to be equal. These may be public sector (government) initiatives (as discussed in Chapter 9). Also, they may be legally mandated or safety improvements. Often an improvement is justified; however, the anticipated revenues or savings are not estimable. In these cases the evaluation is based only on cost estimates.

The alternative selection guidelines developed in the next section are tailored for both types of alternatives.

5.2 PRESENT WORTH ANALYSIS OF EQUAL-LIFE ALTERNATIVES

In present worth analysis, the *P* value, now called *PW,* is calculated at the MARR for each alternative. The present worth method is popular because future cost and revenue estimates are transformed into *equivalent dollars now;* that is, all future cash flows are converted into present dollars. This makes it easy to determine the economic advantage of one alternative over another.

The PW comparison of alternatives with equal lives is straightforward. If both alternatives are used in identical capacities for the same time period, they are termed *equal-service* alternatives.

Whether mutually exclusive alternatives involve disbursements only (service) or receipts and disbursements (revenue), the following guidelines are applied to select one alternative.

One alternative. **Calculate PW at the MARR. If PW ≥ 0, the requested MARR is met or exceeded and the alternative is financially viable.**

Two or more alternatives. **Calculate the PW of each alternative at the MARR.** ***Select the alternative with the PW value that is numerically largest,*** **that is, less negative or more positive, indicating a lower PW of cost cash flows or larger PW of net cash flows of receipts minus disbursements.**

Note that the guideline to select one alternative with the lowest cost or the highest income uses the criterion of *numerically largest*. This is *not the absolute value* of the PW amount, because the sign matters. The selections below correctly apply the guideline for the listed PW values.

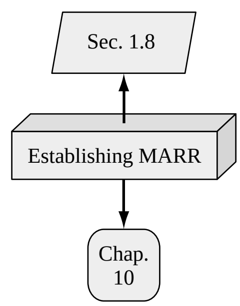
PW_1	PW_2	Selected Alternative
$−1500	$−500	2
−500	+1000	2
+2500	−500	1
+2500	+1500	1

If the projects are *independent*, the selection guideline is as follows:

For one or more independent projects, select all projects with PW ≥ 0 at the MARR.

This compares each project with the do-nothing alternative. The projects must have positive and negative cash flows to obtain a PW value that exceeds zero; that is, they must be revenue projects.

A PW analysis requires a MARR for use as the i value in all PW relations. The bases used to establish a realistic MARR were summarized in Chapter 1 and are discussed in detail in Chapter 10.



EXAMPLE 5.1

Perform a present worth analysis of equal-service machines with the costs shown below, if the MARR is 10% per year. Revenues for all three alternatives are expected to be the same.

	Electric-Powered	Gas-Powered	Solar-Powered
First cost, $	−2500	−3500	−6000
Annual operating cost (AOC), $	−900	−700	−50
Salvage value S, $	200	350	100
Life, years	5	5	5

EXAMPLE 5.1 CONTINUED

Solution

These are service alternatives. The salvage values are considered a "negative" cost, so a + sign precedes them. (If it costs money to dispose of an asset, the estimated disposal cost has a − sign.) The PW of each machine is calculated at $i = 10\%$ for $n = 5$ years. Use subscripts E, G, and S.

$$PW_E = -2500 - 900(P/A,10\%,5) + 200(P/F,10\%,5) = \$-5788$$

$$PW_G = -3500 - 700(P/A,10\%,5) + 350(P/F,10\%,5) = \$-5936$$

$$PW_S = -6000 - 50(P/A,10\%,5) + 100(P/F,10\%,5) = \$-6127$$

The electric-powered machine is selected since the PW of its costs is the lowest; it has the numerically largest PW value.

5.3 PRESENT WORTH ANALYSIS OF DIFFERENT-LIFE ALTERNATIVES

When the present worth method is used to compare mutually exclusive alternatives that have different lives, the procedure of the previous section is followed with one exception:

> **The PW of the alternatives must be compared over the same number of years.**

This is necessary, since a present worth comparison involves calculating the equivalent present value of all future cash flows for each alternative. A fair comparison can be made only when the PW values represent costs (and receipts) associated with equal service. Failure to compare equal service will always favor a shorter-lived alternative (for costs), even if it is not the most economical one, because fewer periods of costs are involved. The equal-service requirement can be satisfied by either of two approaches:

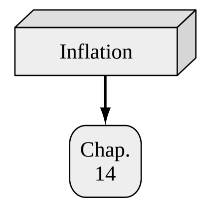
- Compare the alternatives over a period of time equal to the *least common multiple (LCM)* of their lives.
- Compare the alternatives using a *study period of length n years*, which does not necessarily take into consideration the useful lives of the alternatives. This is also called the *planning horizon* approach.

In either case, the PW of each alternative is calculated at the MARR, and the selection guideline is the same as that for equal-life alternatives. The LCM approach automatically makes the cash flows for all alternatives extend to the same time period. For example, alternatives with expected lives of 2 and 3 years are compared over a 6-year time period. Such a procedure requires that some assumptions be made about subsequent life cycles of the alternatives.

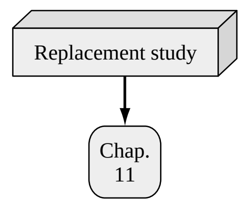
The assumptions of a PW analysis of different-life alternatives are as follows:

1. **The service provided by the alternatives will be needed for the LCM of years or more.**
2. **The selected alternative will be repeated over each life cycle of the LCM in exactly the same manner.**
3. **The cash flow estimates will be the same in every life cycle.**

As will be shown in Chapter 14, the third assumption is valid when the cash flows are expected to change by exactly the inflation (or deflation) rate that is applicable through the LCM time period. If the cash flows are expected to change by any other rate, then the PW analysis must be conducted using constant-value dollars, which considers inflation. A study period analysis is necessary if the first assumption about the length of time the alternatives are needed cannot be made. A present worth analysis over the LCM requires that the estimated salvage values be included in each life cycle.



For the study period approach, a time horizon is chosen over which the economic analysis is conducted, and only those cash flows which occur during that time period are considered relevant to the analysis. All cash flows occurring beyond the study period are ignored. An estimated market value at the end of the study period must be made. The time horizon chosen might be relatively short, especially when short-term business goals are very important. The study period approach is often used in replacement analysis. It is also useful when the LCM of alternatives yields an unrealistic evaluation period, for example, 5 and 9 years.



Example 5.2 includes evaluations based on the LCM and study period approaches. Also, Example 5.12 in Section 5.9 illustrates the use of spreadsheets in PW analysis for both different lives and a study period.

EXAMPLE 5.2

A project engineer with EnvironCare is assigned to start up a new office in a city where a 6-year contract has been finalized to take and to analyze ozone-level readings. Two lease options are available, each with a first cost, annual lease cost, and deposit-return estimates shown below.

	Location A	Location B
First cost, $	−15,000	−18,000
Annual lease cost, $ per year	−3,500	−3,100
Deposit return, $	1,000	2,000
Lease term, years	6	9

(*a*) Determine which lease option should be selected on the basis of a present worth comparison, if the MARR is 15% per year.

(*b*) EnvironCare has a standard practice of evaluating all projects over a 5-year period. If a study period of 5 years is used and the deposit returns are not expected to change, which location should be selected?

EXAMPLE 5.2 CONTINUED

(*c*) Which location should be selected over a 6-year study period if the deposit return at location B is estimated to be \$6000 after 6 years?

Solution

(*a*) Since the leases have different terms (lives), compare them over the LCM of 18 years. For life cycles after the first, the first cost is repeated in year 0 of the new cycle, which is the last year of the previous cycle. These are years 6 and 12 for location A and year 9 for B. The cash flow diagram is in Figure 5–2. Calculate PW at 15% over 18 years.

$$PW_A = -15{,}000 - 15{,}000(P/F,15\%,6) + 1000(P/F,15\%,6) - 15{,}000(P/F,15\%,12) + 1000(P/F,15\%,12) + 1000(P/F,15\%,18) - 3500(P/A,15\%,18)$$

$$= \$-45{,}036$$

$$PW_B = -18{,}000 - 18{,}000(P/F,15\%,9) + 2000(P/F,15\%,9) + 2000(P/F,15\%,18) - 3100(P/A,15\%,18)$$

$$= \$-41{,}384$$

Location B is selected, since it costs less in PW terms; that is, the PW_B value is numerically larger than PW_A.

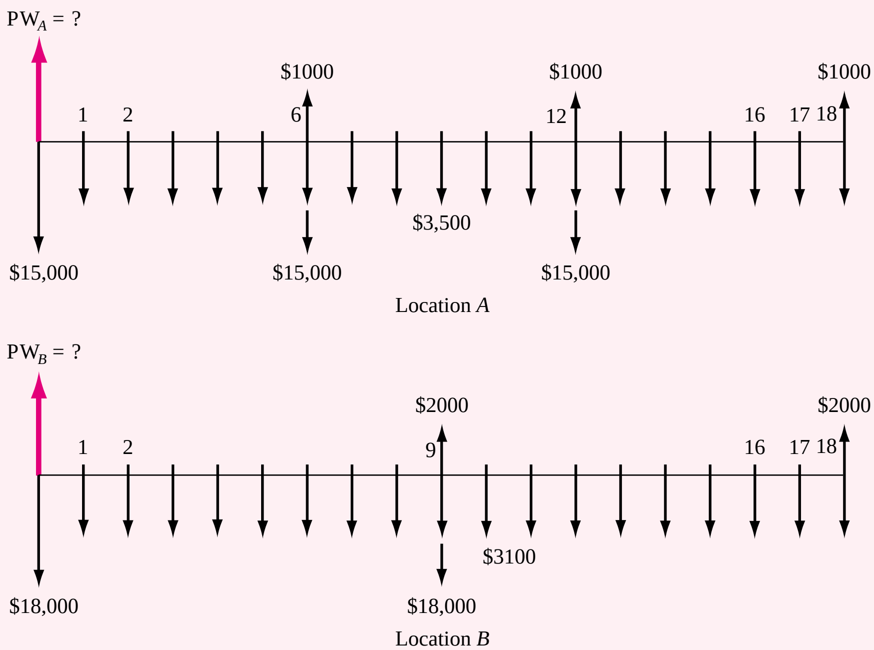


Figure 5–2
Cash flow diagram for different-life alternatives, Example 5.2(*a*).

(*b*) For a 5-year study period no cycle repeats are necessary. The PW analysis is

$$PW_A = -15{,}000 - 3500(P/A{,}15\%{,}5) + 1000(P/F{,}15\%{,}5)$$
$$= \$-26{,}236$$
$$PW_B = -18{,}000 - 3100(P/A{,}15\%{,}5) + 2000(P/F{,}15\%{,}5)$$
$$= \$-27{,}397$$

Location A is now the better choice.

(*c*) For a 6-year study period, the deposit return for B is \$6000 in year 6.

$$PW_A = -15{,}000 - 3500(P/A{,}15\%{,}6) + 1000(P/F{,}15\%{,}6) = \$-27{,}813$$
$$PW_B = -18{,}000 - 3100(P/A{,}15\%{,}6) + 6000(P/F{,}15\%{,}6) = \$-27{,}138$$

Location B now has a small economic advantage. Noneconomic factors are likely to enter into the final decision.

Comments

In part (*a*) and Figure 5–2, the deposit return for each lease is recovered *after each life cycle,* that is, in years 6, 12, and 18 for A and in years 9 and 18 for B. In part (*c*), the increase of the deposit return from \$2000 to \$6000 (one year later), switches the selected location from A to B. The project engineer should reexamine these estimates before making a final decision.

5.4 FUTURE WORTH ANALYSIS

The future worth (FW) of an alternative may be determined directly from the cash flows by determining the future worth value, or by multiplying the PW value by the F/P factor, at the established MARR. Therefore, it is an extension of present worth analysis. The n value in the F/P factor depends upon which time period has been used to determine PW—the LCM value or a specified study period. Analysis of one alternative, or the comparison of two or more alternatives, using FW values is especially applicable to large capital investment decisions when a prime goal is to maximize the *future wealth* of a corporation's stockholders.

Future worth analysis is often utilized if the asset (a corporation, a building, etc.) might be sold or traded at some time after its start-up or acquisition, but before the expected life is reached. An FW value at an intermediate year estimates the alternative's worth at the time of sale or disposal. Suppose an entrepreneur is planning to buy a company and expects to trade it within 3 years. FW analysis is the best method to help with the decision to sell or keep it 3 years hence. Example 5.3 illustrates this use of FW analysis. Another excellent application of FW analysis is for projects that will not come online until the end of the investment period. Alternatives such as electric generation facilities, toll roads, hotels, and the like can be analyzed using the FW value of investment commitments made during construction.

Once the FW value is determined, the selection guidelines are the same as with PW analysis; FW ≥ 0 means the MARR is met or exceeded (one alternative). For two (or more) mutually exclusive alternatives, select the one with the numerically larger (largest) FW value.

EXAMPLE 5.3

A British food distribution conglomerate purchased a Canadian food store chain for $75 million (U.S.) three years ago. There was a net loss of $10 million at the end of year 1 of ownership. Net cash flow is increasing with an arithmetic gradient of $+5 million per year starting the second year, and this pattern is expected to continue for the foreseeable future. This means that breakeven net cash flow was achieved this year. Because of the heavy debt financing used to purchase the Canadian chain, the international board of directors expects a MARR of 25% per year from any sale.

(*a*) The British conglomerate has just been offered $159.5 million (U.S.) by a French company wishing to get a foothold in Canada. Use FW analysis to determine if the MARR will be realized at this selling price.

(*b*) If the British conglomerate continues to own the chain, what selling price must be obtained at the end of 5 years of ownership to make the MARR?

Solution

(*a*) Set up the future worth relation in year 3 (FW_3) at $i = 25\%$ per year and an offer price of $159.5 million. Figure 5–3*a* presents the cash flow diagram in $1 million.

$$FW_3 = -75(F/P,25\%,3) - 10(F/P,25\%,2) - 5(F/P,25\%,1) + 159.5$$

$$= -168.36 + 159.5 = \$-8.86 \text{ million}$$

No, the MARR of 25% will not be realized if the $159.5 million offer is accepted.

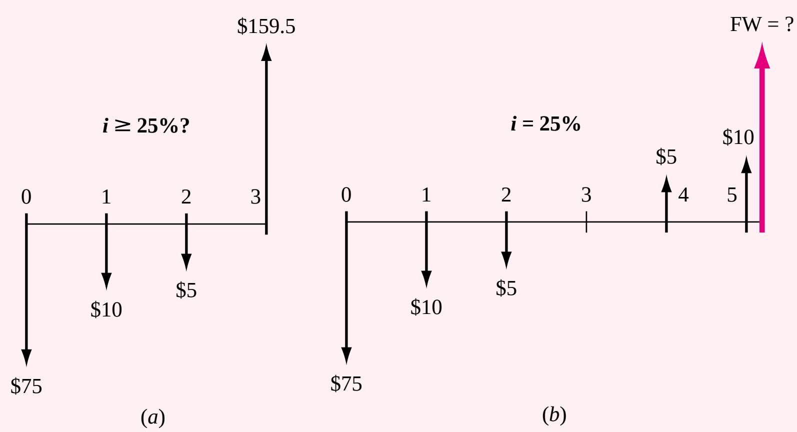


Figure 5–3
Cash flow diagrams for Example 5.3. (*a*) Is MARR = 25% realized? (*b*) What is FW in year 5? Amounts are in 1 million.

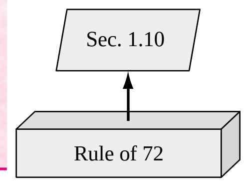
(*b*) Determine the future worth 5 years from now at 25% per year. Figure 5–3*b* presents the cash flow diagram. The A/G and F/A factors are applied to the arithmetic gradient.

$$\text{FW}_5 = -75(F/P,25\%,5) - 10(F/A,25\%,5) + 5(A/G,25\%,5)(F/A,25\%,5)$$
$$= \$-246.81 \text{ million}$$

The offer must be for at least $246.81 million to make the MARR. This is approximately 3.3 times the purchase price only 5 years earlier, in large part based on the required MARR of 25%.

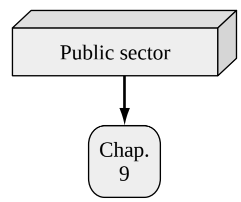
Comment

If the 'rule of 72' in Equation [1.9] is applied at 25% per year, the sales price must double every 72/25% = 2.88 years. This does not consider any annual net positive or negative cash flows during the years of ownership.

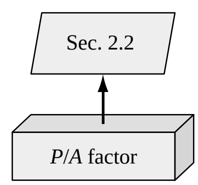


5.5 CAPITALIZED COST CALCULATION AND ANALYSIS

Capitalized cost (CC) is the present worth of an alternative that will last "forever." Public sector projects such as bridges, dams, irrigation systems, and railroads fall into this category. In addition, permanent and charitable organization endowments are evaluated using the capitalized cost methods.



The formula to calculate CC is derived from the relation $P = A(P/A,i,n)$, where $n = \infty$. The equation for P using the P/A factor formula is



$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]$$

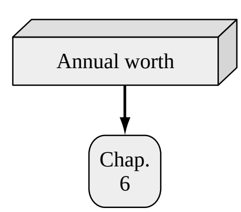
Divide the numerator and denominator by $(1 + i)^n$.

$$P = A\left[\frac{1 - \dfrac{1}{(1+i)^n}}{i}\right]$$

As n approaches ∞, the bracketed term becomes $1/i$, and the symbol CC replaces PW and P.

$$\text{CC} = \frac{A}{i} \qquad [5.1]$$

If the A value is an annual worth (AW) determined through equivalence calculations of cash flows over n years, the CC value is

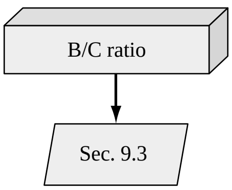


$$\text{CC} = \frac{\text{AW}}{i} \qquad [5.2]$$

The validity of Equation [5.1] can be illustrated by considering the time value of money. If $10,000 earns 20% per year, compounded annually, the maximum amount of money that can be withdrawn at the end of every year for *eternity* is \$2000, or the interest accumulated each year. This leaves the original \$10,000 to earn interest so that another \$2000 will be accumulated the next year. Mathematically, the amount A of new money generated each consecutive interest period for an infinite number of periods is

$$\begin{aligned} A &= Pi \\ &= 10{,}000(0.20) = \$2000 \text{ per period} \end{aligned} \tag{5.3}$$

The capitalized cost calculation in Equation [5.1] is Equation [5.3] solved for P and renamed CC.



For a public sector alternative with an infinite or very long life, the A value determined by Equation [5.3] is used when the benefit/cost (B/C) ratio is the comparison basis for public projects. This method is covered in Chapter 9.

The cash flows (costs or receipts) in a capitalized cost calculation are usually of two types: *recurring*, also called periodic, and *nonrecurring*. An annual operating cost of \$50,000 and a rework cost estimated at \$40,000 every 12 years are examples of recurring cash flows. Examples of nonrecurring cash flows are the initial investment amount in year 0 and one-time cash flow estimates at future times, for example, \$500,000 in royalty fees 2 years hence. The following procedure assists in calculating the CC for an infinite sequence of cash flows.

1. Draw a cash flow diagram showing all nonrecurring (one-time) cash flows and at least two cycles of all recurring (periodic) cash flows.
2. Find the present worth of all nonrecurring amounts. This is their CC value.
3. Find the equivalent uniform annual worth (A value) through one life cycle of all recurring amounts. Add this to all other uniform amounts occurring in years 1 through infinity. This results in a total equivalent uniform annual worth (AW).
4. Divide the AW obtained in step 3 by the interest rate i to obtain a CC value. This is an application of Equation [5.2].
5. Add the CC values obtained in steps 2 and 4.

Drawing the cash flow diagram (step 1) is more important in CC calculations than elsewhere, because it helps separate nonrecurring and recurring amounts. In step 5 the present worths of all component cash flows have been obtained; the total capitalized cost is simply their sum.

EXAMPLE 5.4

The property appraisal district for Marin County has just installed new software to track residential market values for property tax computations. The manager wants to know the total equivalent cost of all future costs incurred when the three county judges agreed to purchase the software system. If the new system will be used for the indefinite future, find the equivalent value (*a*) now and (*b*) for each year hereafter.

The system has an installed cost of \$150,000 and an additional cost of \$50,000 after 10 years. The annual software maintenance contract cost is \$5000 for the first 4 years and

\$8000 thereafter. In addition, there is expected to be a recurring major upgrade cost of \$15,000 every 13 years. Assume that $i = 5\%$ per year for county funds.

Solution

(*a*) The five-step procedure is applied.

1. Draw a cash flow diagram for two cycles (Figure 5–4).
2. Find the present worth of the nonrecurring costs of \$150,000 now and \$50,000 in year 10 at $i = 5\%$. Label this CC_1.

$$CC_1 = -150{,}000 - 50{,}000(P/F{,}5\%{,}10) = \$-180{,}695$$

3. Convert the recurring cost of \$15,000 every 13 years into an annual worth A_1 for the first 13 years.

$$A_1 = -15{,}000(A/F{,}5\%{,}13) = \$-847$$

The same value, $A_1 = \$-847$, applies to all the other 13-year periods as well.

4. The capitalized cost for the two annual maintenance cost series may be determined in either of two ways: (1) consider a series of \$−5000 from now to infinity and find the present worth of −\$8000 − (\$−5000) = \$−3000 from year 5 on; or (2) find the CC of \$−5000 for 4 years and the present worth of \$−8000 from year 5 to infinity. Using the first method, the annual cost (A_2) is \$−5000 forever. The capitalized cost CC_2 of \$−3000 from year 5 to infinity is found using Equation [5.1] times the P/F factor.

$$CC_2 = \frac{-3000}{0.05}(P/F{,}5\%{,}4) = \$-49{,}362$$

The two annual cost series are converted into a capitalized cost CC_3.

$$CC_3 = \frac{A_1 + A_2}{i} = \frac{-847 + (-5000)}{0.05} = \$-116{,}940$$

5. The total capitalized cost CC_T is obtained by adding the three CC values.

$$CC_T = -180{,}695 - 49{,}362 - 116{,}940 = \$-346{,}997$$

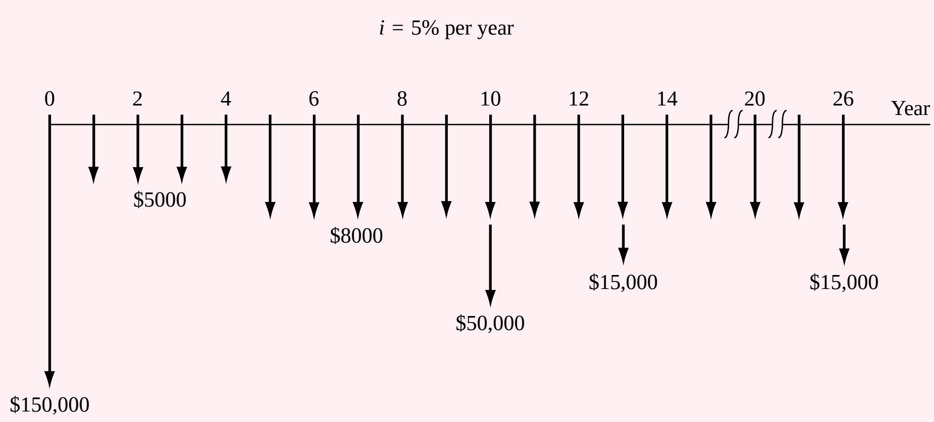


Figure 5–4
Cash flows for two cycles of recurring costs and all nonrecurring amounts, Example 5.4.

EXAMPLE 5.4 CONTINUED

(*b*) Equation [5.3] determines the *A* value forever.

$$A = Pi = \text{CC}_T(i) = \$346{,}997(0.05) = \$17{,}350$$

Correctly interpreted, this means Marin County officials have committed the equivalent of $17,350 forever to operate and maintain the property appraisal software.

Comment

The CC_2 value is calculated using $n = 4$ in the P/F factor because the present worth of the annual $3000 cost is computed in year 4, since P is always one period ahead of the first A. Rework the problem using the second method suggested for calculating CC_2.

For the comparison of two or more alternatives on the basis of capitalized cost, use the procedure above to find CC_T for each alternative. Since the capitalized cost represents the total present worth of financing and maintaining a given alternative forever, the alternatives will automatically be compared for the same number of years (i.e., infinity). The alternative with the smaller capitalized cost will represent the more economical one. This evaluation is illustrated in Example 5.5.

As in present worth analysis, it is only the differences in cash flow between the alternatives that must be considered for comparative purposes. Therefore, whenever possible, the calculations should be simplified by eliminating the elements of cash flow which are common to both alternatives. On the other hand, if true capitalized cost values are needed to reflect actual financial obligations, actual cash flows should be used.

EXAMPLE 5.5

Two sites are currently under consideration for a bridge to cross a river in New York. The north site, which connects a major state highway with an interstate loop around the city, would alleviate much of the local through traffic. The disadvantages of this site are that the bridge would do little to ease local traffic congestion during rush hours, and the bridge would have to stretch from one hill to another to span the widest part of the river, railroad tracks, and local highways below. This bridge would therefore be a suspension bridge. The south site would require a much shorter span, allowing for construction of a truss bridge, but it would require new road construction.

The suspension bridge will cost $50 million with annual inspection and maintenance costs of $35,000. In addition, the concrete deck would have to be resurfaced every 10 years at a cost of $100,000. The truss bridge and approach roads are expected to cost $25 million and have annual maintenance costs of $20,000. The bridge would have to be painted every 3 years at a cost of $40,000. In addition, the bridge would have to be sandblasted every 10 years at a cost of $190,000. The cost of purchasing right-of-way is expected to be $2 million for the suspension bridge and $15 million for the truss bridge. Compare the alternatives on the basis of their capitalized cost if the interest rate is 6% per year.

Solution

Construct the cash flow diagrams over two cycles (20 years). *Capitalized cost of suspension bridge* (CC_S):

$$CC_1 = \text{capitalized cost of initial cost}$$
$$= -50.0 - 2.0 = \$-52.0 \text{ million}$$

The recurring operating cost is $A_1 = \$-35{,}000$, and the annual equivalent of the resurface cost is

$$A_2 = -100{,}000(A/F,6\%,10) = \$-7587$$

$$CC_2 = \text{capitalized cost of recurring costs} = \frac{A_1 + A_2}{i}$$

$$= \frac{-35{,}000 + (-7587)}{0.06} = \$-709{,}783$$

The total capitalized cost is

$$CC_S = CC_1 + CC_2 = \$-52.71 \text{ million}$$

Capitalized cost of truss bridge (CC_T):

$$CC_1 = -25.0 + (-15.0) = \$-40.0 \text{ million}$$
$$A_1 = \$-20{,}000$$
$$A_2 = \text{annual cost of painting} = -40{,}000(A/F,6\%,3) = \$-12{,}564$$
$$A_3 = \text{annual cost of sandblasting} = -180{,}000(A/F,6\%,10) = \$-14{,}415$$
$$CC_2 = \frac{A_1 + A_2 + A_3}{i} = \frac{\$-46{,}979}{0.06} = \$-782{,}983$$
$$CC_T = CC_1 + CC_2 = \$-40.78 \text{ million}$$

Conclusion: Build the truss bridge, since its capitalized cost is lower.

If a finite-life alternative (e.g., 5 years) is compared to one with an indefinite or very long life, capitalized costs can be used for the evaluation. To determine capitalized cost for the alternative with a finite life, calculate the equivalent A value for one life cycle and divide by the interest rate (Equation [5.1]). This procedure is illustrated in the next example.

EXAMPLE 5.6

APSco, a large electronics subcontractor for the Air Force, needs to immediately acquire 10 soldering machines with specially prepared jigs for assembling components onto printed circuit boards. More machines may be needed in the future. The lead production engineer has outlined below two simplified, but viable, alternatives. The company's MARR is 15% per year.

Alternative LT (long-term). For $8 million now, a contractor will provide the necessary number of machines (up to a maximum of 20), now and in the future, for as long as APSco needs them. The annual contract fee is a total of $25,000 with no additional per-machine annual cost. There is no time limit placed on the contract, and the costs do not escalate.

Alternative ST (short-term). APSco buys its own machines for $275,000 each and expends an estimated $12,000 per machine in annual operating cost (AOC). The useful life of a soldering system is 5 years.

Perform a capitalized cost evaluation by hand and by computer. Once the evaluation is complete, use the spreadsheet for sensitivity analysis to determine the maximum number of soldering machines that can be purchased now and still have a capitalized cost less than that of the long-term alternative.

Solution by Hand

For the LT alternative, find the CC of the AOC using Equation [5.1], CC $= A/i$. Add this amount to the initial contract fee, which is already a capitalized cost (present worth) amount.

$$\begin{aligned} CC_{LT} &= \text{CC of contract fee} + \text{CC of AOC} \\ &= -8 \text{ million} - 25{,}000/0.15 = \$-8{,}166{,}667 \end{aligned}$$

For the ST alternative, first calculate the equivalent annual amount for the purchase cost over the 5-year life, and add the AOC values for all 10 machines. Then determine the total CC using Equation [5.2].

$$\begin{aligned} AW_{ST} &= \text{AW for purchase} + \text{AOC} \\ &= -2.75 \text{ million}(A/P{,}15\%{,}5) - 120{,}000 = \$-940{,}380 \\ CC_{ST} &= -940{,}380/0.15 = \$-6{,}269{,}200 \end{aligned}$$

The ST alternative has a lower capitalized cost by approximately $1.9 million present value dollars.

Solution by Computer

E-Solve

Figure 5–5 contains the solution for 10 machines in column B. Cell B8 uses the same relation as in the solution by hand. Cell B15 uses the PMT function to determine the equivalent annual amount A for the purchase of 10 machines, to which the AOC is added. Cell B16 uses Equation [5.2] to find the total CC for the ST alternative. As expected, alternative ST is selected. (Compare CC_{ST} for the hand and computer solutions to note that the round-off error using the tabulated interest factors gets larger for large P values.)

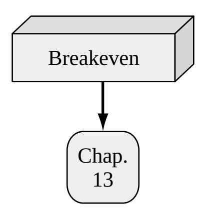
The type of sensitivity analysis requested here is easy to perform once a spreadsheet is developed. The PMT function in B15 is expressed generally in terms of cell B12, the

Figure 5–5
Spreadsheet solution for capitalized cost comparison, Example 5.6.

number of machines purchased. Columns C and D replicate the evaluation for 13 and 14 machines. Thirteen is the maximum number of machines that can be purchased and have a CC less than that of the LT contract. This conclusion is easily reached by comparing total CC values in rows 8 and 16. (*Note:* It is not necessary to duplicate column B into C and D to perform this sensitivity analysis. Changing the entry in cell B12 upward from 10 will provide the same information. Duplication is shown here in order to view all the results on one spreadsheet.)

5.6 PAYBACK PERIOD ANALYSIS

Payback analysis (also called payout analysis) is another extension of the present worth method. Payback can take two forms: one for $i > 0\%$ (also called *discounted payback analysis*) and another for $i = 0\%$. There is a logical linkage between payback and breakeven analysis, which is used in several chapters and discussed in detail in Chapter 13.

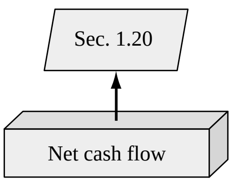


The payback period n_p is the estimated time, usually in years, it will take for the estimated revenues and other economic benefits *to recover the initial investment* *and a stated rate of return.* The n_p value is generally not an integer. It is important to remember the following:

> **The payback period n_p should never be used as the primary measure of worth to select an alternative. Rather, it should be determined in order to provide initial screening or supplemental information in conjunction with an analysis performed using present worth or another method.**

The payback period should be calculated using a required return that is greater than 0%. However, in practice the payback period is often determined with a no-return requirement ($i = 0\%$) to initially screen a project and determine whether it warrants further consideration.

To find the discounted payback period at a stated rate $i > 0\%$, calculate the years n_p that make the following expression correct.



$$0 = -P + \sum_{t=1}^{t=n_p} \text{NCF}_t(P/F,i,t) \qquad [5.4]$$

The amount P is the initial investment or first cost, and NCF is the estimated net cash flow for each year t as determined by Equation [1.8], NCF = receipts − disbursements. If the NCF values are expected to be equal each year, the P/A factor may be used, in which case the relation is

$$0 = -P + \text{NCF}(P/A,i,n_p) \qquad [5.5]$$

After n_p years, the cash flows will recover the investment and a return of i%. If, in reality, the asset or alternative is used for more than n_p years a larger return may result; but if the useful life is less than n_p years, there is not enough time to recover the initial investment and the i% return. It is very important to realize that in payback analysis *all net cash flows occurring after n_p years are neglected.* Since this is significantly different from the approach of PW (or annual worth, or rate of return, as discussed later), where all cash flows for the entire useful life are included in the economic analysis, payback analysis can unfairly bias alternative selection. So use payback analysis only as a screening or supplemental technique.

When $i > 0\%$ is used, the n_p value does provide a sense of the risk involved if the alternative is undertaken. For example, if a company plans to produce a product under contract for only 3 years and the payback period for the equipment is estimated to be 6 years, the company should not undertake the contract. Even in this situation, the 3-year payback period is only supplemental information, not a good substitute for a complete economic analysis.

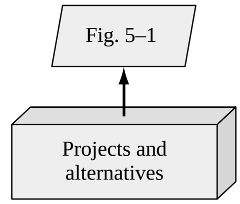
No-return payback (or simple payback analysis determines n_p at $i = 0\%$. This n_p value serves merely as an initial indicator that a proposal is a viable alternative worthy of a full economic evaluation. Use $i = 0\%$ in Equation [5.4] and find n_p.

$$0 = -P + \sum_{t=1}^{t=n_p} \text{NCF}_t \qquad [5.6]$$

For a uniform net cash flow series, Equation [5.6] is solved for n_p directly.

$$n_p = \frac{P}{\ } \qquad [5.7]$$

An example use of n_p as an initial screening of proposed projects is a corporation president who absolutely insists that every project evaluated return the investment in 3 years or less. Therefore, no proposed project with $n_p > 3$ should become an alternative.



It is incorrect to use the no-return payback period to make final alternative selections because it:

1. **Neglects any required return, since the time value of money is omitted.**
2. **Neglects all net cash flows after time n_p, including positive cash flows that may contribute to the return on the investment.**

As a result, the selected alternative may be different from that selected by an economic analysis based on PW (or AW) computations. This fact is demonstrated later in Example 5.8.

EXAMPLE 5.7

The board of directors of Halliburton International has just approved an $18 million worldwide engineering construction design contract. The services are expected to generate new annual net cash flows of $3 million. The contract has a potentially lucrative repayment clause to Halliburton of $3 million at any time that the contract is canceled by either party during the 10 years of the contract period. (*a*) If $i = 15\%$, compute the payback period. (*b*) Determine the no-return payback period and compare it with the answer for $i = 15\%$. This is an initial check to determine if the board made a good economic decision.

Solution

(*a*) The net cash flow each year is $3 million. The single $3 million payment (call it CV for cancellation value) could be received at any time within the 10-year contract period. Equation [5.5] is altered to include CV.

$$0 = -P + \text{NCF}(P/A,i,n) + \text{CV}(P/F,i,n)$$

In $1,000,000 units,

$$0 = -18 + 3(P/A,15\%,n) + 3(P/F,15\%,n)$$

The 15% payback period is $n_p = 15.3$ years. During the period of 10 years, the contract will not deliver the required return.

(*b*) If Halliburton requires absolutely no return on its $18 million investment, Equation [5.6] results in $n_p = 5$ years, as follows (in million $):

$$0 = -18 + 5(3) + 3$$

There is a very significant difference in n_p for 15% and 0%. At 15% this contract would have to be in force for 15.3 years, while the no-return payback period

EXAMPLE 5.7 CONTINUED

Q-Solv

requires only 5 years. A longer time is always required for $i > 0\%$ for the obvious reason that the time value of money is considered.

Use NPER(15%,3,−18,3) to display 15.3 years. Change the rate from 15% to 0% to display the no-return payback period of 5 years.

Comment

The payback calculation provides the number of years required to recover the invested dollars. But from the points of view of engineering economic analysis and the time value of money, no-return payback analysis is not a reliable method for alternative selection.

If two or more alternatives are evaluated using payback periods to indicate that one may be better than the other(s), the second shortcoming of payback analysis (neglect of cash flows after n_p) may lead to an economically incorrect decision. When cash flows that occur after n_p are neglected, it is possible to favor short-lived assets even when longer-lived assets produce a higher return. In these cases, PW (or AW) analysis should always be the primary selection method. Comparison of short- and long-lived assets in Example 5.8 illustrates this incorrect use of payback analysis.

EXAMPLE 5.8

Two equivalent pieces of quality inspection equipment are being considered for purchase by Square D Electric. Machine 2 is expected to be versatile and technologically advanced enough to provide net income longer than machine 1.

	Machine 1	Machine 2
First cost, $	12,000	8,000
Annual NCF, $	3,000	1,000 (years 1–5), 3,000 (years 6–14)
Maximum life, years	7	14

The quality manager used a return of 15% per year and a PC-based economic analysis package. The software utilized Equations [5.4] and [5.5] to recommend machine 1 because it has a shorter payback period of 6.57 years at $i = 15\%$. The computations are summarized here.

Machine 1: $n_p = 6.57$ years, which is less than the 7-year life.

Equation used: $0 = -12{,}000 + 3000(P/A,15\%,n)$

Machine 2: $n_p = 9.52$ years, which is less than the 14-year life.

Equation used:
$$0 = -8000 + 1000(P/A,15\%,5) + 3000(P/A,15\%,n_p-5)(P/F,15\%,5)$$

Recommendation: Select machine 1.

Now, use a 15% PW analysis to compare the machines and comment on any difference in the recommendation.

Solution

For each machine, consider the net cash flows for all years during the estimated (maximum) life. Compare them over the LCM of 14 years.

$$PW_1 = -12{,}000 - 12{,}000(P/F,15\%,7) + 3000(P/A,15\%,14) = \$663$$

$$PW_2 = -8000 + 1000(P/A,15\%,5) + 3000(P/A,15\%,9)(P/F,15\%,5)$$

$$= \$2470$$

Machine 2 is selected since its PW value is numerically larger than that of machine 1 at 15%. This result is the opposite of the payback period decision. The PW analysis accounts for the increased cash flows for machine 2 in the later years. As illustrated in Figure 5–6 (for one life cycle for each machine), payback analysis neglects all cash flow amounts that may occur after the payback time has been reached.

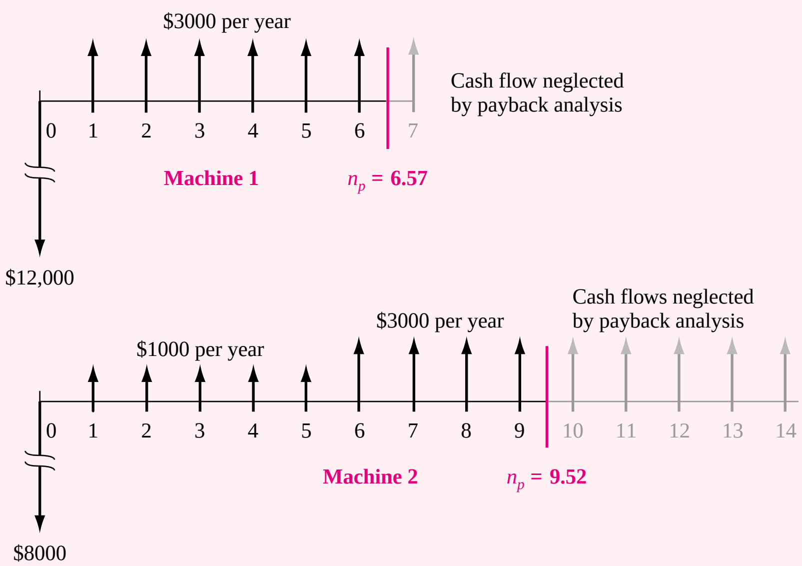


Figure 5–6
Illustration of payback periods and neglected net cash flows, Example 5.8.

Comment

This is a good example of why payback analysis is best used for initial screening and supplemental risk assessment. Often a shorter-lived alternative evaluated by payback analysis may appear to be more attractive, when the longer-lived alternative has cash flows estimated later in life that make it more economically attractive.

5.7 LIFE-CYCLE COST

Life-cycle cost (LCC) is another extension of present worth analysis. The PW value at a stated MARR is utilized to evaluate one or more alternatives. The LCC method, as its name implies, is commonly applied to alternatives with cost estimates over the entire *system life span*. This means that costs from the very early stage of the project (needs assessment) through the final stage (phaseout and disposal) are estimated. Typical applications for LCC are buildings (new construction or purchases), new product lines, manufacturing plants, commercial aircraft, new automobile models, defense systems, and the like.

A PW analysis with all definable costs (and possibly incomes) estimated may be considered a LCC analysis. However, the broad definition of the LCC term *system life span* requires cost estimates not usually made for a regular PW analysis. Also, for large long-life projects, the longer-term estimates are less accurate. This implies that life-cycle cost analysis is not necessary in most alternative analysis. *LCC is most effectively applied when a substantial percentage of the total costs over the system life span, relative to the initial investment, will be operating and maintenance costs* (postpurchase costs such as labor, energy, upkeep, and materials). For example, if Exxon-Mobil is evaluating the purchase of equipment for a large chemical processing plant for $150,000 with a 5-year life and annual costs of $15,000 (or 10% of first cost), the use of LCC analysis is probably not justified. On the other hand, suppose General Motors is considering the design, construction, marketing, and after-delivery costs for a new automobile model. If the total start-up cost is estimated at $125 million (over 3 years) and total annual costs are expected to be 20% of this figure to build, market, and service the cars for the next 15 years (estimated life span of the model), then the logic of LCC analysis will help GM engineers understand the profile of costs and their economic consequences in PW terms. (Of course, future worth and annual worth equivalents can also be calculated). LCC is required for most defense and aerospace industries, where the approach may be called Design to Cost. LCC is usually not applied to public sector projects, because the benefits and costs to the citizenry are difficult to estimate with much accuracy. Benefit/cost analysis is better applied here, as discussed in Chapter 9.

To understand how a LCC analysis works, first we must understand the phases and stages of systems engineering or systems development. Many books and manuals are available on systems development and analysis. Generally, the LCC estimates may be categorized into a simplified format for the major phases of *acquisition* and *operation,* and their respective stages.

Acquisition phase: all activities prior to the delivery of products and services.

- Requirements definition stage—Includes determination of user/customer needs, assessing them relative to the anticipated system, and preparation of the system requirements documentation.
- Preliminary design stage—Includes feasibility study, conceptual, and early-stage plans; final go–no go decision is probably made here.
- Detailed design stage—Includes detailed plans for resources—capital, human, facilities, information systems, marketing, etc.; there is some acquisition of assets, if economically justifiable.

Operations phase: all activities are functioning, products and services are available.

- Construction and implementation stage—Includes purchases, construction, and implementation of system components; testing; preparation, etc.
- Usage stage—Uses the system to generate products and services.
- Phaseout and disposal stage—Covers time of clear transition to new system; removal/recycling of old system.

EXAMPLE 5.9

In the 1860 General Mills Inc. and Pillsbury Inc. both started in the flour business in the Twin Cities of Minneapolis–St. Paul, Minnesota. In the 2000–2001 time frame, General Mills purchased Pillsbury for a combination cash and stock deal worth more than $10 billion. The General Mills promise was to develop Pillsbury's robust food line to meet consumer needs, especially in the "one hand free" prepared-food markets in order to appeal to the rapidly changing eating habits and nutrition needs of people at work and play who have no time for or interest in preparing meals. Food engineers, food designers, and food safety experts made many cost estimates as they determined the needs of consumers and the combined company's ability to technologically and safely produce and market new food products. At this point only cost estimates have been addressed—no revenues or profits.

Assume that the major cost estimates below have been made based on a 6-month study about two new products that could have a 10-year life span for the company. Some cost elements were not estimated (e.g., raw food stuffs, product distribution, and phaseout). Use LCC analysis at the industry MARR of 18% to determine the size of the commitment in PW dollars. (Time is indicated in product-years.)

Consumer habits study (year 0)	$0.5 million
Preliminary food product design (year 1)	0.9 million
Preliminary equipment/plant design (year 1)	0.5 million
Detail product designs and test marketing (years 1, 2)	1.5 million each year
Detail equipment/plant design (year 2)	1.0 million
Equipment acquisition (years 1 and 2)	$2.0 million each year
Current equipment upgrades (year 2)	1.75 million
New equipment purchases (years 4 and 8)	2.0 million (year 4) + 10% per purchase thereafter
Annual equipment operating cost (AOC) (years 3–10)	200,000 (year 3) + 4% per year thereafter
Marketing, year 2	$8.0 million
years 3–10	5.0 million (year 3) and −0.2 million per year thereafter
year 5 only	3.0 million extra
Human resources years 3–10, 100 new employees for 2000 hours per year	$20 per hour (year 3) + 5% per year

EXAMPLE 5.9 CONTINUED

Solution

LCC analysis can get complicated rapidly due to the number of elements involved. Calculate the PW by phase and stage, then add all PW values. Values are in $1 million units.

Acquisition phase:
Requirements definition: consumer study

$$\text{PW} = \$0.5$$

Preliminary design: product and equipment

$$\text{PW} = 1.4\,(P/F,18\%,1) = \$1.187$$

Detailed design: product and test marketing, and equipment

$$\text{PW} = 1.5(P/A,18\%,2) + 1.0(P/F,18\%,2) = \$3.067$$

Operations phase:
Construction and implementation: equipment and AOC

$$\text{PW} = 2.0(P/A,18\%,2) + 1.75(P/F,18\%,2) + 2.0(P/F,18\%,4) + 2.2(P/F,18\%,8)$$

$$+\ 0.2\left[\frac{1-\left(\frac{1.04}{1.18}\right)^{8}}{0.14}\right](P/F,18\%,2) = \$6.512$$

Use: marketing

$$\begin{aligned}\text{PW} &= 8.0(P/F,18\%,2) + [5.0(P/A,18\%,8) - 0.2(P/G,18\%,8)](P/F,18\%,2)\\ &\quad + 3.0(P/F,18\%,5)\\ &= \$20.144\end{aligned}$$

Use: human resources: (100 employees)(2000 h/yr)($20/h) = $4.0 million in year 3

$$\text{PW} = 4.0\left[\frac{1-\left(\frac{1.05}{1.18}\right)^{8}}{0.13}\right](P/F,18\%,2) = \$13.412$$

The total LCC commitment at this time is the sum of all PW values.

$$\text{PW} = \$44.822 \text{ (effectively \$45 million)}$$

As a point of interest, over 10 years at 18% per year, the future worth of the General Mills commitment, thus far, is FW = PW(F/P,18%,10) = $234.6 million.

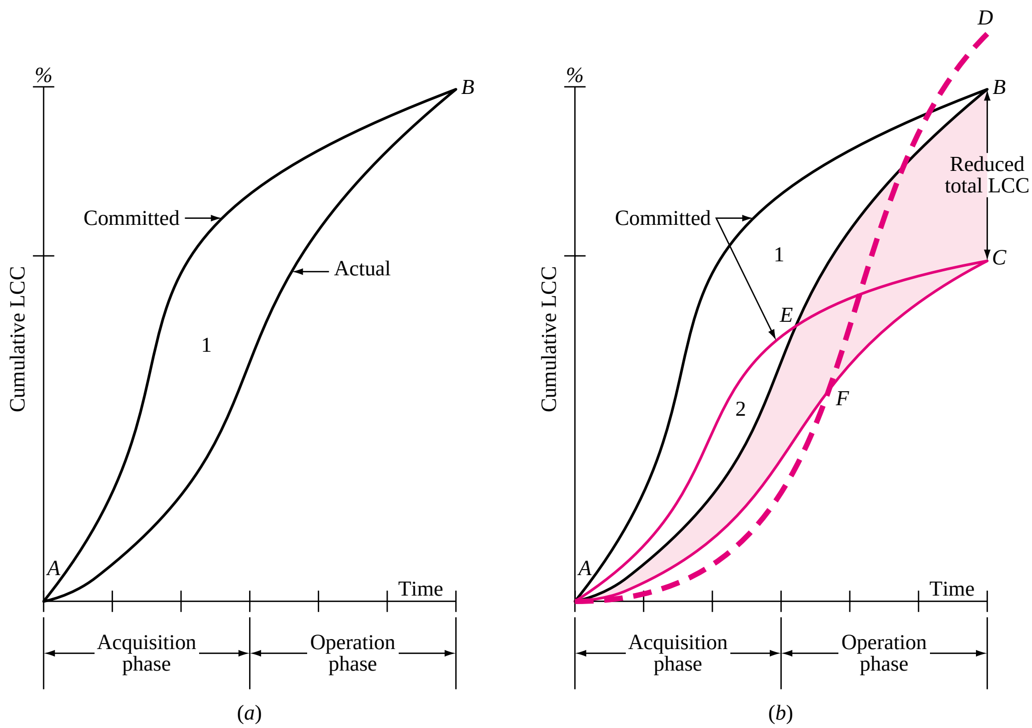


Figure 5–7
LCC envelopes for committed and actual costs: (*a*) design 1, (*b*) improved design 2.

The total LCC for a system is established or locked in early. It is not unusual to have 75 to 85% of the entire life span LCC committed during the preliminary and detail design stages. As shown in Figure 5–7*a*, the actual or observed LCC (bottom curve *AB*) will trail the committed LCC throughout the life span (unless some major design flaw increases the total LCC of design #1 above point *B*). *The potential for significantly reducing total LCC occurs primarily during the early stages.* A more effective design and more efficient equipment can reposition the envelope to design #2 in Figure 5–7*b*. Now the committed LCC curve *AEC* is below *AB* at all points, as is the actual LCC curve *AFC*. It is this lower envelope #2 we seek. The hatched area represents the reduction in actual LCC.

Even though an effective LCC envelope may be established early in the acquisition phase, it is not uncommon that unplanned cost-saving measures are introduced during the acquisition phase and early operation phase. These apparent "savings" may actually increase the total LCC, as shown by curve *AFD*. This style of ad hoc cost savings, often imposed by management early in the design stage and/or construction stage, can substantially increase costs later, especially in the after-sale portion of the use stage. For example, the use of inferior-strength concrete and steel has been the cause of structural failures many times, thus increasing the overall life span LCC.

5.8 PRESENT WORTH OF BONDS

A time-tested method of raising capital is through the issuance of an IOU, which is financing through debt, not equity, as discussed in Chapter 1. One very common form of IOU is a bond—a long-term note issued by a corporation or a government entity (the borrower) to finance major projects. The borrower receives money now in return for a promise to pay the *face value V* of the bond on a stated maturity date. Bonds are usually issued in face value amounts of $100, $1000, $5000, or $10,000. *Bond interest I,* also called *bond dividend*, is paid periodically between the time the money is borrowed and the time the face value is repaid. The bond interest is paid *c* times per year. Expected payment periods are usually quarterly or semiannually. The amount of interest is determined using the stated interest rate, called the *bond coupon rate b.*

$$I = \frac{\text{(face value)(bond coupon rate)}}{\text{number of payment periods per year}}$$

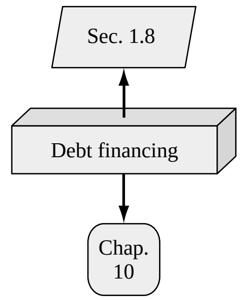
$$I = \frac{Vb}{c} \qquad [5.8]$$

There are many types or classifications of bonds. Four general classifications are summarized in Table 5–1 according to their issuing entity, some fundamental characteristics, and example names or purposes. For example, *Treasury securities* are issued in different monetary amounts ($1000 and up) with varying periods of time to the maturity date (Bills up to 1 year; Notes for 2 to 10 years). In

TABLE 5–1 Classification and Characteristics of Bonds

Classification	Issued by	Characteristics	Examples
Treasury securities	Federal government	Backed by U.S. government	Bills (≤ 1 year) Notes (2–10 years) Bonds (10–30 years)
Municipal	Local governments	Federal tax-exempt Issued against taxes received	General obligation Revenue Zero coupon Put
Mortgage	Corporation	Backed by specified assets or mortgage Low rate/low risk on first mortgage Foreclosure, if not repaid	First mortgage Second mortgage Equipment trust
Debenture	Corporation	Not backed by collateral, but by reputation of corporation Bond rate may 'float' Higher interest rates and higher risks	Convertible Subordinated Junk or high yield

the United States, Treasury securities are considered a very safe bond purchase because they are backed with the "full faith and credit of the U.S. government." The safe investment rate indicated in Figure 1–6 as the lowest level for establishing a MARR is the coupon rate on a U.S. Treasury security. As another illustration, *debenture bonds* are issued by corporations in order to raise capital, but they are not backed by any particular form of collateral. The corporation's reputation attracts bond purchasers, and the corporation may make the bond interest rate 'float' to further attract buyers. Often debenture bonds are *convertible* to common stock of the corporation at a fixed rate prior to their maturity date.



EXAMPLE 5.10

Procter and Gamble Inc. has issued $5,000,000 worth of $5000 ten-year debenture bonds. Each bond pays interest quarterly at 6%. (*a*) Determine the amount a purchaser will receive each 3 months and after 10 years. (*b*) Suppose a bond is purchased at a time when it is discounted by 2% to $4900. What are the quarterly interest amounts and the final payment amount at the maturity date?

Solution

(*a*) Use Equation [5.8] for the quarterly interest amount.

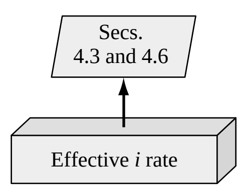
$$I = \frac{(5000)(0.06)}{4} = \$75$$

The face value of $5000 is repaid after 10 years.

(*b*) Purchasing the bond at a discount from face value does not change the interest or final repayment amounts. Therefore, $75 per quarter and $5000 after 10 years remain the amounts.

Finding the PW value of a bond is another extension of present worth analysis. When a corporation or government agency offers bonds, potential purchasers can determine how much they should be willing to pay in PW terms for a bond of a stated denomination. The amount paid at purchase time establishes the rate of return for the remainder of the bond life. The steps to calculate the PW of a bond are as follows:

1. Determine I, the interest per payment period, using Equation [5.8].
2. Construct the cash flow diagram of interest payments and face value repayment.
3. Establish the required MARR or rate of return.
4. Calculate the PW value of the bond interest payments and the face value at i = MARR. (If the bond interest payment period is not equal to the MARR compounding period, that is, PP $\neq$ CP, first use Equation [4.8] to determine the effective rate per payment period. Use this rate and the logic of Section 4.6 for PP $\geq$ CP to complete the PW calculations.)



Use the following logic:

PW $\geq$ bond purchase price; MARR is met or exceeded, buy the bond.
PW $<$ bond purchase price; MARR is not met, do not buy the bond.

EXAMPLE 5.11

Determine the purchase price you should be willing to pay now for a 4.5% \$5000 10-year bond with interest paid semiannually. Assume your MARR is 8% per year, compounded quarterly.

Solution

First, determine the semiannual interest.

$$I = 5000(0.045)/2 = \$112.50 \text{ every 6 months}$$

The present worth of all bond payments to you (Figure 5–8) is determined in either of two ways.

1. *Effective semiannual rate.* Use the approach of Section 4.6. The cash flow period is PP = 6 months, and the compounding period is CP = 3 months; PP $>$ CP. Find the effective semiannual rate, then apply P/A and P/F factors to the interest payments and \$5000 receipt in year 10. The nominal semiannual MARR is $r = 8\%/2 = 4\%$. For $m = 2$ quarters per 6-months, Equation [4.8] yields

$$\text{Effective } i\% = \left(1 + \frac{0.04}{2}\right)^2 - 1 = 4.04\% \text{ per 6-months}$$

The PW of the bond is determined for $n = 2(10) = 20$ semiannual periods.

$$\text{PW} = \$112.50(P/A,4.04\%,20) + 5000(P/F,4.04\%,20) = \$3788$$

2. *Nominal quarterly rate.* Find the PW of each \$112.50 semiannual bond interest receipt in year 0 separately with a P/F factor, and add the PW of the \$5000 in year 10. The nominal quarterly MARR is $8\%/4 = 2\%$. The total number of

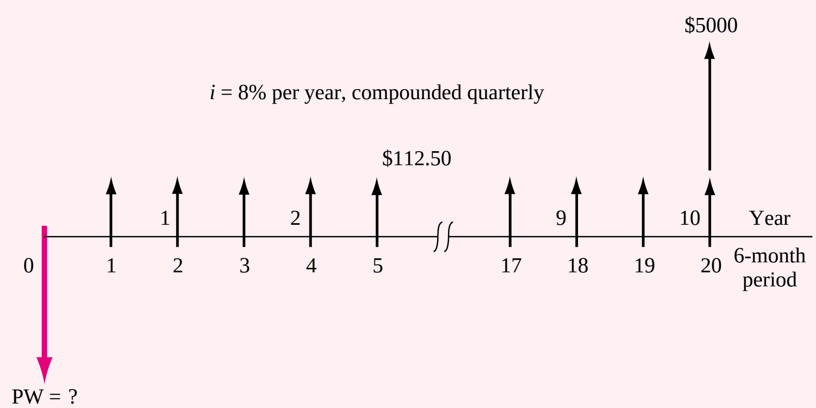


Figure 5–8
Cash flow for the present worth of a bond, Example 5.11.

periods is $n = 4(10) = 40$ quarters, double those shown in Figure 5–8, since the payments are made semiannually while the MARR is compounded quarterly.

$$\begin{aligned} \text{PW} &= 112.50(P/F,2\%,2) + 112.50(P/F,2\%,4) + \cdots + 112.50(P/F,2\%,40) \\ &\quad + 5000(P/F,2\%,40) \\ &= \$3788 \end{aligned}$$

If the asking price is more than \$3788 for the bond, which is a discount of more than 24%, you will not make the MARR.

The spreadsheet function PV(4.04%,20,112.50,5000) displays the PW value of \$3788.

Q-Solv

5.9 SPREADSHEET APPLICATIONS—PW ANALYSIS AND PAYBACK PERIOD

Example 5.12 illustrates how to set up a spreadsheet for PW analysis for different-life alternatives and for a specified study period. Example 5.13 demonstrates the technique and shortcomings of payback period analysis for $i > 0\%$. Both hand and computer solutions are presented.

Some general guidelines help organize spreadsheets for any PW analysis. The LCM of the alternatives dictates the number of row entries for initial investment and salvage/market values, based on the repurchase assumption that PW analysis requires. Some alternatives will be service-based (cost cash flows only); others are revenue-based (cost and income cash flows). Place the annual cash flows in separate columns from the investment and salvage amounts. This reduces the amount of number processing you have to do before entering a cash flow value. Determine the PW values for all columns pertinent to an alternative, and add them to obtain the final PW value.

Spreadsheets can become crowded very rapidly. However, placing the NPV functions at the head of each cash flow column and inserting a separate summary table make the component and total PW values stand out. Finally, place the MARR value in a separate cell, so sensitivity analysis on the required return can be easily accomplished. Example 5.12 illustrates these guidelines.

EXAMPLE 5.12

Southeastern Cement plans to open a new rock pit. Two plans have been devised for movement of raw material from the quarry to the plant. Plan A requires the purchase of two earthmovers and construction of an unloading pad at the plant. Plan B calls for construction of a conveyor system from the quarry to the plant. The costs for each plan are detailed in Table 5–2. (*a*) Using spreadsheet-based PW analysis, determine which plan should be selected if money is worth 15% per year. (*b*) After only 6 years of operation a major environmental problem made Southeastern stop all operations at the rock pit. Use a 6-year study period to determine if plan A or B was economically better. The market value of each mover after 6 years is \$20,000, and the trade-in value of the conveyor after 6 years is only \$25,000. The pad can be salvaged for \$2000.

EXAMPLE 5.12 CONTINUED

TABLE 5–2 Estimates for Plans to Move Rock from Quarry to Cement Plant

	Plan A		Plan B
	Mover	Pad	Conveyor
Initial cost, $	−45,000	−28,000	−175,000
Annual operating cost, $	−6,000	−300	−2,500
Salvage value, $	5,000	2,000	10,000
Life, years	8	12	24

Solution

(*a*) Evaluation must take place over the LCM of 24 years. Reinvestment in the two movers will occur in years 8 and 16, and the unloading pad must be rebuilt in year 12. No reinvestment is necessary for plan B. First, construct the cash flow diagrams for plans A and B over 24 years to better understand the spreadsheet analysis in Figure 5–9. Columns B, D, and F include all investments, reinvestments, and salvage values. (*Remember to enter zeros in all cells with no cash flows, or the NPV function will give an incorrect PW value.*) These are service-based alternatives, so columns C, E, and G display the AOC estimates, labeled "Annual CF". NPV functions provide the PW amounts in row 8 cells. These are added by alternative in cells H19 and H22.

Conclusion: Select plan B because the PW of costs is smaller.

(*b*) Both alternatives are abruptly terminated after 6 years, and current market or trade-in values are estimated. To perform the PW analysis for a severely truncated study period, Figure 5–10 uses the same format as that for the 24-year analysis, except for two major alterations. Cells in row 16 now include the market and trade-in amounts, and all rows after 16 are deleted. See the cell tags in row 9 for the new NPV functions for the 6 years of cash flows. Cells D20 and D21 are the PW values found by summing the appropriate PW values in row 9.

Conclusion: Plan A should have been selected, had the termination after 6 years been known at the design stage of the rock pit.

Comment

The spreadsheet solution for part (*b*) was developed by initially copying the entire worksheet in part (*a*) to sheet 2 of the Excel workbook. Then the changes outlined above were made to the copy. Another method uses the same worksheet to build the new NPV functions as shown in Figure 5–10 cell tags, but on the Figure 5–9 worksheet after inserting a new row 16 for year 6 cash flows. This approach is faster and less formal than the method demonstrated here. There is one real danger in using the one-worksheet approach to solving this (or any sensitivity analysis) problem. The altered worksheet now solves a different problem, so the functions display new answers. For example, when the cash flows are truncated to a 6-year study period, the old NPV functions in row 8 must be changed, or the new NPV functions must be added in row 9. But now the NPV functions of the old 24-year PW analysis display incorrect answers, or possibly an Excel error message. This introduces error possibilities into the decision making. For accurate, correct results, take the time to copy the first sheet to a new worksheet and make the changes on the copy. Store both solutions after documenting what each sheet is designed to analyze. This provides a historical record of what was altered during the sensitivity analysis.

Figure 5–9
Spreadsheet solution using PW analysis of different-life alternatives, Example 5.12(*a*).

EXAMPLE 5.12 CONTINUED

Figure 5–10
Spreadsolvt solution for 6-year study period using PW analysis, Example 5.12(*b*).

EXAMPLE 5.13

Biothermics has agreed to a licensee agreement for safety engineering software that was developed in Australia and is being introduced into North America. The initial license rights cost \$60,000 with annual rights fees of \$1800 the first year, increasing by \$100 per year thereafter until the license agreement is sold to another party or terminated. Biothermics must keep the agreement at least 2 years. Use hand and spreadsheet analysis to determine the payback period (in years) at $i = 8\%$ for two scenarios:

(*a*) Sell the software rights for \$90,000 sometime beyond year 2.
(*b*) If the license is not sold by the time determined in (*a*), the selling price will increase to \$120,000 in future years.

Solution by Hand

(*a*) From Equation [5.4], it is necessary that PW = 0 at the 8% payback period n_p. Set up the PW relation for $n \geq 3$ years, and determine the number of years at which PW crosses the zero value.

$$0 = -60{,}000 - 1800(P/A,8\%,n) - 100(P/G,8\%,n) + 90{,}000(P/F,8\%,n)$$

n, Years	3	4	5
PW Value	\$6562	\$−274	\$−6672

The 8% payback is between 3 and 4 years. By linear interpolation, $n_p = 3.96$ years.

(*b*) If the license is not sold prior to 4 years, the price goes up to \$120,000. The PW relation for 4 or more years and the PW values for *n* are

$$0 = -60{,}000 - 1800(P/A,8\%,n) - 100(P/G,8\%,n) + 120{,}000(P/F,8\%,n)$$

n, Years	5	6	7
PW Value	\$13,748	\$6247	\$−755

The 8% payback is now between 6 and 7 years. By interpolation, $n_p = 6.90$ years.

Solution by Computer

(*a* and *b*) Figure 5–11 presents a spreadsheet that lists the software rights costs (column B) and expected selling price (columns C and E). The NPV functions in column D (selling

E-Solve

Figure 5–11

Determination of payback period using a spreadsheet, Example 5.13(*a*) and (*b*).

EXAMPLE 5.13 CONTINUED

price \$90,000) show the payback period to be between 3 and 4 years, while the NPV results in column F (selling price \$120,000) indicate PW switching from positive to negative between 6 and 7 years. The NPV functions reflect the relations presented in the hand solution, except the cost gradient of \$100 has been incorporated into the costs in column B.

If more exact payback values are needed, interpolate between the PW results on the spreadsheet. The values will be the same as in the solution by hand, namely, 3.96 and 6.90 years.

CHAPTER SUMMARY

The present worth method of comparing alternatives involves converting all cash flows to present dollars at the MARR. The alternative with the numerically larger (or largest) PW value is selected. When the alternatives have different lives, the comparison must be made for equal-service periods. This is done by performing the comparison over either the LCM of lives or a specific study period. Both approaches compare alternatives in accordance with the equal-service requirement. When a study period is used, any remaining value in an alternative is recognized through the estimated future market value.

Life-cycle cost analysis is an extension of PW analysis performed for systems that have relatively long lives and a large percentage of their lifetime costs in the form of operating expenses. If the life of the alternatives is considered to be infinite, capitalized cost is the comparison method. The CC value is calculated as A/i, because the P/A factor reduces to $1/i$ in the limit of $n = \infty$.

Payback analysis estimates the number of years necessary to recover the initial investment plus a stated rate of return (MARR). This is a supplemental analysis technique used primarily for initial screening of proposed projects prior to a full economic evaluation by PW or some other method. The technique has some drawbacks, especially for no-return payback analysis, where $i = 0\%$ is used as the MARR.

Finally, we learned about bonds. Present worth analysis determines if the MARR will be obtained over the life of a bond, given specific values for the bond's face value, term, and interest rate.

PROBLEMS

Types of Projects

5.1 What is the difference between mutually exclusive and independent projects?

5.2 When is the do-nothing alternative usually an option?

5.3 What is the difference in the assumption about revenues between service and revenue projects?

5.4 Read the statement in the following problems and example and determine if the cash flows define a revenue or a service project: (*a*) Problem 1.32 from the bank's perspective; (*b*) Problem 1.33; (*c*) Problem 2.18; (*d*) Example 2.4; and (*e*) Problem 3.21.

5.5 A rapidly growing city is dedicated to neighborhood integrity. However, increasing traffic and speed on a through street are of concern to residents. The city manager has proposed five independent options to slow traffic:

1. Stop sign at corner A.
2. Stop sign at corner B.
3. Low-profile speed bump at point C.
4. Low-profile speed bump at point D.
5. Speed dip at point E.

There cannot be any of the following combinations in the final alternatives:

- No combination of dip and one or two bumps.
- Not two bumps.
- Not two stop signs.

Use the five independent options and the restrictions to determine (*a*) the total number of mutually exclusive alternatives possible and (*b*) the acceptable mutually exclusive alternatives.

Alternative Comparison

5.6 A consulting engineering firm is considering two models of automobiles for the company principals. A U.S. model will have a first cost of $22,000, on operating cost of $2000, and a salvage value of $12,000 after 3 years. A Japanese model will have a first cost of $26,000, an operating cost of $1200, and a $15,000 resale value after 3 years. At an interest rate of 15% per year, which model should the consulting firm buy?

5.7 A remotely located air sampling station can be powered by solar cells or by running an electric line to the site and using conventional power. Solar cells will cost $12,600 to install and will have a useful life of 4 years with no salvage value. Annual costs for inspection, cleaning, etc., are expected to be $1400. A new power line will cost $11,000 to install, with power costs expected to be $800 per year. Since the air sampling project will end in 4 years, the salvage value of the line is considered to be zero. At an interest rate of 14% per year, which alternative should be selected?

5.8 An electric utility is considering two alternatives for satisfying state regulations regarding pollution control for one of its generating stations. This particular station is located at the outskirts of a major U.S. city and a short distance from a large city in a neighboring country. The station is currently producing excess VOC's and oxides of nitrogen. Two plans have been proposed for satisfying the regulators. Plan A involves replacing the burners and switching from fuel oil to natural gas. The cost of the option will be $300,000 initially and an extra $900,000 per year in fuel costs. Plan B involves going to the foreign city and running gas lines to many of the "backyard" brick-making sites that now use wood, tires, and other combustible waste materials for firing the bricks. The idea behind plan B is that by reducing the particulate pollution responsible for smog in the neighboring city, there would be greater benefit to U.S. citizens than would be achieved through plan A. The initial cost of plan B will be $1.2 million for installation of the lines. Additionally, the electric company would subsidize the cost of gas for the brick makers to the extent of $200,000 per year. Extra air monitoring associated with this plan will cost an additional $150,000 per year. For a 10-year project period and no salvage value for either plan, which one should be selected on the basis of a present worth analysis at an interest rate of 12% per year?

5.9 Polymer Molding, Inc., is considering two processes for manufacturing storm drains. Plan A involves conventional injection molding that will require making a steel mold at a cost of $2 million. The cost for inspecting, maintaining, and cleaning the molds is expected to be $5000 per month. Since the cost of materials for this plan is expected to be the same as for the other plan, this cost will not be included in the comparison. The salvage value for plan A is expected to be 10% of the first cost. Plan B involves using an innovative process known as virtual engineered composites wherein a floating mold uses an operating system that constantly adjusts the water pressure around the mold and the chemicals entering the process. The first cost to tool the floating mold is only $22,000, but because of the newness of the process, personnel and product-reject costs are expected to be higher than for a conventional process. The company expects the operating costs to be $45,000 for the first 6 months and then decrease to $10,000 per month thereafter. There will be no salvage value with this plan. At an interest rate of 18% per year, compounded monthly, which process should the company select on the basis of a present worth analysis over a 3-year study period?

5.10 A chemical engineer is considering two styles of pipes for moving distillate from a refinery to the tank farm. A small pipeline will cost less to purchase (including valves and other appurtenances) but will have a high head loss and, therefore, a higher pumping cost. The small pipeline will cost $1.7 million installed and will have an operating cost of $12,000 per month. A larger-diameter pipeline will cost $2.1 million installed, but its operating cost will be only $9000 per month. Which pipe size is more economical at an interest rate of 1% per month on the basis of a present worth analysis? Assume a salvage value at 10% of the first cost for each pipe size at the end of the 10-year project period.

Alternative Comparison over Different Time Periods

5.11 Accurate air flow measurement requires straight unobstructed pipe for a minimum of 10 diameters upstream and 5 diameters downstream of the measuring device. In one particular application, physical constraints compromised the pipe layout, so the engineer was considering installing the air flow probes in an elbow, knowing that flow measurement would be less accurate but good enough for process control. This was plan A, which would be acceptable for only 2 years, after which an accurate flow measurement system would be needed. This plan would have a first cost of $25,000 with annual maintenance estimated at $4000. Plan B involved installation of a recently designed submersible air flow probe. The stainless steel probe could be installed in a drop pipe with the transmitter located in a waterproof enclosure on the handrail. The cost of this system would be $88,000, but because it is accurate, it would not have to be replaced for at least 6 years. Its maintenance cost is estimated to be $1400 per year. Neither system will have a salvage value. At an interest rate of 15% per year, which one should be selected on the basis of a present worth comparison?

5.12 A mechanical engineer is considering two types of pressure sensors for a low-pressure steam line. The costs are shown below. Which should be selected based on using a present worth comparison at an interest rate of 16% per year?

	Type X	Type Y
First cost, $	−7,650	−12,900
Maintenance cost, $/year	−1,200	−900
Salvage value, $	0	2,000
Life, years	2	4

5.13 A metallurgical engineer is considering two materials for use in a space vehicle. The costs are shown below. Which should be selected on the basis of a present worth comparison at an interest rate of 18% per year?

	Material JX	Material KZ
First cost, $	−15,000	−35,000
Maintenance cost, $/year	−9,000	−7,000
Salvage value	2,000	20,000
Life, years	3	6

5.14 An environmental engineer is considering three methods for disposing of a nonhazardous chemical sludge: land application, fluidized-bed incineration, and private disposal contract. The details of each method are shown below. Determine which has the least cost on the basis of a present worth comparison at 15% per year.

	Land Application	Incineration	Contract
First cost, $	−110,000	−800,000	0
Annual cost, $/year	−95,000	−60,000	−190,000
Salvage value, $	15,000	250,000	0
Life, years	3	6	2

Future Worth Comparison

5.15 An industrial engineer is considering two robots for purchase by a fiber-optic manufacturing company. Robot X will have a first cost of $82,000, an annual maintenance and operation (M&O) cost of $30,000, and a $40,000 salvage value. Robot Y will have a first cost of $97,000, an annual M&O cost of $27,000, and a $50,000 salvage value. Which should be selected on the basis of a future worth comparison at an interest rate of 15% per year? Use a 3-year study period.

5.16 The machines shown below are under consideration for an improvement to an automated candy bar wrapping process. Determine which should be selected on the basis of a future worth analysis using an interest rate of 20% per year.

	Machine C	Machine D
First cost, $	−40,000	−65,000
Annual cost, $/year	−10,000	−12,000
Salvage value, $	12,000	25,000
Life, years	3	6

5.17 Two processes can be used for producing a polymer that reduces friction loss in engines. Process K will have a first cost of $160,000, an operating cost of $7000 per month, and a salvage value of $40,000 after its 2-year life. Process L will have a first cost of $210,000, an operating cost of $5000 per month, and a $26,000 salvage value after its 4-year life. Which process should be selected on the basis of a future worth analysis at an interest rate of 12% per year, compounded monthly?

5.18 Two mutually exclusive projects have the estimated cash flows shown below. Use a future worth analysis to determine which should be selected at an interest rate of 15% per year.

	Q	R
First cost, $	−42,000	−80,000
Annual cost, $/year	−6,000	−7,000 year 1, increasing by $1000 per year
Salvage value, $	0	4,000
Life, years	2	4

Capitalized Costs

5.19 Determine the capitalized cost of $100,000 at time 0, $25,000 in years 1 through 5, and $50,000 per year from year 6 on. Use an interest rate of 10% per year.

5.20 Determine the capitalized cost of an alternative that has a first cost of $32,000, an annual maintenance cost of $6000, and a salvage value of $8000 after its 4-year life. Use an interest rate of 14% per year.

5.21 An alumna of Ohio State University wanted to set up an endowment that would award five female engineering students scholarships of $20,000 per year forever. The first five scholarships are to be granted beginning at the end of year 4 and continue forever. How much must the alumna donate now, if the endowment fund is expected to earn interest at a rate of 8% per year?

5.22 What is the present worth *difference* between an investment of $10,000 per year for 100 years and an investment of $10,000 per year forever at an interest rate of 10% per year?

5.23 Two large-scale conduits are under consideration by a large municipal utility district (MUD). The first involves construction of a steel pipeline at a cost of $200 million. The pumping and other operating costs are expected to be $6 million per year. Alternatively, a gravity flow canal can be constructed at a cost of $325 million. The M&O costs for the canal are expected to be $1 million per year. If both conduits are expected to last forever, which should be built at an interest rate of 10% per year?

5.24 Compare the alternatives shown below on the basis of their capitalized costs, using an interest rate of 10% per year.

	Alternative V	Alternative W
First cost, $	−50,000	−500,000
Annual cost, $/year	−30,000	−1,000
Salvage value, $	10,000	500,000
Life, years	10	∞

5.25 Compare the alternatives shown below on the basis of their capitalized costs using an interest rate 12% per year, compounded semiannually.

	Alternative E	Alternative F	Alternative G
First cost, $	−50,000	−300,000	−900,000
Semiannual cost, $/6 months	−30,000	−10,000	−3,000
Salvage value, $	5,000	70,000	200,000
Life, years	2	4	∞

5.26 A stockbroker claims she can consistently earn 15% per year on an investor's money. If she invests $10,000 now, $30,000 three years from now, and $8000 per year for 5 years starting 4 years from now, how much money can the client withdraw every year forever, beginning 12 years from now? Disregard taxes.

Payback Analysis

5.27 An alternative for producing a pesticide will have a first cost of $200,000 with annual costs of $50,000. Income is expected to be $90,000 per year. What is the payback period at (*a*) $i = 0\%$ and (*b*) $i = 15\%$ per year?

5.28 Two machines can be used for producing a certain part from titanium. The costs and other cash flows associated with each alternative are shown below. Determine which alternative(s) should be retained for further analysis if alternatives must have a payback of 5 years or less. Perform the analysis with (*a*) $i = 0\%$ and (*b*) $i = 10\%$ per year.

	Semiautomatic	Automatic
First cost, $	−40,000	−90,000
Net annual income, $/year	10,000	15,000
Maximum life, years	10	10
Salvage value at end of life, $	20,000	30,000

5.29 A window frame manufacturer is searching for ways to improve revenue from its triple-insulated sliding windows, sold primarily in the far northern states of the United States. Alternative A is an increase in TV and radio marketing. A total of $600,000 spent now is expected to increase revenue by $100,000 per year. Alternative B requires the same amount for enhancements to the in-plant manufacturing process that will improve the temperature retention properties of the seals around each glass pane. New revenues start slowly for this alternative at an estimated $15,000 per year, with a growth of 20% per year as the improved product gains reputation among builders. The MARR is 6%, and maximum projection periods are 8 years for A and 16 years for B.

Use both payback analysis and present worth analysis at 6% to select the more economical alternative. State the reason(s) for any difference in the alternative chosen between the two analyses.

5.30 The ANCO insurance agency has a document imaging system that needs replacement. A local salesperson quoted a cost of $10,000 with an estimated salvage of $900 after 5 or more years. If the system is expected to save $1700 per year in clerical time, find the payback time at 8% per year. The office manager has a practice to purchase equipment only when the payback is less than 6 years. Otherwise, he prefers to lease. Should the imaging system be purchased or leased?

5.31 Explain why payback analysis is best used as a supplemental analysis tool when an economic study is performed.

Life-Cycle Costs

5.32 A manufacturing software engineer at a major aerospace corporation has been assigned the management responsibility of a project to design, build, test, and implement AREMSS, a new-generation automated scheduling system for routine and expedited maintenance. Reports on the disposition of each service will also be entered by field personnel, then filed and archived by the system. The initial application will be on existing Air Force inflight refueling aircraft. The system is expected to be widely used over time for other aircraft maintenance scheduling. Once fully implemented, enhancements will have to be made, but the system is expected to serve as a worldwide scheduler for up to 15,000 separate aircraft. The engineer, who must make a presentation next week of the best estimates of costs over a 25-year life period, has decided to use the life-cycle cost approach of cost estimations. Use the information below to determine the current LCC at 6% per year for both the acquisitions and operations phases of AREMSS.

Cost Category	Cost in Year ($ million) 1	2	3	4	5	6 on	10	18
Field study of user groups	0.4							
Design by subcontractors	2.0	1.2						
Software design		0.5	0.9					
Initial hardware purchases			5.0					
Software development—final			0.5	1.5	0.2			
Beta testing		0.1	0.1					
Users manual development		0.1	0.2	0.1	0.1	0.07		
System implementation				1.2	0.8			
Field hardware purchases/upgrades			0.4	5.8	2.5			
Training of trainer personnel			0.4	2.5	2.5	0.7		
Software/hardware upgrades						0.6	2.5	3.5

The field personnel time estimated to be expended in using AREMSS from year 4 on is summarized below, with the average expected cost per person-hour.

	Person-Hours (× 10,000)			Average $ per Person-Hour		
Year	**4**	**5–7**	**8 on**	**4–10**	**11–20**	**21–30**
Domestic	30	20	15	15	20	25
International	60	40	20	20	22	24

5.53 The U.S. Army received two proposals for a turnkey design/build project for barracks for infantry unit soldiers in training. Proposal A involves off-the-shelf "barebones" design and standard grade construction of walls, windows, doors, and other features. With this option, heating and cooling costs will be greater, maintenance costs will be higher, and replacement will be sooner than for proposal B. The initial cost for A will be $750,000. Heating and cooling costs will average $6000 per month, with maintenance costs averaging $2000. A major remodeling after 10 years at a cost of $300,000 will make the buildings usable for 10 more years with no salvage value.

Proposal B will include tailored design and construction costs of $1.1 million initially, with estimated heating and cooling costs of $3000 per month and maintenance costs of $1000 per month. There will be no salvage value at the end of the 20-year life. Which proposal should be accepted on the basis of a life-cycle cost analysis, if the interest rate is 0.75% per month?

5.34 A medium-size municipality plans to develop a software system to assist in project selection during the next 10 years. A life-cycle cost approach has been used to categorize costs into development, programming, operating, and support costs for each alternative. There are three alternatives under consideration, identified as A (tailored system), B (adapted system), and C (current system). The costs are summarized below. Use a life-cycle cost approach to identify the best alternative.

Alternative	Cost Component	Cost
A	Development	$100,000 now, $150,000 year 1
	Programming	$45,000 now, $35,000 year 1
	Operation	$50,000 years 1 through 10
	Support	$30,000 years 1 through 10
B	Development	$10,000 now
	Programming	$45,000 year 0, $30,000 year 1
	Operation	$80,000 years 1 through 10
	Support	$40,000 years 1 through 10
C	Operation	$150,000 years 1 through 10

Bonds

5.35 What is the face value of a bond that has a bond interest rate of 6% per year with semiannual interest payments of $1200?

5.36 What is the bond interest rate on a $50,000 bond that has quarterly interest payments of $1500 and a 20-year maturity date?

5.37 What is the present worth of a $50,000 bond that has interest of 10% per year, payable semiannually? The bond matures in 20 years. The interest rate in the marketplace is 12% per year, compounded semiannually.

5.38 A manufacturing company issued mortgage bonds that had a face value of $10 million with a 20-year maturity. The bond interest rate was 8% per year, payable quarterly. If brokerage fees and marketing costs were $250,000, what is the present worth of receipts for all bond purchasers, if the interest rate in the marketplace rose to 12% per year, compounded quarterly, over the life of the bonds?

5.39 A home appliance manufacturing company plans to invest what it considers "temporary excess funds" in high-quality debenture bonds. How much should the company pay for bonds that have a face value of $10,000, an interest rate of 10% per year, payable quarterly, and a maturity date of 15 years, if the company wants to make 4% per quarter?

5.40 An engineer planning for his retirement thinks that the interest rates in the marketplace will decrease before he retires. Therefore, he plans to invest in corporate bonds. He plans to buy a $50,000 bond that has an interest rate of 14% per year, payable semiannually, and a maturity date 20 years from now. The market interest rate now is 14% per year, compounded semiannually. (*a*) How much should he be able to sell the bond for in 15 years if the market interest rate is then 8% per year, compounded semiannually? (*b*) If he did sell the bond after 15 years, and if he earned a return of 10% per year, compounded semiannually, on all his bond interest receipts, how much money would he have immediately after he sold the bond?

FE REVIEW PROBLEMS

Problems 5.41 through 5.43 are based on the following estimates. The cost of money is 10% per year.

	Machine X	Machine Y
Initial cost, $	−42,000	−66,000
Annual cost, $/year	−20,000	−15,000
Salvage value, $	10,000	23,000
Life, years	2	4

5.41 The present worth of machine Y is closest to:
(*a*) $−82,130
(*b*) $−87,840
(*c*) $−97,840
(*d*) $−103,220

5.42 In comparing the machines on a present worth basis, the present worth of machine X is closest to:
(*a*) $−68,445
(*b*) $−97,840
(*c*) $−125,015
(*d*) $−223,120

5.43 The capitalized cost of machine Y is closest to:
(*a*) $−30,865
(*b*) $−97,840

(*c*) $−308,650
(*d*) $−684,445

5.44 The cost of maintaining a public monument in Washington, DC, occurs as periodic outlays of $1000 every year and $5000 every 5 years. At an interest rate of 10% per year, the capitalized cost of the maintenance is closest to:
(*a*) $−18,190
(*b*) $−19,250
(*c*) $−21,360
(*d*) $−41,045

5.45 The present worth of an alternative that provides infinite service is called its:
(*a*) Net present value
(*b*) Discounted total cost
(*c*) Capitalized cost
(*d*) Perpetual annual cost

5.46 In comparing alternatives with different lives by the present worth method, it is necessary to:
(*a*) Compare them over a period equal to the life of the longer-lived alternative.
(*b*) Compare them over a time period of equal service.
(*c*) Compare them over a period equal to the life of the shorter-lived alternative.
(*d*) Find the present worth over one life cycle of each alternative.

5.47 The capitalized cost of an initial investment of $200,000 and annual investments of $30,000 forever at an interest rate of 10% per year is closest to:
(*a*) $−230,000
(*b*) $−300,000
(*c*) $−500,000
(*d*) $−2,300,000

5.48 The upgraded version of a machine has a first cost of $20,000, an annual operating cost of $6000, and a salvage value of $5000 after its 8-year life. At an interest rate of 10% per year, the capitalized cost is closest to:
(*a*) $−9,312
(*b*) $−10,006
(*c*) $−93,120
(*d*) $−100,060

5.49 Find the capitalized cost of a present cost of $30,000, monthly costs of $1000, and periodic costs every 5 years of $5000. Use an interest rate of 12% per year, compounded monthly.
(*a*) $−80,000
(*b*) $−136,100
(*c*) $−195,200
(*d*) $−3,600,000

EXTENDED EXERCISE

EVALUATION OF SOCIAL SECURITY RETIREMENT ESTIMATES

Charles is a senior engineer who has worked for 18 years since he graduated from college. Yesterday in the mail, he received a report from the U.S. Social Security Administration. In short, it stated that if he continues to earn at the same rate, social security will provide him with the following estimated monthly retirement benefits:

- Normal retirement at age 66; full benefit of $1500 per month starting at age 66.

- Early retirement at age 62; benefit reduced by 25% starting at age 62.
- Extended retirement at age 70; benefit increased by 30% starting at age 70.

Charles never thought much about social security; he usually thought of it as a monthly deduction from his paycheck that helped pay for his parents' retirement benefits from social security. But this time he decided an analysis should be performed. Charles decided to neglect the effect of the following over time: income taxes, cost-of-living increases, and inflation. Also, he assumed the retirement benefits are all received at the end of each year; that is, no compounding effect occurs during the year. Using an expected rate of return on investments of 8% per year and an anticipated death just after his 85th birthday, use a spreadsheet to do the following for Charles:

1. Calculate the total future worth of each benefit scenario through the age of 85.
2. Plot the annual accumulated future worth for each benefit scenario through the age of 85.

The report also mentioned that if Charles dies this year, his spouse is eligible at full retirement age for a benefit of $1600 per month for the remainder of her life. If Charles and his wife are both 40 years old today, determine the following about his wife's survivor benefits, if she starts at age 66 and lives through her 85th birthday:

3. Present worth now.
4. Future worth for his wife after her 85th birthday.

CASE STUDY

PAYBACK EVALUATION OF ULTRALOW-FLUSH TOILET PROGRAM

Introduction

In many cities in the southwestern part of the United States, water is being withdrawn from subsurface aquifers faster than it is being replaced. The attendant depletion of groundwater supplies has forced some of these cities to take actions ranging from restrictive pricing policies to mandatory conservation measures in residential, commercial, and industrial establishments. Beginning in the mid-1990, a city undertook a project to encourage installation of ultralow-flush toilets in existing houses. To evaluate the cost-effectiveness of the program, an economic analysis was conducted.

Background

The heart of the toilet replacement program involved a rebate of 75% of the cost of the fixture (up to $100 per unit), providing the toilet used no more than 1.6 gallons of water per flush. There was no limit on the number of toilets any individual or business could have replaced.

Procedure

To evaluate the water savings achieved (if any) through the program, monthly water use records were searched for 325 of the household participants, representing a sample size of approximately 13%. Water consumption data were obtained for 12 months before and 12 months after installation of the ultralow-flush toilets. If the house changed ownership during the evaluation period, that account was not included in the evaluation. Since water consumption increases dramatically during the hot summer months for lawn watering, evaporative cooling, car washing, etc., only the winter months of December, January, and February were used to evaluate water consumption before and after installation of the toilet. Before any calculations were made, high-volume water users (usually businesses) were screened out by eliminating all records whose average monthly consumption exceeded 50 CCF (1 CCF = 100 cubic feet = 748 gallons). Additionally, accounts which had monthly averages of 2 CCF or less (either before or after installation) were also eliminated because it was believed that such low consumption rates probably represented an abnormal condition, such as a house for sale which was vacant during part of the study period. The 268 records that remained after the screening procedures were then used to quantify the effectiveness of the program.

Results

Water Consumption

Monthly consumption before and after installation of the ultralow-flush toilets was found to be 11.2 and 9.1 CCF, respectively, for an average reduction of 18.8%. When only the months of January and February were used in the before and after calculations, the respective values were 11.0 and 8.7 CCF, resulting in a water savings rate of 20.9%.

Economic Analysis

The following table shows some of the program totals through the first 1¾ years of the program.

Program Summary

Number of households participating	2466
Number of toilets replaced	4096
Number of persons	7981
Average cost of toilet	\$115.83
Average rebate	\$76.12

The results in the previous section indicated monthly water savings of 2.1 CCF. For the average program participant, the payback period n_p in years with no interest considered is calculated using Equation [5.7].

$$n_p = \frac{\text{net cost of toilets} + \text{installation cost}}{\text{net annual savings for water and sewer charges}}$$

The lowest rate block for water charges is \$0.76 per CCF. The sewer surcharge is \$0.62 per CCF. Using these values and a \$50 cost for installation, the payback period is

$$n_p = \frac{(115.83 - 76.12) + 50}{(2.1 \text{ CCF/month} \times 12 \text{ months})\,(0.76 + 0.62)/\text{CCF}}$$

$$= 2.6 \text{ years}$$

Less expensive toilets or lower installation costs would reduce the payback period accordingly, while consideration of the time value of money would lengthen it.

From the standpoint of the utility which supplies water, the cost of the program must be compared against the marginal cost of water delivery and wastewater treatment. The marginal cost c may be represented as

$$c = \frac{\text{cost of rebates}}{\text{volume of water not delivered} + \text{volume of wastewater not treated}}$$

Theoretically, the reduction in water consumption would go on for an infinite period of time, since replacement will never be with a less efficient model. But for a worst-case condition, it is assumed the toilet would have a "productive" life of only 5 years, after which it would leak and not be repaired. The cost to the city for the water not delivered or wastewater not treated would be

$$c = \frac{\$76.12}{(2.1 + 2.1 \text{ CCF/month})(12 \text{ months})(5 \text{ years})}$$

$$= \frac{\$0.302}{\text{CCF}} \text{ or } \frac{\$0.40}{1000 \text{ gallons}}$$

Thus, unless the city can deliver water and treat the resulting wastewater for less than \$0.40 per 1000 gallons, the toilet replacement program would be considered economically attractive. For the city, the operating costs alone, that is, without the capital expense, for water and wastewater services that were not expended were about $1.10 per 1000 gallons, which far exceeds $0.40 per 1000 gallons. Therefore, the toilet replacement program was clearly very cost-effective.

Case Study Exercises

1. For an interest rate of 8% and a toilet life of 5 years, what would the participant's payback period be?
2. Is the participant's payback period more sensitive to the interest rate used or to the life of the toilet?
3. What would the cost to the city be if an interest rate of 6% per year were used with a toilet life of 5 years? Compare the cost in $/CCF and $/1000 gallons to those determined at 0% interest.
4. From the city's standpoint, is the success of the program sensitive to (*a*) the percentage of toilet cost rebated, (*b*) the interest rate, if rates of 4% to 15% are used, or (*c*) the toilet life, if lives of 2 to 20 years are used?
5. What other factors might be important to (*a*) the participants and (*b*) the city in evaluating whether the program is a success?