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CHAPTER 9

Benefit/Cost Analysis and Public Sector Economics

The evaluation methods of previous chapters are usually applied to alternatives in the private sector, that is, for-profit and not-for-profit corporations and businesses. Customers, clients, and employees utilize the installed alternatives. This chapter introduces *public sector alternatives* and their economic consideration. Here the owners and users (beneficiaries) are the citizens of the government unit—city, county, state, province, or nation. Government units provide the mechanisms to raise (investment) capital and operating funds for projects through taxes, user fees, bond issues, and loans. There are substantial differences in the characteristics of public and private sector alternatives and their economic evaluation, as outlined in the first section. Partnerships of the public and private sector have become increasingly common, especially for large infrastructure construction such as major highways, power generation plants, water resource projects, and the like.

The benefit/cost (B/C) ratio was developed, in part, to introduce objectivity into the economic analysis of public sector evaluation, thus reducing the effects of politics and special interests. However, there is always predictable disagreement among citizens (individuals and groups) about how the benefits of an alternative are defined and economically valued. The different formats of B/C analysis, and associated disbenefits of an alternative, are discussed here. The B/C analysis can use equivalency computations based on PW, AW, or FW values. Performed correctly, the benefit/cost method will always select the same alternative as PW, AW, and ROR analyses.

A public sector project to enhance freeway lighting is the subject of the case study.

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LEARNING OBJECTIVES

Purpose: Understand public sector economics; evaluate a project and compare alternatives using the benefit/cost ratio method.

Public sector

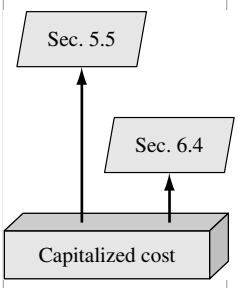
B/C for single project

Alternative selection

Multiple alternatives

This chapter will help you:

1. Identify fundamental differences between public and private sector economic alternatives.
2. Use the benefit/cost ratio to evaluate a single project.
3. Select the better of two alternatives using the incremental B/C ratio method.
4. Select the best from multiple alternatives using the incremental B/C method.



9.1 PUBLIC SECTOR PROJECTS

Public sector projects are owned, used, and financed by the citizenry of any government level, whereas projects in the private sector are owned by corporations, partnerships, and individuals. The products and services of private sector projects are used by individual customers and clients. Virtually all the examples in previous chapters have been from the private sector. Notable exceptions occur in Chapters 5 and 6 where capitalized cost was introduced as an extension to PW analysis for long-life alternatives and perpetual investments.

Public sector projects have a primary purpose to provide services to the citizenry for the public good at no profit. Areas such as health, safety, economic welfare, and utilities comprise a majority of alternatives that require engineering economic analysis. Some public sector examples are

- Hospitals and clinics
- Parks and recreation
- Utilities: water, electricity, gas, sewer, sanitation
- Schools: primary, secondary, community colleges, universities
- Economic development
- Convention centers
- Sports arenas
- Transportation: highways, bridges, waterways
- Police and fire protection
- Courts and prisons
- Food stamp and rent relief programs
- Job training
- Public housing
- Emergency relief
- Codes and standards

There are significant differences in the characteristics of private and public sector alternatives.

Characteristic	Public sector	Private sector
Size of investment	Larger	Some large; more medium to small

Often alternatives developed to serve public needs require large initial investments, possibly distributed over several years. Modern highways, public transportation systems, airports, and flood control systems are examples.

Life estimates	Longer (30–50+ years)	Shorter (2–25 years)

The long lives of public projects often prompt the use of the capitalized cost method, where infinity is used for n and annual costs are calculated as $A = P(i)$. As n gets larger, especially over 30 years, the differences in calculated A values become small. For example, at $i = 7\%$, there will be a very small difference in 30 and 50 years, because $(A/P,7\%,30) = 0.08059$ and $(A/P,7\%,50) = 0.07246$.

Annual cash flow estimates	No profit; costs, benefits, and disbenefits, are estimated	Revenues contribute to profits; costs are estimated

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Public sector projects (also called publicly-owned) do not have profits; they do have costs that are paid by the appropriate government unit; and they benefit the citizenry. Public sector projects often have undesirable consequences, as stated by some portion of the public. It is these consequences that can cause public controversy about the projects. The economic analysis should consider these consequences in monetary terms to the degree estimable. (Often in private sector analysis, undesirable consequences are not considered, or they may be directly addressed as costs.) To perform an economic analysis of public alternatives, the costs (initial and annual), the benefits, and the disbenefits, if considered, must be estimated as accurately as possible in *monetary units.*

Costs—estimated expenditures *to the government entity* for construction, operation, and maintenance of the project, less any expected salvage value.

Benefits—advantages to be experienced *by the owners, the public.*

Disbenefits—expected undesirable or negative consequences *to the owners* if the alternative is implemented. Disbenefits may be indirect economic disadvantages of the alternative.

The following is important to realize:

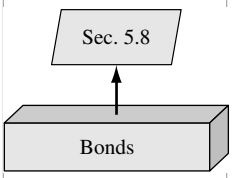
It is difficult to estimate and agree upon the economic impact of benefits and disbenefits for a public sector alternative.

For example, assume a short bypass around a congested area in town is recommended. How much will it benefit a driver in *dollars per driving minute* to be able to bypass five traffic lights while averaging 35 miles per hour, as compared to currently driving through the lights averaging 20 miles per hour and stopping at an average of two lights for an average of 45 seconds each? The bases and standards for benefits estimation are always difficult to establish and verify. Relative to revenue cash flow estimates in the private sector, benefit estimates are much harder to make, and vary more widely around uncertain averages. And the disbenefits that accrue from an alternative are harder to estimate. In fact, the disbenefit itself may not be known at the time the evaluation is performed.

Funding	Taxes, fees, bonds, private funds	Stocks, bonds, loans, individual owners

The capital used to finance public sector projects is commonly acquired from taxes, bonds, and fees. Taxes are collected from those who are the owners—the citizens (e.g., federal gasoline taxes for highways are paid by all gasoline users). This is also the case for fees, such as toll road fees for drivers. Bonds are often issued: U.S. Treasury bonds, municipal bond issues, and special-purpose bonds, such as utility district bonds. Private lenders can provide up-front financing. Also, private donors may provide funding for museums, memorials, parks, and garden areas through gifts.

Interest rate	Lower	Higher, based on market cost of capital



Because many of the financing methods for public sector projects are classified as *low-interest,* the interest rate is virtually always lower than for private sector alternatives. Government agencies are exempt from taxes levied by higher-level units. For example, municipal projects do not have to pay state taxes. (Private corporations and individual citizens do pay taxes.) Many loans are very low-interest, and grants with no repayment requirement from federal programs may share project costs. This results in interest rates in the 4 to 8% range. It is common that a government agency will direct that all projects be evaluated at a specific rate. For example, the U.S. Office of Management and Budget (OMB) declared at one time that federal projects should be evaluated at 10% (with no inflation adjustment). As a matter of standardization, directives to use a specific interest rate are beneficial because different government agencies are able to obtain varying types of funding at different rates. This can result in projects of the same type being rejected in one city or county, but accepted in a neighboring district. Therefore, standardized rates tend to increase the consistency of economic decisions and to reduce gamesmanship.

The determination of the interest rate for public sector evaluation is as important as the determination of the MARR for a private sector analysis. The public sector interest rate is identified as i; however, it is referred to by other names to distinguish it from the private sector rate. The most common terms are *discount rate* and *social discount rate.*

Alternative selection criteria	Multiple criteria	Primarily based on rate of return

Multiple categories of users, economic as well as noneconomic interests, and special-interest political and citizen groups make the selection of one alternative over another much more difficult in public sector economics. Seldom is it possible to select an alternative on the sole basis of a criterion such as PW or ROR. It is important to describe and itemize the criteria and selection method prior to the analysis. This helps determine the perspective or viewpoint when the evaluation is performed. Viewpoint is discussed below.

Environment of the evaluation	Politically inclined	Primarily economic

There are often public meetings and debates associated with public sector projects to accommodate the various interests of citizens (owners). Elected officials commonly assist with the selection, especially when pressure is brought to bear by voters, developers, environmentalists, and others. The selection process is not as "clean" as in private sector evaluation.

The viewpoint of the public sector analysis must be determined before cost, benefit, and disbenefit estimates are made and before the evaluation is formulated and performed. There are several viewpoints for any situation, and the different perspectives may alter how a cash flow estimate is classified.

Some example perspectives are the citizen; the city tax base; number of students in the school district; creation and retention of jobs; economic development

potential; a particular industry interest, such as agriculture, banking, or electronics manufacturing; and many others. In general, the viewpoint of the analysis should be as broadly defined as those who will bear the costs of the project and reap its benefits. Once established, the viewpoint assists in categorizing the costs, benefits, and disbenefits of each alternative, as illustrated in Example 9.1.

EXAMPLE 9.1

The citizen-based Capital Improvement Projects (CIP) Committee for the city of Dundee has recommended a $5 million bond issue for the purchase of greenbelt/floodplain land to preserve low-lying green areas and wildlife habitat on the east side of this rapidly expanding city of 62,000. The proposal is referred to as the Greenway Acquisition Initiative. Developers immediately opposed the proposal due to the reduction of available land for commercial development. The city engineer and economic development director have made the following preliminary estimates for some obvious areas, considering the Initiative's consequences in maintenance, parks, commercial development, and flooding over a projected 15-year planning horizon. The inaccuracy of these estimates is made very clear in the report to the Dundee City Council. The estimates are not yet classified as costs, benefits, or disbenefits. If the Greenway Acquisition Initiative is implemented, the estimates are as follows.

Economic Dimension	Estimate
1. Annual cost of $5 million in bonds over 15 years at 6% bond interest rate	$300,000 (years 1–14) $5,300,000 (year 15)
2. Annual maintenance, upkeep, and program management	$75,000 + 10% per year
3. Annual parks development budget	$500,000 (years 5–10)
4. Annual loss in commercial development	$2,000,000 (years 8–10)
5. State sales tax rebates not realized	$275,000 + 5% per year (years 8 on)
6. Annual municipal income from park use and regional sports events	$100,000 + 12% per year (years 6 on)
7. Savings in flood control projects	$300,000 (years 3–10) $1,400,000 (years 10–15)
8. Property damage (personal and city) not experienced due to flooding	$500,000 (years 10 and 15)

Identify three different viewpoints for the economic analysis of the proposal, and classify the estimates accordingly.

Solution

There are many perspectives to take; three are addressed here. The viewpoints and goals are identified and each estimate is classified as a cost, benefit, or disbenefit. (How the classification is made will vary depending upon who does the analysis. This solution offers only one logical answer.)

Viewpoint 1: Citizen of the city. Goal: Maximize the quality and wellness of citizens with family and neighborhood as prime concerns.

Costs: 1, 2, 3 Benefits: 6, 7, 8 Disbenefits: 4, 5

Viewpoint 2: City budget. Goal: Ensure the budget is balanced and of sufficient size to fund rapidly growing city services.

Costs: 1, 2, 3, 5 Benefits: 6, 7, 8 Disbenefits: 4

Viewpoint 3: Economic development. Goal: Promote new commercial and industrial economic development for creation and retention of jobs.

Costs: 1, 2, 3, 4, 5 Benefits: 6, 7, 8 Disbenefits: none

Classification of estimates 4 (loss of commercial development) and 5 (loss of sales tax rebates) changes depending upon the view taken for the economic analysis. If the analyst favors the economic development goals of the city, commercial development losses are considered real costs, whereas they are undesirable consequences (disbenefits) from the citizen and budget viewpoints. Also, the loss of sales tax rebates from the state is interpreted as a real cost from the budget and economic development perspectives, but as a disbenefit from the citizen viewpoint.

Comment

Disbenefits may be included or disregarded in an analysis, as discussed in the next section. This decision can make a distinctive difference in the acceptance or rejection of a public sector alternative.

During the last several decades, larger public sector projects have been developed increasingly often through public-private partnerships. This is the trend in part because of the greater efficiency of the private sector and in part because of the sizable cost to design, construct, and operate such projects. Full funding by the government unit may not be possible using traditional means of government financing—fees, taxes, and bonds. Some examples of the projects are as follows:

Project	Some Purposes of the Project
Bridges and tunnels	Speed traffic flows; reduce congestion; improve safety
Ports and harbors	Increase cargo capacity; support industrial development
Airports	Increase capacity; improve passenger safety; support development
Water resources	Increased desalination for drinking water; meet irrigation and industrial needs; improve wastewater treatment

In these joint ventures, the public sector (government) is responsible for the cost and service to the citizenry, and the private sector partner (corporation) is responsible for varying aspects of the projects as detailed below. The government unit cannot make a profit, but the corporation(s) involved can realize a reasonable profit; in fact the profit margin is usually written into the contract that governs the design, construction, operation, and ownership of the project.

Traditionally, such construction projects have been designed for and financed by a government unit with a contractor doing the construction under either a lump-sum (*fixed-price*) contract or a cost reimbursement (*cost-plus*) contract that specifies the agreed upon margin of profit. In these cases, the contractor does not share the risk of the project's success with the government "owner." When a

partnership of public and private interests is developed, the project is commonly contracted under an arrangement called *build-operate-transfer (BOT)*, which may also be referred to as BOOT, where the first O is for *own.* The BOT-administered project may require that the contractor be responsible partially or completely for design and financing, and completely responsible for the construction (the build element), operation (operate), and maintenance activities for a specified number of years. After this time period, the owner becomes the government unit when the title of ownership is transferred (transfer) at no or very low cost. This arrangement may have several advantages, some of which are

- Better efficiency of resource allocation of private enterprise
- Ability to acquire funds (loans) based on financial record of the government and corporate partners
- Environmental, liability, and safety issues addressed by the private sector, where there usually is greater expertise
- Contracting corporation(s) able to realize a return on the investment during the operation phase

Many of the projects in international settings and in developing countries utilize the BOT form of partnership. There are, of course, disadvantages to this arrangement. One risk is that the amount of financing committed to the project may not cover the actual build cost because it is considerably higher than estimated. A second risk is that a reasonable profit may not be realized by the private corporation due to low usage of the facility during the operate phase. To plan against such problems, the original contract may provide for special loans guaranteed by the government unit and special subsidies. The subsidy may cover costs plus (contractually agreed-to) profit if usage is lower than a specified level. The level used may be the breakeven point with the agreed-to profit margin considered.

A variation of the BOT/BOOT method is BOO (build-own-operate), where the transfer of ownership never takes place. This form of public-private partnership may be used when the project has a relatively short life or the technology deployed is changing quickly.

9.2 BENEFIT/COST ANALYSIS OF A SINGLE PROJECT

The benefit/cost ratio is relied upon as a fundamental analysis method for public sector projects. The B/C analysis was developed to introduce more objectivity into public sector economics, and as one response to the U.S. Congress approving the Flood Control Act of 1936. There are several variations of the B/C ratio; however, the fundamental approach is the same. All cost and benefit estimates must be converted to a common equivalent monetary unit (PW, AW, or FW) at the discount rate (interest rate). The B/C ratio is then calculated using one of these relations:

$$\text{B/C} = \frac{\text{PW of benefits}}{\text{PW of costs}} = \frac{\text{AW of benefits}}{\text{AW of costs}} = \frac{\text{FW of benefits}}{\text{FW of costs}} \qquad [9.1]$$

Present worth and annual worth equivalencies are more used than future worth values. The sign convention for B/C analysis is positive signs, so *costs are preceded by a + sign.* Salvage values, when they are estimated, are subtracted from

costs. Disbenefits are considered in different ways depending upon the model used. Most commonly, disbenefits are subtracted from benefits and placed in the numerator. The different formats are discussed below.

The decision guideline is simple:

If B/C $\geq$ 1.0, accept the project as economically acceptable for the estimates and discount rate applied.

If B/C $<$ 1.0, the project is not economically acceptable.

If the B/C value is exactly or very near 1.0, noneconomic factors will help make the decision for the "best" alternative.

The *conventional B/C ratio,* probably the most widely used, is calculated as follows:

$$\text{B/C} = \frac{\text{benefits} - \text{disbenefits}}{\text{costs}} = \frac{B - D}{C} \qquad [9.2]$$

In Equation [9.2] disbenefits are subtracted from benefits, not added to costs. The B/C value could change considerably if disbenefits are regarded as costs. For example, if the numbers 10, 8, and 8 are used to represent the PW of benefits, disbenefits, and costs, respectively, the correct procedure results in B/C = $(10 - 8)/8 = 0.25$. The incorrect placement of disbenefits in the denominator results in B/C = $10/(8 + 8) = 0.625$, which is more than twice the correct B/C value of 0.25. Clearly, then, the method by which disbenefits are handled affects the magnitude of the B/C ratio. However, no matter whether disbenefits are (correctly) subtracted from the numerator or (incorrectly) added to costs in the denominator, a B/C ratio of less than 1.0 by the first method will always yield a B/C ratio less than 1.0 by the second method, and vice versa.

The *modified B/C ratio* includes maintenance and operation (M&O) costs in the numerator and treats them in a manner similar to disbenefits. The denominator includes only the initial investment. Once all amounts are expressed in PW, AW, or FW terms, the modified B/C ratio is calculated as

$$\text{Modified B/C} = \frac{\text{benefits} - \text{disbenefits} - \text{M\&O costs}}{\text{initial investment}} \qquad [9.3]$$

Salvage value is included in the denominator as a negative cost. The modified B/C ratio will obviously yield a different value than the conventional B/C method. However, as with disbenefits, *the modified procedure can change the magnitude of the ratio but not the decision to accept or reject the project.*

The *benefit and cost difference* measure of worth, which does not involve a ratio, is based on the difference between the PW, AW, or FW of benefits and costs, that is, $B - C$. If $(B - C) \geq 0$, the project is acceptable. This method has the advantage of eliminating the discrepancies noted above when disbenefits are regarded as costs, because B represents *net benefits.* Thus, for the numbers 10, 8, and 8 the same result is obtained regardless of how disbenefits are treated.

Subtracting disbenefits from benefits: $B - C = (10 - 8) - 8 = -6$

Adding disbenefits to costs: $B - C = 10 - (8 + 8) = -6$

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Before calculating the B/C ratio by any formula, check whether the alternative with the larger AW or PW of costs also yields a larger AW or PW of benefits. It is possible for one alternative with larger costs to generate lower benefits than other alternatives, thus making it unnecessary to further consider the larger-cost alternative.

EXAMPLE 9.2

The Ford Foundation expects to award $15 million in grants to public high schools to develop new ways to teach the fundamentals of engineering that prepare students for university-level material. The grants will extend over a 10-year period and will create an estimated savings of $1.5 million per year in faculty salaries and student-related expenses. The Foundation uses a rate of return of 6% per year on all grant awards.

This grants program will share Foundation funding with ongoing activities, so an estimated $200,000 per year will be removed from other program funding. To make this program successful, a $500,000 per year operating cost will be incurred from the regular M&O budget. Use the B/C method to determine if the grants program is economically justified.

Solution

Use annual worth as the common monetary equivalent. All three B/C models are used to evaluate the program.

AW of investment cost.	$\$15{,}000{,}000(A/P,6\%,10) = \$2{,}038{,}050$ per year
AW of benefit.	$1,500,000 per year
AW of disbenefit.	$200,000 per year
AW of M&O cost.	$500,000 per year

Use Equation [9.2] for conventional B/C analysis, where M&O is placed in the denominator as an annual cost.

$$\text{B/C} = \frac{1{,}500{,}000 - 200{,}000}{2{,}038{,}050 + 500{,}000} = \frac{1{,}300{,}000}{2{,}538{,}050} = 0.51$$

The project is not justified, since B/C < 1.0.

By Equation [9.3] the modified B/C ratio treats the M&O cost as a reduction to benefits.

$$\text{Modified B/C} = \frac{1{,}500{,}000 - 200{,}000 - 500{,}000}{2{,}038{,}050} = 0.39$$

The project is also not justified by the modified B/C method, as expected.

For the $(B - C)$ model, B is the net benefit, and the annual M&O cost is included with costs.

$$B - C = (1{,}500{,}000 - 200{,}000) - (2{,}038{,}050 + 500{,}000) = \$-1.24 \text{ million}$$

Since $(B - C) < 0$, the program is not justified.

EXAMPLE 9.3

Aaron is a new project engineer with the Arizona Department of Transportation (ADOT). After receiving a degree in engineering from Arizona State University, he decided to gain experience in the public sector before applying to master's degree programs. Based on annual worth relations, Aaron performed the conventional B/C analysis of the two separate proposals shown below.

Bypass proposal: new routing around part of Flagstaff to improve safety and decrease average travel time.

Source of proposal: State ADOT office of major thoroughfare analysis.

Initial investment in present worth: $P = \$40$ million.

Annual maintenance: \$1.5 million.

Annual benefits to public: $B = \$6.5$ million.

Expected life: 20 years.

Funding: Shared 50–50 federal and state funding; federally required 8% discount rate applies.

Upgrade proposal: widening of roadway through parts of Flagstaff to alleviate traffic congestion and improve traffic safety.

Source of proposal: Local Flagstaff district office of ADOT.

Initial investment in present worth: $P = \$4$ million.

Annual maintenance: \$150,000.

Annual benefits to public: $B = \$650{,}000$.

Expected life: 12 years.

Funding: 100% state funding required; usual 4% discount rate applies.

Aaron used a hand solution for the conventional B/C analysis in Equation [9.2] with AW values calculated at 8% per year for the bypass proposal and at 4% per year for the upgrade proposal.

Bypass proposal: AW of investment = $\$40{,}000{,}000(A/P,8\%,20) = \$4{,}074{,}000$ per year

$$\text{B/C} = \frac{6{,}500{,}000}{4{,}074{,}000 + 1{,}500{,}000} = 1.17$$

Upgrade proposal: AW of investment = $\$4{,}000{,}000(A/P,4\%,12) = \$426{,}200$ per year

$$\text{B/C} = \frac{650{,}000}{426{,}200 + 150{,}000} = 1.13$$

Both proposals are economically justified since B/C > 1.0.

(*a*) Perform the same analysis by computer, using a minimum number of computations.

(*b*) The discount rate for the upgrade proposal is not certain, because ADOT is thinking of asking for federal funds for it. Is the upgrade economically justified if the 8% discount rate also applies to it?

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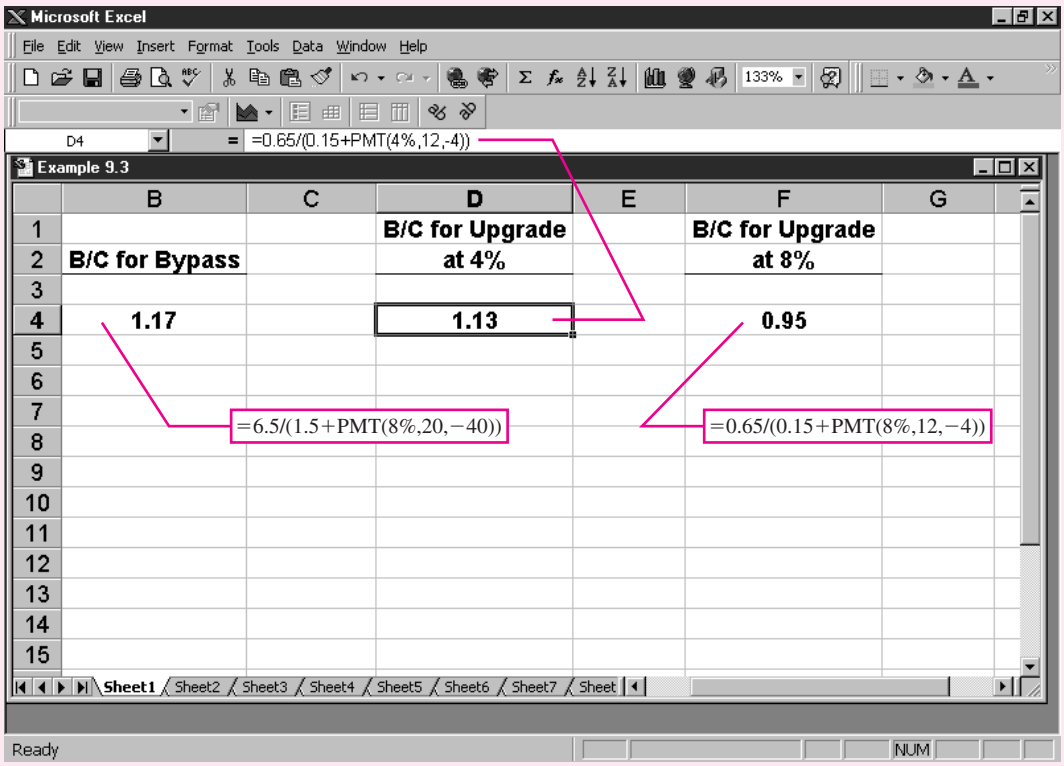
Solution by Computer

(*a*) See Figure 9–1*a*. The B/C values of 1.17 and 1.13 are in B4 and D4 ($1 million units). The function PMT(*i*%,*n*,−*P*) plus the annual maintenance cost calculates the AW of costs in the denominator. See the cell tags.

(*b*) Cell F4 uses an *i* value of 8% in the PMT function. There is a real difference in the justification decision. At the 8% rate, the upgrade proposal is no longer justified.

Comment

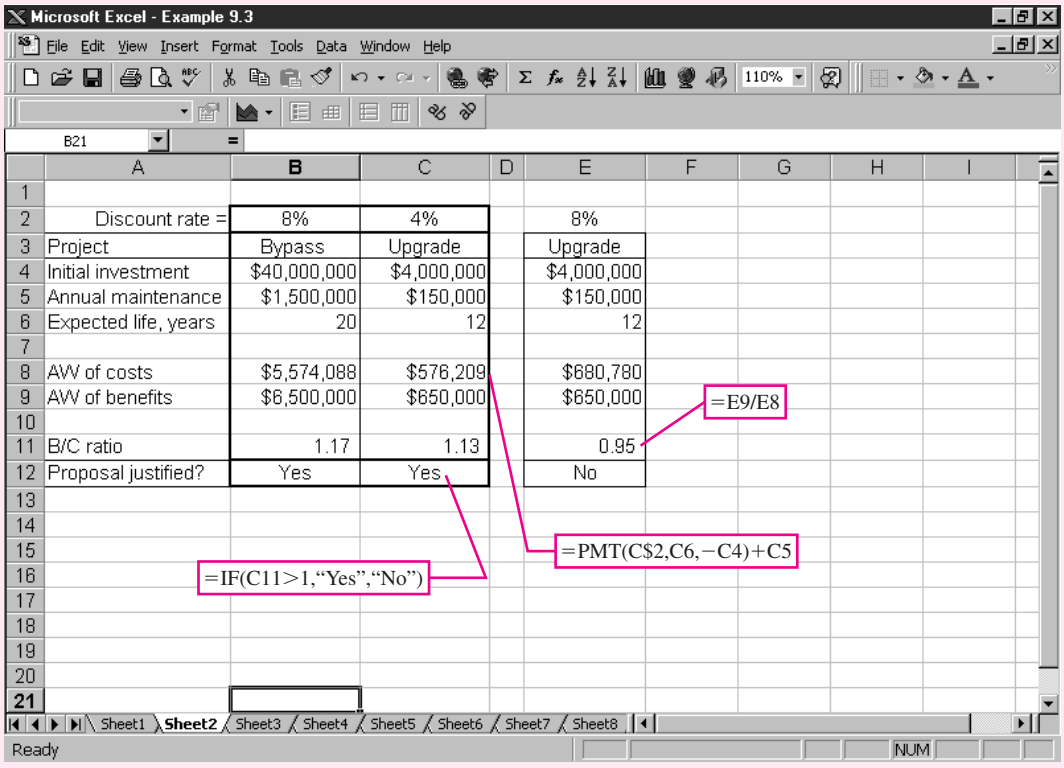
Figure 9–1*b* presents a complete B/C spreadsheet solution. There are no differences in the conclusions from those in the Q-solv spreadsheet, but the proposal estimates and B/C results are shown in detail on this spreadsheet. Also, additional sensitivity analysis is easily performed on this expanded version, because of the use of cell reference functions.



(*a*)

Figure 9–1

Spreadsheet for B/C ratio of two proposals: (*a*) Q-solv solution and (*b*) expanded solution, Example 9.3.



	A	B	C	D	E	F	G	H	I
1									
2	Discount rate =	8%	4%		8%				
3	Project	Bypass	Upgrade		Upgrade				
4	Initial investment	$40,000,000	$4,000,000		$4,000,000				
5	Annual maintenance	$1,500,000	$150,000		$150,000				
6	Expected life, years	20	12		12				
7									
8	AW of costs	$5,574,088	$576,209		$680,780				
9	AW of benefits	$6,500,000	$650,000		$650,000				
10									
11	B/C ratio	1.17	1.13		0.95				
12	Proposal justified?	Yes	Yes		No				
13									
14									
15									
16									
17									
18									
19									
20									
21									

(*b*)

Figure 9–1
(Continued).

9.3 ALTERNATIVE SELECTION USING INCREMENTAL B/C ANALYSIS

The technique to compare two mutually exclusive alternatives using benefit/cost analysis is virtually the same as that for incremental ROR in Chapter 8. The incremental (conventional) B/C ratio is determined using PW, AW, or FW calculations, and the extra-cost alternative is justified if this B/C ratio is equal to or larger than 1.0. The selection rule is as follows:

If incremental B/C $\geq$ 1.0, choose the higher-cost alternative, because its extra cost is economically justified.

If incremental B/C $<$ 1.0, choose the lower-cost alternative.

To perform a correct incremental B/C analysis, it is required that each alternative be compared only with another alternative for which the incremental cost is already justified. This same rule was used previously in incremental ROR analysis.

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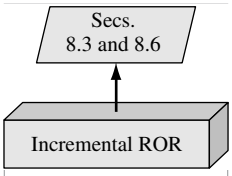


There are several special considerations for B/C analysis that make it slightly different from that for ROR analysis. As mentioned earlier, all costs have a positive sign in the B/C ratio. Also, the *ordering of alternatives is done on the basis of total costs* in the denominator of the ratio. Thus, if two alternatives, A and B, have equal initial investments and lives, but B has a larger equivalent annual cost, then B must be incrementally justified against A. (This is illustrated in the next example.) If this convention is not correctly followed, it is possible to get a negative cost value in the denominator, which can incorrectly make B/C < 1 and reject a higher-cost alternative that is actually justified.

Follow these steps to correctly perform a conventional B/C ratio analysis of two alternatives. Equivalent values can be expressed in PW, AW, or FW terms.

1. Determine the total equivalent costs for both alternatives.
2. Order the alternatives by total equivalent cost; smaller first, then larger. Calculate the incremental cost (ΔC) for the larger-cost alternative. This is the denominator in B/C.
3. Calculate the total equivalent benefits and any disbenefits estimated for both alternatives. Calculate the incremental benefits (ΔB) for the larger-cost alternative. (This is $\Delta(B - D)$ if disbenefits are considered.)
4. Calculate the incremental B/C ratio using Equation [9.2], $(B - D)/C$.
5. Use the selection guideline to select the higher-cost alternative if B/C ≥ 1.0.

When the B/C ratio is determined for the lower-cost alternative, it is a comparison with the do-nothing (DN) alternative. If B/C < 1.0, then DN should be selected and compared to the second alternative. If neither alternative has an acceptable B/C value, the DN alternative must be selected. In public sector analysis, the DN alternative is usually the current condition.

EXAMPLE 9.4

The city of Garden Ridge, Florida, has received designs for a new patient room wing to the municipal hospital from two architectural consultants. One of the two designs must be accepted in order to announce it for construction bids. The costs and benefits are the same in most categories, but the city financial manager decided that the three estimates below should be considered to determine which design to recommend at the city council meeting next week and to present to the citizenry in preparation for an upcoming bond referendum next month.

	Design A	Design B
Construction cost, $	10,000,000	15,000,000
Building maintenance cost, $/year	35,000	55,000
Patient usage cost, $/year	450,000	200,000

The patient usage cost is an estimate of the amount paid by patients over the insurance coverage generally allowed for a hospital room. The discount rate is 5%, and the life of

the building is estimated at 30 years.

(*a*) Use conventional B/C ratio analysis to select design A or B.

(*b*) Once the two designs were publicized, the privately owned hospital in the directly adjacent city of Forest Glen lodged a complaint that design A will reduce its own municipal hospital's income by an estimated $500,000 per year because some of the day-surgery features of design A duplicate its services. Subsequently, the Garden Ridge merchants' association argued that design B could reduce its annual revenue by an estimated $400,000, because it will eliminate an entire parking lot used by their patrons for short-term parking. The city financial manager stated that these concerns would be entered into the evaluation as disbenefits of the respective designs. Redo the B/C analysis to determine if the economic decision is still the same as when disbenefits were not considered.

Solution

(*a*) Since most of the cash flows are already annualized, the incremental B/C ratio will use AW values. No disbenefit estimates are considered. Follow the steps of the procedure above:

1. The AW of costs is the sum of construction and maintenance costs.

$$AW_A = 10{,}000{,}000(A/P,5\%,30) + 35{,}000 = \$685{,}500$$

$$AW_B = 15{,}000{,}000(A/P,5\%,30) + 55{,}000 = \$1{,}030{,}750$$

2. Design B has the larger AW of costs, so it is the alternative to be incrementally justified. The incremental cost value is

$$\Delta C = AW_B - AW_A = \$345{,}250 \text{ per year}$$

3. The AW of benefits is derived from the patient usage costs, since these are consequences to the public. The benefits for the B/C analysis are not the costs themselves, but the *difference* if design B is selected. The lower usage cost each year is a positive benefit for design B.

$$\Delta B = \text{usage}_A - \text{usage}_B = \$450{,}000 - \$200{,}000 = \$250{,}000 \text{ per year}$$

4. The incremental B/C ratio is calculated by Equation [9.2].

$$B/C = \frac{\$250{,}000}{\$345{,}250} = 0.72$$

5. The B/C ratio is less than 1.0, indicating that the extra costs associated with design B are not justified. Therefore, design A is selected for the construction bid.

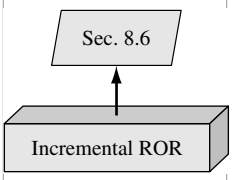
(*b*) The revenue loss estimates are considered disbenefits. Since the disbenefits of design B are $100,000 less than those of A, this positive difference is added to the $250,000 benefits of B to give it a total benefit of $350,000. Now

$$B/C = \frac{\$350{,}000}{\$345{,}250} = 1.01$$

Design B is slightly favored. In this case the inclusion of disbenefits has reversed the previous economic decision. This has probably made the situation more difficult politically. New disbenefits will surely be claimed in the near future by other special-interest groups.

Like other methods, B/C analysis requires *equal-service comparison* of alternatives. Usually, the expected useful life of a public project is long (25 or 30 or more years), so alternatives generally have equal lives. However, when alternatives do have unequal lives, the use of PW to determine the equivalent costs and benefits requires that the LCM of lives be used. This is an excellent opportunity to use the AW equivalency of costs and benefits, if the implied assumption that the project could be repeated is reasonable. Therefore, use AW-based analysis for B/C ratios when different-life alternatives are compared.

9.4 INCREMENTAL B/C ANALYSIS OF MULTIPLE, MUTUALLY EXCLUSIVE ALTERNATIVES



The procedure necessary to select one from three or more mutually exclusive alternatives using incremental B/C analysis is essentially the same as that of the last section. The procedure also parallels that for incremental ROR analysis in Section 8.6. The selection guideline is as follows:

Choose the largest-cost alternative that is justified with an incremental B/C $\geq$ 1.0 when this selected alternative has been compared with another justified alternative.

There are two types of benefit estimates—estimation of *direct benefits,* and implied benefits based on *usage cost* estimates. Example 9.4 is a good illustration of the second type of implied benefit estimation. *When direct benefits are estimated,* the B/C ratio for each alternative may be calculated first as an initial screening mechanism to eliminate unacceptable alternatives. At least one alternative must have B/C $\geq$ 1.0 to perform the incremental B/C analysis. If all alternatives are unacceptable, the DN alternative is indicated as the choice. (This is the same approach as that of step 2 for "revenue alternatives only" in the ROR procedure of Section 8.6. However, the term "revenue alternative" is not applicable to public sector projects.)

As in the previous section comparing two alternatives, selection from multiple alternatives by incremental B/C ratio utilizes total equivalent costs to initially order alternatives from smallest to largest. Pairwise comparison is then undertaken. Also, remember that all costs are considered positive in B/C calculations. The terms *defender* and *challenger alternative* are used in this procedure, as in a ROR-based analysis. The procedure for incremental B/C analysis of multiple alternatives is as follows:

1. Determine the total equivalent cost for all alternatives. (Use AW, PW, or FW equivalencies for equal lives; use AW for unequal lives.)
2. Order the alternatives by total equivalent cost, smallest first.
3. Determine the total equivalent benefits (and any disbenefits estimated) for each alternative.
4. *Direct benefits estimation only:* Calculate the B/C for the first ordered alternative. (In effect, this makes DN the defender and the first alternative the challenger.) If B/C $<$ 1.0, eliminate the challenger, and go to the next

challenger. Repeat this until B/C $\geq$ 1.0. The defender is eliminated, and the next alternative is now the challenger. (For analysis by computer, determine the B/C for all alternatives initially and retain only acceptable ones.)

5. Calculate incremental costs (ΔC) and benefits (ΔB) using the relations

$$\Delta C = \text{challenger cost} - \text{defender cost} \quad [9.4]$$

$$\Delta B = \text{challenger benefits} - \text{defender benefits} \quad [9.5]$$

If relative *usage costs* are estimated for each alternative, rather than direct benefits, ΔB may be found using the relation

$$\Delta B = \text{defender usage costs} - \text{challenger usage costs} \quad [9.6]$$

6. Calculate the incremental B/C for the first challenger compared to the defender.

$$\text{B/C} = \Delta B/\Delta C \quad [9.7]$$

If incremental B/C $\geq$ 1.0 in Equation [9.7], the challenger becomes the defender and the previous defender is eliminated. Conversely, if incremental B/C $<$ 1.0, remove the challenger and the defender remains against the next challenger.

7. Repeat steps 5 and 6 until only one alternative remains. It is the selected one.

In all the steps above, incremental disbenefits may be considered by replacing ΔB with $\Delta(B - D)$, as in the conventional B/C ratio, Equation [9.2].

EXAMPLE 9.5

The Economic Development Corporation (EDC) for the city of Bahia, California, and Moderna County is operated as a not-for-profit corporation. It is seeking a developer that will place a major water park in the city or county area. Financial incentives will be awarded. In response to a request for proposal (RFP) to the major water park developers in the country, four proposals have been received. Larger and more intricate water rides and increased size of the park will attract more customers, thus different levels of initial incentives are requested in the proposals. One of these proposals will be accepted by the EDC and recommended to the Bahia City Council and Moderna County Board of Trustees for approval.

Approved and in-place economic incentive guidelines allow entertainment industry prospects to receive up to $500,000 cash as a first-year incentive award and 10% of this amount each year for 8 years in property tax reduction. All the proposals meet the requirements for these two incentives. Each proposal includes a provision that residents of the city or county will benefit from reduced entrance (usage) fees when using the park. This fee reduction will be in effect as long as the property tax reduction incentive continues. The EDC has estimated the annual total entrance fees with the reduction included for local residents. Also, EDC estimated the extra sales tax revenue expected for the four park designs. These estimates and the costs for the initial incentive and annual 10% tax reduction are summarized in the top section of Table 9–1.

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TABLE 9–1 Estimates of Costs and Benefits, and the Incremental B/C Analysis for Four Water Park Proposals, Example 9.5

	Proposal 1	Proposal 2	Proposal 3	Proposal 4
Initial incentive, $	250,000	350,000	500,000	800,000
Tax incentive cost, $/year	25,000	35,000	50,000	80,000
Resident entrance fees, $/year	500,000	450,000	425,000	250,000
Extra sales taxes, $/year	310,000	320,000	320,000	340,000
Study period, years	8	8	8	8
AW of total costs, $	66,867	93,614	133,735	213,976
Alternatives compared		2-to-1	3-to-2	4-to-2
Incremental costs ΔC, $/year		26,747	40,120	120,360
Entrance fee reduction, $/year		50,000	25,000	200,000
Extra sales tax, $/year		10,000	0	20,000
Incremental benefits ΔB, $/year		60,000	25,000	220,000
Incremental B/C ratio		2.24	0.62	1.83
Increment justified?		Yes	No	Yes
Alternative selected		2	2	4

Utilize hand and computer analysis to perform an incremental B/C study to determine which park proposal is the best economically. The discount rate used by the EDC is 7% per year. Can the current incentive guidelines be used to accept the winning proposal?

Solution by Hand

The viewpoint taken for the economic analysis is that of a resident of the city or county. The first-year cash incentives and annual tax reduction incentives are real costs to the residents. Benefits are derived from two components: the decreased entrance fee estimates and the increased sales tax receipts. These will benefit each citizen indirectly through the increase in money available to those who use the park and through the city and county budgets where sales tax receipts are deposited. Since these benefits must be calculated indirectly from these two components, the initial proposal B/C values cannot be calculated to initially eliminate any proposals. A B/C analysis incrementally comparing two alternatives at a time must be conducted.

Table 9–1 includes the results of applying the procedure above. Equivalent AW values are used for benefit and cost amounts per year. Since the benefits must be derived indirectly from the entrance fee estimates and sales tax receipts, step 4 is not used.

1. For each alternative, the capital recovery amount over 8 years is determined and added to the annual property tax incentive cost. For proposal #1,

$$\text{AW of total costs} = \text{initial incentive}(A/P,7\%,8) + \text{tax cost}$$
$$= \$250{,}000(A/P,7\%,8) + 25{,}000 = \$66{,}867$$

2. The alternatives are ordered by the AW of total costs in Table 9–1.
3. The annual benefit of an alternative is the incremental benefit of the entrance fees and sales tax amounts. These are calculated in step 5.
4. This step is not used.
5. Table 9–1 shows incremental costs calculated by Equation [9.4]. For the 2-to-1 comparison,

$$\Delta C = \$93{,}614 - 66{,}867 = \$26{,}747$$

Incremental benefits for an alternative are the sum of the resident entrance fees compared to those of the next-lower-cost alternative, plus the increase in sales tax receipts over those of the next-lower-cost alternative. Thus, the benefits are determined incrementally for each pair of alternatives. For example, when proposal #2 is compared to proposal #1, the resident entrance fees decrease by $50,000 per year and the sales tax receipts increase by $10,000. Then the total benefit is the sum of these, that is, $\Delta B = \$60{,}000$ per year.

6. For the 2-to-1 comparison, Equation [9.7] results in

$$\text{B/C} = \$60{,}000/\$26{,}747 = 2.24$$

Alternative #2 is clearly incrementally justified. Alternative #1 is eliminated, and alternative #3 is the new challenger to defender #2.

7. This process is repeated for the 3-to-2 comparison, which has an incremental B/C of 0.62 because the incremental benefits are substantially less than the increase in costs. Therefore, proposal #3 is eliminated, and the 4-to-2 comparison results in

$$\text{B/C} = \$220{,}000/\$120{,}360 = 1.83$$

Since B/C > 1.0, proposal #4 is retained. Since proposal #4 is the one remaining alternative, it is selected.

The recommendation for proposal #4 requires an initial incentive of $800,000, which exceeds the $500,000 limit of the approved incentive limits. The EDC will have to request the City Council and County Trustees to grant an exception to the guidelines. If the exception is not approved, proposal #2 is accepted.

Solution by Computer

Figure 9–2 presents a spreadsheet using the same calculations as those in Table 9–1. Row 8 cells include the function PMT(7%,8,−initial incentive) to calculate the capital recovery for each alternative, plus the annual tax cost. These AW of total cost values are used to order the alternatives for incremental comparison.

The cell tags for rows 10 through 13 detail the formulas for incremental costs and benefits used in the incremental B/C computation (row 14). Note the difference in row 11 and 12 formulas, which find the incremental benefits for entrance fees and sales tax, respectively. The order of the subtraction between columns in row 11 (e.g., =B5 − C5, for the 2-to-1 comparison) must be correct to obtain the incremental entrance fees benefit. The IF operators in row 15 accept or reject the challenger, based upon the size of B/C. After the 3-to-2 comparison with B/C = 0.62 in cell D14, alternative #3 is eliminated. The final selection is alternative #4, as in the solution by hand.

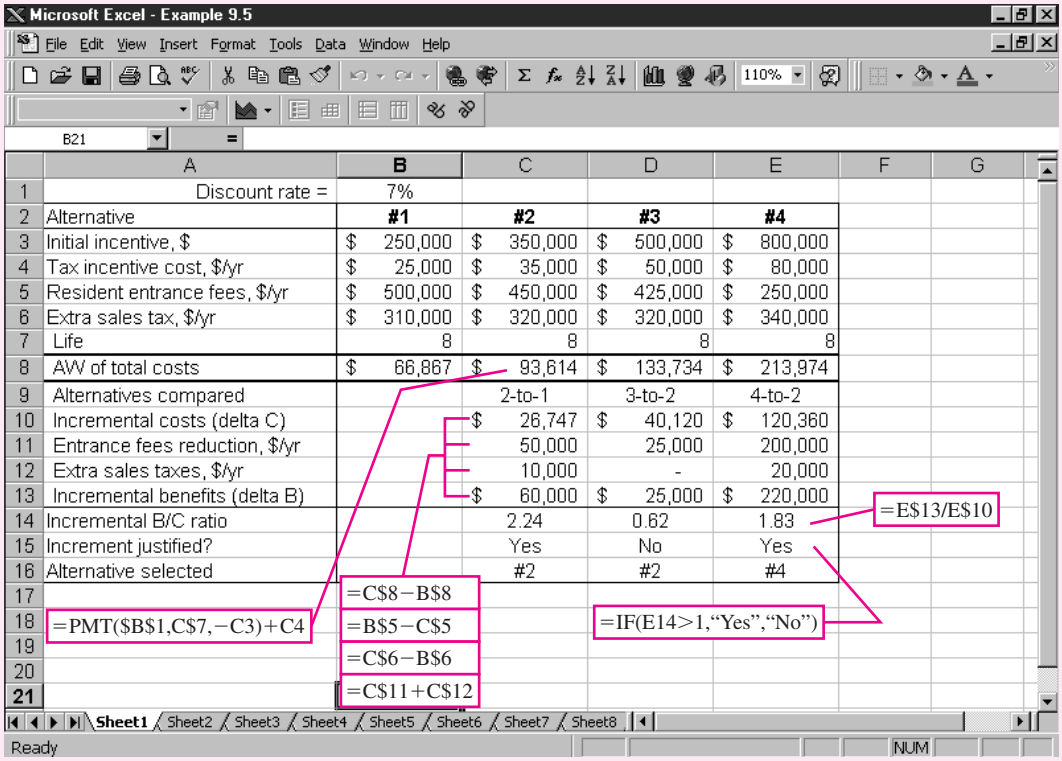
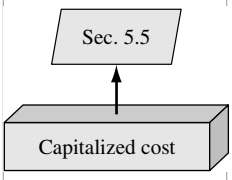


Figure 9–2
Spreadsheet solution for an incremental B/C analysis of four mutually exclusive alternatives, Example 9.5.

When the lives of alternatives are so long that they can be considered infinite, the capitalized cost is used to calculate the equivalent PW or AW values for costs and benefits. Equation [5.3], $A = P(i)$, is used to determine the equivalent AW values in the incremental B/C analysis.

If two or more *independent projects* are evaluated using B/C analysis and there is no budget limitation, no incremental comparison is necessary. The only comparison is between each project separately with the do-nothing alternative. The project B/C values are calculated, and those with B/C $\geq$ 1.0 are accepted. This is the same procedure as that used to select from independent projects using the ROR method (Chapter 8). When a budget limitation is imposed, the capital budgeting procedure discussed in Chapter 12 must be applied.



EXAMPLE 9.6

The Army Corps of Engineers wants to construct a dam on a flood-prone river. The estimated construction cost and average annual dollar benefits are listed below. (*a*) If a 6% per year rate applies and dam life is infinite for analysis purposes, select the one best location using the B/C method. If no site is acceptable, other sites will be determined later. (*b*) If more than one dam site can be selected, which sites are acceptable, using the B/C method?

Site	Construction Cost, $ millions	Annual Benefits, $
A	6	350,000
B	8	420,000
C	3	125,000
D	10	400,000
E	5	350,000
F	11	700,000

Solution

(*a*) The capitalized cost $A = Pi$ is used to obtain AW values for annual capital recovery of the construction cost, as shown in the first row of Table 9–2. Since benefits are estimated directly, the site B/C ratio can be used for initial screening. Only sites E and F have B/C > 1.0, so they are evaluated incrementally. The E-to-DN comparison is performed because it is not required that one site must be selected. The analysis between the mutually exclusive alternatives in the lower portion of Table 9–2 is based on Equation [9.7].

$$\text{Incremental B/C} = \frac{\Delta \text{ annual benefits}}{\Delta \text{ annual costs}}$$

Since only site E is incrementally justified, it is selected.

(*b*) The dam site proposals are now independent projects. The site B/C ratio is used to select from none to all six sites. In Table 9–2, B/C > 1.0 for sites E and F only; they are acceptable, the rest are not.

TABLE 9–2 Use of Incremental B/C Ratio Analysis for Example 9.6 (Values in $1000)

	C	E	A	B	D	F
Capital recovery cost, $	180	300	360	480	600	660
Annual benefits, $	125	350	350	420	400	700
Site B/C	0.69	1.17	0.97	0.88	0.67	1.06
Decision	No	Retain	No	No	No	Retain
Comparison		E-to-DN				F-to-E
Δ Annual cost, $		300				360
Δ Annual benefits, $		350				350
Δ (B/C) ratio		1.17				0.97
Increment justified?		Yes				No
Site selected		E				E

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Comment

In part (*a*), suppose that site G is added with a construction cost of $10 million and an annual benefit of $700,000. The site B/C is acceptable at B/C = 700/600 = 1.17. Now, incrementally compare G-to-E; the incremental B/C = 350/300 = 1.17, in favor of G. In this case, site F must be compared with G. Since the annual benefits are the same ($700,000), the B/C ratio is zero and the added investment is not justified. Therefore, site G is chosen.

CHAPTER SUMMARY

The benefit/cost method is used primarily to evaluate projects and to select from alternatives in the public sector. When one is comparing mutually exclusive alternatives, the incremental B/C ratio must be greater than or equal to 1.0 for the incremental equivalent total cost to be economically justified. The PW, AW, or FW of the initial costs and estimated benefits can be used to perform an incremental B/C analysis. If alternative lives are unequal, the AW values should be used, provided the assumption of project repetition is not unreasonable. For independent projects, no incremental B/C analysis is necessary. All projects with B/C $\geq$ 1.0 are selected provided there is no budget limitation.

Public sector economics are substantially different from those of the private sector. For public sector projects, the initial costs are usually large, the expected life is long (25, 35, or more years), and the sources for capital are usually a combination of taxes levied on the citizenry, user fees, bond issues, and private lenders. *It is very difficult to make accurate estimates of benefits for a public sector project.* The interest rates, called the discount rates in the public sector, are lower than those for corporate capital financing. Although the discount rate is as important to establish as the MARR, it can be difficult to establish, because various government agencies qualify for different rates. Standardized discount rates are established for some federal agencies.

PROBLEMS

Public Sector Economics

9.1 State the difference between public and private sector alternatives with respect to the following characteristics.
- (*a*) Size of investment
- (*b*) Life of project
- (*c*) Funding
- (*d*) MARR

9.2 Indicate whether the following characteristics are primarily associated with public sector or private sector projects.
- (*a*) Profits
- (*b*) Taxes
- (*c*) Disbenefits
- (*d*) Infinite life
- (*e*) User fees
- (*f*) Corporate bonds

9.3 Identify each cash flow as a benefit, disbenefit, or cost.
(*a*) $500,000 annual income from tourism created by a freshwater reservoir
(*b*) $700,000 per year maintenance by container ship port authority
(*c*) Expenditure of $45 million for tunnel construction on an interstate highway
(*d*) Elimination of $1.3 million in salaries for county residents based on reduced international trade
(*e*) Reduction of $375,000 per year in car accident repairs because of improved lighting
(*f*) $700,000 per year loss of revenue by farmers because of highway right-of-way purchases

9.4 During its 20 years in business, Deware Construction Company has always developed its contracts under a fixed-fee or cost-plus arrangement. Now it has been offered an opportunity to participate in a project to provide cross-country highway transportation in an international setting, specifically, a country in Africa. If accepted, Deware will work as subcontractor to a larger European corporation, and the BOT form of contracting will be used with the African country government. Describe for the president of Deware at least four of the significant differences that may be expected when the BOT format is utilized in lieu of its more traditional forms of contract making.

9.5 If a corporation accepts the BOT form of contracting, (*a*) identify two risks taken by a corporation and (*b*) state how these risks can be reduced by the government partner.

Project B/C Value

9.6 The estimated annual cash flows for a proposed city government project are costs of $450,000 per year, benefits of $600,000 per year, and disbenefits of $100,000 per year. Determine the (*a*) B/C ratio and (*b*) value of B − C.

9.7 Use spreadsheet software such as Excel, PW analysis, and a discount rate of 5% per year to determine that the B/C value for the following estimates is 0.375, making the project not acceptable using the benefit/cost method. (*a*) Enter the values and equations on the spreadsheet so they may be changed for the purpose of sensitivity analysis.

First cost = $8 million
Benefit = $550,000 per year
Annual cost = $800,000/year
Disbenefit = $100,000/year

(*b*) Do the following sensitivity analysis by changing only two cells on your spreadsheet. Change the discount rate to 3% per year, and adjust the annual cost estimate until B/C = 1.023. This makes the project just acceptable using benefit/cost analysis.

9.8 A proposed regulation regarding the removal of arsenic from drinking water is expected to have an annual cost of $200 per household per year. If it is assumed that there are 90 million households in the country and that the regulation could save 12 lives per year, what would the value of a human life have to be for the B/C ratio to be equal to 1.0?

9.9 The U.S. Environmental Protection Agency has established that 2.5% of the median household income is a reasonable amount to pay for safe drinking water. The median household income is $30,000 per year. For a regulation that would affect the health of people in 1% of the households, what would the health benefits have to equal in dollars per household (for that 1% of

the households) for the B/C ratio to be equal to 1.0?

9.10 Use a spreadsheet to set up and solve Problem 9.9, and then apply the following changes. Observe the increases and decreases in the required economic value of the health benefits for each of these changes.

(*a*) Median income is $18,000 (poorer country), and percentage of household income is reduced to 2%.

(*b*) Median income is $30,000 and 2.5% is spent on safe water, but only 0.5% of the households are affected.

(*c*) What percentage of the households must be affected if the required health benefit and annual income both equal $18,000? Assume the 2.5% of income estimate is maintained.

9.11 The fire chief of a medium-sized city has estimated that the initial cost of a new fire station will be $4 million. Annual upkeep costs are estimated at $300,000. Benefits to citizens of $550,000 per year and disbenefits of $90,000 per year have also been identified. Use a discount rate of 4% per year to determine if the station is economically justified by (*a*) the conventional B/C ratio and (*b*) the B − C difference.

9.12 As part of the rehabilitation of the downtown area of a southern U.S. city, the Parks and Recreation Department is planning to develop the space below several overpasses into basketball, handball, miniature golf, and tennis courts. The initial cost is expected to be $150,000 for improvements which are expected to have a 20-year life. Annual maintenance costs are projected to be $12,000. The department expects 24,000 people per year to use the facilities an average of 2 hours each. The value of the recreation has been conservatively set at $0.50 per hour. At a discount rate of 3% per year, what is the B/C ratio for the project?

9.13 The B/C ratio for a new flood control project along the banks of the Mississippi River is required to be 1.3. If the benefit is estimated at $600,000 per year and the maintenance cost is expected to total $300,000 per year, what is the allowed maximum initial cost of the project? The discount rate is 7% per year, and a project life of 50 years is expected. Solve in two ways: (*a*) by hand and (*b*) using a spreadsheet set up for sensitivity analysis.

9.14 Use the spreadsheet developed in Problem 9.13(*b*) to determine the B/C ratio if the initial cost is actually $3.23 million and the discount rate is now 5% per year.

9.15 The modified B/C ratio for a city-owned hospital heliport project is 1.7. If the initial cost is $1 million and the annual benefits are $150,000, what is the amount of the annual M&O costs used in the calculation, if a discount rate of 6% per year applies? The estimated life is 30 years.

9.16 Calculate the B/C ratio for the following cash flow estimates at a discount rate of 6% per year.

Item	Cash Flow
PW of benefits, $	3,800,000
AW of disbenefits, $/year	45,000
First cost, $	2,200,000
M&O costs, $/year	300,000
Life of project, years	15

9.17 Hemisphere Corp. is considering a BOT contract to construct and operate a large dam with a hydroelectric power generation facility in a developing nation in the southern hemisphere. The initial cost of the dam is expected to be $30 million, and it is expected to cost $100,000 per year

to operate and maintain. Benefits from flood control, agricultural development, tourism, etc., are expected to be $2.8 million per year. At an interest rate of 8% per year, should the dam be constructed on the basis of its conventional B/C ratio? The dam is assumed to be a permanent asset for the country. (*a*) Solve by hand. (*b*) Using a spreadsheet, find the B/C ratio with only a single cell computation.

9.18 The U.S. Army Corps of Engineers is considering the feasibility of constructing a small flood control dam in an existing arroyo. The initial cost of the project will be $2.2 million, with inspection and upkeep costs of $10,000 per year. In addition, minor reconstruction will be required every 15 years at a cost of $65,000. If flood damage will be reduced from the present cost of $90,000 per year to $10,000 annually, use the benefit/cost method to determine if the dam should be constructed. Assume that the dam will be permanent and the interest rate is 12% per year.

9.19 A highway construction company is under contract to build a new roadway through a scenic area and two rural towns in Colorado. The road is expected to cost $18 million, with annual upkeep estimated at $150,000 per year. Additional income from tourists of $900,000 per year is estimated. If the road is expected to have a useful commercial life of 20 years, use one spreadsheet to determine if the highway should be constructed at an interest rate of 6% per year by applying (*a*) the B − C method, (*b*) the B/C method, and (*c*) the modified B/C method. (Additionally, if the instructor requests it: Set up the spreadsheet for sensitivity analysis and use the Excel IF operator to make the build–don't build decision in each part of the problem.)

9.20 The U.S. Bureau of Reclamation is considering a project to extend irrigation canals into a desert area. The initial cost of the project is expected to be $1.5 million, with annual maintenance costs of $25,000 per year. (*a*) If agricultural revenue is expected to be $175,000 per year, do a B/C analysis to determine whether the project should be undertaken, using a 20-year study period and a discount rate of 6% per year. (*b*) Rework the problem, using the modified B/C ratio.

9.21 (*a*) Set up the spreadsheet and (*b*) use hand calculations to calculate the B/C ratio for Problem 9.20 if the canal must be dredged every 3 years at a cost of $60,000 and there is a $15,000 per year disbenefit associated with the project.

Alternative Comparison

9.22 Apply incremental B/C analysis at an interest rate of 8% per year to determine which alternative should be selected. Use a 20-year study period, and assume the damage costs might occur in year 6 of the study period.

	Alternative A	Alternative B
Initial cost, $	600,000	800,000
Annual M&O costs, $/year	50,000	70,000
Potential damage costs, $	950,000	250,000

9.23 Two routes are under consideration for a new interstate highway segment. The long route would be 25 kilometers and would have an initial cost of $21 million. The short transmountain route would span 10 kilometers and would have an initial cost of $45 million. Maintenance costs are estimated at $40,000 per year for the long route and $15,000 per year for the short route. Additionally, a major overhaul and

resurfacing will be required every 10 years at a cost of 10% of the first cost of each route. Regardless of which route is selected, the volume of traffic is expected to be 400,000 vehicles per year. If the vehicle operating expense is assumed to be $0.35 per kilometer and the value of reduced travel time for the short route is estimated at $900,000 per year, determine which route should be selected, using a conventional B/C analysis. Assume an infinite life for each road, an interest rate of 6% per year, and that one of the roads will be built.

9.24 A city engineer and economic development director of Buffalo are evaluating two sites for construction of a multipurpose sports arena. At the downtown site, the city already owns enough land for the arena. However, the land for construction of a parking garage will cost $1 million. The west side site is 30 kilometers from downtown, but the land will be donated by a developer who knows that an arena at this site will increase the value of the remainder of his land holdings by many times. The downtown site will have extra construction costs of about $10 million because of infrastructure relocations, the parking garage, and drainage improvements. However, because of its centralized location, there will be greater attendance at most of the events held there. This will result in more revenue to vendors and local merchants in the amount of $350,000 per year. Additionally, the average attendee will not have to travel as far, resulting in annual benefits of $400,000 per year. All other costs and revenues are expected to be the same at either site. If the city uses a discount rate of 8% per year, where should the arena be constructed? One of the two sites must be selected.

9.25 A country with rapid economic expansion has contracted for an economic evaluation of possibly building a new container port to augment the current port. The west coast site is on deeper water so the dredging cost is lower than that for the east coast site. Also, the redredging of the west site will be required only every 6 years while the east site must be reworked each 4 years. Redredging, which is expected to increase in cost by 10% each time, will not take place in the last year of a port's commercial life. Disbenefit estimates vary from west (fishing revenue loss) to east (fishing and resort revenue losses). Fees to shippers per 20-foot STD equivalent are expected to be higher at the west site due to greater difficulty in handling ships because of the ocean currents present in the area and a higher cost of labor in this area of the country. All estimates are summarized below in $1 million, except annual revenue and life. Use spreadsheet analysis and a discount rate of 4% per year to determine if either port should be constructed. It is not necessary that the country build either port since one is already operating successfully.

	West Coast Site	East Coast Site
Initial cost, $		
Year 0	21	8
Year 1	0	8
Dredging cost, $, year 0	5	12
Annual M&O, $/year	1.5	0.8
Recurring dredging cost, $	2 each 6 years with increase of 10% each time	1.2 each 4 years with increase of 10% each time
Annual disbenefits, $/year	4	7
Annual fees: number of 20-foot. STD at $/container	5 million/year at $2.50 each	8 million/year at $2 each
Commercial life, years	20	12

9.26 A privately owned utility is considering two cash rebate programs to achieve water conservation. Program 1, which is expected to cost an average of $60 per household, would involve a rebate of 75% of the purchase and installation costs of an ultralow-flush toilet. This program is projected to achieve a 5% reduction in overall household water use over a 5-year evaluation period. This will benefit the citizenry to the extent of $1.25 per household per month. Program 2 would involve grass replacement with desert landscaping. This is expected to cost $500 per household, but it will result in reduced water cost at an estimated $8 per household per month (on the average). At a discount rate of 0.5% per month, which program, if either, should the utility undertake? Use the B/C method.

9.27 Solar and conventional alternatives are available for providing energy at a remote space research site. The costs associated with each alternative are shown below. Use the B/C method to determine which should be selected at an discount rate of 0.75% per month over a 6-year study period.

	Conventional	Solar
Initial cost, $	2,000,000	4,500,000
M&O cost, $/month	50,000	10,000
Salvage value, $	0	150,000

9.28 The California Forest Service is considering two locations for a new state park. Location E would require an investment of $3 million and $50,000 per year in maintenance. Location W would cost $7 million to construct, but the Forest Service would receive an additional $25,000 per year in park use fees. The operating cost of location W will be $65,000 per year. The revenue to park concessionaires will be $500,000 per year at location E and $700,000 per year at location W. The disbenefits associated with each location are $30,000 per year for location E and $40,000 per year for location W. Use (*a*) the B/C method and (*b*) the modified B/C method to determine which location, if either, should be selected, using an interest rate of 12% per year. Assume that the park will be maintained indefinitely.

9.29 Three engineers made the estimates shown below for two optional methods by which new construction technology would be implemented at a site for public housing. Either one of the two options or the current method may be selected. Set up a spreadsheet for B/C sensitivity analysis, and determine if option 1, option 2, or the do-nothing option is selected by each of the three engineers. Use a life of 5 years and a discount rate of 10% per year for all analyses.

	Engineer Bob		Engineer Judy		Engineer Chen	
	Option 1	Option 2	Option 1	Option 2	Option 1	Option 2
Initial cost, $	50,000	90,000	75,000	90,000	60,000	70,000
Cost, $/year	3,000	4,000	3,800	3,000	6,000	3,000
Benefits, $/year	20,000	29,000	30,000	35,000	30,000	35,000
Disbenefits, $/year	500	1,500	1,000	0	5,000	1,000

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Multiple Alternatives

9.30 One of four new techniques, or the current method, can be used to control mildly irritating chemical fume leakage into the surounding air from a mixing machine. The estimated costs and benefits (in the form of reduced employee health costs) are given below for each method. Assuming that all methods have a 10-year life with zero salvage value, determine which one should be selected, using a MARR of 15% per year and the B/C method.

	Technique			
	1	2	3	4
Installed cost, $	15,000	19,000	25,000	33,000
AOC, $/year	10,000	12,000	9,000	11,000
Benefits, $/year	15,000	20,000	19,000	22,000

9.31 Use a spreadsheet to perform a B/C analysis for the techniques in Problem 9.30 provided they are independent projects. Assume the benefits are cumulative if more than one technique is used in addition to the current method.

9.32 The Water Service Authority of Dubay is considering four sizes of pipe for a new water line. The costs per kilometer ($/km) for each size are given in the table. Assuming that all pipes will last 15 years and the MARR is 8% per year, which size pipe should be purchased based on a B/C analysis? Installation cost is considered a part of the initial cost.

	Pipe Size, Millimeters			
	130	150	200	230
Initial eqiuipment cost, $/km	9,180	10,510	13,180	15,850
Installation cost, $/km	600	800	1,400	1,500
Usage cost, $/km per year	6,000	5,800	5,200	4,900

9.33 The federal government is considering three sites in the National Wildlife Preserve for mineral extraction. The cash flows (in millions) associated with each site are given below. Use the B/C method to determine which site, if any, is best, if the extraction period is limited to 5 years and the interest rate is 10% per year.

	Site A	Site B	Site C
Initial cost, $	50	90	200
Annual cost, $/year	3	4	6
Annual benefits, $/year	20	29	61
Annual disbenefits, $/year	0.5	1.5	2.1

9.34 Over the last several months, seven different toll bridge designs have been proposed and estimates made to connect a resort island to the mainland of an Asian country.

Location	Construction Cost, $ Millions	Annual Excess Fees Over Expenses, $100,000
A	14	4.0
B	8	6.1
C	22	10.8
D	9	8.0
E	12	7.5
F	6	3.9
G	18	9.3

A public-private partnership has been formed, and the national bank will be providing funding at a rate of 4% per year. Each bridge is expected to have a very long useful life. Use B/C analysis to answer the following. Solution by spreadsheet or by hand is acceptable.

(*a*) If one bridge design must be selected, determine which one is the best economically.

(*b*) An international bank has offered to fund as many as two additional bridges, since it is estimated that the trafffic and trade between the island and mainland will increase significantly. Determine which are the three best designs economically, if there is no budget restraint for the purpose of this analysis.

9.35 Three alternatives identified as X, Y, and Z were evaluated by the B/C method. The analyst, Joyce, calculated project B/C values of 0.92, 1.34, and 1.29. The alternatives are listed in order of increasing total equivalent costs. She isn't sure whether an incremental analysis is needed.

(*a*) What do you think? If no incremental analysis is needed, why not; if so, which alternatives must be compared incrementally?

(*b*) For what type of projects is incremental analysis never necessary? If X, Y, and Z are all this type of project, which alternatives are selected for the B/C values calculated?

9.36 The four mutually exclusive alternatives below are being compared using the B/C method. What alternative, if any, should be selected?

Alternative	Initial Investment, $ Millions	B/C Ratio	Incremental B/C When Compared with Alternative			
			J	K	L	M
J	20	1.10	—			
K	25	0.96	0.40	—		
L	33	1.22	1.42	2.14	—	
M	45	0.89	0.72	0.80	0.08	—

9.37 The city of Ocean View, California, is considering various proposals regarding the disposal of used tires. All the proposals involve shredding, but the charges for the service and handling of the tire shreds differ in each plan. An incremental B/C analysis was initiated, but the engineer conducting the study left recently. (*a*) Fill in the blanks in the incremental B/C portion of the table. (*b*) What alternative should be selected?

Alternative	Initial Investment, $ Millions	B/C Ratio	Incremental B/C When Compared with Alternative			
			P	Q	R	S
P	10	1.1	—	2.83		
Q	40	2.4	2.83	—		
R	50	1.4			—	
S	80	1.5				—

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FE REVIEW PROBLEMS

9.38 When a B/C analysis is conducted,
(*a*) The benefits and costs must be expressed in terms of their present worths.
(*b*) The benefits and costs must be expressed in terms of their annual worths.
(*c*) The benefits and costs must be expressed in terms of their future worths.
(*d*) The benefits and costs can be expressed in terms of PW, AW, or FW.

9.39 In a conventional B/C ratio,
(*a*) Disbenefits and M&O costs are subtracted from benefits.
(*b*) Disbenefits are subtracted from benefits, and M&O costs are added to costs.
(*c*) Disbenefits and M&O costs are added to costs.
(*d*) Disbenefits are added to costs, and M&O costs are subtracted from benefits.

9.40 In a modified B/C ratio analysis,
(*a*) Disbenefits and M&O costs are subtracted from benefits.
(*b*) Disbenefits are subtracted from benefits, and M&O costs are added to costs.
(*c*) Disbenefits and M&O costs are added to costs.
(*d*) Disbenefits are added to costs, and M&O costs are subtracted from benefits.

9.41 An alternative has the following cash flows: benefits = $60,000 per year, disbenefits = $17,000 per year, and costs = $35,000 per year. The B/C ratio is closest to
(*a*) 0.92
(*b*) 0.96
(*c*) 1.23
(*d*) 2.00

9.42 In evaluating three mutually exclusive alternatives by the B/C method, the alternatives were ranked in terms of increasing total equivalent cost (A, B, and C, respectively), and the following results were obtained for the project B/C ratios: 1.1, 0.9, and 1.3. On the basis of these results, you should
(*a*) Select A.
(*b*) Select C.
(*c*) Select A and C.
(*d*) Compare A and C incrementally.

9.43 Four independent projects are evaluated, using B/C ratios. The ratios are as follows:

Project	A	B	C	D
B/C ratio	0.71	1.29	1.07	2.03

On the basis of these results, you should
(*a*) Reject B and D.
(*b*) Select D only.
(*c*) Reject A only.
(*d*) Compare B, C and D incrementally.

9.44 If two mutually exclusive alternatives have B/C ratios of 1.5 and 1.4 for the lower first-cost and higher first-cost alternatives, respectively,
(*a*) The B/C ratio on the increment between them is less than 1.4.
(*b*) The B/C ratio on the increment between them is between 1.4 and 1.5.
(*c*) The B/C ratio on the increment between them is greater than 1.4.
(*d*) The lower-cost alternative is the better one.

EXTENDED EXERCISE

COSTS TO PROVIDE LADDER TRUCK SERVICE FOR FIRE PROTECTION

For many years, the city of Medford has paid a neighboring city (Brewster) for the use of its ladder truck when needed. The charges for the last few years have been $1000 per event when the ladder truck is only dispatched to a site in Medford, and $3000 each time the truck is activated. There has been no annual fee charged. With the approval of the Brewster city manager, the newly hired fire chief has presented a substantially higher cost to the Medford fire chief for the use of the ladder truck:

Annual flat fee	$30,000 with 5 years' fees paid up front (now)
Dispatch fee	$3000 per event
Activation fee	$8000 per event

The Medford chief has developed an alternative to purchase a ladder truck, with the following cost estimates for the truck and the fire station addition to house it:

Truck:	
Initial cost	$850,000
Life	15 years
Cost per dispatch	$2000 per event
Cost per activation	$7000 per event
Building:	
Initial cost	$500,000
Life	50 years

The chief has also taken data from a study completed last year and updated it. The study estimated the insurance premium and property loss reductions that the citizenry experienced by having a ladder truck available. The past savings and current estimates, if Medford had its own truck for more rapid response, are as follows:

	Past Average	Estimate If Truck Is Owned
Insurance premium reduction, $/year	100,000	200,000
Property loss reduction, $/year	300,000	400,000

Additionally, the Medford chief obtained the average number of events for the last 3 years and estimated the future use of the ladder truck. He believes there has been a reluctance to call for the truck from Brewster in the past.

	Past Average	Estimate If Truck Is Owned
Number of dispatches per year	10	15
Number of activations per year	3	5

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Either the new cost structure must be accepted, or a truck must be purchased. The option to have no ladder truck service is not acceptable. Medford has a good rating for its bonds; a discount rate of 6% per year is used for all proposals.

Questions

Use a spreadsheet to do the following.

1. Perform an incremental B/C evaluation to determine if Medford should purchase a ladder truck.
2. Several of the new city council members are "up in arms" over the new annual fee and cost structure. However, they do not want to build more fire station capacity or own a ladder truck that will be used an average of only 20 times per year. They believe that Brewster can be convinced to reduce or remove the annual $30,000 fee. How much must the annual fee be reduced for the alternative to purchase the ladder truck to be rejected?
3. Another council member is willing to pay the annual fee, but wants to know how much the building cost can change from $500,000 to make the alternatives equally attractive. Find this first cost for the building.
4. Finally, a compromise proposal offered by the Medford mayor might be acceptable to Brewster. Reduce the annual fee by 50%, and reduce the per event charges to the same amount that the Medford fire chief estimates it will cost if the truck is owned. Then Medford will possibly adjust (if it seems reasonable) the sum of the insurance premium reduction and property loss reduction estimates to just make the arrangement with Brewster more attractive than owning the truck. Find this sum (for the estimates of premium reduction and property loss reduction). Does this new sum seem reasonable relative to the previous estimates?

CASE STUDY

FREEWAY LIGHTING

Introduction

A number of studies have shown that a disproportionate number of freeway traffic accidents occur at night. There are a number of possible explanations for this, one of which might be poor visibility. In an effort to determine whether freeway lighting was economically beneficial for reducing nighttime accidents, data were collected regarding accident frequency rates on lighted and unlighted sections of certain freeways. This case study is an analysis of part of those data.

Background

The Federal Highway Administration (FHWA) places value on accidents depending on the severity of the crash. There are a number of crash categories, the most severe of which is fatal. The cost of a fatal accident is placed at $2.8 million. The most common type of accident is not fatal or injurious and involves only property damage. The cost of this type of accident is placed at $4500. The ideal way to determine whether lights reduce traffic accidents is through

before-and-after studies on a given section of freeway. However, this type of information is not readily available, so other methods must be used. One such method compares night to day accident rates for lighted and unlighted freeways. If lights are beneficial, the ratio of night to day accidents will be lower on the lighted section than on the unlighted one. If there is a difference, the reduced accident rate can be translated into benefits which can be compared to the cost of lighting to determine its economic feasibility. This technique is used in the following analysis.

Economic Analysis

The results of one particular study conducted over a 5-year period are shown on the following page. For illustrative purposes, only the property damage category will be considered.

The ratios of night to day accidents involving property damage for the unlighted and lighted freeway sections are $199/379 = 0.525$ and $839/2069 = 0.406$, respectively. These results indicate that the lighting was beneficial. To quantify the benefit, the accident-rate ratio from the unlighted section will be applied to the lighted section. This will yield the number of accidents that were prevented. Thus, there would have been $(2069)(0.525) = 1086$ accidents instead of the 839 if there had not been lights on the freeway. This is a difference of 247 accidents. At a cost of \$4500 per accident, this results in a net benefit of

$$B = (247)(\$4500) = \$1{,}111{,}500$$

To determine the cost of the lighting, it will be assumed that the light poles are center poles 67 meters apart with 2 bulbs each. The bulb size is 400 watts, and the installation cost is \$3500 per pole. Since these data were collected over 87.8 kilometers (54.5 miles) of lighted freeway, the installed cost of the lighting is

$$\begin{aligned}\text{Installation cost} &= \$3500\left(\frac{87.8}{0.067}\right)\\ &= 3500(1310.4)\\ &= \$4{,}586{,}400\end{aligned}$$

The annual power cost based on 1310 poles is

$$\begin{aligned}&\text{Annual power cost}\\ &= 1310 \text{ poles}(2 \text{ bulbs/pole})(0.4 \text{ kilowatts/bulb})\\ &\quad \times (12 \text{ hours/day})(365 \text{ days/year})\\ &\quad \times (\$0.08/\text{kilowatt-hour})\\ &= \$367{,}219 \text{ per year}\end{aligned}$$

These data were collected over a 5-year period. Therefore, the annualized cost C at $i = 6\%$ per year is

$$\begin{aligned}\text{Total annual cost} &= \$4{,}586{,}400(A/P,6\%,5)\\ &\quad + 367{,}219\\ &= \$1{,}456{,}030\end{aligned}$$

Freeway Accident Rates, Lighted and Unlighted

	Unlighted		Lighted	
Accident Type	Day	Night	Day	Night
Fatal	3	5	4	7
Incapaciting	10	6	28	22
Evident	58	20	207	118
Possible	90	35	384	161
Property damage	379	199	2069	839
Totals	540	265	2697	1147

Source: Michael Griffin, "Comparison of the Safety of Lighting Options on Urban Freeways," *Public Roads,* 58 (Autumn 1994), pp. 8–15.

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The B/C ratio is

$$B/C = \frac{\$1,111,500}{\$1,456,030} = 0.76$$

Since B/C < 1, the lighting is not justified on the basis of property damage alone. To make a final determination about the economic viability of the lighting, the benefits associated with the other accident categories would obviously also have to be considered.

Case Study Exercises

1. What would the B/C ratio be if the light poles were twice as far apart as assumed above?
2. What is the ratio of night to day accidents for fatalities?
3. What would the B/C ratio be if the installation cost were only $2500 per pole?
4. How many accidents would be prevented on the unlighted portion of freeway if it were lighted? Consider the property damage category only.
5. Using only the category of property damage, what would the lighted night-to-day accident ratio have to be for the lighting to be economically justified?