Chapter 4

Benefit/Cost Analysis

LEARNING OUTCOMES

1. **Explain difference in public vs. private sector projects**
2. **Calculate B/C ratio for single project**
3. **Select better of two alternatives using B/C method**
4. **Select best of multiple alternatives using B/C method**
5. **Use cost-effectiveness analysis (CEA) to evaluate service sector projects**
6. **Describe how ethical compromises may enter public sector projects**

Pubic sector projects

A public sector project is a product, service, or system used, financed, and owned by the citizens of any government level.

The primary purpose is to provide service to the citizenry for the public good at no profit.

Areas such as public health, criminal justice, safety, transportation, welfare, and utilities are publically owned and require economic evaluation.

Differences: Public vs. Private Projects

Characteristic	Public	Private
Size of Investment	Large	Small, medium, large
Life	Longer (30 – 50+ years)	Shorter (2 – 25 years)
Annual CF	No profit	Profit-driven
Funding	Taxes, fees, bonds, etc.	Stocks, bonds, loans, etc.
Interest rate	Lower	Higher
Selection criteria	Multiple criteria	Primarily ROR
Environment of evaluation	Politically inclined	Economic

Types of Contracts

Most of the large public sector projects are developed through PPPs.
Reasons: Greater efficiency of private sector and the sizable cost to design, construct, and operate where full funding by the govt. may not be possible using fees, taxes, and bonds.

Types of PPPs

- Design-build projects - Contractor responsible from design stage to operations stage
- Design-build-operate-maintain-finance (DBOMF) projects - Turnkey project with contractor managing financing (manage cash flow); government obtains funding for project
- DBOM- When the financing activity is not managed by a contractor, the contractor is a DBOM.

PPP examples: **Construction of Dhaka Elevated Expressway**
Private Partner: Italian-Thai Development Company Ltd (International)

Cash Flow Classifications

- 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.

Note: Savings to government are subtracted from costs

Benefit/Cost Analysis of a Single Project

- 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:

$$\frac{B}{C} = \frac{PW\ of\ benefits}{PW of\ costs} = \frac{AW\ of\ benefits}{AW of\ costs} = \frac{FW\ of\ benefits}{FW of\ costs}$$

Note 1: **All terms must be expressed in *same units*, i.e., PW, AW, or FW**
Note 2: *Do not use minus sign* ahead of costs

Benefit/Cost Analysis of a Single Project

The decision guideline is simple:

If B/C ≥ 1.0, accept the project as economically justified 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.

Benefit/Cost Analysis of a Single Project

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

$$\frac{B}{C} = \frac{benefits - disbenefits}{costs} = \frac{B-D}{C}$$

Disbenefits are subtracted from benefits, not added to costs. The B/C value could change considerably if disbenefits are regarded as costs.

However, regardless of 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.

Benefit/Cost Analysis of a Single Project

The modified B/C ratio includes all the estimates associated with the project.

Annual operating costs (AOC) and maintenance and operation (M&O) costs are placed in the numerator and treated 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

Benefit/Cost Analysis of a Single Project

- Salvage value is usually 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 decision guideline for the modified B/C ratio is the same as that for the conventional B/C ratio.

Defender, Challenger and Do Nothing Alternatives

When selecting from two or more ME alternatives, there is a:

✓ **Defender –** in-place system or currently selected alternative

✓ **Challenger –** Alternative challenging the defender

✓ **Do-nothing option –** Status quo system

Incremental B/C Analysis (Two Alternatives)

The incremental (conventional) B/C ratio, which is identified as ΔB/C, is determined using PW, AW, or FW calculations. The higher-cost alternative is justified if ΔB/C is equal to or larger than 1.0. The selection rule is as follows:

The selection rule is as follows

- If ΔB/C ≥ 1.0, choose the higher-cost alternative, because its extra cost is economically justified.
- If ΔB/C < 1.0, choose the lower-cost alternative.

Incremental B/C Analysis (Two Alternatives)

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 equivalent total costs for both alternatives.
2. Order the alternatives by equivalent total cost: first smaller, then larger. Calculate the incremental cost (ΔC) for the larger-cost alternative. This is the denominator in ΔB/C.

3. Calculate the equivalent total benefits and any disbenefits estimated for both alternatives. Calculate the incremental benefits (ΔB) for the larger-cost alternative. This is Δ(B − D) if disbenefits are considered.

4. Calculate the ΔB/C ratio using Equation [9.2], (B − D)/C. 5.

5. Use the selection guideline to select the higher-cost alternative if ΔB/C ≥ 1.0.

B/C Analysis – Single Project

$$\text{Conventional B/C ratio} = \frac{B - D}{C}$$

$$\text{Modified B/C ratio} = \frac{B - D - M\&O}{C}$$

If B/C ≥ 1.0,
accept project;
otherwise, reject

$$PI = \frac{\text{PW of } NCF_t}{\text{PW of initial investment}}$$

Denominator is initial investment

If PI ≥ 1.0,
accept project;
otherwise, reject

Decision rules-the Net Present Value(NPV)

The Net Present Value (NPV) Criterion

The NPV of a project simply expresses the *difference between* the discounted present value of future benefits and the discounted present value of future costs: NPV = PV (Benefits) – PV (Costs). A positive NPV value for a given project tells us that the project benefits are greater than its costs, and *vice versa*. When we compare the project's total discounted costs and discounted benefits, we derive the NPV:

Example 3.4: Comparison of Projects A and B using Net Present Value

Project A:

Year	0	1	2	3
(1) Cash Flow	–100	+50	+40	+30
(2) Discount Factor (at 10%)	1.00	0.909	0.826	0.751
(3) Discounted cash flow (=1x2)	–100.00	45.45	33.04	22.53

$$\begin{aligned} NPV(A)_{0.1} &= -\$100(1.0) + \$50(0.909) + \$40(0.826) + \$30(0.751) \\ &= \$101.02 - 100.00 \\ &= \$1.02 \end{aligned}$$

As NPV(A) > 0, accept the project (when cost of capital = 10%).

Decision rules-the Net Present Value(NPV)

Summary of NPV Decision-Rules

(1) For accept or reject decisions:

if $NPV \geq 0$, accept
if $NPV < 0$, reject

(2) When choosing or ranking alternatives:

if $NPV(A) > NPV(B)$, choose A
if $NPV(B) > NPV(A)$, choose B

At this stage we should point out that no mention has been made of the size of the available investment budget. The *implicit* assumption is that there is no budget constraint. As we shall see later, in situations of a budget constraint, other decision-rules are needed to rank projects.

Decision rules: Benefit-Cost Ration

Benefit-Cost Ratio Decision-Rule

Another form of the NPV decision-rule is called the **Benefit-Cost Ratio** (or BCR) decision-rule, which is, in effect, another way of comparing the present value of a project's costs with the present value of its benefits. Instead of calculating the NPV by *subtracting* the PV of Costs from the PV of Benefits, we *divide* the PV of Costs into the PV of Benefits, i.e.

$$BCR = \frac{PV\ (Benefits)}{PV\ (Costs)}$$

(It should be noted that the denominator of the BCR includes the present value of all project costs, not just the capital costs. Later on we discuss a variant of this rule that includes only the capital costs in the denominator.)

If this ratio is equal to or greater than unity, then accept the project. If it is less than unity, then reject the project. It should be clear that when:

$$NPV \geq 0, \text{ then } BCR \geq 1$$

$$\text{and,} \quad NPV < 0, \text{ then } BCR < 1$$

Decision rules: The Internal Rate of Return (IRR) Criterion

- The discount rate at which the NPV becomes “0” is called the Internal Rate of Return (IRR).
- Once we know the IRR of an investment we can compare this with the cost of financing our project.
- In a project, the IRR was found to lie between 20 and 25%, approximately 23%. Let us say, in this case, the cost of financing the project is 15%. Now, as the rate of return, the IRR, is greater than the cost of financing the project, we should accept the investment.
- In fact, in the case of this investment, we would accept the investment at any cost of finance that is below 23%. When the IRR is less than the cost of finance, the project should be rejected

Decision rules: The Internal Rate of Return (IRR) Criterion

when IRR $\geq$ r, then accept

and when IRR < r, then reject

where r = the interest rate (cost of financing the project)

When considering an individual project, the IRR decision-rule will always give exactly the same result as the NPV decision-rule:

Example: B/C Analysis – Single Project

A flood control project will have a first cost of \$1.4 million with an annual maintenance cost of \$40,000 and a 10 year life. Reduced flood damage is expected to amount to \$175,000 per year. Lost income to farmers is estimated to be \$25,000 per year. At an interest rate of 6% per year, should the project be undertaken?

Solution: Express all values in AW terms and find B/C ratio

B = \$175,000

D = \$25,000

C = 1,400,000(A/P,6%,10) + \$40,000 = \$230,218

B/C = (175,000 – 25,000)/230,218
= 0.65 < 1.0

Do not build project

Example: Incremental B/C Analysis

Compare two alternatives using i = 10% and B/C ratio

Alternative	X	Y
~~First cost, $~~	~~320,000~~	~~540,000~~
M&O costs, $/year	45,000	35,000
Benefits, $/year	110,000	150,000
Disbenefits, $/year	20,000	45,000
Life, years	10	20

Solution: First, calculate equivalent total cost

AW of costs_X = 320,000(A/P,10%,10) + 45,000 = $97,080

AW of costs_Y = 540,000(A/P,10%,20) + 35,000 = $98,428

Order of analysis is X, then Y

X vs. DN: (B-D)/C = (110,000 – 20,000) / 97,080 = 0.93 Eliminate X

Y vs. DN: (150,000 – 45,000) / 98,428 = 1.07 Eliminate DN

Select Y

Example: ΔB/C Analysis; Selection Required

Must select one of two alternatives using i = 10% and ΔB/C ratio

Alternative	X	Y
First cost, $	320,000	540,000
M&O costs, $/year	45,000	35,000
Benefits, $/year	110,000	150,000
Disbenefits, $/year	20,000	45,000
Life, years	10	20

Solution: Must select X or Y; DN not an option, *compare Y to X*

AW of costs_X = $97,080 AW of costs_Y = $98,428

Incremental values: ΔB = 150,000 – 110,000 = $40,000

ΔD = 45,000 – 20,000 = $25,000

ΔC = 98,428 – 97,080 = $1,348

Y vs. X: (ΔB - ΔD) / ΔC = (40,000 – 25,000) / 1,348 = 11.1

Eliminate X

Select Y

B/C Analysis of Independent Projects

- Independent projects comparison does not require incremental analysis
- Compare each alternative's overall B/C with DN option

+ No budget limit: Accept all alternatives with $B/C \geq 1.0$

+ Budget limit specified: capital budgeting problem; selection follows different procedure (discussed in chapter 12)

Cost Effectiveness Analysis

Service sector projects primarily involve **intangibles**, **not physical facilities**; examples include health care, security programs, credit card services, etc.

Cost-effectiveness analysis (CEA) combines monetary cost estimates with ***non-monetary*** benefit estimates to calculate the

Cost-effectiveness ratio (CER)

$$\textbf{CER} = \frac{\text{Equivalent total costs}}{\text{Total effectiveness measure}}$$

$$= C/E$$

CER Analysis for Independent Projects

Procedure is as follows:

(1) Determine equivalent total cost **C**, total effectiveness measure **E** and **CER**
(2) **Order projects by smallest to largest CER**
(3) Determine cumulative cost of projects and compare to budget limit ***b***
(4) Fund all projects such that ***b* is not exceeded**

Example: The effectiveness measure ***E*** is the number of graduates from adult training programs. For the CERs shown, determine which ***independent*** programs should be selected; b = $500,000.

Program	CER, $/graduate	Program Cost, $
A	1203	305,000
B	752	98,000
C	2010	126,000
D	1830	365,000

Example: CER for Independent Projects

First, rank programs according to increasing CER:

Program	CER, $/graduate	Program Cost, $	Cumulative Cost, $
B	752	98,000	98,000
A	1203	305,000	403,000
D	1830	365,000	768,000
C	2010	126,000	894,000

Next, select programs until budget is not exceeded

Select programs B and A at total cost of $403,000

Note: To expend the entire $500,000, accept as many additional individuals as possible from D at the per-student rate

CER Analysis for Mutually Exclusive Projects

Procedure is as follows

(1) Order alternatives smallest to largest by effectiveness measure *E*

(2) Calculate **CER for first alternative** (defender) and compare to DN option

(3) Calculate incremental cost (ΔC), effectiveness (ΔE), and incremental measure **ΔC/E for challenger** (next higher *E* measure)

(4) If $\Delta C/E_{challenger} < C/E_{defender}$ challenger becomes defender **(dominance);** otherwise, **no dominance** is present and both alternatives are retained

(5) **Dominance present:** Eliminate defender and compare next alternative to new defender per steps (3) and (4).

Dominance not present: Current challenger becomes new defender against next challenger, **but old defender remains viable**

(6) Continue steps (3) through (5) until only **1 alternative remains** or only **non-dominated alternatives remain**

(7) Apply budget limit or other criteria to **determine which of remaining non-dominated alternatives** can be funded

Example: CER for ME Service Projects

The effectiveness measure **E is wins per person**. From the cost and effectiveness values shown, determine which alternative to select.

Program	Cost (C) $/person	Effectiveness (E) wins/person	CER $/win
A	2200	4	550
B	1400	2	700
C	6860	7	980

Example: CER for ME Service Projects

Solution:

Order programs according to increasing effectiveness measure E

Program	Cost (C) $/person	Effectiveness (E) wins/person	CER $/win
B	1,400	2	700
A	2,200	4	550
C	6,860	7	980

B vs. DN: $C/E_B = 1400/2 = 700$

A vs. B: $\Delta C/E = (2200 - 1400)/(4 - 2) = 400$ Dominance; eliminate B

C vs. A: $\Delta C/E = (6860 - 2200)/(7 - 4) = 1553$ No dominance; retain C

Must use other criteria to select either A or C

Ethical Considerations

Engineers are routinely involved in two areas where ethics may be compromised:

Public policy making – **Development of strategy**, e.g., water system management (supply/demand strategy; ground vs. surface sources)

Public planning - **Development of projects**, e.g., water operations (distribution, rates, sales to outlying areas)

Engineers must maintain integrity and impartiality and *always* adhere to Code of Ethics

Summary of Important Points

- B/C method used in ***public sector*** project evaluation
- Can use PW, AW, or FW for incremental B/C analysis, but must ***be consistent*** with units for B,C, and D estimates
- For multiple mutually exclusive alternatives, compare two at a time and eliminate alternatives until ***only one remains***
- For independent alternatives with no budget limit, compare each against **DN** and select ***all alternatives that have B/C ≥ 1.0***
- **CEA analysis** for service sector projects combines cost and ***nonmonetary measures***
- Ethical dilemmas are ***especially prevalent*** in public sector projects