Chapter 9

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

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

Contractors does not share project risk

- **Fixed price** - lump-sum payment
- **Cost reimbursable** - Cost plus, as negotiated

Contractor shares in project risk

- **Public-private partnerships (PPP)**, such as:
  - **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

Cash Flow Classifications and B/C Relations

Must identify each cash flow as either benefit, disbenefit, or cost

Benefit (B) -- Advantages to the *public*

Disbenefit (D) -- Disadvantages to the *public*

Cost (C) -- Expenditures by the *government*

Note: Savings to government are subtracted from costs

Conventional B/C ratio = (B–D) / C

Modified B/C ratio = [(B–D) – C] / Initial Investment

Profitability Index = NCF / Initial Investment

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

Decision Guidelines for B/C and PI

Benefit/cost analysis

If B/C ≥ 1.0, project **is** economically justified at discount rate applied

If B/C < 1.0, project **is not** economically acceptable

Profitability index analysis of revenue projects

If PI ≥ 1.0, project **is** economically justified at discount rate applied

If PI < 1.0, project **is not** economically acceptable

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

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

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

General approach for incremental B/C analysis of two ME alternatives:

- Lower total cost alternative is first compared to ***Do-nothing (DN)***
- If B/C for the lower cost alternative is < 1.0, the DN option is compared to ΔB/C of the higher-cost alternative
- If both alternatives lose out to DN option, DN prevails, unless overriding needs requires selection of one of the alternatives

Alternative Selection Using Incremental B/C Analysis – Two or More ME Alternatives

Procedure similar to ROR analysis for multiple alternatives

(1) Determine *equivalent total cost* for each alternative
(2) Order alternatives by increasing total cost
(3) Identify *B and D for each alternative*, if given, or go to step 5
(4) Calculate B/C for each alternative and eliminate all with B/C < 1.0
(5) Determine incremental costs and benefits for first two alternatives
(6) Calculate ΔB/C; if >1.0, higher cost alternative becomes defender
(7) Repeat steps 5 and 6 until only one alternative remains

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 ≥ 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)

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

$$= C/E$$

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 **$\Delta C/E$ 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