In the name of Allah

Amirkabir University of Technology
(Tehran Polytechnic)
Industrial Engineering Department

Course Title:
Engineering Economics

9. Benefit/Cost Analysis and Public Sector Economics

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Learning Stage 2: Basic Analysis Tools

- Chapter 5
  - Present Worth Analysis
- Chapter 6
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- Chapter 7
  - Rate of Return Analysis: One Project
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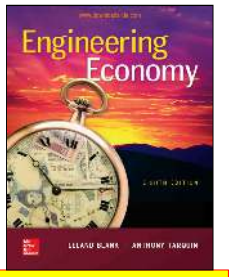
- Chapter 9
  - Benefit/Cost Analysis and Public Sector Economics



Chapter 9 of EE (BT) book 8th edition

LEARNING OUTCOMES

- Purpose:
  - Understand public sector projects and select the best alternative on the basis of incremental benefit /cost analysis.

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

- How to Select the Basic Analysis Tool

Public Projects

- Public sector project
  - A product, service, or system used, financed, and owned by the citizens of any government level.
- The primary purpose:
  - 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/ Financing	Taxes, fees, bonds, etc.	Stocks, bonds, loans, etc.
Interest rate	Lower	Higher
Selection criteria	Multiple criteria	Primarily ROR
Environment of evaluation	Politically motivated	Economic

Types of Contracts

- Contractor does not share in project risk
  - A government unit took responsibility for funding and possibly some of the design elements, and later all operation activities, while the contractor did not share in the risks involved.
  - Fixed price - lump-sum payment
  - Cost reimbursable - Cost plus, as negotiated

- Contractor shares in project risk
  - Public-private partnerships (PPP), such as:
    - Design-build (DB) projects: Contractor responsible from design to operations stages
    - 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 one of the followings:
  - Benefit (B): advantages to be experienced by the owners & public
  - Disbenefit (D): expected undesirable/negative consequences to the owners if the alternative is implemented.
    - Disbenefits may be indirect economic disadvantages of the alternative.
  - Cost (C): estimated expenditures to the government for construction, operation, and maintenance of the project,
    - less any expected salvage value.

Cash Flow Classifications and B/C Relations

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

- Conventional, (the most widely used) B/C ratio = (B − D) / C
- Modified B/C ratio = [(B − D) − M&O] / Initial Investment
  - M&O: Maintenance & Operating costs
- Profitability Index (PI) = 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

$$\mathbf{B} = \$\mathbf{175,000}, \qquad \mathbf{D} = \$\mathbf{25,000}$$

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

$$\mathbf{B/C} = (\mathbf{175,000} - \mathbf{25,000})/\mathbf{230,218} = \mathbf{0.65} < \mathbf{1.0}$$

Do not build the 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 (selected), 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 alternatives 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

So, 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 is not an option, compare Y to X

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

Incremental values: $\Delta B = 150{,}000 - 110{,}000 = \$40{,}000$

$\Delta D = 45{,}000 - 20{,}000 = \$25{,}000$

$\Delta C = 98{,}428 - 97{,}080 = \$1{,}348$

Y vs. X: $(\Delta B - \Delta D)/\Delta C = (40{,}000 - 25{,}000)/1{,}348 = 11.1$ 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 of your book)

Example 9.3: B/C analysis for a PPP

- A Government office is considering a PPP with a private Co. as the prime contractor using a DBFOM contract for a new 22.51-mile toll road.
  - The design includes three 4-mile-long commercial/retail corridors on both sides of the toll road.
  - Highway construction is expected to require 5 years at an average cost of $3.91 million per mile.
    - The discount rate is 4% per year, and the study period is 30 years.
  - Evaluate the economics of the proposal using
    - (a) the modified B/C analysis from the Government perspective, and
    - (b) the profitability index (PI) from the Co. viewpoint in which disbenefits are not included.

Example 9.3: B/C analysis for a PPP

- Example
  - Initial investment:
    - $88 M distributed over 5 years so that $4 M now and in year 5; and $20 M in each of years 1 through 4.
  - Annual M&O cost:
    - $1 M per year, plus an additional $3 M each fifth year, including Year 30.
  - Annual revenue/benefits:
    - Tolls & retail/commercial growth; start at $2 M in year 1, increasing by a constant $0.5 M annually through year 10, and then increasing by a constant $1 M per year through year 20 and remaining constant thereafter.
  - Estimable disbenefits:
    - Include loss of business income, taxes, and property value in surrounding areas; start at $10 M in year 1, decrease by $0.5 M per year through year 21, and remain at zero thereafter.

Example 9.3: B/C analysis for a PPP

- Solution
  - The PW values in year 0 for all estimates must be developed.
    - All values are positive because of the sign convention for B/C and PI.
  - PW of investment
    - = 4 + 4(P/F, 4%, 5)+20(P/A, 4%, 4) = $71.89M
  - PW of benefits
    - = 2(P/A, 4%, 30)+0.5(P/G, 4%, 10) +1(P/G, 4%, 11)(P/F, 4%, 9)+14.5(P/A, 4%, 10)(P/F, 4%, 20) + 4.5(P/A, 4%, 10)(P/F, 4%, 10) = $167.41M
  - PW of costs
    - = (1+3(A/F, 4%, 5))(P/A, 4%, 30) = $26.87M
  - PW of disbenefits
    - = 10(P/A, 4%, 20) – 0.5(P/G, 4%, 20) = $80.12M

Example 9.3: B/C analysis for a PPP

- Solution
  - (a) From the public project perspective

$$\text{Modified B/C} = \frac{167.41 - 80.12 - 26.87}{71.89} = 0.84$$

    - The toll road proposal is not economically acceptable, since B/C < 1.0.
  - (b) From the private corporation viewpoint

$$\text{PI} = \frac{167.41 - 26.87}{71.89} = 1.95$$

    - The proposal is justified without the disbenefits, since PI > 1.0.
    - i.e., every investment dollar will return an equivalent of $1.95 over 30 years at a 4% per year discount rate.

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)

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

CER Analysis for Independent Projects

- Procedure is as follows:
  - Determine equivalent total cost C, total effectiveness measure E & CER
  - Order projects by smallest to largest CER
  - Determine cumulative cost of projects & compare to budget limit b
  - 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/spend 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) & compare to DN option
  - 3) Calculate incremental cost (ΔC), effectiveness (ΔE), and incremental measure ΔC/E for challenger (next higher E measure)
  - 4) If ΔC/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 (retains)
  - 6) Continue steps 3 – 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 (1)

- Incremental measure of ΔC/E for challenger

$$\Delta C/E = \frac{\text{cost of challenger} - \text{cost of defender}}{\text{effectiveness of challenger} - \text{effectiveness of defender}} = \frac{\Delta C}{\Delta E}$$

- The effectiveness measure E is no. of wins/successes per person.
  - From the cost and effectiveness values shown, determine which alternative/program to select.

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

Example: CER for ME Service Projects (2)

- Solution:
  - Order programs according to increasing effectiveness measure E

Training 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: $C/EB = 1400/2 = 700$
  - A(chal.) vs. B (def.): $\Delta C/E = (2200 - 1400)/(4 - 2) = 400$
    - Since 400 < 700 dominance exist; so eliminate B
  - C(chal.) vs. A(def.): $\Delta C/E = (6860 - 2200)/(7 - 4) = 1553$
    - Since 1553 > 550, No dominance exist; so retain C
  - Therefore, 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(fairness) and always adhere to Code of Ethics.

Some Ethical Considerations When Performing B/C & CEA Analysis

What the Study Includes	Ethical Dimension	Example
Audience for study	Is it ethical to select a specific group of people affected by the project and neglect possible effects on other groups?	Construct children's health care clinics for city dwellers, but neglect rural families with poor transportation means.
Impact time of decision	Is it ethical to decide now for future generations who may be adversely and economically affected by the current project decision?	Accomplish financial bailouts of corporations when future generations' taxes will be significantly higher to recover the costs, plus interest and inflation effects.
Greater good for community as a whole	Vulnerable minority groups, especially economically deprived ones, may be disproportionally affected. Is this ethical if the impact is predictable?	Allow a chemical plant that is vital to the community's employment to pollute a waterway when a minority group is known to eat fish from the water that is predictably contaminated.
Reliance on economic measures only	Is it acceptable to reduce all costs and benefits to monetary estimates for a decision, then subjectively impute nonquantified factors in the final decision?	Softening of building codes can improve the financial outlook for home builders; however, increased risks of fire loss, storm and water damage to structures, and reduced future resale values are considered only in passing as a new subdivision is approved by the planning and zoning committee.
Scope of disbenefits estimated and evaluated	Is it ethical to disregard any disbenefits in the B/C study or use indirect effectiveness measures in a CEA study based on the difficulty to estimate some of them?	Noise and air pollution caused by a planned open-pit quarry will have a negative effect on area ranchers, residents, wildlife, and plant life; but the effectiveness measure considers only suburban residents due to estimation difficulty of effects on other constituencies.

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 & select all alternatives that B/C $\geq$ 1.0
- CEA analysis for service sector projects
  - combines cost and nonmonetary measures
- Ethical dilemmas are especially prevalent in public sector projects.

LEARNING STAGE 2: EPILOGUE

Selecting the Basic Analysis Tool

Recommended Method to Compare Mutually Exclusive Alternatives, Provided the Method Is Not Preselected

Evaluation Period	Type of Alternatives	Recommended Method	Series to Evaluate
Equal lives of alternatives	Revenue or cost	AW or PW	Cash flows
	Public sector	B/C, based on AW or PW	Incremental cash flows
Unequal lives of alternatives	Revenue or cost	AW	Cash flows
	Public sector	B/C, based on AW	Incremental cash flows
Study period	Revenue or cost	AW or PW	Updated cash flows
	Public sector	B/C, based on AW or PW	Updated incremental cash flows
Long to infinite	Revenue or cost	AW or PW	Cash flows
	Public sector	B/C, based on AW	Incremental cash flows

Characteristics of an Economic Analysis of Mutually Exclusive Alternatives, Once the Evaluation Method Is Determined

Evaluation Method	Equivalence Relation	Lives of Alternatives	Time Period for Analysis	Series to Evaluate	Rate of Return; Interest Rate	Decision Guideline: Select[1]
Present worth	PW	Equal	Lives	Cash flows	MARR	Numerically largest PW
	PW	Unequal	LCM	Cash flows	MARR	Numerically largest PW
	PW	Study period	Study period	Updated cash flows	MARR	Numerically largest PW
	CC	Long to infinite	Infinity	Cash flows	MARR	Numerically largest CC
Future worth	FW	Same as present worth for equal lives, unequal lives, and study period				Numerically largest FW
Annual worth	AW	Equal or unequal	Lives	Cash flows	MARR	Numerically largest AW
	AW	Study period	Study period	Updated cash flows	MARR	Numerically largest AW
	AW	Long to infinite	Infinity	Cash flows	MARR	Numerically largest AW
Rate of return	PW or AW	Equal	Lives	Incremental cash flows	Find Δi^*	Last $\Delta i^* \geq$ MARR
	PW or AW	Unequal	LCM of pair	Incremental cash flows	Find Δi^*	Last $\Delta i^* \geq$ MARR
	AW	Unequal	Lives	Cash flows	Find Δi^*	Last $\Delta i^* \geq$ MARR
	PW or AW	Study period	Study period	Updated incremental cash flows	Find Δi^*	Last $\Delta i^* \geq$ MARR
Benefit/cost	PW	Equal or unequal	LCM of pairs	Incremental cash flows	Discount rate	Last $\Delta B/C \geq 1.0$
	AW	Equal or unequal	Lives	Incremental cash flows	Discount rate	Last $\Delta B/C \geq 1.0$
	AW or PW	Long to infinite	Infinity	Incremental cash flows	Discount rate	Last $\Delta B/C \geq 1.0$

[1]Lowest equivalent cost or largest equivalent income.