Southeast University
School of Transportation

Urban Transportation Planning

Chinese-English course (2019)

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Lecture review

- **Overview of engineering economic**
  - Discount rate and time value of money
  - Net present value (NPV)
  - Internal rate of return(IRR)
  - Incremental rate of return(ΔROR)
  - Payback period
- **Discounting**
  - Discounting methods
  - NPV=PV (B) – PV(C) & NPV=PV(NB)
  - Timing of benefits and costs
  - Long-lived projects
  - Comparing projects with different time duration

Lecture schedule

Lecture	Week	Date/Time	Topic
1	9	28 April 9: 50-12: 15	Transportation planning & demand and supply & trip-based model
2	10	5 May 9: 50-12: 15	ABM: data process
3	11	10 May 9: 50-12: 15	ABM: scheduling
4	12	17 May 9: 50-12: 15	ABM: uncertainty analysis
5	13	24 May 9: 50-12: 15	ABM: sensitivity analysis
6	14	31 May 9: 50-12: 15	Project Evaluation I
7	15	7 June 9: 50-12: 15	Festival
8	16	14 June 9: 50-12: 15	Project Evaluation II

Long-lived projects

NPV over multiple years

- The net present value ***NPV*** for ***n*** years with compounded interest rate ***i*** is:

$$NPV = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t}$$

- Or, the NPV of a project equals the present value of the net benefits:

$$NPV = \sum_{t=0}^{n} \frac{NB_t}{(1+i)^t}$$

- Some projects may have benefits (and costs) that occur far in the future. We can use a generalized version of equation with infinity ∞ replacing n:

$$NPV = \sum_{t=0}^{\infty} \frac{NB_t}{(1+i)^t}$$

Long-lived projects

NPV over multiple years

- Some projects can be reasonably divided into two periods:

1. a "near future" (the discounting period), which pertains to the first k periods,

2. and a "far future", which pertains to the subsequent periods and is captured by the horizon value, H_K.

$$NPV = \sum_{t=0}^{k} \frac{NB_t}{(1+i)^t} + PV(H_k)$$

- Where, $PV(H_k)$ is the present value of the horizon value (i.e. the PV of all benefits and costs arise after the first K periods).
- Usually, there is a natural choice for k, the "useful" life of the project, such as when the asset are sold.

Comparing projects with different time duration

- If the time spans are different, such projects are not directly comparable.
- Two methods to evaluate projects with different life spans:
  1. Rolling over the shorter project (滚动短期项目)
  2. Equivalent annual benefit method（等效年度收益法)

Comparing projects with different time duration

1. Rolling over the shorter project

   - If project A spans n times the number of years as project B, then assume that project B is repeated n times and compare the NPV of n repeated project Bs to the NPV of project A.
   - For example, if project A lasts 30 years and project B lasts 15 years, compare the NPV of project A to the NPV of 2 Project B's, where the latter is computed:

$$NPV = x + \frac{x}{(1+i)^{15}}$$

   - Where, x =NPV of project B (15-year)

Comparing projects with different time duration

2. Equivalent annual net benefit method

- The EANB is the amount received each year for the life of the project that has the same NPV as the project itself.
- The EANB of a project is computed by dividing the NPV by the appropriate annuity factor, a_i^n

$$EANB = \frac{NPV}{a_i^n}$$

- The annuity factor a_i^n is the present value of an annuity of $1 for the life of the project (n years), where i=interest rate used to compute the NPV.
- Obviously, we would choose the project with the highest EANB.

(等效年度收益)

Present value of an Annuity

- The present value of an annuity of \$A per year (with payments received at the end of each year) for n years with interest at i percent is given by:

$$PV = \sum_{t=1}^{n} \frac{A}{(1+i)^t}$$

- This is the sum of n terms of a geometric series with the common ratio equal to 1/(1+i). Consequently,

$$PV = Aa_i^n, \qquad where\ a_i^n = \frac{1-(1+i)^{-n}}{i}, \qquad a_i^n = \sum_{t=1}^{n} \frac{1}{(1+i)^t}$$

- The term a_i^n, called an annuity factor, which equals to the present value of an annuity of \$1 per year for n years when the interest rate is i percent.

Example of equivalent annual net benefit method

水电站大坝

$$EANB = \frac{NPV}{a_i^n}, \mathrm{i} = 8\%$$

热电联厂

Hydroelectric dam (HED)	Cogeneration plant (CGP)
n= 75 years	n= 15 years
NVP = $ 30 mln	NVP = $ 24 mln
$a_{0,08}^{75} = 12.461$	$a_{0,08}^{15} = 8.559$
EANB = $ 30 mln / 12.461	EANB = $ 24 mln / 8.559
= $ 2,407 mln	= $ 2,804 mln

- Shorter projects also have an additional benefit (not included in EANB) because one does not necessarily have to roll-over the shorter project with identical installation when it's finished.
- A better option might be available at that time.

Project evaluation

❑ Methods:

A variety of valuable approaches exist for project evaluation and decision-making, such as traditional ecnomic-based techniques (Cost-benefit analysis成本效益分析，Life cycle cost analysis生命周期成本分析) and multi-criteria analysis (MCA).

– Engineering economic methods: using engineering economic concepts, discounting of future costs and generating benefit-cost ratios. These methods are straightforward in calculation, converting all evaluation criteria to a common monetary unit, ratio, or percentage, and the results are easily interpretable.

Project evaluation

❑ Methods:

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– Multi-criteria analysis (MCA): for complex decisions that involve qualitative criteria and quantitative criteria MCA methods may be more appropriate, as they convert all criteria measures to a common scale to be evaluated in a composite score. While, the output composite scores are less easily understood, as they are not unit specific.

Note: CBA can be a component within MCA analysis.

Life cycle cost analysis (生命周期成本分析)

Life cycle cost analysis (LCCA):

– The life cycle cost (LLC) is defined as "the total discounted dollar cost of owning, operating, maintaining, and disposing of a building or a building system over a period of time ".

– LCCA considers all of the benefits and costs associated with different project alternatives over the project's lifetime can be applied to assess the total cost of a project. It's particularly useful when deciding between various *project alternatives that all meet project scope requirements, but have different initial and operating costs.*

– For projects with comparable benefits over the same lifetime, the alternative with the lowest LCC is usually preferred. For alternatives with different lifetime, the one with the lowest Equivalent uniform annual cost is more desirable.

Example of LCCA

A district is deciding between flexible and rigid pavement for a new roadway. Engineers expect required surface rehabilitation after 20 years for flexible pavement and 40 years for rigid pavement. The following LCCA table was created for a 40-year analysis period, with initial and rehabilitation costs considered for each pavement type. Flexible pavement would cost $4 million initially and $2 million to rehabilitate 20 years later. Rigid pavement would cost $6 million for initial construction. Benefits for flexible pavement are reduced when travel times increase during resurfacing times.

Because rehabilitation costs are to occur 20 years in the future, they must be translated to present value before they can be compared with initial costs. Benefits are already provided in present value. Assume a 2% annual interest rate.

Example of LCCA

Example of LCCA

Present worth of flexible pavement rehabilitation costs in year 20:

$$P=\$2{,}000{,}000\times(1+0.02)P = \$2{,}000{,}000 \times \frac{1}{(1+0.02)^{20}} = \$1{,}345{,}943$$

	Rigid	Flexible
Initial Costs	$6,000,000	$4,000,000
Rehabilitation Costs	-	$1,345,943
Total Costs	$6,000,000	$5,345,943
Total Benefits	$11,000,000	$10,000,000
NPV	$5,000,000	$4,654,057

The rigid pavement returns a higher NPV and would therefore serve as a better choice.

Cost-benefit analysis 成本效益分析

Cost-benefit analysis (CBA)

- Cost-benefit analysis (CBA) is a policy assessment method that quantifies all the relative direct economic impacts of public investment projects.
- It's useful tool for decision-making in planning and evaluation of projects, CBA can be used to determine whether and when a project should be undertaken and to rank or prioritize projects.
- CBA is a method for determining social costs and benefits.
- CBA calculates net social benefits (NSB) for each policy alternative.

Net social benefits (NSB)
= social benefits (B) minus social costs (C)

The purpose and types of CBA

- **Purpose:**
  - To help effective social decision making through efficient allocation of society's resources when markets fail
- **Types of CBA:**
  1. Ex ante CBA – conducted prior to the intervention. Useful to show whether resources should be used on a project.
  2. Ex post CBA – conducted at the end of the intervention. Provides information about the particular class of intervention.
  3. In medias res CBA – conducted during the intervention.
  4. Comparative CBA – compares the ex ante predictions to ex post results for the same project.

	Class of Analysis			
Value	***Ex Ante***	***In Medias Res***	***Ex Post***	***Ex Ante/Ex Post or Ex Ante/In Medias Res Comparison***
Resource allocation decision for this project.	Yes—helps to select best project or make "go" versus "no-go" decisions, if accurate.	If low sunk costs, can still shift resources. If high sunk costs, usually recommends continuation.	Too late—the project is over.	Same as *in medias res* or *ex post* analysis.
Learning about actual value of specific project.	Poor estimate—high uncertainty about future benefits and costs.	Better—reduced uncertainty.	Excellent—although some errors may remain. May have to wait long for study.	Same as *in medias res* or *ex post* analysis.
Contributing to learning about actual value of similar projects.	Unlikely to add much.	Good—contribution increases as performed later. Need to adjust for uniqueness.	Very useful—although may be some errors and need to adjust for uniqueness. May have to wait long for project completion.	Same as *in medias res* or *ex post* analysis.
Learning about omission, forecasting, measurement and evaluation errors in CBA.	No	No	No	Yes, provides information about these errors and about the accuracy of CBA for similar projects.

The basic steps of CBA

- Major steps:
  1. Specify the set of alternative projects.
  2. Decide whose benefits and costs (standing)
  3. List the impacts and select measurement indicators
  4. Predict the impacts quantitatively over the life of the project
  5. Monetize (attach dollar values to) all impacts
  6. Discount benefits and costs to obtain present values
  7. Compute the net present value of each alternative
  8. Perform sensitivity analysis
  9. Make a recommendation

The basic steps of CBA

- Step 1: Specify the set of alternative projects.
  - There are usually a huge number of potential alternative projects, for example, n dimensions with k possible values $= k^n$ alternatives

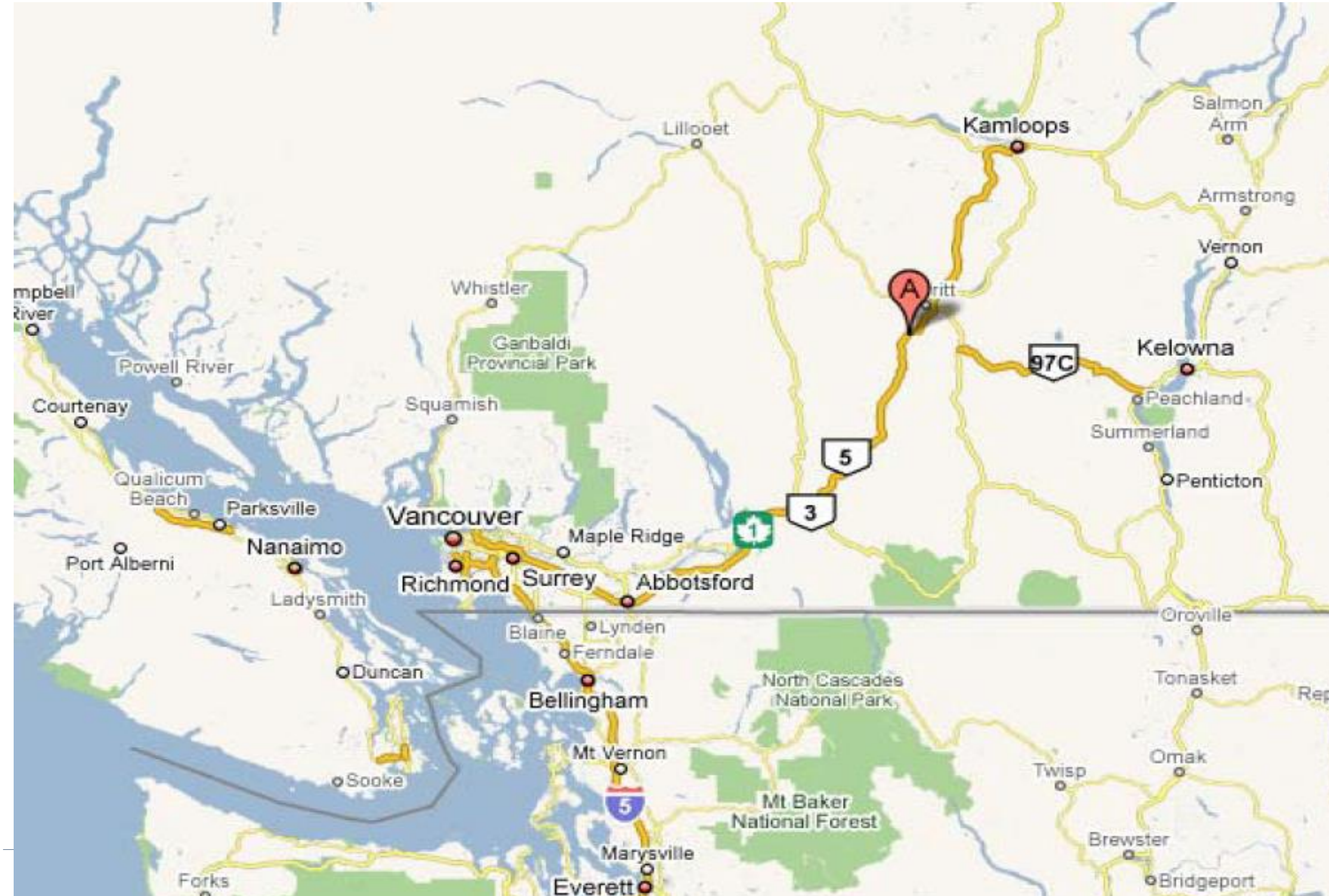
Dimension (n)	Value (k)
Ecology	1, 2, 3
Economy	1, 2, 3
Alternatives:	$3^2 = 9$

  - Minimally, the CBA compares the net social benefits of the project with the net social benefits of a hypothetical project or specific project that would be displaced. This hypothetical project is called the counter-factual case.

The basic steps of CBA

- Step 2: Decide whose benefits and costs.
  - Standing determines whose benefits and costs will count.
  - Standing is usually specified at the national level.
  - Standing is specified at the global level especially when there are international spillovers (e.g., for many environmental issues).
  - For other kinds of projects, some advocate standing at a lower lever, such as state/province or local government.

Example: the Coquihalla Highway (Canada)



Example: the Coquihalla Highway (Canada)

TABLE 1-3 Coquihalla Highway CBA (1986 $ Million)

	No Tolls		*With Tolls*	
	***A* Global Perspective**	***B* Provincial Perspective**	***C* Global Perspective**	***D* Provincial Perspective**
Project Benefits:				
Time and Operating Cost Savings	389.8	292.3	290.4	217.8
Horizon Value of Highway	53.3	53.3	53.3	53.3
Safety Benefits (Lives)	36.0		25.2	18.9
Alternative Routes Benefits	14.6		9.4	7.1
Toll Revenues	—	—	—	37.4
New Users	0.8	0.6	0.3	0.2
Total Benefits	494.5	384.1	378.6	334.7
Project Costs:				
Construction	338.1	338.1	338.1	338.1
Maintenance	7.6	7.6	7.6	7.6
Toll Collection	—	—	8.4	8.4
Toll Booth Construction	—	—	0.3	0.3
Total Costs	345.7	345.7	354.4	354.4
Net Social Benefits	148.8	38.4	24.2	−19.7

transfer

Source: Adapted from Anthony Boardman, Aidan Vining, and W. G. Waters II, "Costs and Benefits through Bureaucratic Lenses: Example of a Highway Project," *Journal of Policy Analysis and Management,* 12(3) 1993, 532–555, Table 1, p. 537.

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532–555, Table 1, p. 537.

Coquihalla highway from a Provincial Guardian's perspective

revenue inflows = "benefits"; expenditure outflows = "costs".

TABLE 1-4 Coquihalla Highway from a Provincial Guardian's Perspective (1986 $ Million)

	No Tolls	*With Tolls*
Revenues ("Benefits"):		
Toll revenues from British Columbia residents	0	112.1
Toll revenues from non-British Columbia residents	0	$\boxed{37.4}$
	0	149.5
Expenditures ("Costs"):		
Construction	338.1	338.1
Maintenance	7.6	7.6
Toll collection	—	8.4
Toll booth construction	—	0.3
	345.7	354.4
Net Revenue-Expenditure "Benefits"	−345.7	−204.9

The basic steps of CBA

- Step3: List the impacts and select measurement indicators.

List the impacts indicators for benefits and costs. And specify the impacts units.

- Impacts indicators include both inputs and outputs. (e.g., congestion reducing)
- Only include impacts that affect individual utility. There must be a cause and effect relationship between project outcome and the individual’s utility.
- Different individuals might give an opposite value for some impact categories (i.e., some individuals view the impact as a cost while others view it as a benefit). In such circumstance, it is often more useful to create two separate impact categories.
- Natural measurement units may not be feasible (e.g., crimes avoided); in such cases, substitute indicators can be used. (e.g., crime rate)

The basic steps of CBA

- Step 4: Predict the impacts quantitatively over the life of the project.
  - Prediction is difficult when supply and demand curves are unknown or uncertain.
  - In general, it's more difficult to predict impacts:
    - if the project has a long time horizon;
    - if the relationships between variables are complex.

The basic steps of CBA

- **Step 5: Monetize all impacts.**
  - In CBA, value is measured in terms of “willingness to pay” (obtained from demand curves).
  - Many impacts are difficult to value in money terms because they are not traded in markets (e.g., life).
  - If no individual is willing to pay for an impact, it has a 0 value.
  - In the Conquihalla example:
    - Leisure time saved per vehicle: $6,68 per vehicle hour (25% of gross wages times the average number of passengers)
    - Business time saved per vehicle: $12 per vehicle-hour
    - Truck driver’s time saved per vehicle: $14 per vehicle-hour
    - Value of life saved: $500,000 per life

The basic steps of CBA

- Step 6: Discount benefits and costs to obtain present values.
  - Impacts are discounted because almost everybody has a preference for consumption now rather than later.
  - The appropriate discount value method and level is controversial.
  - Usually the discount rate is mandated by a government agency responsible for financial and budgetary oversight.

The basic steps of CBA

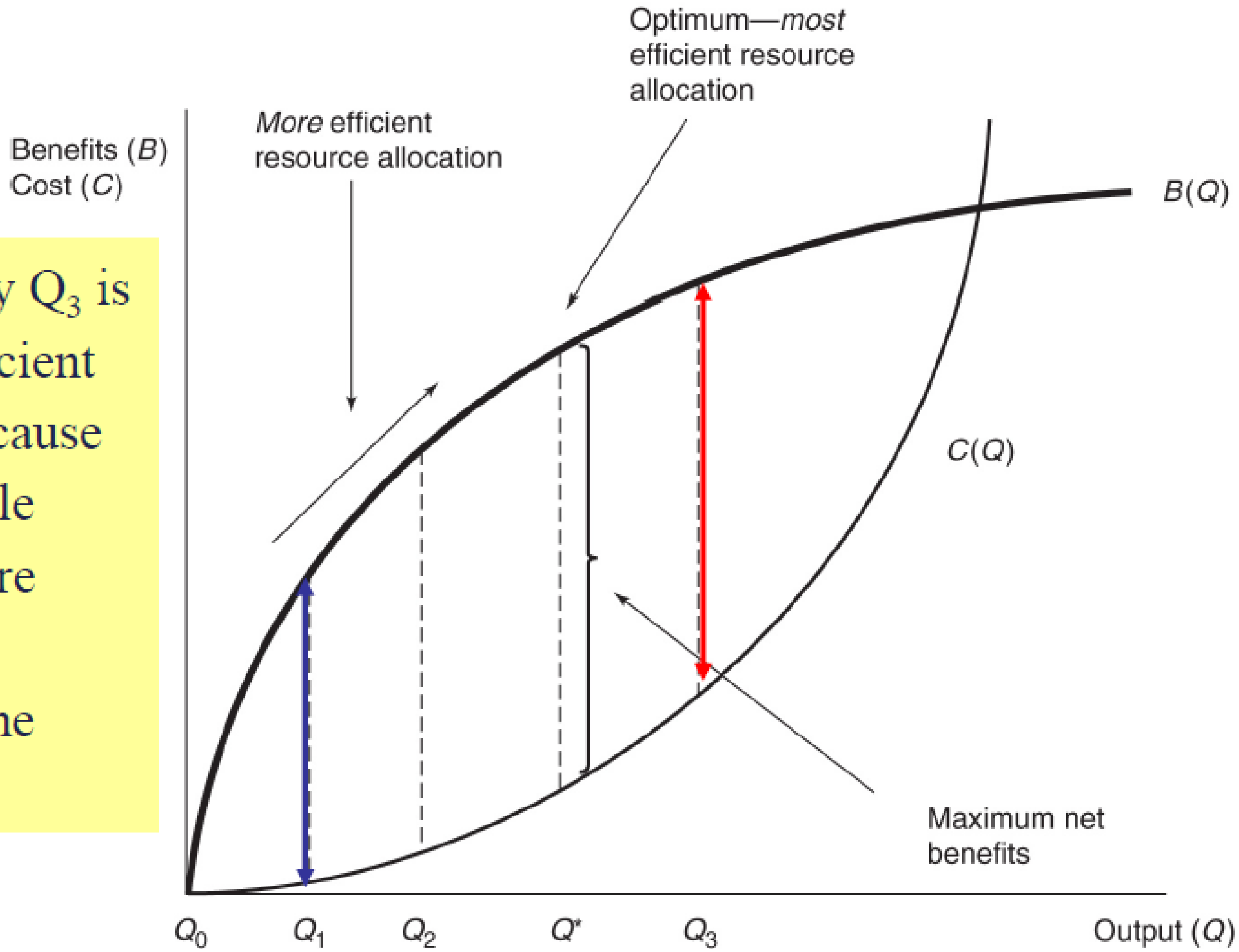
- Step 7: Compute the net present value of each alternative.
  - The net present value (NPV) equals the present value of benefits minus the present value of costs.

  Note: The selection of alternatives also considers the benefit and cost ratio (B/C ratio=total discounted benefits/total discounted costs). Options with B/C ratios greater than 1.0 are preferable.

  - Choose the alternative with the largest NPV. The alternative with the largest NPV at least represents a more efficient allocation of resources.
  - One can’s say it’s the most efficient allocation because not all possible alternatives are necessarily analyzed in the CBA.

CBA seeks more efficient resource allocation

One **can't** say Q_3 is **the most** efficient allocation because not all possible alternatives are necessarily analyzed in the CBA



Moving beyond Q* reduces efficiency; but: Q_3 is more efficient than Q_0 :

$NPV(Q^*) > NPV(Q_3) > NPV(Q_1) > NPV(Q_0)$

The basic steps of CBA

- Step 8: Perform sensitivity analysis.
  - There is usually considerable uncertainty about both predicted impacts and their appropriate monetary valuation.
  - Sensitivity analysis clarifies how these uncertainties affect the CBA results and figure out the factors that have an important effect on the output.
- Step 9: Make a recommendation.
  - Normally recommend the alternative with the highest NPV, but also take into account sensitivity analysis.

Example of CBA

Example of CBA #2

A bridge linking two towns over a river is close to failing and will be decommissioned in 5 years if repairs are not made. TxDOT is calculating a B/C ratio to compare the benefits of travel time savings, reduced operating expenses, crashes, and pollution to construction and maintenance costs. Following are the calculation steps taken to determine the B/C ratio.

Removing the bridge will require some users to travel further out of their way to reach destinations across the river, resulting in increased VMT overall. Assuming a lifespan of 50 years for the rebuilt bridge, TxDOT projects VMT in the area to be as follows:

	Total VMT	Total VHT
No-build	1,400,500	40,800
Bridge rebuild	1,275,000	39,100

Example of CBA

Example of CBA #2

Benefits

TxDOT estimates that travel time savings over the 50-year period would be $250 million. Vehicle operating costs, crashes, and emissions are also functions of VMT, so if the bridge helps reduce VMT, then all crashes (fatal, major, minor, property damage), operating costs, and emissions will correspondingly decrease. TxDOT estimates that reduced operating costs will save $185 million, crash costs will decrease by $65 million, and emissions reductions will save another $45 million. Total benefit from bridge repair in present terms is $545 million.

Costs

Closing the bridge would require some funds, as would deconstruction. Bridge repair has been estimated at $100 million, with total operating and maintenance costs being $85 million over a 50-year lifespan, in present costs. Total cost in present terms for bridge repair is $185 million.

$$\frac{B}{C} = \frac{\$545{,}000{,}000}{\$185{,}000{,}000} = 2.95$$

This B/C ratio is greater than 1, indicating that the project returns more benefits than costs.

Cost-benefit analysis 成本效益分析

- Two arguments against the use of CBA:
  1. Some dispute the fundamental assumptions of CBA:
     - i.e. that the sum of individual utility should be maximized and that one can trade off utility gains and losses among people.
     - They argue that there is no theoretical basis for making trade offs between one person’s benefits and another person’s costs.
  2. Public policy participants disagree about specific issues in CBA:
     - Such as how to monetize costs and benefits,
     - What impacts are (especially over time),
     - Whether an impact is a cost or a benefit,
     - And how to make trade-offs between the present and the future.

Options

- CBA ratios
- Cost-effectiveness index
- Cost utility analysis

Multicriteria analysis (MCA)

- Economic methods: discuss purely based on economic calculation, and all variable effects are measured in monetary units. It is limited in its ability to incorporate all considerations selecting between alternatives, particularly those criteria (e.g., environmental and safety impacts) cannot be easily measured in money terms.
- Multicriteria analysis (MCA) allows alternatives analysis to be conducted across different types of criteria with various dimensions of benefits.

Multicriteria analysis

- MCA allows assessment of variables on any quantitative or qualitative scale.
- The underlying concept involves creating a composite measure consisting of the sum of the weighted criteria scores.
- The best alternative is the one which scores highest on this compound measure.
- Compared to CBA, MCA is more flexible, but the subjectivity of the scoring and weighting process can significantly influence outcomes.

Simple additive weighting (SAW)

❑ Simple additive weighting (加权相加法)

- One of the most widely used MCA methods is simple additive weighting. SAW converts a multi-criterion problem into a single-dimension by calculation a weighted score V_i, for each project alternative i evaluated across each criterion j as follows:

$$V_i = \sum_{j=1}^{n} w_j \, r_{ij}$$

- Where, w_j represents the weight for criterion j and r_{ij} represents the rating score for alternative i on criterion j. The various criteria- whether economic, environmental, social, or technical- are converted to a common scale before employing SAW. The alternative with the highest V_i is selected.

Example of SAW

Example of SAW

TxDOT is considering three alignment options for a new route highway and has decided to compare the alignments based on the following hierarchy of criteria and their weights:

- Operations and safety considerations (0.35)
    - Congestion impacts (0.15)
    - Safety impacts (0.15)
    - Network connectivity impacts (0.05)
- Environmental considerations (0.3)
    - Noise pollution impacts (0.1)
    - Air pollution impacts (0.1)
    - Landscape (e.g., parks, wildlife and refuge) and historical site impacts (0.1)
- Cost considerations (0.25)
    - Construction cost (0.2)
    - Efficiency of construction (0.05)
- Political/community considerations (0.1)
    - Community preferences at a local level (0.05)
    - Political acceptability at a regional level (0.05)

(The weights are assumed to be previously determined but are not meant to reflect a real-world situation.)

Example of SAW

Alternative A: no build option with no construction costs, no environmental impacts, no improvement in congestion, safety, or network connectivity.
Alternative B: with great impacts to landscape and historical sites, lower construction cost
Alternative C: more expensive to construct compared to alternative B, fewer impacts to the landscape, better received by the local community.

Assume the following alternative scores (converted to a common scale between 0 and 3 with the highest score the most desirable) in each criterion:

Criterion (Weight)	Alt. A	Alt. B	Alt. C
Congestion (0.15)	0	3	3
Safety (0.15)	1	2	2
Network connectivity (0.05)	0	3	3
Noise Pollution (0.1)	3	2	2
Air Pollution (0.1)	3	2	2
Landscape & Historical Sites (0.1)	3	2	1
Construction Cost (0.2)	3	1	2
Efficiency of Construction (0.05)	3	2	1
Community Preferences (0.05)	2	1	3
Political Acceptability (0.05)	0	3	3

Example of SAW

The weighted scores and the composite scores (sum of weighted scores) for each alternative are shown in the following table. Each score is the product of the alternative score multiplied by the weight.

	Alt. A	Alt. B	Alt. C
Congestion (0.15)	$0 \times 0.15 = 0$	$3 \times 0.15 = 0.45$	$3 \times 0.15 = 0.45$
Safety (0.15)	0.15	0.3	0.3
Network connectivity (0.05)	0	0.15	0.15
Noise Pollution (0.1)	0.3	0.2	0.2
Air Pollution (0.1)	0.3	0.2	0.2
Landscape & Historical Sites (0.1)	0.3	0.2	0.1
Construction Cost (0.2)	0.6	0.2	0.4
Efficiency of Construction (0.05)	0.15	0.1	0.05
Community Preferences (0.05)	0.1	0.05	0.15
Political Acceptability (0.05)	0	0.15	0.15
Composite (Sum) of Weighted Scores (V_i)	*1.9*	*2*	*2.15*

SAW analysis indicates that Alternative C with the highest composite score should be selected.

Questions

1. What are the main differences between trip based approach, tour based approach and activity based approach?
2. Calculation of Gini Index
3. Calculation of Information Gain
4. one-at-a-time sensitivity analysis measure
5. Please discuss the main difference between uncertainty analysis and sensitivity analysis.
6. What's the main (dis)advantage of global sensitivity analysis approach contrast to local sensitivity analysis approach?

Questions

7. Internal rate of return(IRR)

8. Incremental rate of return(ΔROR)

9. Timing of benefits and costs

10. Comparing projects with different time duration

Thanks for your attention!

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