CHAPTER 7 – Benefit/Cost Analysis

Lecture 24
Benefit/Cost Analysis for a Single Project

Many engineers, especially civil engineers, spend a significant part of their careers working on public works projects. Public works projects differ from the typical manufacturing projects we've been dealing with all semester in several important ways:

1. They have very long time horizons (often decades).
2. They are financed through taxes or low-interest municipal bonds, so the cost of capital is much lower than for privately funded projects.
3. They are not intended to produce a profit. They are designed to protect life, health, and/or property; provide a public service; or create jobs.
4. They often have multiple benefits, many of which are non-monetary (since making a profit is not the goal).

Consider a dam project. Its primary purpose might be to alleviate flooding, but it may also provide hydroelectric power and create a lake for recreational boating and fishing.

5. They may also have negative benefits (***disbenefits***).

For example, I-69 will be a boon to truckers and will provide communities along the way with opportunities for growth, but it will also displace hundreds of families and tens of thousands of acres of farmland and may end up splitting some communities in two.

For projects such as these, we have some questions:

- How do you compare economic alternatives when profit is not a motive?
- How do you determine if a project is economically justified when there is no profit?

The ***Flood Control Act of 1936*** declared that "the Federal Government should improve … navigable waters … for flood-control if the benefits … are in excess of the estimated costs." Thus was born the ***benefit-cost-ratio*** method of analyzing public works projects.

At its simplest, the benefit-cost-ratio method simply says to calculate the benefits and the costs and if the ratio of the two is ***greater than or equal to one***, the project is justified.

However, since money has a ***time value***, you can't just sum the benefits and costs; you have to use some measure of ***equivalent worth*** such as PW, AW, or FW:

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

Using PW as an example, the ***conventional*** way to define the Benefit-Cost Ratio is

$$B/C = \frac{PW(\text{benefits}) - PW(\text{disbenefits})}{PW(\text{capital costs}) + PW(\text{O\&M costs})}$$

Note that the costs are expressed as positive, not negative, numbers.

Here, the denominator contains all of the "***tangible costs***," by which we mean dollars that actually change hands. This includes things like construction costs, maintenance costs, utility costs, and even the salvage value (which is treated as a kind of cost rebate).

The values in the numerator are typically "***intangible***" and include things such as the dollar value of reduced flooding or increased recreation or averted deaths. This is where it gets a bit tricky because those dollar values can be hard to determine and open to interpretation.

If we're evaluating a dam to alleviate flooding, for example, we might look back in the historical record and determine how many times the river has flooded in the last 50 years and what the estimated dollar amount of the damage was (adjusted for inflation, of course). Using statistics, we can determine the average annual savings to the public if that flooding is eliminated.

If those floods were bad enough that lives were lost, we might also include a value for each fatality. That gets even trickier. There's an entire field of research called Mortality Risk Valuation that attempts to assign a dollar figure to each life lost. Rather than simply ask people what their lives are worth (which wouldn't yield a very reliable value) the value is found by looking at things like how much people are willing to spend for safety measures like air bags that could reduce their lifetime risk of dying in an automobile accident from 0.15% to 0.05%. Or how much of a wage premium is associated with jobs that have a 0.01% chance of dying on the job instead of a 0.001% chance. These analyses provide something called the ***value of a statistical life*** (VSL). The USDOT uses (as of 2015) a VSL of $9.4 million.

If we're trying to decide whether or not a traffic signal is warranted at an intersection, we would need to determine how many accidents are alleviated by the traffic signal and how many accidents are caused by the traffic signal. (Yes, traffic signals cause accidents. They may alleviate a fatal side-impact crash that occurs, on average, once per decade but they also produce dozens of lesser accidents such as rear-ending the car in front of you when he stops for an amber signal and you don't.) Then we can assign a dollar value to each accident in order to determine the benefits and disbenefits of installing the traffic signal.

Many government agencies publish tables of values to use for accidents of different severity, ranging from property damage only (PDO) to fatalities. The FHWA publishes tables based on the Abbreviated Injury Scale (AIS) used by the medical profession and the KABCO scale used by law enforcement.

Costs by AIS Severity
(1994 Dollars)

Severity	Descriptor	Cost
AIS 1	Minor	5,000
AIS 2	Moderate	40,000
AIS 3	Serious	150,000
AIS 4	Severe	490,000
AIS 5	Critical	1,980,000
AIS 6	Fatal	2,600,000

Costs by KABCO Scale
(1994 Dollars)

Severity	Descriptor	Cost
K	Fatal	2,600,000
A	Disabling	180,000
B	Evident	36,000
C	Possible	19,000
O	Property Damage Only	2,000

It is important to use the same costs every time, otherwise you can be accused of changing the value of the benefits and disbenefits to skew the results.

Note that in the conventional benefit-cost ratio definition, all of the ***benefits*** typically accrue to the ***users*** of the project (the ***public***) while all of the ***costs*** are borne by the ***owner*** of the project (the ***government***).

An alternative is the ***modified*** benefit-cost ratio, which treats the O&M or ***usage*** costs as a ***disbenefit*** and puts them in the numerator, leaving only ***capital costs*** in the denominator:

$$\text{modified B/C} = \frac{\text{PW}(\text{benefits}) - \text{PW}(\text{disbenefits}) - \text{PW}(\text{usage costs})}{\text{PW}(\text{capital costs})}$$

The ***capital costs*** include the ***initial investment*** and any ***salvage value*** (which is included as a negative cost). If you use annual worth to account for the time value of money, then the denominator of the modified B/C ratio is simply the ***capital recovery*** amount:

$$\text{modified B/C} = \frac{\text{AW}(\text{benefits}) - \text{AW}(\text{disbenefits}) - \text{AW}(\text{usage costs})}{\text{CR}}$$

One use of the modified B/C ratio is when the only "benefit" is a reduction in O&M costs. If we don't put the O&M costs in the numerator, the numerator will be zero! If we reduce the O&M costs, we produce a negative disbenefit, which is the same as a positive benefit.

The ***modified*** B/C ratio will lead to the same conclusion as the ***conventional*** B/C ratio, but the numerical value of the ratio will be slightly different. In other words, moving values between the numerator and the denominator will never cause a ratio greater than one to suddenly become less than one or vice versa. To illustrate this:

$$\frac{B}{CC+OM} > 1 \quad \Rightarrow \quad B > CC + OM \quad \Rightarrow \quad B - OM > CC + \cancel{OM} - \cancel{OM} \quad \Rightarrow \quad \frac{B-OM}{CC} > 1$$

$$\frac{B}{CC+OM} < 1 \quad \Rightarrow \quad B < CC + OM \quad \Rightarrow \quad B - OM < CC + \cancel{OM} - \cancel{OM} \quad \Rightarrow \quad \frac{B-OM}{CC} < 1$$

Let's look at a couple of examples:

Railroad Crossing Example

A major city in Tennessee is studying the feasibility of eliminating a railroad grade crossing by building an overpass. Traffic engineers have estimated that 1000 vehicles per day are delayed an average of 2 minutes each due to trains at the crossing. Trucks comprise 40% of the vehicles and the cost of their delay is estimated to be $30/hr. The cost of delay for the rest of the vehicles is estimated to be $20/hr. The overpass will cost $1.5 million to build, have a useful life of 40 years, and a salvage value of $200,000. Maintenance costs for the overpass are estimated to be $10,000 more per year than for the grade crossing. If the city's cost of capital is 4% per year, should the city build the overpass?

The first question we have to ask is "what are the costs and what are the benefits?"

Obviously, the time savings to the motoring public is the primary benefit. The average delay cost per vehicle is

$$0.4 \times \$30/\text{hr/veh} + 0.6 \times \$20/\text{hr/veh} = \$24/\text{hr/veh}$$

If 1000 vehicles per day suffer delay and the average delay for each is 2 minutes, then the annual cost of delay is

$$\$24/\text{hr/veh} \times 2\text{ min} \times (1\text{ hr}/60\text{ min}) \times 1000\text{ veh/day} \times 365\text{ days/yr} = \$292{,}000/\text{year}$$

The annual worth of the capital costs (the ***capital recovery*** amount) is

$$\$1{,}500{,}000\overset{0.0505}{\left(A\,|\,P,4\%,40\right)} - \$200{,}000\overset{0.0105}{\left(A\,|\,F,4\%,40\right)} = \$73{,}700/\text{yr}$$

The ***conventional*** benefit-cost ratio puts the $10,000/year O&M costs in the denominator:

$$B/C = \frac{\$292{,}000}{\$73{,}700 + \$10{,}000} = 3.49$$

and the ***modified*** benefit-cost ratio puts the O&M costs in the numerator as a disbenefit:

$$B/C = \frac{\$292{,}000 - \$10{,}000}{\$73{,}700} = 3.83$$

Either way, we conclude that the city should build the overpass.

One difficulty in applying the B-C method is in assigning an interest rate or time value of money. Government entities really don't have an ***MARR*** because government projects are not designed to provide a return on investment.

There are at least two issues that may be considered in choosing an interest rate:

1. The interest rate of the borrowed capital (e.g., the cost of issuing municipal bonds)

2. The opportunity cost of capital to the taxpayers who will ultimately pay for the project

If a project is being paid for by issuing bonds, then it's logical to use the cost of issuing those bonds (e.g., the coupon rate) to establish the appropriate interest rate.

Using the opportunity cost of capital to the taxpayers is based on the idea that government spending takes potential investment capital away from taxpayers, so a project's "return" should exceed what taxpayers could earn on their money elsewhere.

This is actually the approach taken by the federal government.

In 1972, the Office of Management and Budget (OMB) published Circular A-94, titled "Discount Rates to be used in Evaluating Time-Distributed Costs and Benefits." It stipulated that a ***real*** interest rate of 7% per year should be used for evaluating most government projects. That rate was chosen because taxpayers at that time were earning an average of 7% per year above the inflation rate on private investments like stocks, bonds, and mutual funds. (Remember, we're using real interest rates so we don't have to worry about the effects of inflation on the cash flows.)

Circular A-94 has since been revised and the rate now depends on the life of the project and is tied to the current interest rates for Treasury Notes and Bonds having a lifespan similar to the project life. The assumption is that these are the safest investments taxpayers can make and don't carry the risk premium associated with investing in stocks and corporate bonds. Periodically, OMB releases a new Appendix C with updated rates. The December 2019 version gives a real interest rate of 0.4% per year for 30-year bonds and –0.4% for 3-year bonds. That means the bond yields for 3-year Treasury Bonds is less than the inflation rate!

Often, government projects have very long lives. In those cases, it might be acceptable to assume the life is infinite and use capitalized cost instead of present worth. For example:

Blood Alley Example

Highway 101 leading into San Jose, CA has been nicknamed "Blood Alley" because of the high number of head-on crashes on the undivided 4-lane highway. CalDOT is evaluating a proposal to rebuild Highway 101 as a divided highway. The initial cost of the project is $230 million and maintenance costs will be $350,000 per year. It is estimated that the number of fatalities will drop by 6 per year. If each life saved is valued at $4.9 million, is this project justified on a benefit-cost basis? Assume the cost of capital for the project is 4% per year and the highway improvements are permanent?

Since the highway improvements are considered "permanent" we can use the capitalized cost to compare costs and benefits:

$$CC = P + \frac{A}{i}$$

The costs for this project are the initial cost and the annual maintenance cost. The present worth of these is

$$\text{Costs} = P + \frac{A}{i} = \$230{,}000{,}000 + \frac{\$350{,}000}{0.04} = \$238{,}750{,}000$$

The benefits are the value of the lives saved:

$$\text{Benefits} = \frac{A}{i} = \frac{6 \times \$4{,}900{,}000}{0.04} = \$735{,}000{,}000$$

So the B/C ratio for this project is

$$B / C = \frac{\$735{,}000{,}000}{\$238{,}750{,}000} = 3.08$$

Therefore, the project is justified on an economic basis.