PDHonline Course P107 (4 PDH)

Basic Engineering Economics

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Basic Engineering Economics

Course Content

Course Introduction

Engineers and Architects are extremely well trained in all the technical aspects of their professions. However, most decisions made by these professionals involve the commitment of financial resources in the hundreds, thousands or millions of dollars. In addition, these monies are likely spent over an extended period of time for larger projects, necessitating ascertaining such factors as the cost of money over time, the value of money or accomplishment in the future and the best way to proceed given seemingly equal alternatives. Typical college training does not always provide training in these areas known as Engineering Economics.

Course Content

Engineering Economics is a set of tools and guidelines that are useful to Engineers, Architects and other professionals in evaluating design alternatives based on budgetary cost considerations. The best way to implement something may not be within the allowable budget and may require weighing alternatives on other than purely technical factors. Welcome to the real world.

This course is divided into 6 sections each addressing one of the following topics:

Section 1 - Time Value of Money
Section 2 - Benefit to Cost Analysis
Section 3 - Depreciation
Section 4 - Replacement Analysis
Section 5 - Break Even Analysis
Section 6 - Life Cycle Cost

Section 1 - Time Value of Money

Interest – Interest is a charge applied to loans granted by financial institutions or individuals. The rate and calculation of interest depends on factors such as economic climate, size of the loan, loan duration and payback method. The real lesson here is that money is not free. All projects need to be funded and they are usually funded by borrowed money. Even if the project is funded with cash, the loss of interest that could have been earned by that money must be taken into consideration in determining the true cost of the project.

Note: All calculations in this course are based on "end of period" payments. What that means is that if you made a payment on Day 1 it would be viewed as being made in Period "0". Since no time has passed, no interest can accrue. The first time you see any effect by interest is at the end of period "1". So if you make a deposit and want to know what its value is after one period, you would use n=1 in the equations that follow.

Future Value - This represents the value of an amount of money after being invested at a particular interest rate over a period of time. The formulas below apply to a single payment investment rather than periodic installments.

The formula used to calculate Future Value is called the Compound* Interest Equation and is shown below:

$$FV=P(1+r/t)^{nt}$$

Where FV = Future value
P = Starting Principle
r = interest rate (i.e. .06 =6%)
n = number of years of investment
t = number of times interest is compounded a year

*Compounding is calculating interest on the original sum invested plus the interest accrued to that time.

Example: Find the future value of a $500 investment @ 3% interest after 15 years where interest in compounded weekly.

$$FV= 500\ (1+ .03/52)^{15 \times 52} = \$784.05$$

For simple interest, where interest is only compounded once a year, t=1 and the equation simplifies to:

$$FV=P\ (1+r)^{n}$$

Example: Find the future value of a $1000 investment @ 4% interest after 15 years.

$$FV= 1000\ (1.04)^{15} = \$1800.94$$

If interest is compounded continuously* (i.e. n= infinity), then the equation appears as below:

$$FV=Pe^{rn}$$

Where $e \cong 2.718281828$

*This is rare in typical transactions but is shown for completeness.

For a Uniform annual series of Payments or investments the following factor can be calculated.

Future Value factor for a uniform annual series of payments given the interest rate r is shown below:

$$\mathbf{FV_{us} = ((1+r)^{n}-1)/r}$$

This factor when multiplied by the amount annually invested yields the Future Value of the entire series.

Example: Find the future value of a uniform annual series of payments of $10 each @ 4% interest after 10 years.

$$\mathbf{FVus= ((1+.04)^{10}-1)/.04 = 12.006}$$

To calculate Future Value multiply this by the total amount annually invested

$$\mathbf{(\$10) \times 12.006 = \$120.06}$$

Present Worth – This value is useful in determining how much one should invest to obtain a particular return in the future. It may also be used to determine what interest rate or rate of return is necessary to realize a particular investment amount. The equation for Present Worth is shown below:

$$\mathbf{Present\ Worth = S/ (1+ r)^{n}}$$

Where PW = Present Worth factor
S = Future value
r = interest rate (i.e. .06)
n = number years invested

Example: Find the Sum of money needed to invest today at 6% interest to have $10,000 in 5 years.

$$\mathbf{PW = 10{,}000/ (1+ .06)^{5} = \$7472.58}$$

To determine what rate of return is required to achieve a certain investment goal, we solve the equation for r (interest rate) and simply plug in values for the other variables. P and PW are used interchangeably. See equation below:

$$\mathbf{r = (S/P)^{1/n} -1}$$

In this application, the interest rate may also be referred to as the “discount rate”, “rate of return”, or “Compound Annual Growth Rate (CAGR)”.

Example: Find the rate of return needed to generate $20,000 in 5 years from an initial investment of $15,000 assuming annual compounding.

$$\mathbf{r = (20{,}000/15{,}000)^{1/5} -1 = .0592 = 5.92\%}$$

For a Uniform annual series of Payments or investments the following factors can be calculated:

Present Worth factor for a uniform annual series of payments given the interest rate r is shown below:

$$PW_{us} = ((1+r)^n - 1) / r(1+r)^n$$

The annual payment, when multiplied by this factor yields the present worth of the entire series of payments.

So, **Present Worth of the series = PW_{us} x annual payment**

Example: Find the Present Worth of a series of 10 annual payments of $350 each. The interest rate is 6%.

$$PW_{us} = ((1.06)^{10} - 1) /(.06 \times (1.06)^{10}) = 7.360$$

Present Worth = 7.360 x $350 = $2576

Sinking Fund **-** This is a factor that when multiplied by a future sum S yields the amount to be invested every year to achieve that sum at an interest rate after a number of years. It is actually the reciprocal of the FV factor (alternately known as Compound Amount Factor) for a uniform annual series FV_{us}. It is defined by the following formula:

$$\text{Sinking Fund Factor (SFF)} = r / ((1+r)^n - 1)$$

Therefore, R (annual investment) = S (future Sum) x SFF

Example: Find the amount of each annual payment required to generate a future sum of $120.06 @ 4% interest after 10 years.

$$SFF = .04 / ((1+.04)^{10} - 1) = .08329$$

Therefore: R = $120.06 x (.08329) SFF = $9.9999 or $10.00

Notice how this agrees with the Future Value for a uniform annual series example.

Annual Worth – This is a method that enables the comparison of alternatives on an average worth versus time period basis. It enables evaluating alternatives that have unequal lives that would otherwise be difficult to gauge.

Like Present Worth, one must know interest rates, payments and periods. There can be an initial as well as periodic payments. There can also be a salvage value, which in AW is referred to as a refund. Below is an attempt to express AW in understandable terms:

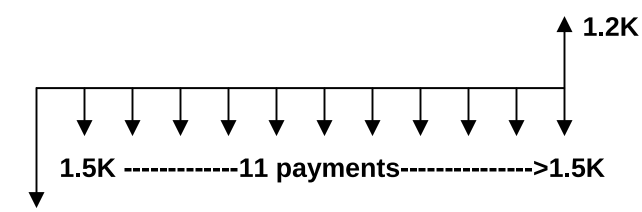
AW = equal uniform annual value of all expenses and income over the life of a project

Example: Find the annual worth of a $10,000 initial payment followed by eleven $1,500 annual payments concluding with a $1,200 refund. The interest rate is 5%.

Therefore: the interest rate r or i = 5% = .05

n = number of years or periods = 11

A cash flow diagram would look as follows:



CASH FLOW DIAGRAM

To calculate Annual Worth we need to use PW and FV factors for uniform annual series so that we can find the Present Worth of all payments and income and annualize them over the 11 years. First we already have the $10K in the present. Next we find the Present Worth of a uniform annual series of $1500 payments over 11 years @ 5% interest.

Present Worth Factor = PW_{us} = $((1+r)^{n} - 1) / r(1+r)^{n}$ = 8.306

Therefore: Present Worth of the 11 $1500 payment ($1500, 11, .05)

= $1500 x 8.306 = $12,459.00

Now we must find the Present Worth of the $1,200 refund at the end.

Present Worth Factor (PW) for single payment = $1/(1+r)^{n}$

PW = 1200 / $(1/(1.05)^{11}$ = 1200 / 1.7102 = $701.62

Therefore: The Present Worth of all payments and refunds =

-$10,000 –$12,459.00 + $701.62 = -$ 21,757.38

Now we must use the Capital Recovery Factor to annualize this amount over the 11 periods to find the Annual Worth.

Annual Worth (Capital Recovery) Factor ($AW_{us)}$= $r(1+r)^{n}/((1+r)^{n}-1)$ =.12039

Therefor the Annual Worth of the cash flow diagram is

-$21,757.38 x .12039 = -$2619.37

By comparing alternatives on a yearly basis, even if their duration is different provides a valid tool for making the best choice.

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NOTE: These calculations are somewhat cumbersome. It is suggested either that a business calculator including these features is employed or that the student make use of interest tables that are available in such references as Engineering Manual, Third Edition by Robert H. Perry or similar works.

END SECTION 1

Section 2 - Benefit/Cost Ratio Method

The Benefit/Cost Ratio Method is used to determine whether a project is worth doing based on the investment required versus the return on investment.

Terminology:

Benefits - the favorable consequences of the project.

Costs - monetary disbursements or investments required.

Multi-purpose - many projects have multiple purposes, objectives or by-products. Ex. Building a high-speed train from Tampa to Orlando in Florida. This project may serve to:

- Generate revenue from train fare
- Increase number of visitors to Orlando attractions
- Increase business and tourist visitors to Tampa
- Reduce pollution from automobile traffic
- Reduce wear and tear on roads
- Spur more housing development between Orlando and Tampa

Example:

It has been mandated by the voters that a high-speed rail system shall be built in Florida. Let's look at some of the benefits and costs associated with this project.

Benefits to Cost Analyses are best used as figures of merit versus absolute quantitative evaluations. The reason for this is that many of the factors you are trying to classify and quantify as a benefit or cost are inexact, variable over time and generally kind of squishy.

In this example, things that might fall into benefits include revenue from train fares. These numbers are derived from proposed fares multiplied by an average number of riders over some period. Are the proposed fares going to be approved, is the number of riders going to be realized immediately or built up over time? Does the average account for this or will more money come in later rather than sooner as the numbers of riders grows? Does the benefit of less maintenance on the roads due to decreased traffic account for the normal increase in traffic over time as well as the increase in traffic that will be realized if the train produces a growth in business to the Tampa area as expected? And there goes the pollution benefit.

It is very difficult to accurately quantify any of these things, but a decent attempt will yield, for the most part, accurate trends if all factors are considered. This will in turn lead to a valid and valuable Benefit to Cost Analysis. Like anything else, garbage in, garbage out, so do the best you can at maintaining the quality of your inputs.

Benefit/Cost Ratio Method

All comparisons must be made at a single time reference point. You can use PW (Present Value), FV (Future Value) or AW (Annual Worth) as a basis. (PW and AW are the most commonly used). We will look at Present Worth.

If the Benefit to Cost Ratio (B/C) $\geq$ 1.0 then the project is a **go**

The Conventional B/C Ratio calculation with Present Worth is:

$B/C = PW(B)/(I + PW(O\&M))$

Where:

PW (?)	=	present worth of (?) In this case B or O&M
B	=	benefits
O&M	=	operating and maintenance Costs
I	=	initial investment

Please review Present Worth to calculate PW (?)

Example - B/C ratio method

The county is planning a new park with a boat ramp. Three sites are being considered. The estimated initial cost of Site 1 is $500,000, Site 2 is $600,000, and Site 3 is $700,000. Operating and maintenance expenses would amount to $10,000 per year for Site 1, $15,000 per year for Site 2, and $20,000 per year for Site 3. Boat ramp fees are expected to be $100,000 per year for Site 1, $120,000 per year for Site 2, and $150,000 per year for Site 3.

Assume the interest rate is 10% and the life of each park is 20 years.

	Site 1	Site 2	Site 3
Initial Cost	$500,000	$600,000	$700,000
O&M Cost per year	$10,000	$15,000	$20,000
Boat Ramp Fees per year	$100,000	$120,000	$150,000

Find the B/C ratio for each alternative using the conventional formulas.

Benefits (site1) = Present Worth of $100,000 per year boat ramp fees for 20 years @10%

From the interest tables or by calculation, PW (Benefits) = 8.514 x $100,000 = $851,400

Costs (site 1) = Initial Cost +Present Worth of $10,000/year O&M

From the interest tables or by calculation, PW (O&M) = 8.514 x $10,000 = $85,140

Therefore: B/C (Site 1) = $851,400/($500,000+$85,140) = 1.455

Similarly, B/C (Site 2) = $1,021,680/($600,000+$127,710)=1.403

And B/C (Site 3)= $1,277,100/($700,000+$170,280)=1.467

Although it's a close decision, Site C would bring the most tangible benefit to the county.

Remember, B/C ratio is only a guideline in making a choice. The professional must pay attention to the intangibles, in combination with analysis, to make the best choice. For instance, suppose Site 3 is near heavy traffic or next to a garbage dump, it might not really be the best selection.

END SECTION 2

Section 3 - Depreciation

Overview and Definitions

Almost every project or business requires some sort of capital investment for equipment. Over time, this equipment ages and loses value. It is important to be able to measure the rate of this loss in value and in expected life of the asset. Depreciation allows us to quantify this loss for both planning and tax purposes. Two definitions are offered for Depreciation. The first addresses the applicability towards tax deductions and the second applies toward project planning.

Definition 1 – depreciation is the allocation of the value of an asset over a period of time for accounting and tax purposes.

Definition 2 – depreciation is the decline in the value of an asset due to general wear and tear or obsolescence.

It is important to remember that depreciation is an expense. It is treated that way by the IRS and must be considered in project planning.

Types of Depreciation

There are several types of depreciation including straight-line, declining-balance, sum-of-the years-digits, Accelerated Cost Recovery, net domestic product, pre-depreciation profit, etc. this course will address the two most common types.

Straight-line Method

The most common method is the straight-line method due to its ease of calculation. The straight-line method assumes that an asset depreciates the same amount each year of its use. The factors that must be known or assumed to use this method are 1) the acquisition cost of the asset, 2) its useful life in years, and 3) its estimated salvage value at the end of its useful life.

The depreciation for each year is calculated by the following formula:

Depreciation per year = (Acquisition Cost - salvage value) x (100%/useful life in years)

Example: If you buy something for \$100, can use if for 5 years and sell it for \$10 then the depreciation per year would be = (100 – 10) x 100%/5 = 90 x 20% =\$18/year

This is the same for all 5 years. The year-end book value is simply the Acquisition cost or previous year-end book value minus that year's depreciation.

Declining-balance Method

This method allows a more rapid depreciation of an asset in the early years of its useful life. The benefit of this method is that more of the expense of acquiring the asset can offset by tax deductions sooner. Why would this allowed by the IRS? The downside to this is if you sell the asset before its useful life is over, you would have more capital gains since you are probably selling it far above its estimated book value using this method. Therefore, the IRS gets you a little later. This method is a little more involved to calculate. The first year's depreciation can be calculated using the following formula:

Depreciation (year 1) = Acquisition cost x (100% / useful life in years) x 2

For year 2 and successive years the following formula may be used:

Depreciation (year 2+) = Previous year-end Book value x (100% / useful life in years) x 2

In this method, the percentage of depreciation is the same but the actual dollar value decreases every year. You might also notice that the last year book value and the assumed salvage value are different. Again, the depreciation is faster but there is a capital gains impact when the item is sold.

A comparison of the two most common methods of depreciation

Assume you buy a forklift for $5000 and plan to use it for 5 years. At the end of this time you think you could sell it for $800. Let's look at using straight-line and declining-balance depreciation methods and see which is better.

The acquisition cost = $5000

The useful life is 5 years and the salvage value is assumed to be $800.

Using the respective formulas and substituting values, we get the table below:

	Straight Line Method		Declining Balance Method	
Year	Annual Depreciation	Year-End Book Value	Annual Depreciation	Year-end Book Value
1	$4200 x 20%=$840	$5000-$840=$4160	$5000 x 40%=$2000	$5000-$2000=$3000
2	$4200 x 20%=$840	$4160-$840=$3320	$3000 x 40%=$1200	$3000-$1200=$1800
3	$4200 x 20%=$840	$3320-$840=$2480	$1800 x 40%=$720	$1800-$720=$1080
4	$4200 x 20%=$840	$2480-$840=$1640	$1080 x 40%=$432	$1080-$432=$648
5	$4200 x 20%=$840	$1640-$840=$800	$648 x 40%=$259.20	$648-$259.20=$388.80

Which is better? It depends on your situation. If it didn't depend, there would only be one method. If you stick to your plan and keep the tractor for 5 years, the declining balance method will allow more rapid depreciation and better tax benefits. If you choose to sell the tractor in year 3 to get a better one, then the straight-line method would produce a smaller difference between that sale price and the estimated book value, reducing your capital gains liability.

Depreciation is a valuable tool, but it must be used in combination with other factors and your own judgment.

END SECTION 3

Section 4 - Replacement Analysis

Replacement analysis is concerned with determining the appropriate time to replace an existing asset with another. Even when the decision is obvious, i.e. something breaks, it is not obvious whether to repair or replace something, or even with what to replace it.

Several types of replacement decisions are discussed here that will cover most of the situations one would normally encounter.

For aging, but functional assets one could

1) Keep it without major modifications (i.e. baby it along)

2) Remove it entirely – "we didn't really need that function anyway" or the function can be distributed to existing assets

3) Overhaul the asset to restore original performance or even enhance performance.

4) Replace it with something else

Terminology: The unit already in place, which you are considering replacing is often referred to as the "Incumbent" or the "Defender". The potential replacement is known as the "Challenger".

The Incumbent has several advantages over the Challenger. Firstly, if it's working, you don't have to do anything, at least not right now. Secondly, it going to cost something to get rid of, either a hauling charge or scrapping fees. Thirdly, you have to spend time trying to figure out what to replace it with. Wow, why even bother?

Here's why. It's either old or outdated and inefficient. It's going to break. As assets get older, their maintenance cost naturally increases. You pay money every time you maintain or repair it and it may not be giving you the most economical performance. Wow how could I possibly keep it? Hold on. It depends.

The Challenger cost money to install, as well as, the actual capital expense of buying it. Its maintenance cost will undoubtedly be lower due to warranties and newness and the performance of a more modern device may generate significant savings in operating costs. But, remember the cost to get rid of the Incumbent? Well, what if it's not scrap, but can actually be sold? Someone might actually pay money for it and take it away.

Obviously a more organized approach to this analysis is required. Its not complicated, just a side-by-side comparison of all relevant factors estimated to the best of your ability.

Several concepts must now be introduced to be able to make intelligent replacement decision. First is the idea of an "Economical Life" of an asset. This simply means that there is a period after which an asset costs more to keep than to get rid of. Wow, if we knew that we would know everything! Well, close.

The concept that is missing is how to effectively compare assets as time goes by and pick the right point in time to switch. This is where Equivalent Annual Cost (EAC) comes in. This is a method of estimating and evaluating the cost to run and maintain an asset each year over its useful life.

Let's consider what we need to know. The following table lists the key items and some of their characteristics.

	Defender or Incumbent	Challenger
Capital Cost	Amortized over years used	All in first year. Decreases as amortized over years used.
Installation Cost	Non recoverable or sunk cost	Part of Capital cost
Disposal Costs	May be offset by salvage value	N/A
Operating and Maintenance Costs	Gets higher and higher each year	Starts very low and builds slowly
Performance Benefits	Less each year	Could be significantly more for a good long time
Salvage Value	Estimated	Future estimate

Example. You bought a generator 20 years ago for $10,000. It can be sold this year for $1,000. It costs $7,500 in fuel costs to run for a year. Maintenance costs are $4,500 per year.

The EAC for this generator would be:

EAC = ((Capital cost-salvage value)/years used)) + (Annual O&M Cost)

EAC = $9,000/20 yrs + $12,000 = $ 12,450/year

A new, more efficient generator costs $9,000 installed. Maintenance cost for the first year would be zero since its still in warranty and will stay low for the first years. Fuel costs are estimated at $3,500 per year.

The EAC for the new generator in the first year would be:

EAC(new) = (Capital cost/1 year) + (Annual O&M Cost)

EAC(new) = $9,000 + $3,500 = $12,500/year

Just from this year's snapshot of EACs, you might think about keeping the old generator. Actually next year the component of EAC from the capital cost of the old unit will decrease with time, but remember so will the new asset. It will cut in half! The clincher here to convince you to replace the generator is that the maintenance cost will skyrocket as the generator gets really old and the fuel efficiency will likely suffer also. This is probably the time to replace it.

The EAC is an excellent tool for replacement analysis, but must be used only as a good guideline. Other factors of a business or project also weigh in, so combine this tool with your judgment and good documentation of the process to make and defend the right call.

END SECTION 4

Section 5 - Break Even Analysis

The concept of break-even point is fairly simple and finds applications in many areas. The most common area is in business, particularly manufacturing and sales. Simply stated it is used to determine how many items must be sold at a particular price in order to cover the cost of making and marketing them. Above this break-even point is where profit is starting to be generated.

This can be stated in several ways. Since profit = sales price – manufacturing & marketing cost:

The Break-Even point is where:

Manufacturing & marketing costs = Number of units sold x Unit price

or where the profit is exactly equal to $0.

This seems pretty simple but the determination of the manufacturing and marketing costs are not that straightforward and present somewhat of a moving target.

Let's look at what types of costs are involved. There are costs that are commonly referred to as

Fixed Costs -These represent money that must be spent regardless of how many units you produce. Examples of this are rent, utilities salaries, capital equipment and tooling costs.

The other costs involved that do change with the number of units produced are referred to as **Variable Costs**. Examples of this are materials, shipping, packaging, production labor, etc.

A third useful term is **Variable Cost percentage per Unit.** Adding all the variable costs involved in each sale and dividing by the average sales price calculate this.

For example if you sell something for $8.00 and the variable costs are $2.00, then the Variable Cost percent per Unit = $2.00/$8.00= .25 = 25%.

To determine the Break-Even Point ($ in sales) you would use the following formula:

Break-Even Point ($) = Fixed Cost/(1- Variable Cost Percentage Per Unit)

So for the previous example if we assume a fixed cost of $1,000 the

Break-Even Point = $1000/(1-.25) =$1,000/ .75 = $1,333.33

which is equal to $1,333.33/($8/unit) = 166.66 or 167 units to break even. This also indicates that every unit sold above 167 will return a 75% profit. What this means is that units number 1 to 167 were *contributing* to covering the fixed costs. Unit 167 and above *contribute* to profit.

So the real money is made after reaching the break-even point.

END SECTION 5

Section 6 - Life Cycle Cost

Entire courses could be given and many books could be written about life cycle costs. Although originally highlighted on military programs, it is crucially important as a consideration for any project. It is so important that it almost totally ignored in engineering education. Life cycle cost stems from the fact that no matter how much you think a project costs you're wrong, it costs much more. I am not going to introduce endless equations or theories here, just a few thinking points and examples.

Let's start with a definition.

Life Cycle Cost stated simply, is the total amount of money expended to get a project up and running and to keep it up and running for an intended period.

Too often, we just consider what it takes to complete the design and implementation part of a project. Many times the continuing operation and repair costs to keep a system performing to original performance specifications over time dwarf the original system expenditure.

For example, suppose you are evaluating two proposals for a communications system for a satellite. Proposal 1 costs 2 million dollars and has a reliability or "mean-time-between-failure" (MTBF) of 1,000 operating hours. Proposal 2 costs 10 million dollars, but has a MTBF of 10,000 hours. The quick answer is to buy the less expensive one and save 8 million dollars.

However, you have to consider the total number of hours the system is intended to last. If you only operate the system for 10 hours a month for 5 years, that's 600 hours with still a good margin. However, if heavier usage or longer life is required, I don't think you want to be the one to fund the trip to repair or replace that system. When you look at the total life cycle of the project including potential repair costs, you can make a better decision.

Therefore, the lesson here is to consider as many pertinent factors as possible that the user of the system has to deal with after the designer is long gone. In this way, there are fewer operational and monetary surprises and your reputation stays intact a little longer.

END SECTION 6