**Plant Design and Economics**
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**Lecture No -25**
**Alternative Investment, Replacement and Sensitivity Analysis**

Welcome to lecture 25 of plant design and economics. In this module as of now, we have talked about various methods for profitability analysis. In today's lecture we will talk about alternative investments replacement analysis and sensitivity analysis. So this will be today's topic. We will start with some irregular cash flow diagrams, then we will talk about alternative investment: incremental analysis, replacement analysis sensitivity analysis and we will take several numerical examples to understand these concepts better.

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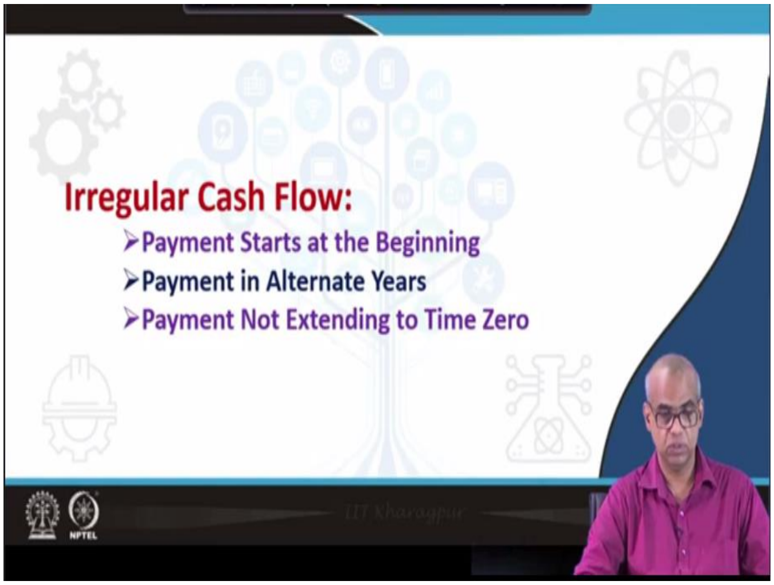


So let us start with irregular cash flow diagrams. We will talk about 3 different types of cash flow diagrams which are irregular. Why irregular? It will be clear as we start discussing. Payments starts at the beginning, payment in alternate years, payment not exceeding to time 0. So these features make these cash flow diagrams irregular.

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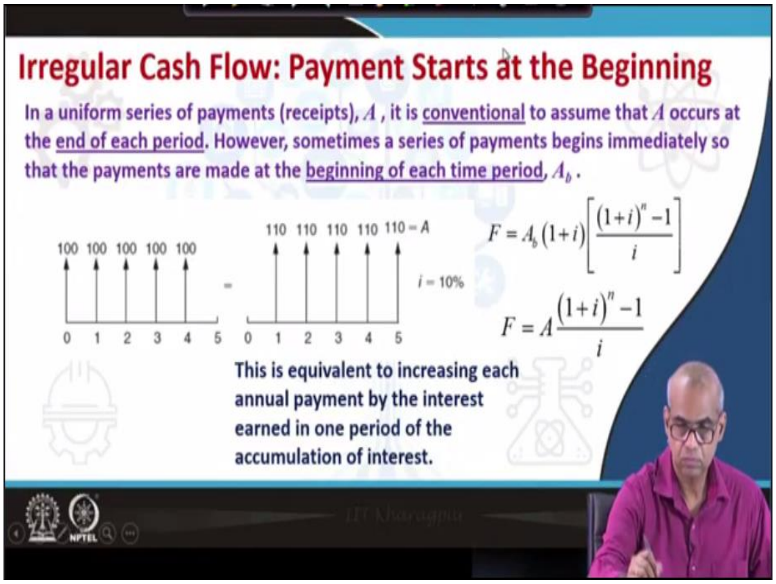


Payment starts at the beginning. In a uniform series of payments, it is conventional to assume that the payment A occurs at the end of each period. However, sometimes a series of payments begins immediately so that the payments are made at the beginning of each time period. So you look at this cash flow diagram and compare it with this cash flow diagram. So here the payment has started at the beginning of each time period whereas here the payment is taking place at the end of each time period.

Now, this will be equivalent to increasing each annual payment by the interest earned in one period of the accumulation of interest. So if we have 10% rate of interest, this 100 rupees will earn 10 rupees at the end of one interest period. So if you compare this cash flow diagram with this, this cash flow diagram will have A that is the payment equal to 110 rupees made at the end of each interest period. So the familiar formula will also be modified slightly to take this into account.

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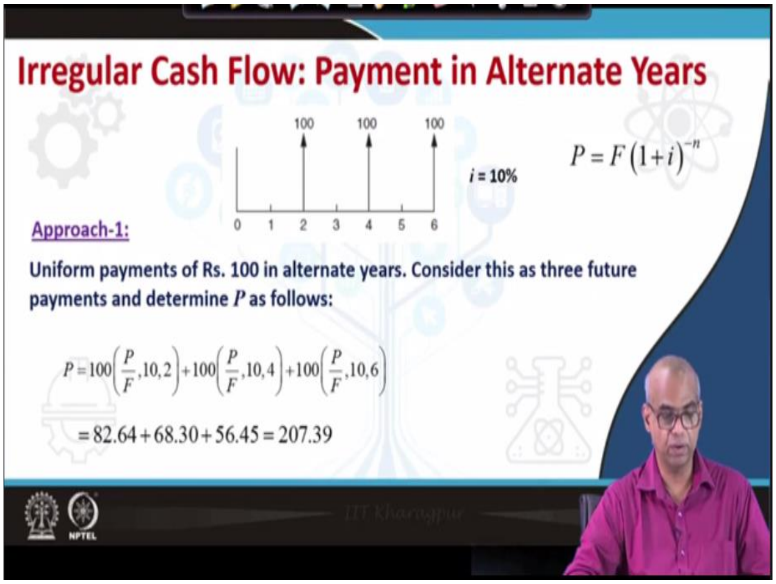


Now let us talk about second type of irregular cash flow diagram: payment in alternate years. So look at the cash flow diagram, the payment is a at year equal to 2, 4 and 6. Let us consider interest at 10%. So uniform payment of rupees 100 in alternate years is made. Now to handle such cash flow diagrams we have 2 approaches; the first approach we can consider this as 3 future payments and determine the present worth P, how?

See we can consider the present worth P as sum of 3 future payments, one works for 2 years, another works for 4 years and the third one works for 6 years. 2, 4 and 6. So this computation will give you the value of P as 207.39.

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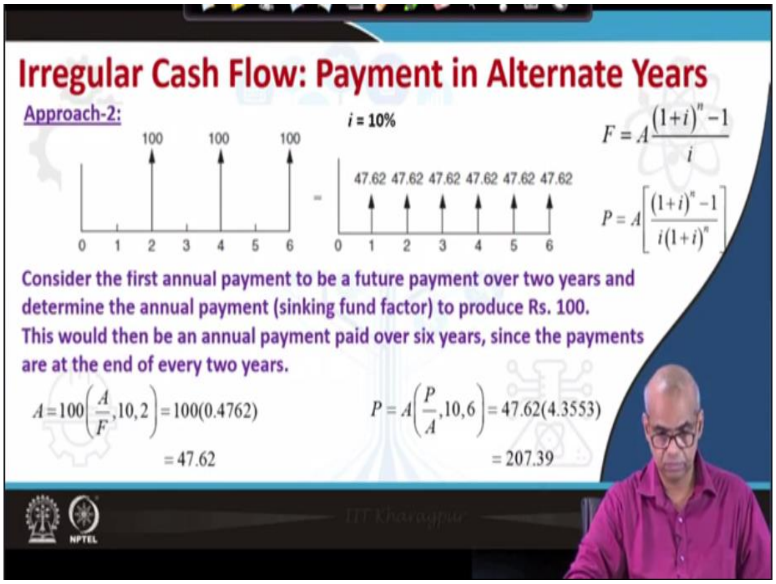

The other approach, consider the first annual payment to be a future payment over 2 years and determine the annual payment to produce rupees 100. So consider this you have to produce rupees 100 at the end of second year. So consider the sinking fund factor and find out what should be A invested every year. That amount happens to be 47.62. So this 47.62 will be an annual payment paid over entire 6 years because the payments are at the end of every 2 years.

So every 2 years can be analyzed same way. So this cash flow diagram is equivalent to a cash flow diagram where the uniform payment takes place at the end of every interest period. The P value can be computed as 207.39.

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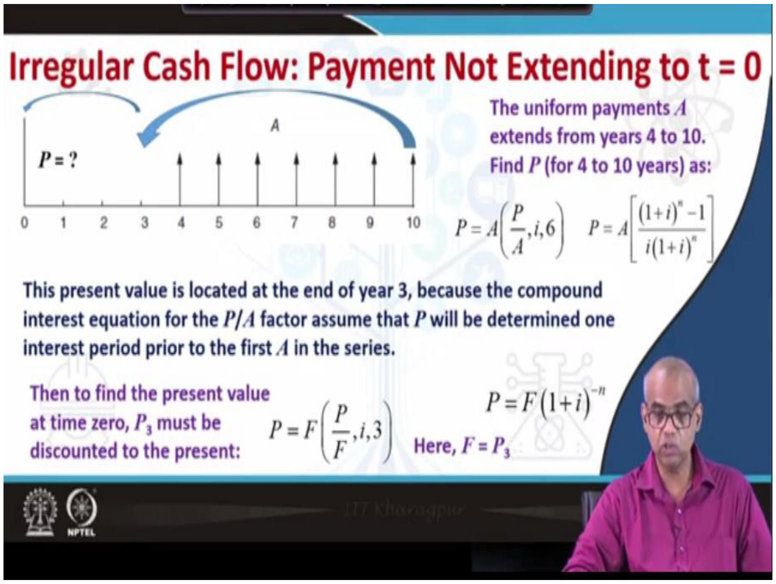


The third type of irregular cash flow diagram where payment does not extend to time t equal to 0. Note in this cash flow diagram, the payment is over year 4 to year 10. So how will you handle such cash flow diagram? The uniform payment A extends from years 4 to 10. So you have to find P first for year 4 to 10. So find the present worth value for this part of the cash flow diagram and place that P value at the end of third year.

And then from there again you find out the P value at time 0 years. So this present value can be computed as, find out the P by A factor, interest rate i and extends over 6 years, 4 to 10. So this present value is located at the end of year 3, because the compound interest evaluation for P by A factor assume that P will be determined 1 interest period prior to the first A in the series. Next you find the present value at time 0. So whatever you obtain here, if you call that as P3 that should now be discounted to time t equal to 0.

So this can be again obtained by P by A factor where F is equal to P3 here. And then you can obtain P equal to F into 1 plus i to the power - n. Here n equal to 3.

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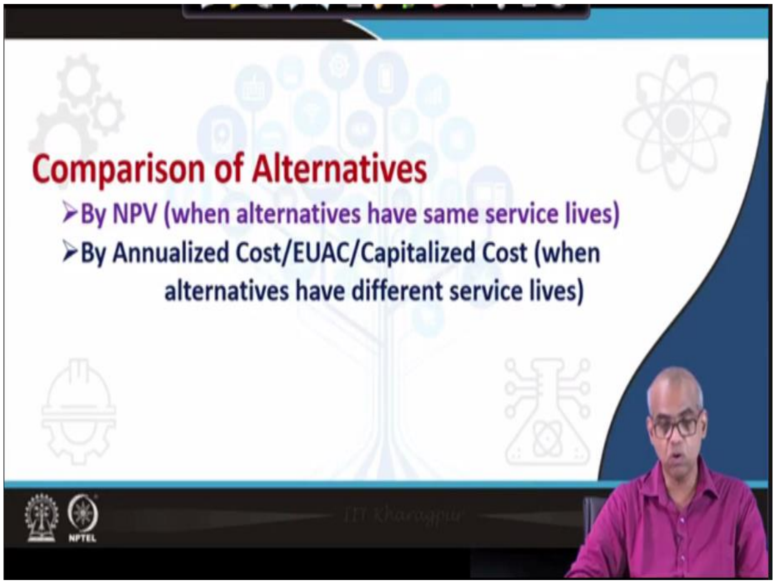


Now we talk about comparison of alternatives. We will talk about comparison of alternatives the 2 different methods; net present value, and we will use net present value and alternative have same service lives. We will use annualized cost method or equivalent uniform annual cost or capitalized cost when alternatives have different service lives.

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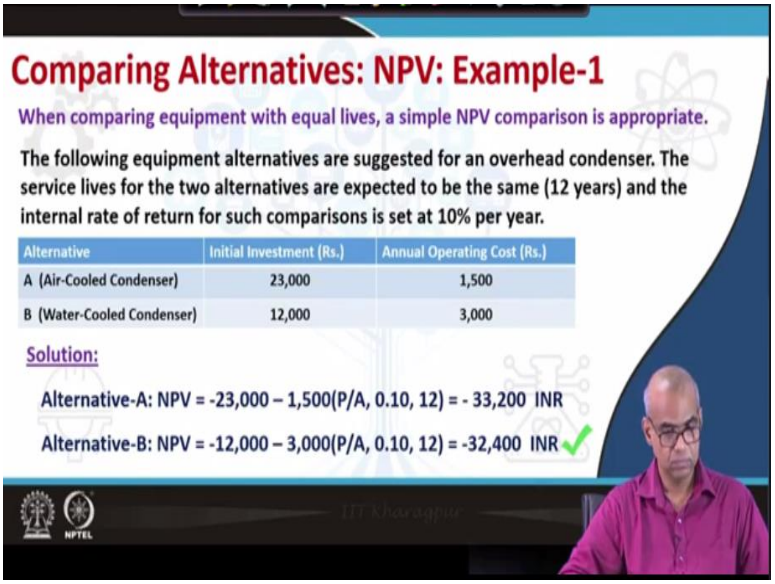


Now we will take examples and try to understand how to compare alternatives. So, first example will be based on use of net present value. When comparing equipment with equal lives, a simple NPV comparison is appropriate. The following equipment alternatives are suggested for an overhead condenser. The service lives for the 2 alternatives are expected to be the same, 12 years.

So you can make use of the NPV. And the internal rate of return for such comparisons is set as 10%. So you have 2 alternatives, A and B. A is air-cooled condenser and B is water-cooled condenser. Initial investment of A is 23000, initial investment of B is 12000. Annual operating cost for A is 1500 and annual operating cost for B is 3000. So find out NPV for alternate A. We have seen earlier how to compute NPV.

You have to add this part which is the annual operating cost. So find the P by A factor for the 12 years service life at interest rate 10%. Multiply that with the operating cost 1500. With and that this should be added to the initial investment 23000. So this way you compute NPV for alternate A is 33200. For alternative B is this 32400. So alternative B is economical and should be recommended.

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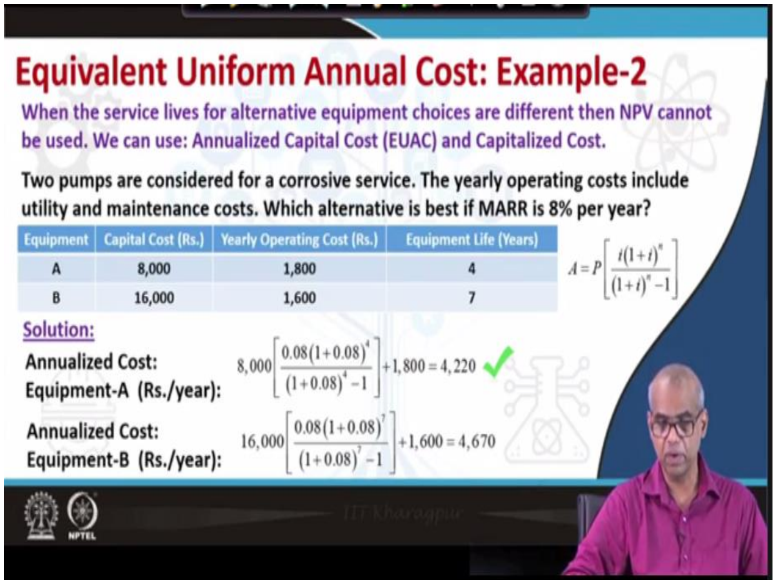


Now let us look at another example where you have to compare equipments with different service lives. When the service lives for alternative equipment choices are different, then NPV cannot be used. We can use annualized capital cost, equivalent uniform annual cost and capitalized cost. 2 pumps are considered for a corrosive service. The yearly operating cost include utility and maintenance costs.

Which alternative is best if the minimum acceptable rate of return is 8% per year. So find out the annualized cost of equipment A in rupees per year. You have the formula. So P equal to 8000 here. Interest rate i is 8%, so 0.08. And n equal to number of years 4. Similarly compute the annualized cost for equipment B. You can see that the annualized cost for equipment A is smaller compared to that of equipment B. So equipment A is better alternative and recommended.

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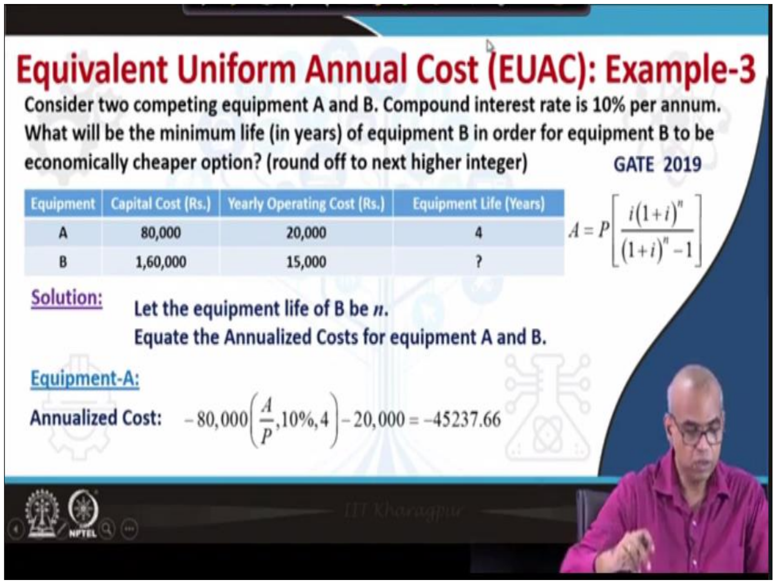


Let us take another example. We consider 2 competing equipment A and B. Compound interest rate is 10% per annum. What will be the minimum life in years of equipment B in order for equipment B to be economically cheaper option? So equipment A and equipment B are given. Capital cost of equipment A is 80000 rupees, capital cost of equipment B is 160000 rupees. Yearly operating cost for equipment A is 20000 rupees, yearly operating cost for equipment B 15000 rupees.

Equipment life for A is 4 years. You have to find out the equipment life for B such that equipment B is economically cheaper. See equipment B will be economically competitive to equipment A when the equivalent uniform annual cost of equipment A and equipment B are same. So what we will do is we will consider the equipment life of equipment B is n, and then find the annualized cost for both equipment A and equipment B and we will equate the annualized cost and then compute n.

So for equipment A we obtain the annualized cost. So I have to find out A by P factor for the capitalized cost 80000 rupees. 80000 rupees has to be annualized for 4 years with interest rate 10%. So this gives you this quantity and annual operating cost is already given as 20000. So their sum is the annualized cost for equipment A, 45237.66.

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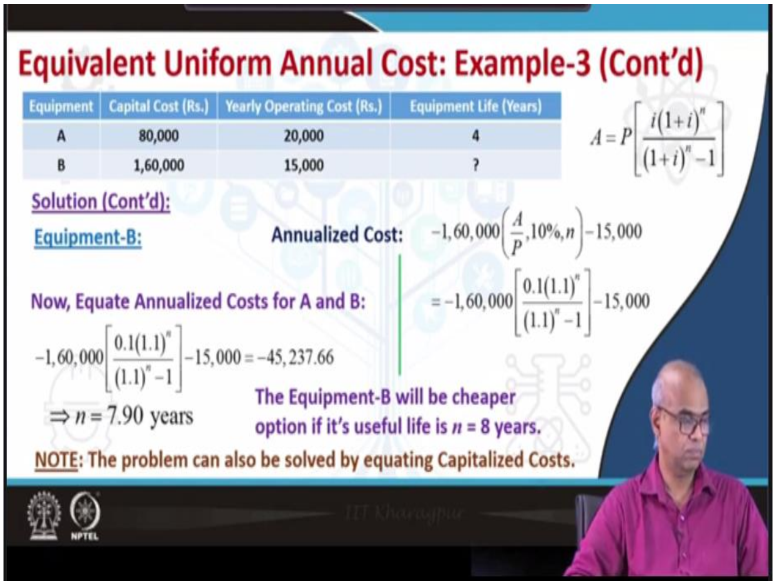


Let us repeat the same for equipment B. So for equipment B 160000 has to be annualized over n years, that unknown n, interest rate 10%. So you know the expression for that. So this expression becomes the annualized cost for equipment B when I assume that its service life this n. Now, we equate annualized cost for equipment A and equipment B. Annualized cost for equipment was obtained as 45237.66.

So, I equate this with this. And solve the resulting expression. We obtain n as 7.90 years. So 7.90 years the equipment B will become competitive with equipment A. The equipment B will be cheaper option if its useful life is 8 years. This problem can also be solved by equating capitalized cost.

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Now let us talk about alternative investments: incremental analysis.

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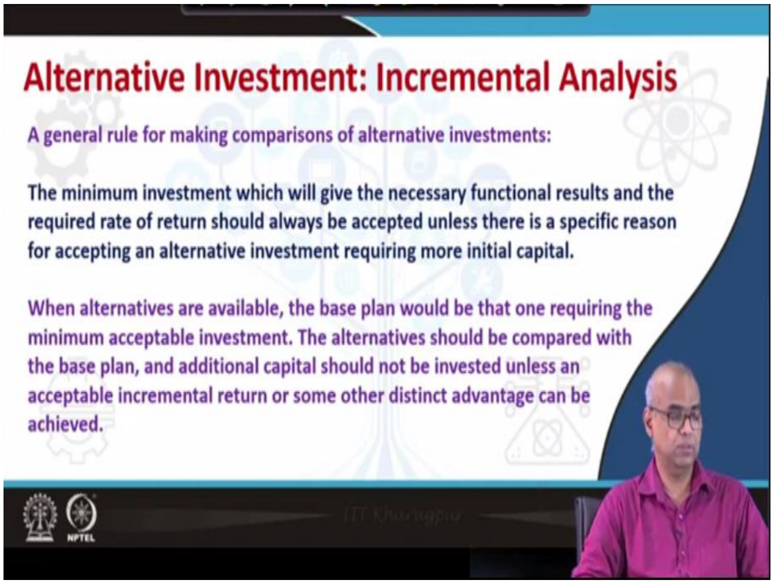


A general rule for making comparisons of alternative investments is as follows. The minimum investment which will give the necessary functional results and the required rate of return should always be accepted unless there is a specific reason for accepting an alternative investment requiring more initial capital. When alternatives are available, the base plan would be that one requiring the minimum acceptable investment.

The alternatives should be compared with the base plan and additional capital should not be invested unless an acceptable incremental return or some other distinct advantage can be achieved. So first you will have a base plan when you have several alternatives. Now these alternatives should be compared with the base plan. The base plan is the one which requires the minimum acceptable investment.

The other alternatives must be compared with the base plan. And additional capital should not be invested unless an acceptable incremental return or some other distinct advantage can be achieved. So other alternatives should be compared against the base plan. And then you invest further amount of capital or you recommend to invest further amount of capital only when an acceptable incremental return is achieved or some other distinct advantage is achieved.

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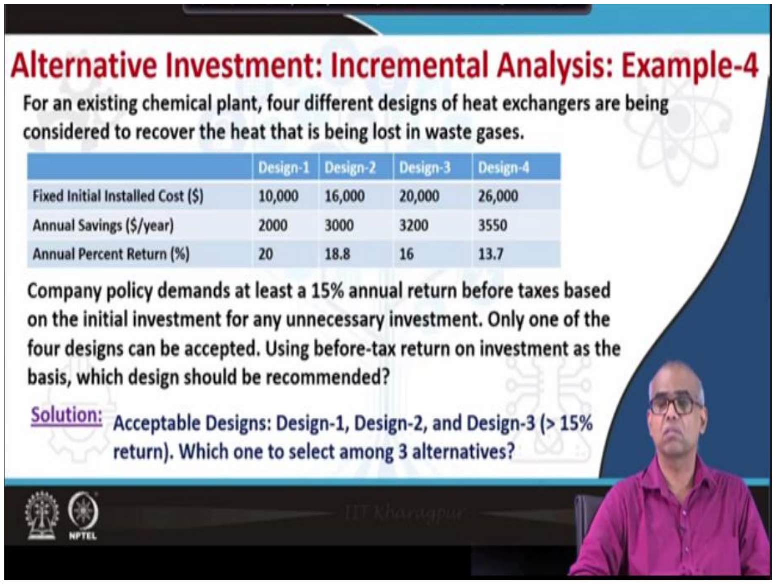


Let us try to understand that with the help of an example. For an existing chemical plant, 4 different designs of heat exchangers are being considered to recover the heat that is being lost in waste gases. So 4 designs; design 1, design 2, design 3 and design 4. Fixed initial cost for each designs are given as 10000 dollars, 16000 dollar, 20000 dollars and 26000 dollar. Annual savings in terms of dollar per year is given for each design.

Annual percent return are computed and tabled as 20% for design 1, 18.8% for design 2, 16% for design 3 and 13.7% for design 4. Now the company policy demands at least 15% annual return before taxes based on the initial investment for any unnecessary investment. So you must obtain at least 15% annual return. Otherwise there will not be any further investments. Only one of the

4 designs can be accepted.

Using before-tax return on investment as the basis, which designs should be recommended? Now if you look at the table, you see that design 1, design 2 and design 3 all give annual return, which is higher than the desirable 15%. So design 1, design 2 and design 3 are acceptable. But design 4 is not acceptable because it gives 13.7% return which is less than the desired return of 15%. So acceptable designs are design 1, design 2, design 3.

So I have to compare this design 1, design 2 and design 3 and select the best one. If you look at design 1, design 2 and design 3, the design 1 is the acceptable design which requires minimum investment. So let us consider this as the base case, this is the base plan. So design 2 and design 3 will be compared against design 1 and will see by doing incremental analysis whether further investment is recommended or not.

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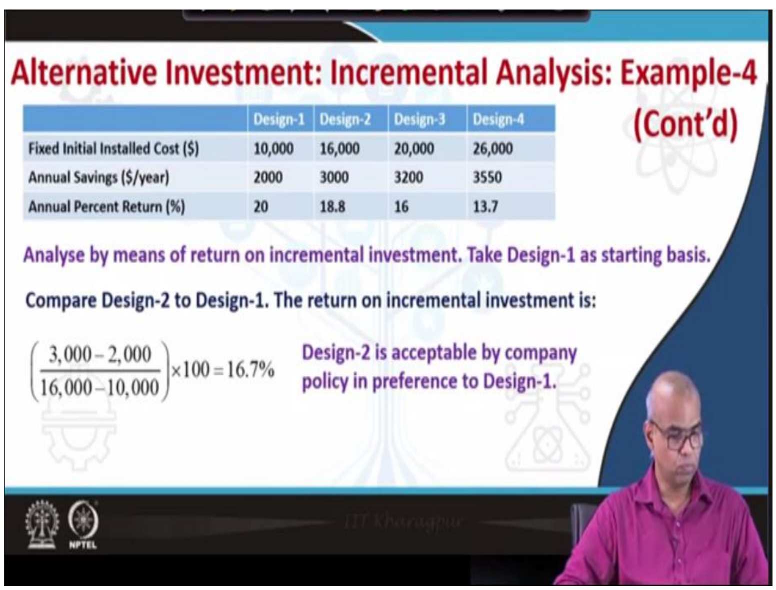


So we will analyze by means of return on incremental investment, we take design 1 as the base plan or starting basis. So let us first compare design 2 to design 1. So what is the return on incremental investment? You see that in case of design 2 the annual savings is rupees 3000 but annual savings for design 1 is 2000. So the extra saving is 1000, which is 3000 - 2000. And that comes at an expense of 16000 - 10000.

So the return on incremental investment is 16.7%. Now 16.7% is greater than the acceptable 15% rate of return. So design 2 is acceptable by the company policy in preference to design 1. So you accept design 2 as of now. So in preference to design 1, design 2 is accepted as of now.

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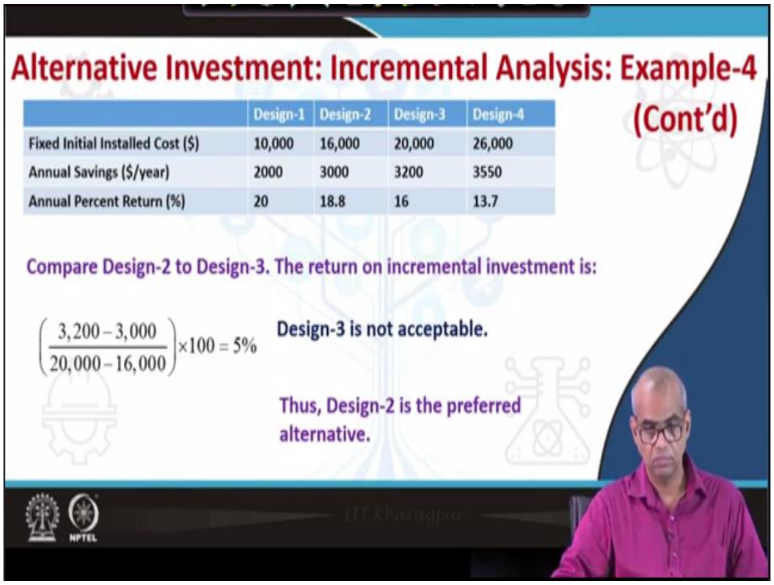


Now, we need to compare design 2 design 3. So in case of design 3 we are receiving annual savings 3200. So 3200 minus 3000, which is the annual savings of design 2. And investment for design 3 is 20000 compared to 16000 for design 2. So divide it by 20000 - 16000. So rate of return you obtain as 5% which is much less than the standard set by the company policy which is 15%. So design 3 is not acceptable. So design 2 is the most preferred choice. So that is the alternative.

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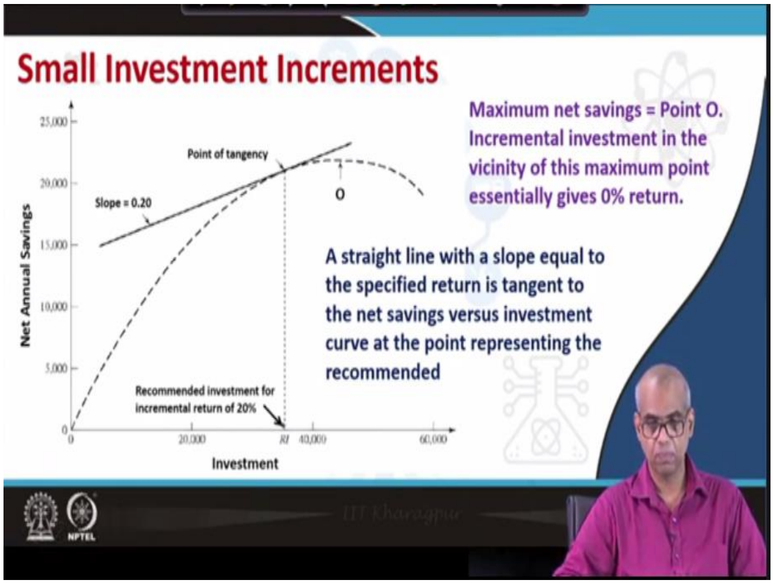


Now we talk about a situation where, the small investment is possible. Let us take an example from heat exchanger design for recovering waste heat. Each square meter of additional heat transfer area can cause a reduction in the amount of heat loss. So we are designing heat exchanger for recovering waste heat. So as you go on adding heat transfer area, the heat loss decreases. You recover wasted heat loss decreases.

But the amount of heat recovered per square meter of the heat transfer area will decrease as the area increase. So if we plot net annual saving versus investment, the plot will look like as shown in the figure. It will first increase then saturate and then decrease. Note that when you start increasing the additional heat transfer area, you recover more and more waste heat. So the amount of savings increases.

So the amount of heat recovered per square meter of heat transfer, which is savings, will increase the beginning. But later on it will decrease. And later on a situation will come where your investment is more compared to savings. Note that as you go on increasing the area of heat transfer you are investing more and more amount of money. So initially when you invest, that is when you increase the surface area, you recover lot of waste heat, so you do more savings.

But as you go on increasing the heat transfer area that means as you go on investing, the amount of heat recovered per square meter of heat transfer area, which is savings, decreases. So you will get a plot as shown in the figure. Now this plot if you look at it goes to a maximum and then comes down. Now if you look at the maximum point indicated by point O that of course corresponds to the theoretical maximum net saving.

But if you look at in the vicinity of point O, you see that the incremental rate of return is extremely low, next to 0 there because the curve is almost flat over there. So to find out the investment for a given net savings, what you need to do is you first define the specified savings of specified return. Let us say I want 20% return. So I draw a straight line with slope 0.2. And find out the point of tangency of the straight line on the curve of net annual savings versus investments.

So the point of tangency gives me the recommended investment for the incremental specified rate of return, which is 20% here. So this gives me the investment required for 20% return. So this is how we can do the incremental analysis.

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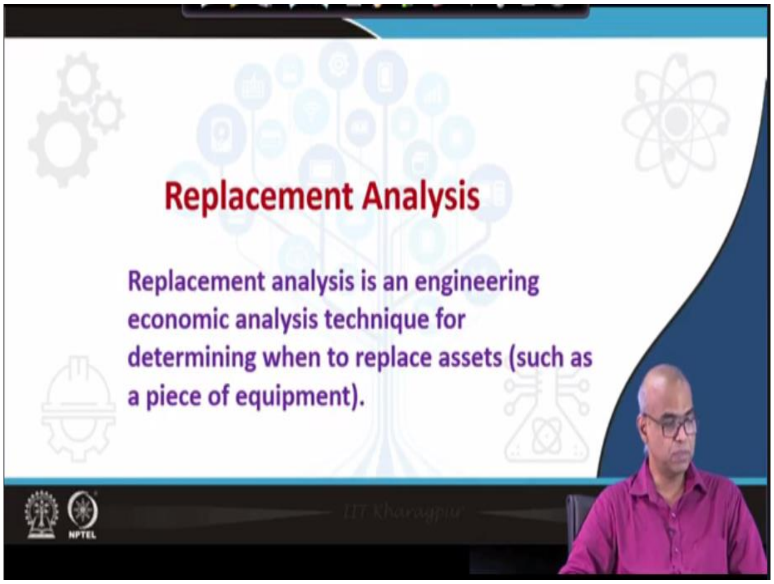


Now we will talk about another important aspects of economic analysis which is known as replacement analysis. Replacement analysis is an engineering economic analysis technique for determining when to replace assets. For example how will you determine when you have to replace an equipment which is there in service for quite some time. This is done by replacement analysis.

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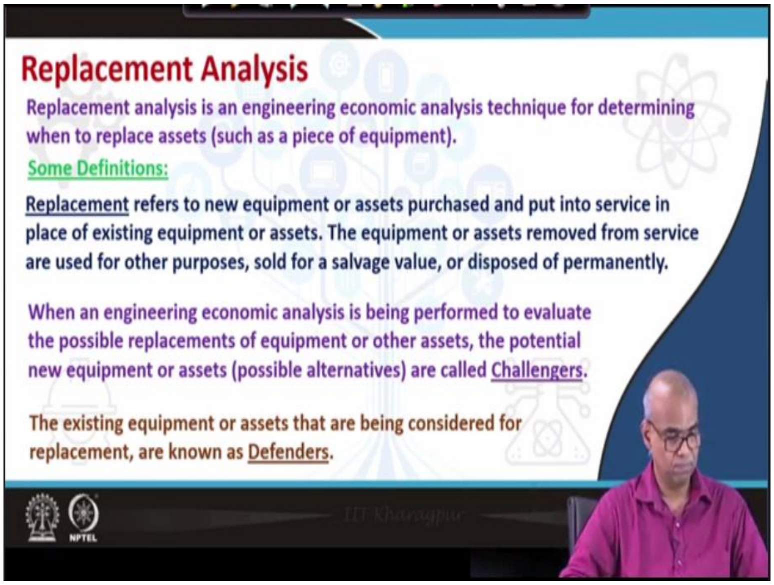


So what will do is we first start with some definitions. Replacement refers to new equipment or assets purchased and put into service in place of existing equipment or assets. The equipment or assets removed from service are used for other purposes, sold for a salvage value or disposed of permanently. When an engineering economic analysis is being performed to evaluate the possible replacements of equipment or other assets the potential new equipment or assets, that is possible alternatives are called challengers.

The existing equipment or assets that are being considered for replacement are known as defenders. So replacement means that you are replacing an existing equipment or asset by a new one. Now the new equipment which is replacing the existing equipment is known as challengers. So the new equipment is known as challenger. So there may be many challengers that means there may be many possible alternatives and you have to find the best alternative.

That means when you are going to decide that you have to replace an equipment, so you have to decide you have to replace an equipment, yes or no. And if you have possible alternatives then which one you will choose to replace the existing equipment. So the new equipment is known as challenger and the existing equipment which is being replaced is known as defender.

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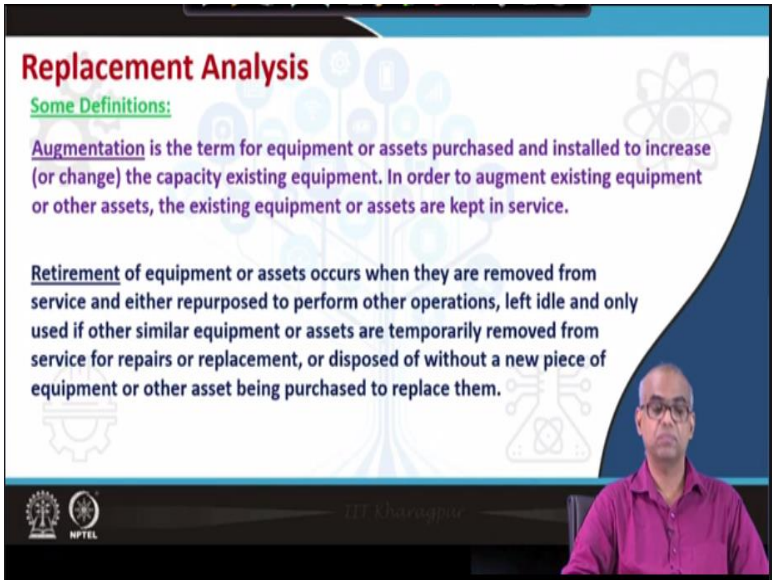


Still some more definitions. Augmentation is the term for equipment or assets purchased and installed to increase or change the capacity of existing equipment. In order to augment existing equipment or other assets, the existing equipment or assets are kept in service. Retirement of equipment or assets occurs when they are removed from service.

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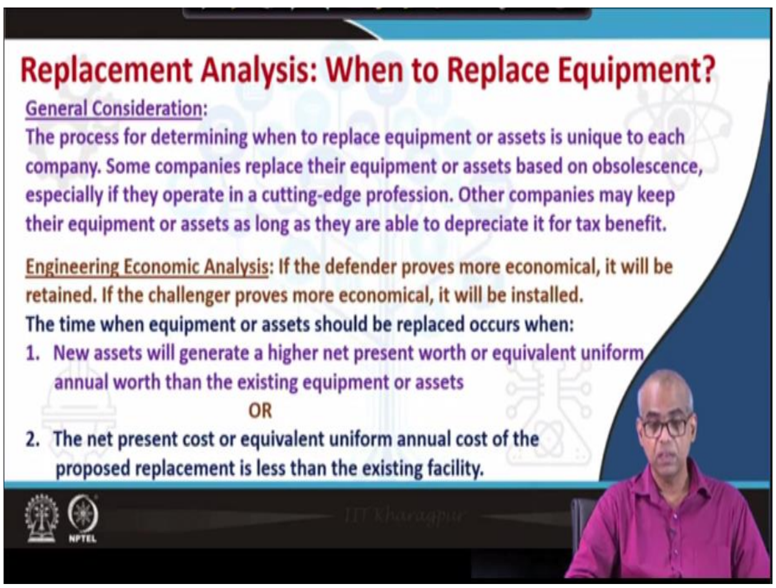


Now let us try to understand when to replace a piece of equipment. Now first general considerations. The process for determining when to replace equipment or assets is unique to each company. Some companies replace their equipment or assets based on obsolescences, especially if they operate in a cutting-edge profession. So they will always like to use newer and newer technology and so newer and newer equipment.

Other companies may keep their equipment or assets as long as they are able to depreciate for tax benefit. Now in terms of engineering economic analysis, if the defender that means the proposed new equipment proves to be more economical it will be retained, sorry, if the defender that means the existing equipment proves to be more economical it will be retained. But if the challenger that means the proposed new equipment proves to be more economical, it will be installed.

So whichever is more economical needs to be installed or retained. If the existing equipment is more economical, it will be retained. If a new equipment or challenger happens to be more economical, it will be installed and replace the existing equipment. The time when equipment or assets should be replaced occurs when new assets will generate a higher net present worth or equivalent uniform annual worth, then the existing equipment or assets or the net present cost or equivalent uniform annual cost of the proposed replacement is less than the existing facility.

See these two sentences essentially mean that if the defender is more economical it will be retained or if the challenger is more economical it will be installed.

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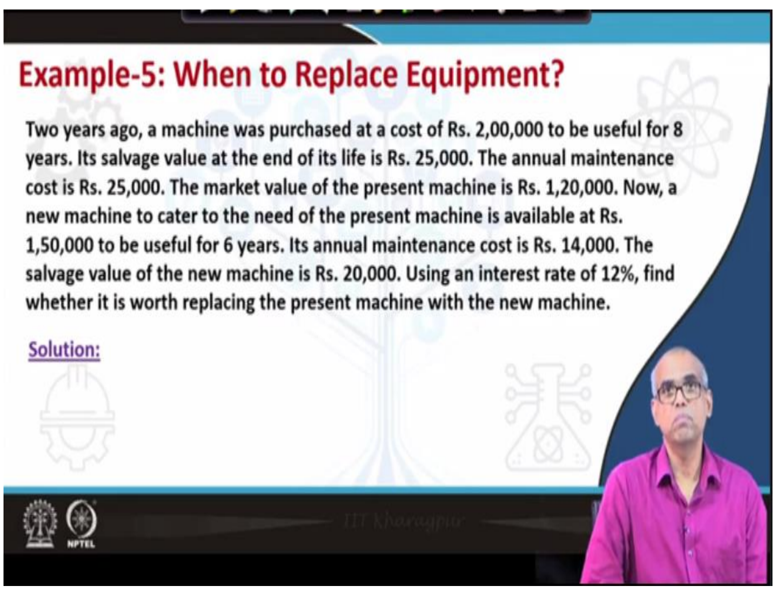


Now, let us try to understand replacement analysis with help of an example. 2 years ago, a machine was purchased at a cost of rupees 200000 to be useful for 8 years. Its salvage value at the end of its life is rupees 25000. The annual maintenance cost is rupees 25000. The market value of the present machine is rupees 120000. Now a new machine to cater to the need of the present machine is available at rupees 150000 to be useful for 6 years.

Its annual maintenance cost is rupees 14000. The salvage value of the new machine is rupees 20000. Using an interest rate of 12%, find whether it is worth replacing the present machine with the new machine. Now, to solve this problem what we will do is we will find out equivalent uniform annual cost for both the machines. And depending on the magnitude of equivalent uniform annual cost we will be able to decide whether the existing machine can continue or it will has to be replaced by the proposed new machine.

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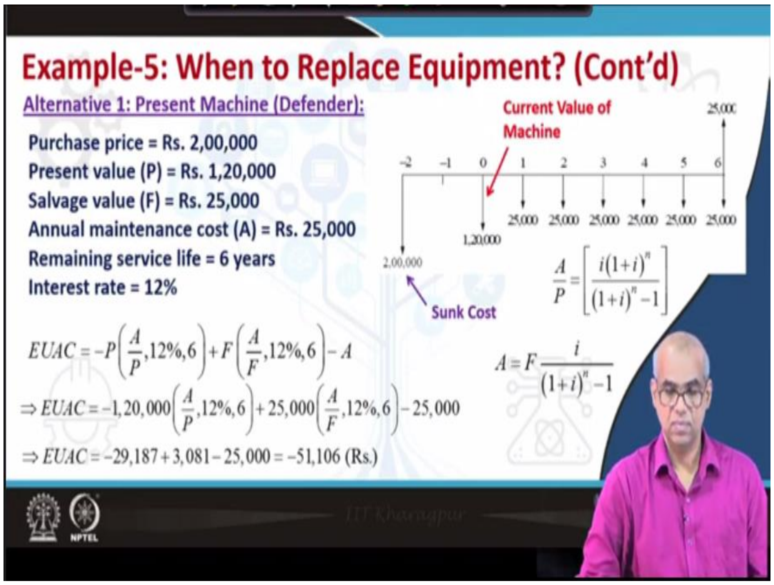


So first let us find out the equivalent uniform annual cost for the present machine which is also known as defender. So purchase price is rupees 200000. Present value is rupees 120000. Salvage value is 25000. And the annual maintenance cost is rupees 25000. Remaining service life is 6 years. Interest rate is 12%. Now we need to understand one thing here that the current value of the machine is 120000. So that is my time t equal to 0.

And the purchase price of 200000 rupees is a some cost which was invested 2 years ago. And this some cost will not be considered in to the calculation of economic evaluation. So economic evaluation will be based on the current value of the machine 120000. So now it is state forward to compute equivalent uniform annualized cost. So you have at time t equal to 0 and negative cash flow of 120000. So let us annualize it over a period of 6 years at interest rate of 12%.

Then at 6th year I have a positive cash flow of rupees 25000. Again we annualize it for 6 years at interest rate of 12%. And then we have already specified annual cost of 25000 every year. So a negative cash flow 25000 every year. So we will require A by P and A by F factors which can be computed from the formulas given. So if you compute this you will obtain the equivalent uniform annual cost of the present machine or defender as rupees 51106.

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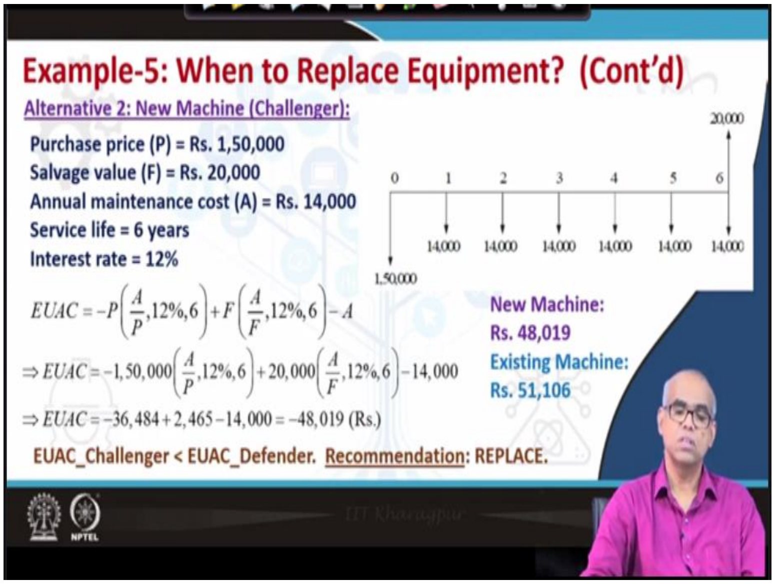


Now let us compute the equivalent uniform annual cost for alternative to or new machine also known as challenger. Here the purchase price is 150000 at time t equal to 0. Salvage value is rupees 20000. Annual maintenance cost is rupees 14000 and service life is 6 years. Interest rate is 12 years. So the same way you find out the equivalent uniform annual cost. And you obtain the value as 48019 rupees.

Note that this is annualized over 6 year period with 12% interest. This is also annualized over 6 years period at 12% interest. While 150000 is a negative cash flow, rupees 20000 is a positive cash flow. So if you compare the equivalent uniform annual cost for both the machines, we find that the equivalent uniform annual cost for challenger is less than that of defender. So the recommendation will be you replace the existing machine with the proposed new machine.

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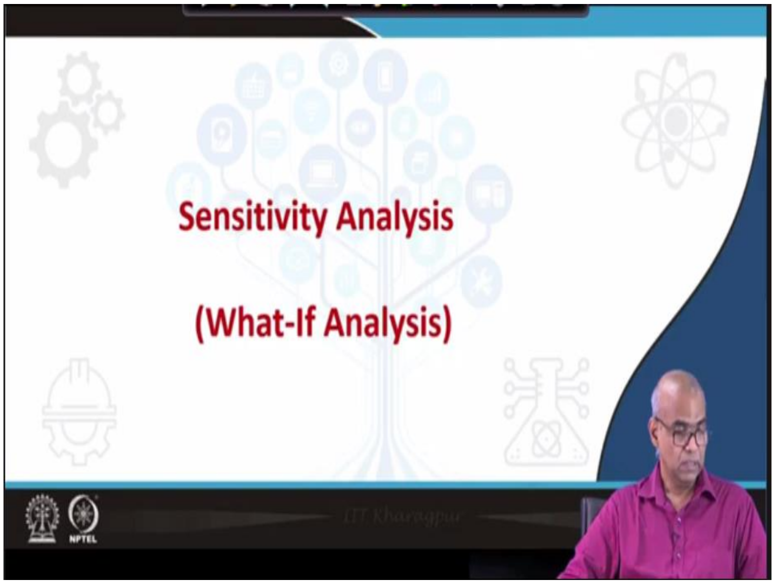


Now will briefly touch upon an important aspects known as sensitivity analysis. These are also known as what-if analysis. Meaning what will happen to my profitability analysis if let us say the fixed cost changes, let us say the sales changes, the revenues changes by certain percentage what will happen to the profitability analysis. There are uncertainties to these input values. So what happens to this profitability analysis when the inputs on which the sensitivity analysis are based on changes.

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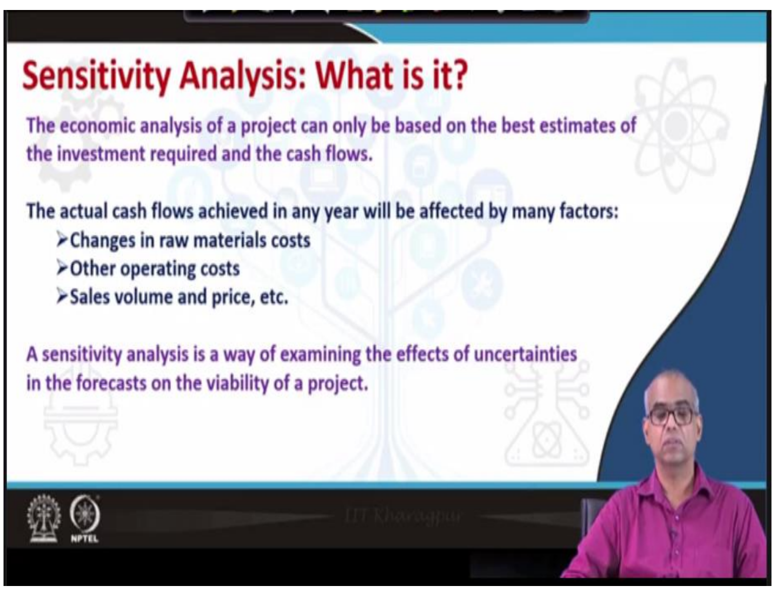


The Economic analysis of a project can only be based on the best estimates of the investment required and the cash flows. The actual cash flows achieved in any year will be affected by several factors such as changes in raw material cost, other operating costs, sales volume and price etcetera. A sensitivity analysis is a way of examining the effects of uncertainties in the forecast on the viability of a project.

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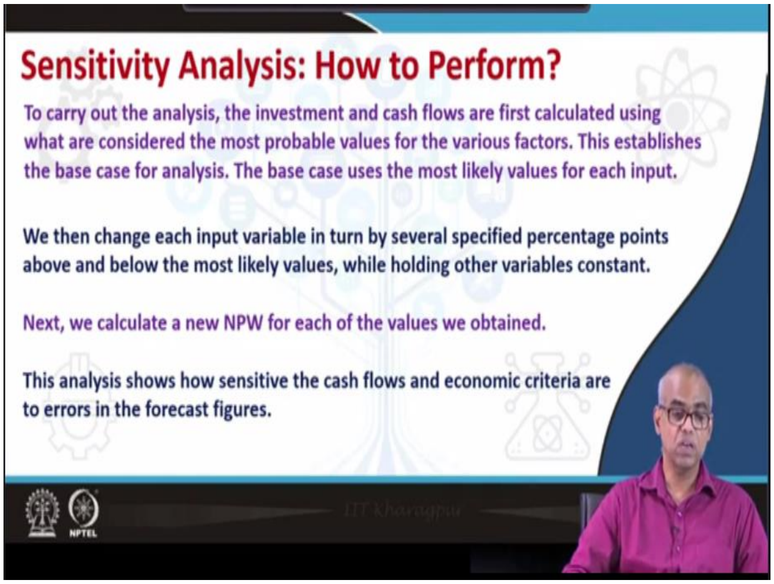


To carry out the analysis, the investment and cash flows are first calculated using what are considered the most probable values of the various factors. This establishes the base case for analysis. The base case uses the most likely values for each input. So to perform sensitivity analysis, first you get the base case. So what is the base case? The base case is the most likely values for the inputs.

That goes for calculation of the profitability analysis. So investment and cash flows will be first computed using the most probable or most likely values of various inputs of factors. This will establish the base case for future analysis. We then change each input variable in turn by several specified percentage points above and below the most likely values while holding other variables constant.

So what we will do is we have obtained the base case. Now there are several factors, let us say there are 5 factors. So I take each factor in turn and changes by say minus 5%, minus 10%, minus 20%. On the other end plus 5%, plus 10%, plus 20% and compute the net present worth.

So we then change each input variable in turn by several specified percentage points above and below the most likely values while holding other variable constant.

Next we calculate a new net present worth or net present value for each of the values we obtained. This analysis will show how sensitive the cash flows and economic criteria are to errors in the forecast figures.

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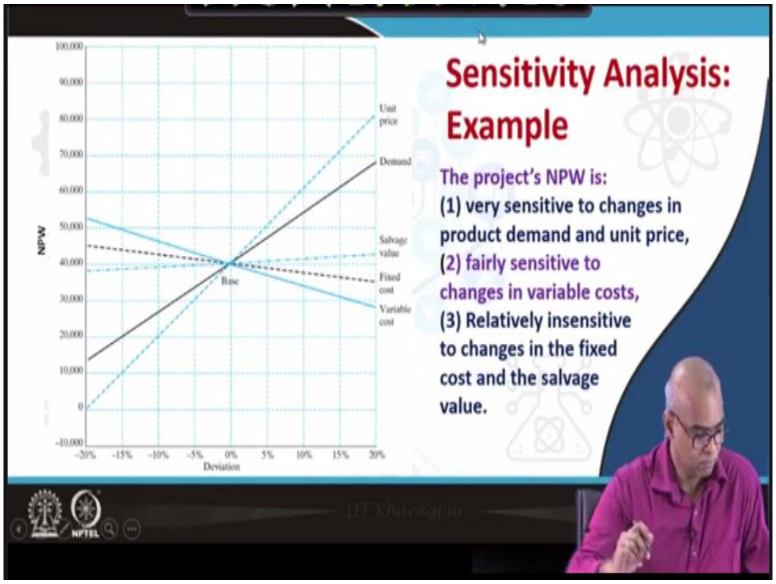


So this figure is a typical example of sensitivity analysis. So there are several factors you see; unit price demand, salvage value, fixed cost and variable cost. So these factors have been varied on both sides of base case. So this is the base case corresponds to 0% deviation. So each factor in turn has been varied by 5%, 10%, 15%, 20%, minus 5%, minus 10%, minus 15%, minus 20% holding all of this constant.

And in each case we have found out the net present value, NPV or NPW. Then you have made this plot. Now look at this plot. If you look at the plot, you see that the Unit price and unit demand to these 2 factors the net present worth is very sensitive. Look at the high slop. Whereas the variable cost is fairly sensitive. Is not as sensitive as unit price or demand factors. But if you look at salvage value or fixed cost, the net present value is relatively insensitive to changes in fixed costs or salvage value.

So we get a total picture of how these different factors or changes in these different factors affect the net present value or the profitability analysis of the project cash flow diagram. So the projects profitability, sensitivity of the projects profitability on various factors can be obtained by the sensitivity analysis.

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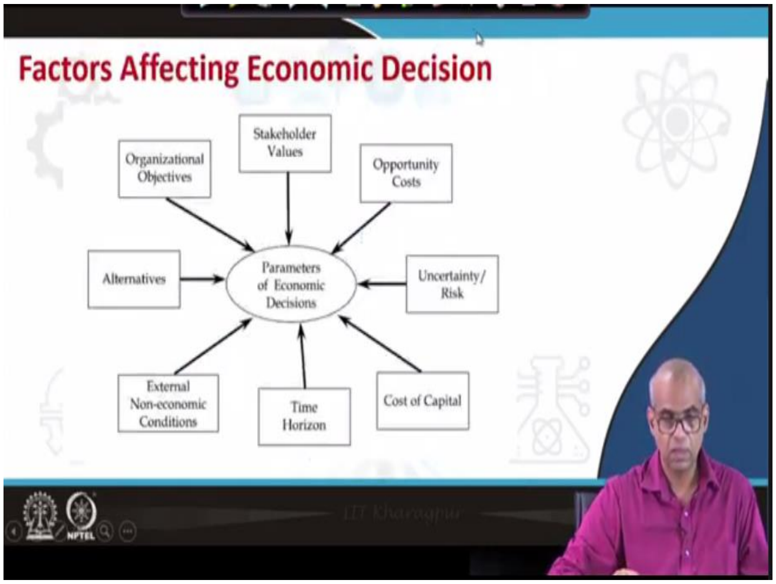


So there are several factors which affect economic decision. We discussed quite a few of them.

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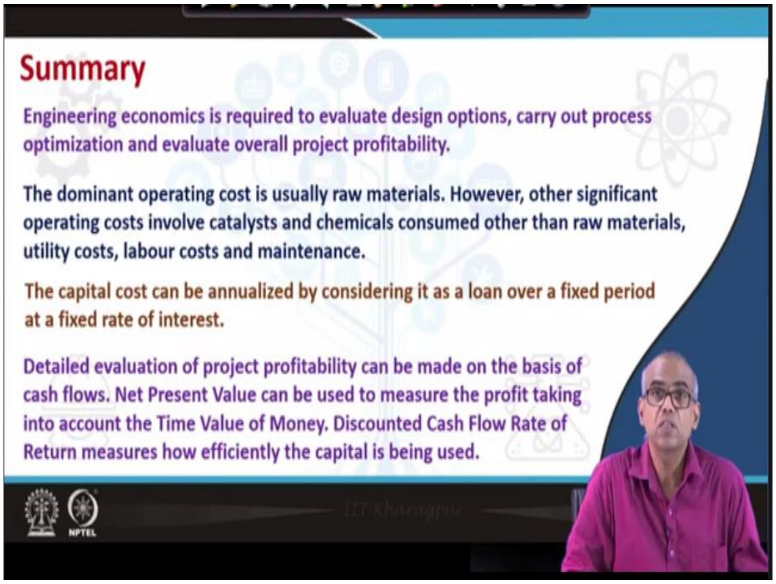


To conclude let me summarize engineering economics is required to evaluate design options, carry out process optimization and evaluate overall projects profitability. The dominant operating cost is usually raw materials. However, other significant operating costs involve catalysts and chemicals consumed other than raw materials, utility cost, labour cost and maintenance. The capital cost can be annualized by considering it as a loan over a fixed period at a fixed rate of interest.

Detailed evaluation of project profitability can be made on the basis of cash flows. Net present value can be used to measure the profit taking into account the time value of money. Discounted cash flow rate of return measures how efficiently the capital is being used.

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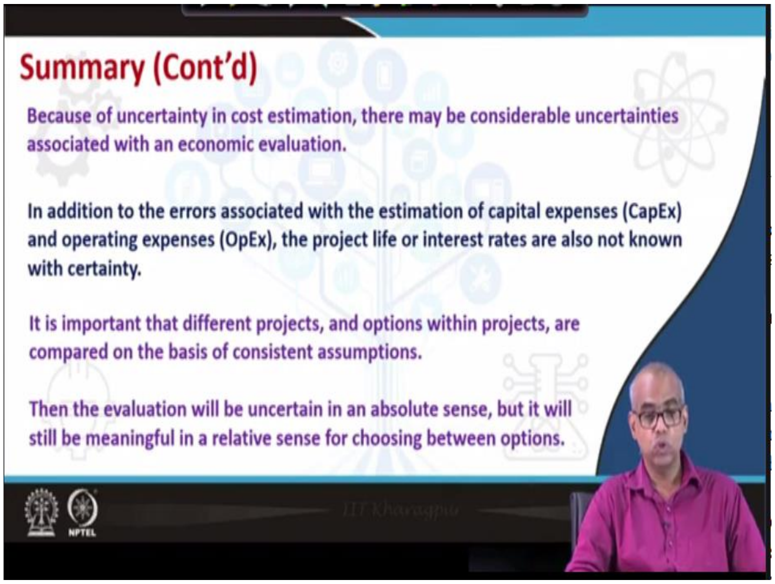


Because of uncertainty in cost estimation, there may be considerable uncertainties associated with an economic evaluation. In addition to the errors associated with the estimation of capital expenses also known as CapEx and operating expenses known as OpEx, the project life of interest rates are also known with less certainty that means it is not only there is uncertainty in the various factors.

There is uncertainty also in the project life and interest rate. It is important that different projects and options within projects are compared on the basis of consistent assumptions. Then what will happen is the evolution will be uncertain in an absolute sense, but it will still be meaningful in a relative sense for choosing possible alternatives when you have various options. So with this we conclude our discussion on engineering economics part 3.