Principles of Engineering System Design

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Lecture - 29
Decision Making in System Design

Dear friends, welcome back to one more lecture on Systems Engineering. Today we will discuss about the decision making process in system design. We need to make many decisions about the various processes involved in the design. We need to make decision at various stages about the next level of the design, or we need to make we have to get something outsourced from other sources or we need to make manufactures some of the products, or will get it readymade products, or making some decisions about logical decisions or some decisions on the logistics of the project. So, like that there are various decisions to be made during the system design.

We will try to see some of the methods which can be employed in order to make some decisions, where we apply a the principles as well as use the existing knowledge and the current database available and based on this we make some decisions. Most of the times decisions are made under a lot of uncertainty, we may be knowing some of the facts and but we may be having a lot of uncertainties, that may be lot of information lacking in the decision making process, or due to lack of information the decision may not be full proof or there may be some mistakes coming in the decisions. So, how do we actually reduce these problems and how do we actually make a good decision based on the available data; so that is the question under the decision making under uncertainty or we are going to discuss today.

We discussed about the Columbia disaster and then mentioned that mainly it was an issue of decision made by the top level management, to continue with the mission even when they were aware of a small problem with the vehicle; the space vehicle which was launched for the mission, while during takeoff itself had some problems and lot of finances was carried out and then the decision was made to continue with the mission.

Let us have a relook at this decision and then see how this could have been avoided or what are the possibilities or what are the decision tools we can use in such situations.

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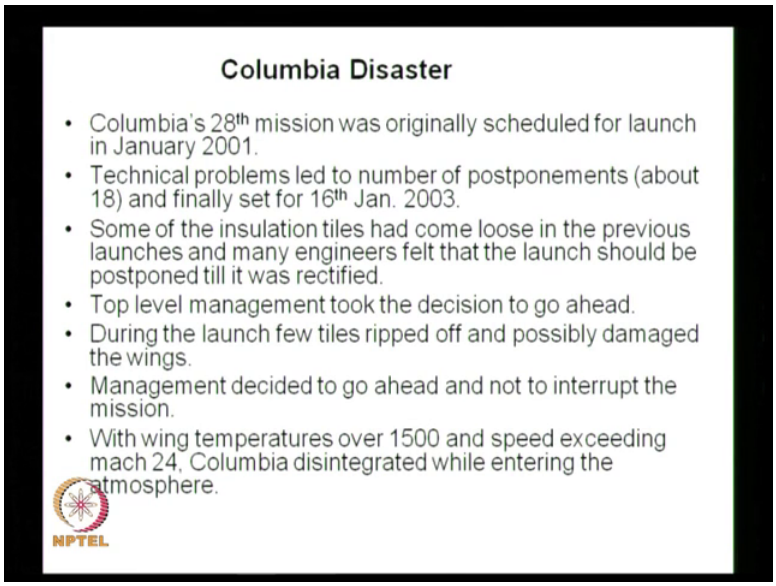

Let us have a relook at this Columbia disaster, as mentioned this was the 28th which was originally scheduled for launch in January 2001, but the technical problems led to an number of postponements about 18 and finally, the mission was set for 16 January 2003. So, there were so many delays and so many problems. And finally, after 2 years of delay it was set for 16 January 2003. So, some of the insulation tiles had come loose in the previous launches and many engineers felt that the launch should be postponed till it was rectified.

So, this was a non problem there were some problem with the tiles and during the previous mission some of the tiles had fallen and then many people felt that there should be a further postponement of the mission because unless we rectify this problem it is not safe to have the mission or to continue with the mission, but then there were so many delays and then the management was not in favor of one more delay. And therefore, they wanted to take a risk or they wanted to analyze the risk involved in this and then take a decision.

So, the top level management took the decision to go ahead, considering various reasons, but then during the launch few tiles ripped off and possibly damaged the wings. So, again initially there were some damages, but then during the take off few more tiles actually ripped off from the surface and then actually they probably hit the wings of the vehicle.

And then again management decided to go ahead and not to interrupt the mission. So, they realize that there is a problem some tiles have come out and it has actually hit the wings. They are conducted many trials many simulation studies on ground and tried to find out what will be the impact of losing this tiles. And they actually took a decision based on to enhances they took a decision to continue with the mission saying that it may not affect the performance of the vehicle. While the returning to the earth and while (Refer Time: 04:35) the atmosphere actually because of the high temperature over 1500 degrees and speed exceeding 24, Columbia disintegrated while entering the atmosphere.

So, that was what actually happened and the whole Columbia vehicle was lost and for the astronauts was killed in this accident. So, here you can see that there was a very critical decision making processing involved, and considering all the facts available with the team they took a decision. So, decision making is always a process where we look at the facts and figures available at present and always assume that the probability of the incidents or the events going to happen have I mean some values for this probability and then take a decision.

This may be correct or it may be wrong that actually depends on various other scenarios, but the team has to take a decision, when there need to take a decision they have to rely on the existing data and then take a decision. So, that is the decision making under lot of uncertainties.

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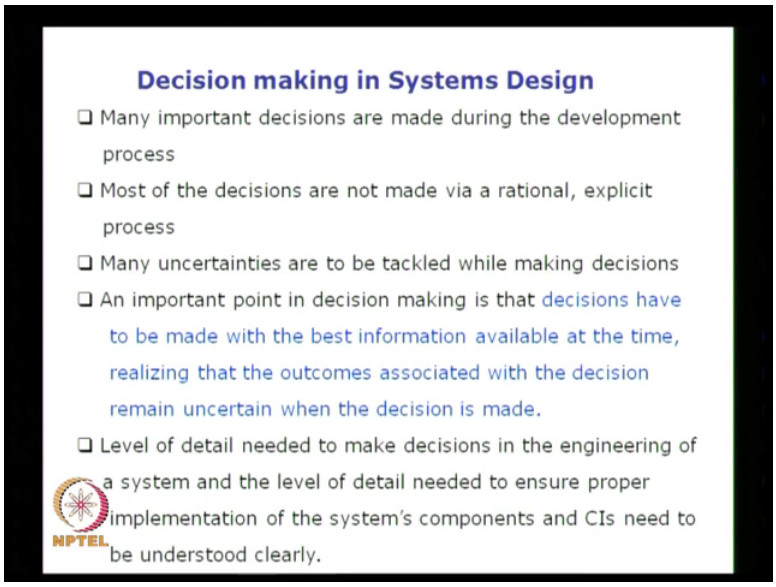

So, in system design also we need to make lot of decision like this, it is not only during the mission, but while decision taking is a continuous process in the engineering system design process, because at various stages we may have to take decision about the structure, strength requirement, or the forces appearing or the decision to make a product or to outsource a particular service. So, all those are decision to be a taken by the design engineers.

So, in this decision making so we need to make a lot of important decisions and then most of the decisions are not made rational or explicit process. So, you can see that not always you can have a rational or an explicit process for decision making. There are many other situation where you cannot have a rational decision to be made because the available data may not be sufficient, or there will be lot of other factors which cannot be considered at that stage. So, many uncertainties are to be tackled while making decisions, and important point in decision making is that decisions have to be made with the best information available at that time, realizing that the outcomes associated with the decision is remain uncertain when the decision is made.

So, that is one of the most important point, decisions have to be made with the best information available at the time, realizing that the outcomes associated with the decision remain uncertain when the decision is made. So, we have to rely on the information available at that time and then the outcomes associated with the decision remain uncertain till when we are making the decisions. So, this is the one important point which we need to be aware of that you have to rely on that information as well as the outcome is uncertain

Level of detail needed to make a decision in the engineering of a system and the level of detail needed to ensure proper implementation of the system components and c I need to be understood clearly. So, in order to make a decision we need to understand all the level of details we may have to understand the many factors involved in that particular decision. So, we need to look at the details of this system level and component level details and understood them clearly. So, that whatever the decisions we are making is based on those information what is available at that time.

So, here when we make the decision, we need to be aware of these facts that there are lot of uncertainties and there are lot of information to be collected and there are lot of information which is not available also. So, based on this we need to make a decision.

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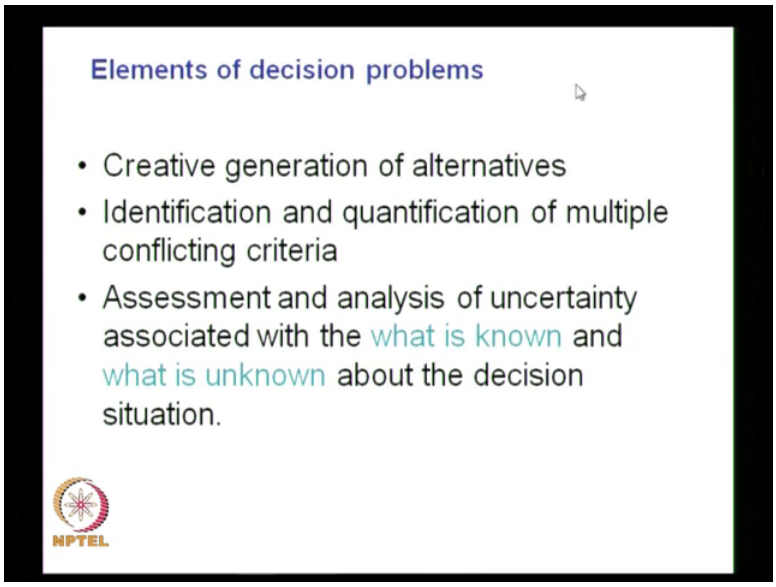

And in the main elements of the decision problem are the creative generation of alternatives. So, whenever we need to make a decision we need to look at all the alternatives possible. We should not rely on one or two alternatives we have to look at what are the all possibilities existing, and then identification and quantification of multiple conflicting criteria and you will be having a lot of conflicting criteria. So, we need to identify them and quantify them, we need to look at the criteria and as well as quantify the risks involved those particular events as well as the probability of those events. So, the identification and quantification becomes important. Then assessment and analysis of uncertainty associated with what is known and what is unknown about the decision situation.

So, again as I mentioned there are many things known and there are many things unknown; so we need to look at these factors and unless the uncertainty associated with the known and unknown factors. We look at those known factors and unknown factors and identify the uncertainties involved and then make a decision. So, here will use many statistical techniques as well as logical techniques to find out the uncertainties and then quantify them. So, that will get some kind of quantitative information to make a

decision; so in the getting the alternatives. So, I mentioned about there are many alternatives to be considered.

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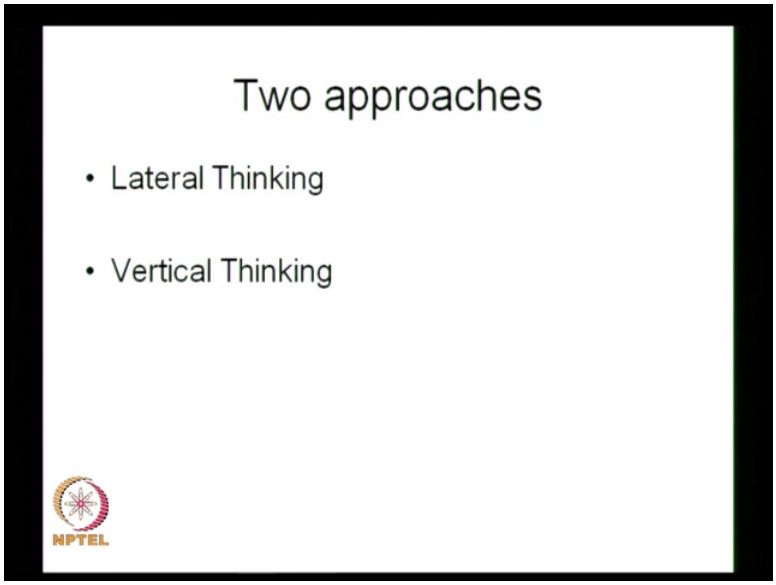

So, in getting the alternatives there are two approaches, basically one is known as lateral thinking, the other one is a vertical thinking. I will explain these two methods, basically the lateral thinking starts with a basic problem or a single problem it begins with a single problem that is the lateral thinking.

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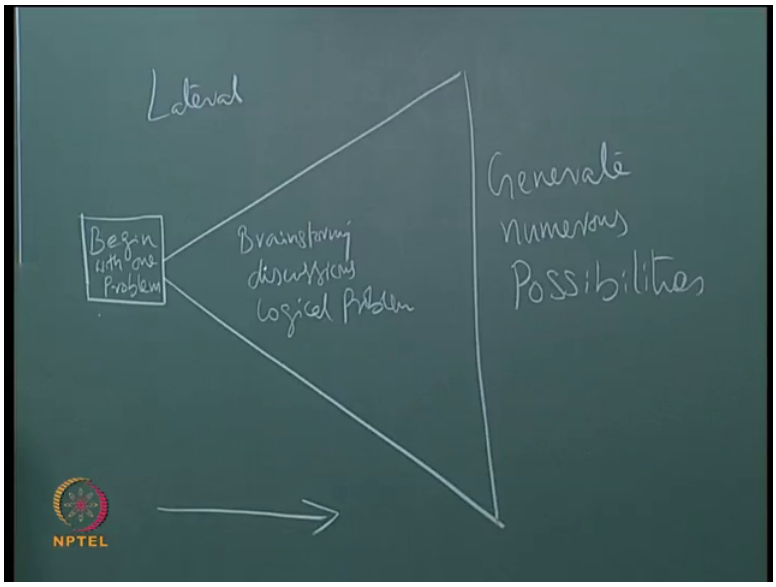

Begin with one problem, and then look for alternatives through various concept generation or ideal generation techniques and then develop many alternatives over here. So, here we generate numerous possibilities. So, we start with the single problem and generate numerous possibilities for a period of time. So, we will start with a single problem and we use many methods like brain storming, discussions, discussion within the team or with the experts, or we can use some other method like, different brain storming techniques like 6 3 5 method or (Refer Time: 11:06) logical solving problems logical problems solving methods.

So, we can actually use many methods to get numerous possibilities. So, this is the lateral thinking process where, we generate many ideas or many alternatives for a particular problem. So, when we have to make a decision, we look for all the alternatives, generate all the alternatives and then try to select one among this possibilities based on some other methods. That is you need to quantify those possibilities or the uncertainties and then select one solution for that particular problem.

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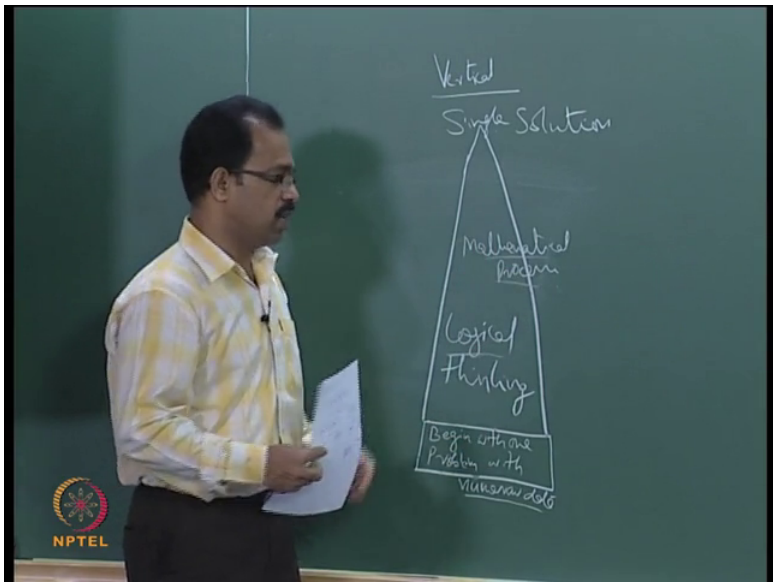

The other one is known as the vertical thinking; in vertical thinking begin with one problem with numerous data, with lot of information with numerous data. So, we start with one problem and with lot of data. So, we have lot of data available for that particular problem, and we need to narrow down to a single solution. So, we start with like this. So, this is the vertical thinking we have one problem, but lot of intermission or

lot of alternatives available and then we go for logical thinking over here, and then try to get a single solution or we can use the mathematical modeling and processes techniques, and get a single solution.

So, here it is more like a rational approach in this case, we are having one problem with lot of information or lot of alternatives, lot of possibilities and then we go for the logical thinking and mathematical modeling or processing to get in to a single solution. So, that is the vertical thinking or approach for getting the solution. So, we have can actually the decision making problems can be approached both the ways can go for a lateral thinking or for a vertical thinking both will actually give you a solution.

But the approach will be different we start with the single problem and then try to generate lot of alternatives and then choose one solutions. In vertical method we actually start with one problem with of data and then we try to narrow down to a single solution based on this information available. So, here we can use logical thinking methods as well as mathematical processes to do this.

So, these are the two approaches and another method the decision making by search process. So, search process is look at the alternatives available. So, we have some problem and you want to take a decision about that for example, if a company finds that their products are not selling in the market or their profit is falling. So, what will be the decision where then it to reduce the price or increase the marketing strategy or what other things to be done. So, in this case we can actually go for a search process and try to find out the solution say actually it starts with the problem.

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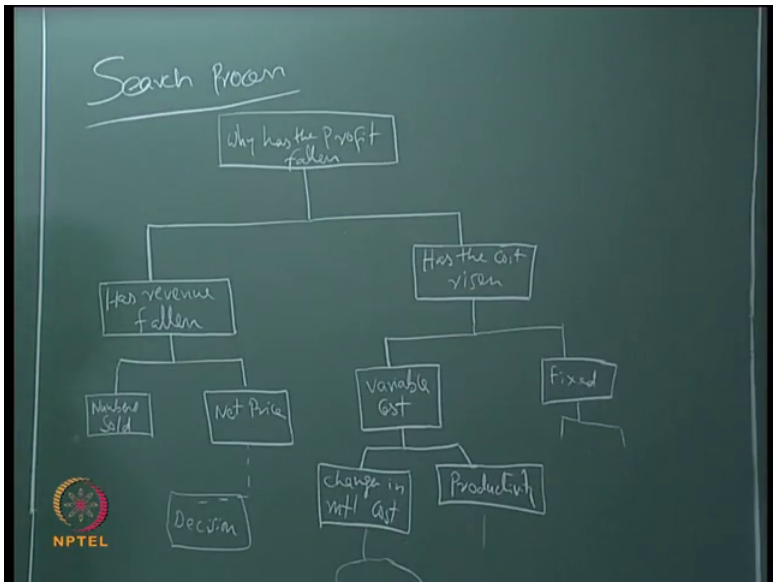

So, for example, if you take the profit the company has making lot of losses, actually the company can start thinking what could be the decision whether to reduce the price or to reduce the manufacturing cost or to increase the marketing. So, what is the decision to be made in this case? So, the problem is basically why has the profit fallen, there is a problem the company has to answer and then the other possibilities are here we actually start whether the cost tree has gone up, has the cost increased or the revenue of the sales decreased.

This is the cost of production or manufacturing sales that is increased or the revenue has fallen, revenue from the sales. And the company is making losses then this could be two possibilities. So, they need to analyze what is the real issue here. And again can actually look at the possibilities. So, this the numbers sold whether total sales has gone down, numbers sold that the cost number of products being sold is reduced over the cost. The net price has changed. And then we take a decision whether (Refer Time: 16:30) should be the possible option.

So, the decision has to be taken based on this analysis this is a search process they will try to search for the solution over here to make a decision and here again you can have multiple options. So, whether the cost if the cost is change then whether it is the fixed cost or the variable cost. So, here also there may be some issues, we can actually identify you can search further if the fixed cost is changed we can search further or the variable

cost is changed we can look at what is actually making it whether the productivity has changed reduced. So, the productivity of the plant or the people whether reduced or the changes in the cost changes in material cost or other cost variable cost involved that has changed, and again based on this we need to make a decision. Whether what is the decision to be made if this is the situation what should be the decision and if this is the situation what is the decision.

So, this is the basic search process. So, you search for the solution or the decision through a process of looking at various steps involved and such through this steps and then try to find out what is the actual problem and what is the solution we can achieve. So, that is one way of making the decision. So, this is known as the search process of making decisions.

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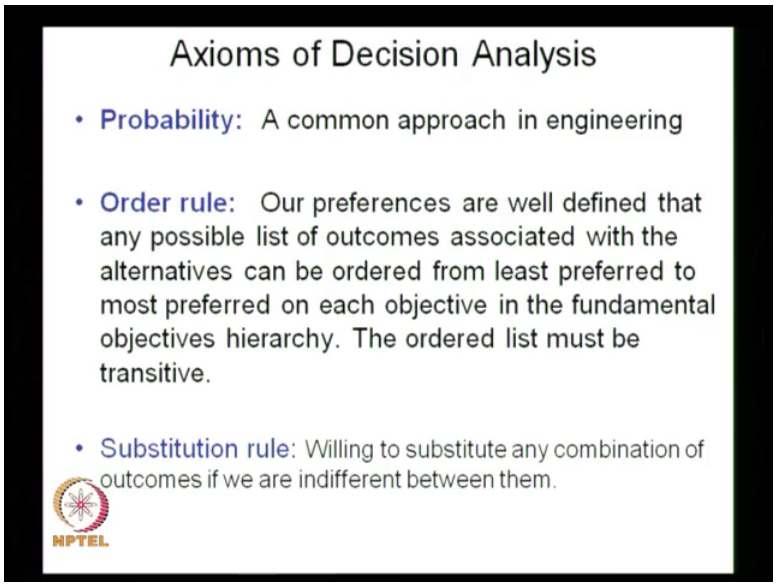

And then coming to the decision analysis, there are various axioms such you can see here the various axioms used in decision analysis, one of the most important axiom is the probability. As we know there are lot of uncertainties. So, we need to use the probability methods to find out or to quantify the decisions or quantify those situations. So, that is a common approach in engineering used for analysis. The other one is known as order rule order rule states that our preferences are well defined that any possible list of outcomes associated with the alternatives can be ordered from least preferred to most preferred on each objective in the fundamental objectives hierarchy.

So, we assume that there is a particular order in which we can always put them and then take a decision based on that. So, it is actually it is not that we have everything as equal. So, we always put that they can be arranged in a particular order. So, that we can choose from this order least preferred or the most preferred based on the objective hierarchy. The third one is the substitution rule we are willing to substitute any combination of outcomes, if we are indifferent between them. So, if we have we are indifferent between two decisions then we are willing to take any one of this. So, that is the substitution rule. So, this are the three axioms we normally use in decision analysis the probability order rule and substitution rule.

We need to learn little bit of probability fundamentals in order to understand how we use the probability theory and the probability associated with various events in the decision making analysis. So, I will just give you a brief idea about what are the different probabilities we normally encounter or what are the basics of probability analysis. So, of course this is not detailed analysis on probability, but just to make you understand that some of the terms what we are using during the analysis are familiar to you. So, most of you may be aware of some of this fundamentals.

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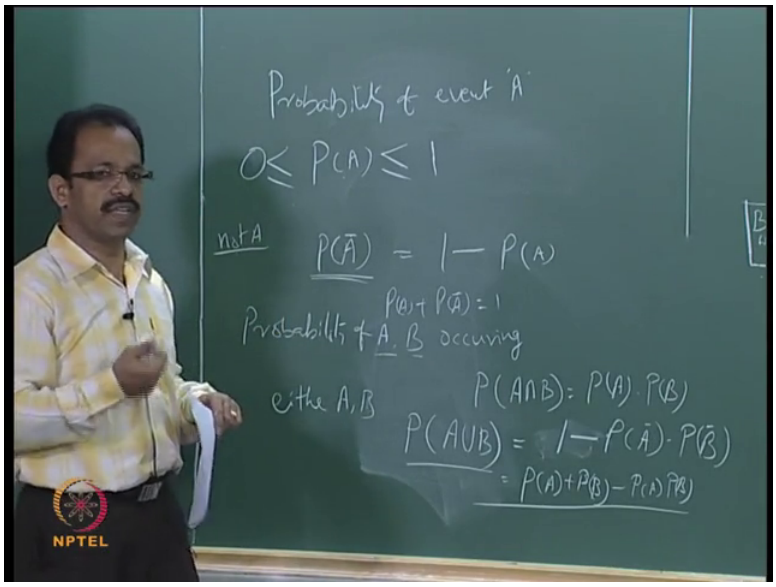

So, normally when we say probability of any event A, event A occurring is given as P of A, and that is always greater than or equal to 0 or less than or equal to 1; so 0 less than or equal to probability of A less than or equal to 1. So, that is the probability of an event a

happening and then we have another probability where the probability of event not happening. So, not A, so if the probability is will is not happening then we put it as probability of A or the a compliment. So, this is the probability of A compliment, that P A is not happening normally equal to 1 minus P A, that is P A is not happening the probability of A not happening, is 1 minus probability of A. And always this will be P A plus probability of A plus probability of A compliment will be 1 because, we can see this can be if we add this will be getting 1. So, a probability of a happening and not happening total probability will be always 1

And then we have few other things like probability of A and B, probability of event A B occurring both the events occurring, that is given as probability of A intersection B, which is given as probability of A multiplied by probability of B. So, here if the two events are happening simultaneously or same time then we get probability of A intersection B is equal to probability of A multiplied by probability of B. Similarly probability of either of this A or B, either A or B happening is given as probability of A union B. So, that is given as P of A compliment multiplied by P of B compliment, that is P of A union B either A or B happening is given by 1 minus P A minus P A multiplied by P B and if you can simplify you will be getting it as this is equal to P A plus P B, it is probability of A plus probability of B minus P A P B. There is either of A or B happening.

So, in many cases in decision making we will have to use the probabilities associated with various events and try to see what will be the total probability of this events three events happening together or any one of this happening. So, those things we need to analyze quantitatively using the probability theory.

And there is another term associated with this analysis.

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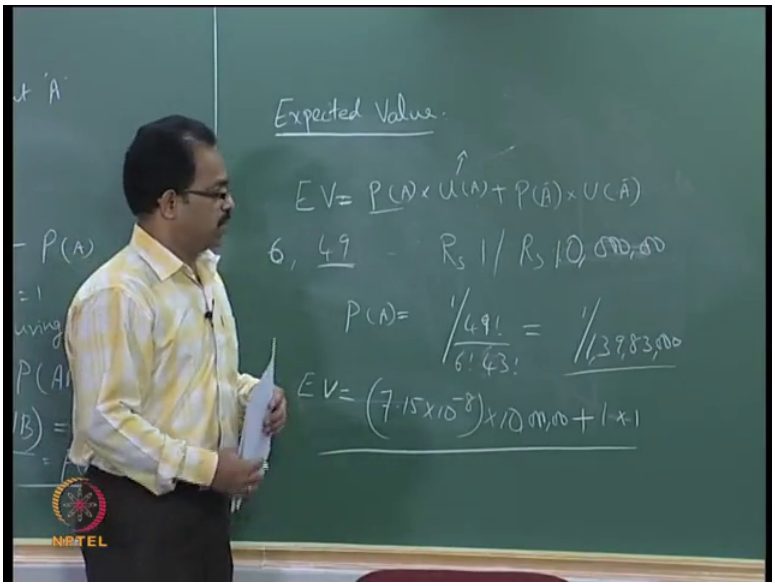

So, this is known as expected value, expected value of an event, again we know that there may be many events happening and we can actually identify the probability of this events, but then what will be the outcome of this events some events will be having a preference and some events will not be having that much preference. So, how do we actually calculate the expected value of this events.

That can actually be done by this term expected value is equal to probability of A, that is the events happening A probability of the event happening multiplied by the utility of this event A, plus probability of A not happening multiplied by the utility of A not happening. That is given as the expected value that is if we have an event A which has got a probability of P A, and it has got a utility of U, then the expected value is given as P A multiplied by U A plus P A compliment multiplied by U A compliment that is it is not happening what is the utility and if it is happening is a utility and you multiply the probability with the utility and add them then you will be getting the expected value of that particular event. We can explain this with an example for a lottery, if you consider the lottery there is an example, we have many lotteries and there are lots of other involved in this kind of lotteries.

So, if you want to find out the expected value of a lottery, we can actually use this principle of P A multiplied by U A plus P A P A compliment multiplied by U A compliment, now consider a lottery where you have a 6 digit lottery here to select from

49 digits and set a rupees 1 for each lottery cost 1 rupee for you to buy and the expected amount will be assume that it is 10 lakh.

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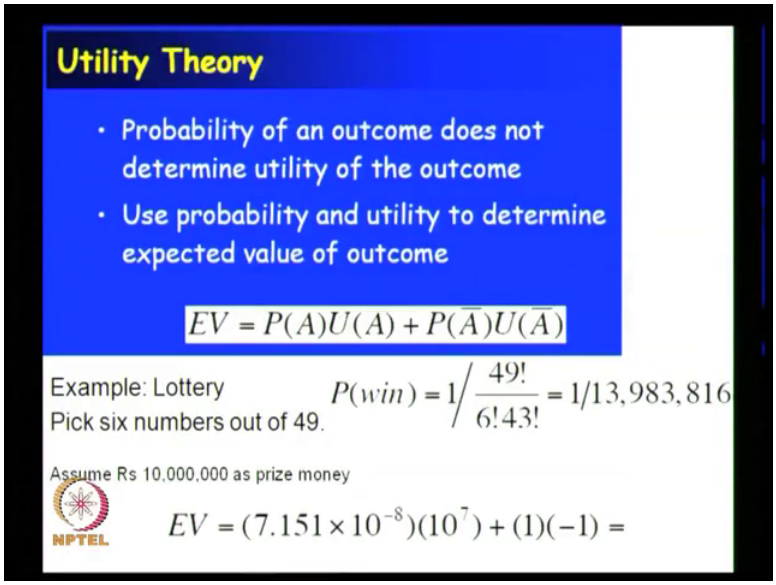

So, you can consider the lotteries 10 lakh rupees the outcome. So, you should pay 1 rupees you can get maximum of 10 lakhs, and this actually a 6 digit. So, if all the 6 digits are matching, there are actually 49 possibilities. So, you take 6 digits from and then we will get 10 lakhs. So, what is the expected value of this lottery whenever we talk to a person about lottery he will always tell there is a 50 percent possibility, he can get or he cannot get the lottery? So, he always thinks the probabilities only. 5, but actually the expected value of the lottery is much low compared to the expectation or understanding.

So, here you can see that probability of the win a. So, will given as 1 factorial, 1 over 49 factorial divided by 6 factorial multiplied by 43. So, this is the possibilities. So, you have 49 factorial divided by 6 factorial multiplied by 6 43 factorial because of 6 digits and then remains 43 totally we have 49, and this is given as almost like, 1 over 1398300, 1 over 139800 is the probability of A win. So, we can see that the probability is so small for getting a lottery, it is not. 5 as pursued by those who are actually going behind lotteries.

Now if you look at the expected value the expected value is that you have a probability of this multiplied by the utility of winning, the utility of winning is around 1000000. So, that is the utility and utility of not winning is rupees 1, you are losing 1 rupee, but this is

probability of not winning this 1. So, now, if you take the utility value we will see that the utility value is 7.15 multiply 10 to the power of minus 8 multiplied by 1000000 plus the probability of not happening that is 1 minus this value. So, this will be almost 1 we just write as 1 multiplied by 1. So, this is the expected value of this particular lottery we can see this would be very small or the expected value of this lottery will be too small for you to find to at any particular benefit from this.

If you multiply this you will see that the value is very small. So, the expected value of any lottery is very small, compared to what actually we are thinking that it will be providing. So, based on this kind of principle, we can actually find out the expected value and this kind of analysis will be very useful in analyzing the expected value of various functions or various options.

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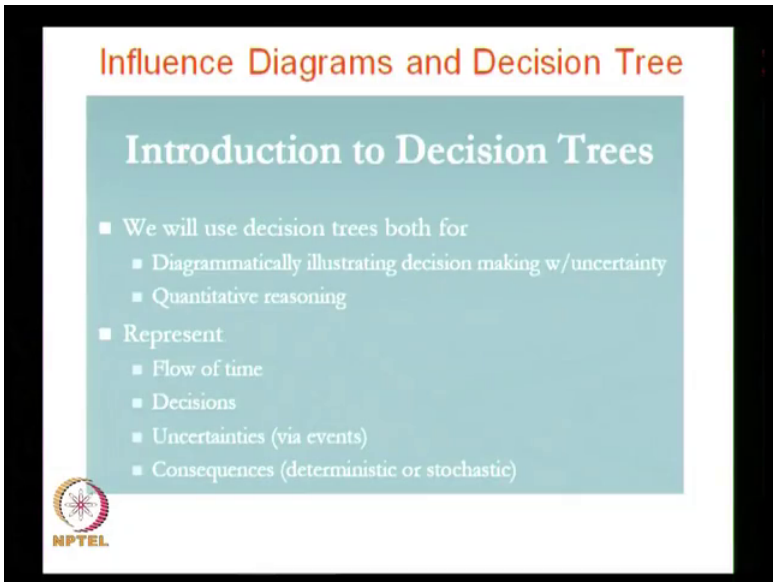

So, that is how we use this one for analyzing the decision making process and quantifying the various options available for the decision makers; in to do this decision making we normally use various kinds of tools. So, one of the tools is influence diagram and the other one is the decision tree. We will discuss about the decision tree first and then I will take an example and then shoe how decision tree can be used for making some decision using the principle of probability and expected value.

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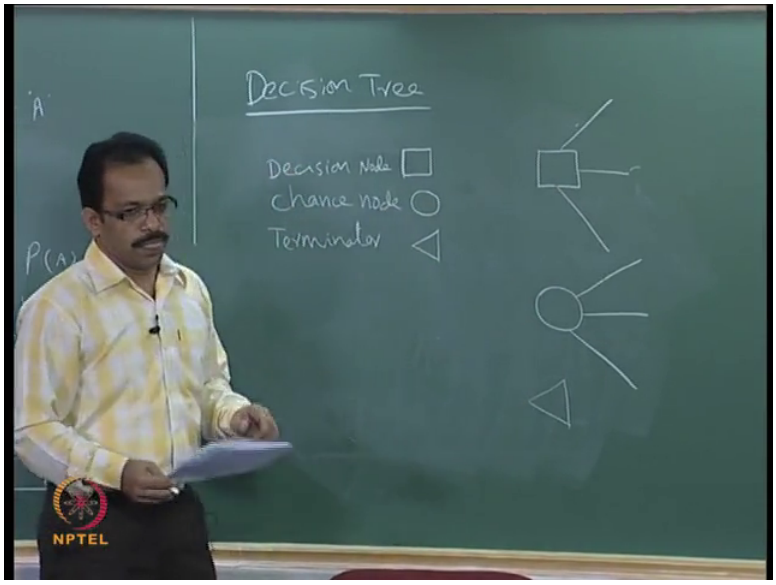

In decision making what we do is, we let us discuss about the decision tree first, in decision tree we use three kinds of nodes. So, first one is known as a decision nodes, so basically it is a diagrammatic representation of the decision process that is why it is known as decision tree. So, we have a decision node which is represented by a rectangle or a square that is the decision node.

Then we have the chance node is represented by a circle and then we have the terminator or the final decision, where that particular tree branch comes to an end that is known as the terminator. So, this are the three nodes used in the decision trees. So, here it we have a decision node suppose we have to make decisions various decision thought this may be decision one decision two or the probability of decision.

So, you have to make a decision this or this, when you want to buy the product or one to manufacture the product. So, that those are the decision you want to make. So, this actually shows a decision node and then we have many choices. So, when you come to one particular stage will have the choices of various options you can go for a low cost product or you can at a high cost product or a medium cost product when you want to buy the products. So, we have many choices over there. So, the choices are shown by this choice node and the terminator the final decision is shown as like this, these are the nodes by which we can actually develop the decision tree. So, decision tree will start with decision nodes and there may be more than one node in particular in a tree; so here behind decision nodes choice nodes and terminators. I will show you an example how to create a decision tree for a particular event.

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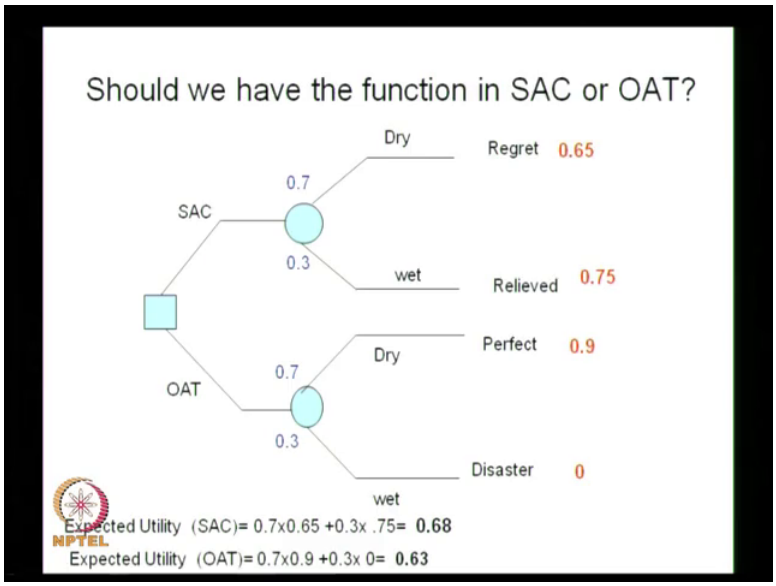

So, let us take an example where we want to conduct a function in an institute like IIT we want to have a function which actually preferred to be conducted in a open air theatre that actually the utility of that event is very high.

But then there is a possibility of rain. So, if you have a function in the air open air theatre and if it rains then the whole thing will be failure and the expected utility will be 0 for that one, but then if you have the function in the auditorium then actually the utility of that function is reducing because it is perfect to have it in the open air theatre, but because of the rain we need to move it to the indoor stadium or the indoor facilities. So, how do we make a decision and how do we calculate the expected utility of these two and then make a decision what will be the probability of rain and what will be the utility of these events and based on that we need to make a decisions.

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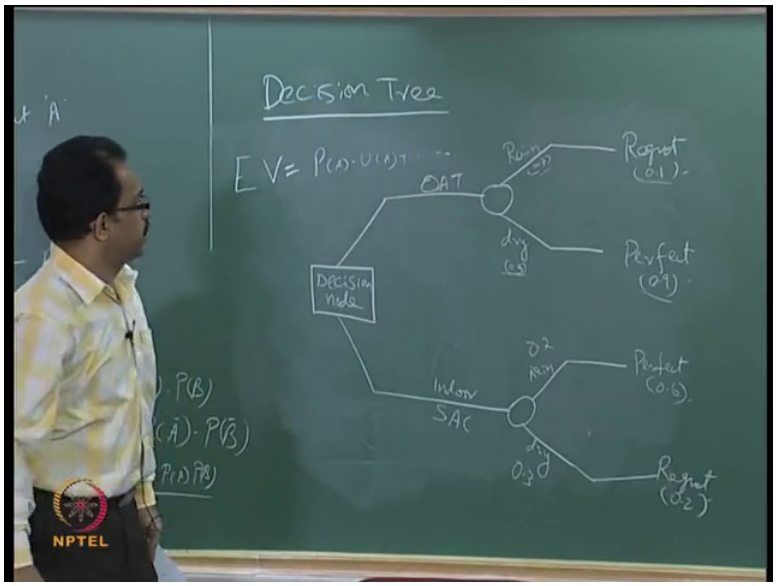

So, this kind of decision process can be represented using a decision tree. We will see how to use the decision tree to represent this kind of decision making process. So, we can see here the nodes the decision node shows the this is the decision nodes and we have two decisions whether to have it in open air theatre or the indoor facility, student activity center or indoor facility and there are two chances, here the chances are basically there could be a rain or no rain.

So, chances are rain or dry weather. So, this are the two chances similarly here also when we have it in here actually we have a both chances of rain or a dry weather now based on this how do we actually make a decision; so if you take the decision here and what is the utility of this functions or this particular branch. So, this is one branch where the function is O A T other one is in the indoor stadium. So, if it rains basically when you have this function in O A T and it rains of course, the utility with basically a regret for the decision because you will be regretting for arranging the function in the O A T if it rains.

And if it is dry you will be very happy and it will be the perfect choice, and similarly here if it is in indoor and if it rains we will actually feel this perfect to have it there, and if it is sac and dry you will be having some regrets that you could have done it there. So, this will be a O A T rain a regret, and this will be again a regret that you could have done the program in sac sorry which is a dry weather you will feel that you could have done it O A T because it will be that would have been the perfect one. Now this is the way how

actually we create the decision tree and then analysis the utility of these decisions. So, here for the probability we can actually give a probability value here also we can give a probability value suppose you have a probability of. 7 for rain and there is a probability of 3 for the dry climate. So, the same will be applicable here also. 7 and. 3, then again you can give a utility value for this one. So, regrets may be disaster here if it is in open air theatre and if it rains it will be a disaster.

So, we can actually give the value as. 1 that is the very low utility and this will be the. 9 where you have the best performance and this will be perfect of course, but it will be not as good as this one, but then here it will be regret will be. 2 it will not be as regretted as this one. So, like this we can have them utility values and then find out which one will be the best option or best decision which we can do here; so whether to do it in O A T or indoor stadium can be analyze decision can be made on this.

Of course these values will change. So, this value is actually depends on the particular situation as well as the perception of the designer or the person who makes the decision. So, the values to be given it will depends on the that decision maker, but whatever may be this values the principle actually remains same the expected value the expected value of the decision can be calculated by taking the probability of A multiplied by the utility of A plus not happening that particular event. So, this probability of A not happening and the utility of A not happening, that is the compliment that way we can actually calculate the values. So, here I have assigned some values different from what I have shown in the board you can see here the regret value is given as. 65 for the dry weather and it is given as. 75 for the relieved condition and then perfect is. 9 and disaster is 0.

Now if you want to calculate the expected value you will see that the expected utility of sac will be. 68 and the expected utility of O A T that open air theatre will be. 63. So, it shows that the best decision is to go for the indoor or the student activity center to do the function, because the probability of rain is very high in this case the utility of that particular decision to go for O A T will be very low because the expected value will be low mainly because the regret decision because the probability is given as 0 for that one this case. So, you will be finding that it is better to go for the sac instead of O A T.

So, this is the way how we are actually use the decision trees to make decisions. I will show you one more example where actually a company wants to make a decision on whether to buy a particular component or to build it or manufacture it by themselves.

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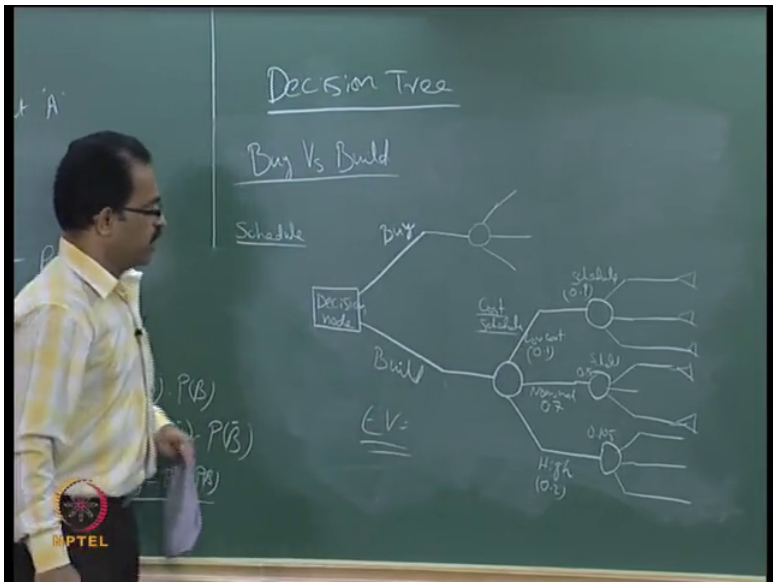

So, here it is a buy verses build. So, what is the decision to be made of course I will not to be calculating the expected value of this I will leave this to you as an exercise to assign some values and then calculate the expected value of each decision. So, here we have a decision nodes, and we have two decisions one is to buy and the other one is to build. So, you have a buy decision and build decision these are the two nodes which can either and now of course.

So, we can actually have different options for buy we can have many chances over here that you go for low cost manufacturer or you go for highly reputed manufacturer and then buy the product or we can build yourself. So, you can actually build a low cost product again we can have choices of making the products. So, you can go for a low cost one, or you can go for a nominal one, or you can go for a high cost one. So, basically when we try to build the main issue is were about the schedule. So, whether you can meet the schedule or not, of course when you are going to buy then actually you can meet the schedule provided you actually buy from somebody who can actually meet your schedule, but when you are manufacturing or building it then the schedule becomes important.

So, we have to have a balance between the cost of manufacture, cost and schedule. So, there is a probability of scheduled delay and probability of the costing increasing. So, you need to find out the cost and schedule and then find out the utility if that particular decision. So, here you can actually take that you go for a low cost one, low cost with a probability of. 1 and we can go for a nominal one or you can go for a high cost, if it is on probability. So, we have this 7 and 2 as the values here. And then you have a choice here, again you have a choices various choices are there you can actually go for different schedules fast schedule.

So, the schedule here the schedule will be if you go for this particular low cost option then schedule uncertainty in schedule will be. 9. So, this is the uncertainty in schedule that is the schedule delay probability of schedule delay will be. 9, and here the schedule delay will be will be. 5 then you go for a nominal one and if you go for a high cost one high cost manufacturing probably the delay will be less. So, this may be point. 105, again you can have various choices over here.

And then finally, take a decision which may be the terminator here it is own. So, here you can see the choices are there low cost one and nominal one or high cost with it is own probability on the cost and then you have the schedule getting affected because of this. So, this is basically the utility of going for this and this is the risk involved in the particular decision. So, we have the 9 risk in schedule there is low cost one, have. 5 risk in nominal one, and. 105 high risk high cost one. So, this is how we actually can create the decision trees and then analyzes the expected value of each decision and once you have this expected values we can find out the actual utility of that particular decision and based on that we can take the decision.

So, these are some of the methods by which we can actually make the decisions. I can show you one more example where actually a company wants to make a decision whether to go for an automated plant or for a conventional plant based on so many criteria about the cost of building the plant as well as the forecast for the sales for the next 10 years. So, how do we actually use a decision tree to model this particular decision process and then how do we find out the expected value of those decisions and then make a decision from that one.

So, this we will see in the next class, along with some other methods that also we will see in the next class. Till we meet goodbye to all of you.