Industrial Safety Engineering
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Lecture - 16
Fault Tree Analysis : Importance Measures

Hello, welcome we will continue Fault Tree Analysis> Today our discussion point is Importance Measures.

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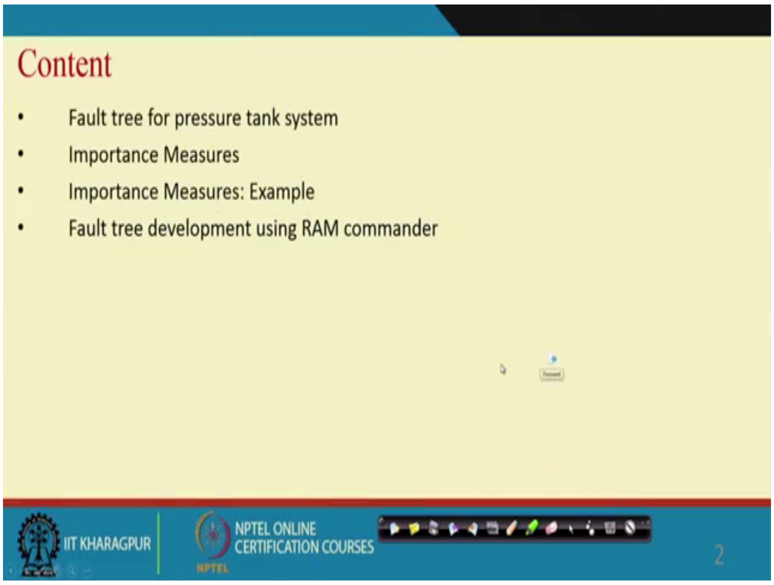

So, what I will do, I will start with a example; that example is our so, this pressure tank system and we will develop the fault tree for this system already we have seen it and then with reference to fault the pressure tank system there are different basic events. So, what is the contribution of the basic events in realising the top event for a fault tree? So, by importance measures we want to say that; given a fault tree given a fault tree there are there definitely there will definitely be definitely be several basic events. And you can develop several; several cut set also by cut set we mean that is a set of the basic events which if occur the top event will occur.

Now, let us know that; the top event the contribution of basic events to top events means if there are suppose K number of basic events K number of basic events. So, you may be interested to know which of these basic events is having the maximum contribution in realising the top event or which of the cut sets having the maximum contribution in realising the basic events. So this is basically talks about the importance.

So, what will happen if we know the importance? We will take necessary care and it also gives us the opportunity to rank the basic events in terms of occurrence of the top event. And then you will take necessary action according to the rank of their contribution. So, that mean the one which is contributing the maximum for the top event to occur you put barriers so that that failure will not take place.

So, the importance measures as such the fault tree development also it is manually intractable what do I mean that manually combustion. So, when you have a system which is sufficiently large enough and you must rely on some software for developing the fault tree. So, RAM commander is say once a software which basically helps in developing fault tree, and analysing the fault tree in terms of finding out the top event probability given the bottom event probability finding out the your importance measure finding out cut sets. So that RAM commander can be used.

So, we will we will show you that with the with reference to this pressure tank system so that the result obtained using fault tree. Result obtained using fault tree and through RAM commander. So, by saying this we are not saying that the RAM commander is the solution to fault tree analysis only, because there are many software's available which can be used, but we have RAM commander we have used this one.

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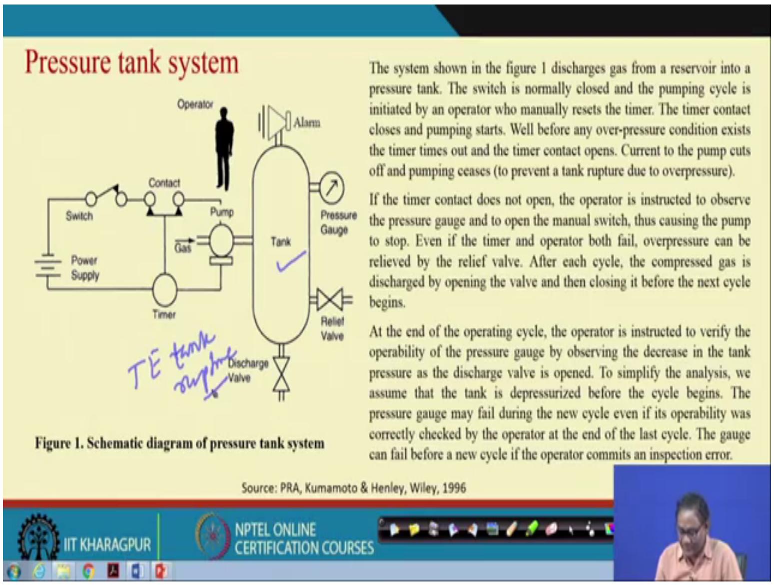

So, let us see one after another so this I should not discuss further because, I have discussed it several times that this is our example. And I also say to you all that we have taken this example from the book written by Kumamoto and Henley probabilistic risk assessment for engineer and scientists. So, if you purchased this book or if you have access to this book; then definitely what will happen the many of the tools and techniques; and the concept what I am teaching to you will revisit all those things through in the book and ultimately your understanding will be more clear, but I will try my level best to clarify the things.

And I hope that; if you go through some standard literature not necessarily the same book, but standard literature on it and then it will be beneficial to you. So, as you know that there is a tank and your pumping system. So, we want to suppose we are interested to know the fault tree analysis of the system where the top event top event is tank rupture ok.

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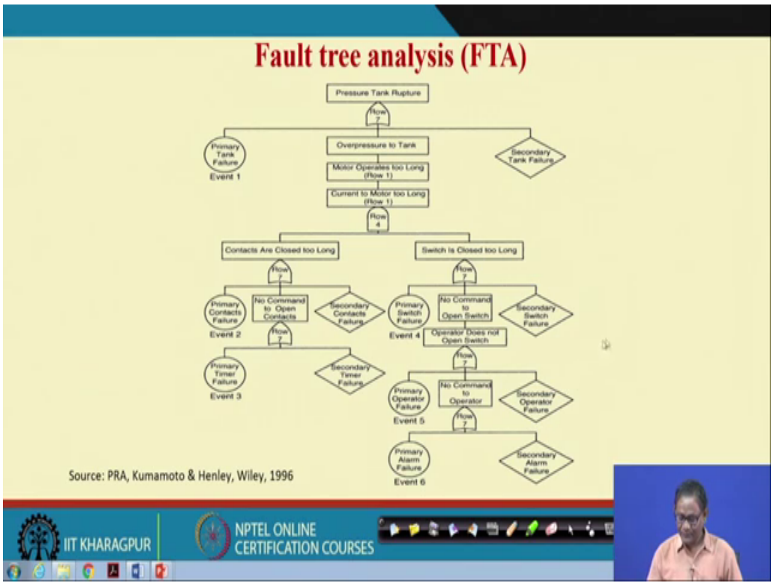

So, you see that is what we have developed here and I have taken these from this book it is already developed there. So, pressure tank rupture this is the system level mishap or accident you do not want this rupture to take place. So, as a result you want to know; what are the reasons of pressure tank rupture and what are the basic events that alone or in combination contributing to the pressure tank rupture?

So, first one is the pressure tank itself, this is the primary cause, so I have explained to you that P S C concept Primary Secondary and Common failure; means if the suppose there tank itself, because of usage over the year there can be wear tear and there can be corrosion and another issues. So, ultimately what will happen the tank itself may fail even within the desired pressure level, that is for which it is intended because, this is related to the tank itself.

Now, second one is that there is secondary tank failure, what I told you earlier that secondary failure tank failure means something which is basically that some excessive stress. And other things which are caused by may be neighbouring component and others, but whose actual region may not be further explore at this point it is underdeveloped event. So, essentially we will be interested to we will be going through by P and C that is primary and common failure.

Now, what are the common failure to this: so, as you have seen that the timer is say to a particular time and accordingly the pump will run for that time. So, if everything goes while what will happen that ultimately that the pump C just to work after the desired desired amount of gas fed into the tank and the pressure in the tank will be within the design intent, but it may not happen. So that means, it may so, happen that, that you care more because of many reasons that is what is basically command. So, if there is command failure then over pressure 2 tank will occur.

Why over pressure 2 tank will occur because, pump operates too long so why pump operates too long because current is too long. Now if current is too long why current is too long, because contact are close too long and switch is closed too long. So, when contacts are close too long that primary contacts failure then no command to open contact and then secondary failure. So, in using P S C concept, we have found out the final fault tree.

The fault tree what happen what are the basic event, basic event B 1 is primary tank failure, basic event B 2 is primary contact failure, basic event B 3 is primary timer failure, then event B 4 is primary switch failure, then event B 5 operator failure, B 6 alarm failure. So, as this I have discussed earlier also.

So, now if we ignore the secondary failures, because we are not in a position to know; what is the probability of these as well as these, as well as these, and these I am putting 0, because we do not know the thing. So, for the time being their probability will be definitely very small almost near about 0 then you ignore it. Otherwise if you think know that some of the secondary issues are there, then you have to you have to brainstorm within the team and then explore it further that is; what is the general procedure.

Now, my question here is that I have I have found that there are 6 number of basic events though so, though the basic set is now 6 B 1 B 2 B 3 B 4 B 5 and B 6. So, you may be interested to know that; which of these contributing maximum for the tank rupture or already we have seen the cut sets; how to compute the cut set? So, that means which cut set is contributing maximum to the top event to occur. Here we will concentrate on the basic events.

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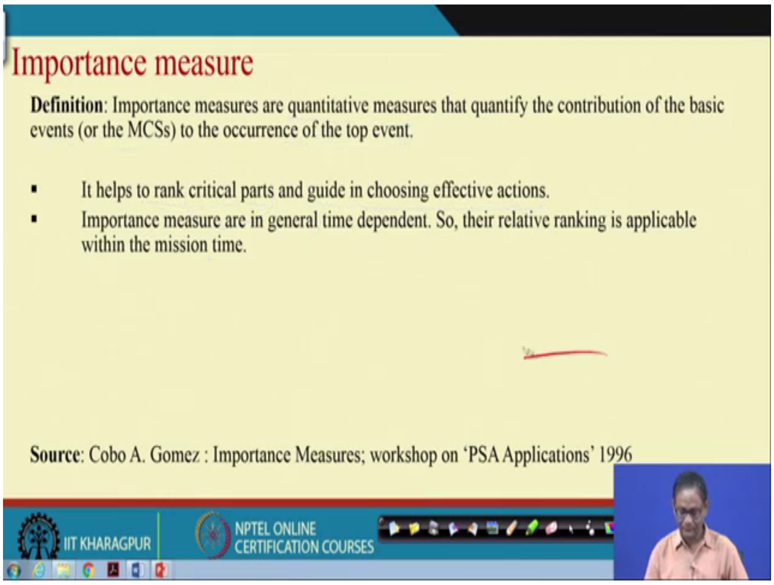

So, then what are the importance measures, there are that; there are many importance measures and the importance measures are quantitative measures what it does it quantify the contribution of the basic events or the M C S, what is M C S; Minimal Cut Set to the occurrence of the top event. You are seen earlier that B1-B 6. So, these are the basic events, you want to have a quantity measure that will tell you what is the contribution of this event in the top event the tank rapture to occur, that is what we are saying. Why we should do these I let me explain further; it helps to rank the critical parts and guide in choosing effective actions.

Let me go back; what you see the what are the critical parts here suppose tank is one, contact another one, timer another one, then your press switch then alarm. And so, these are the things basically we have considered here ok. So, now which one of these that contact or that basically what I am mean to the switch or alarm or tank which a one is the most critical one? So, you may be interested to know these that which is the critical part which are the critical parts? So, you have to take action against failure of those critical parts.

So, importance measures are generally time dependent. Generally, time dependent so their relative ranking is applicable within the machine time, what we mean by this; that that it may so happen that within the set time it will fail. Then in this case it is basically or much before in particular within this with this example we have a set time this is that pump time within this it may fail.

So, that can be set the machine time; here in this particular case may be the success and failure is important, but there may be situation when you will not preset the time that how long it will work you continue working with that system and accordingly the component also exposed or under operation. And then what will happen the probability of failure of those events; probability of failure of those components ultimately depend on the time of use. So, under such situation when you talk about the importance measure then you have to clearly mention the machine time.

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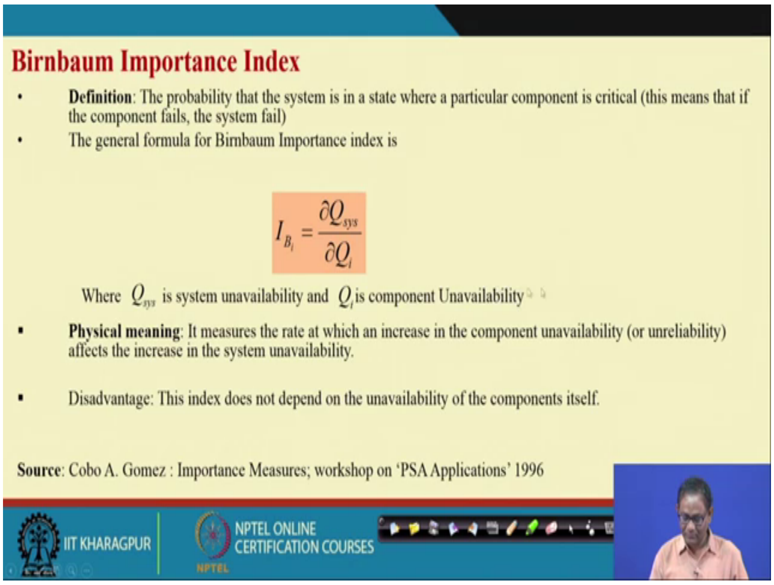

Let us see that what are those measures available, the measure first measure is this Brinbaum importance index. What it is given to us? It given that the probability that the system is in a state where a particular component is critical ok. Suppose the tank our the pressure tank the system, the system will be under normal state under, abnormal state may be over pressure condition or maybe the rupture condition that is tank rupture.

So, what we mean to say that the system can be in a particular state given a component is critical; means the component may fail. So, this means that if the component fails the system fail. So, system fail, here in the sense that system may be under over pressure since tank rupture has taken place something like this.

So, how it is computed the formula is these that importance measure for a particular event B I. So, B I relates to a particular component. So, then this is basically del Q s by del Q i, where Q s is the system level un unavailability and Q i is the component level unavailability. So, the pressure tank system is available or not available, if there are something abnormal takes place it is unavailable for example, tank rupture means it is completely unavailable.

So, now the component for example, the timer may be unavailable under failed state. So, then the rate the rate is del Q s by del Q i that is that is what is basically our Brinbaum importance measures. So, what it talks about: it is it measure the rate at which an increase in component unavailability or unreliability affects the increase in the system unavailability or system unreliability ok. So, that mean, if this component fails, what will happen to the system? The rate of increase in component system unavailability depends on the increase in the system a component unavailability. We want to know this then this is basically Brinbaum measure.

Now, there are so many basic events so many components so, find out this I B i and then if and accordingly you just rank them which one is the having the maximum contribution followed by minimum contribution. So, if we use this formula; then we will able to find out the component level or event basic event level contribution and the physical meaning is this. This one has certain problem because it does not depend on the unavailability of the component itself.

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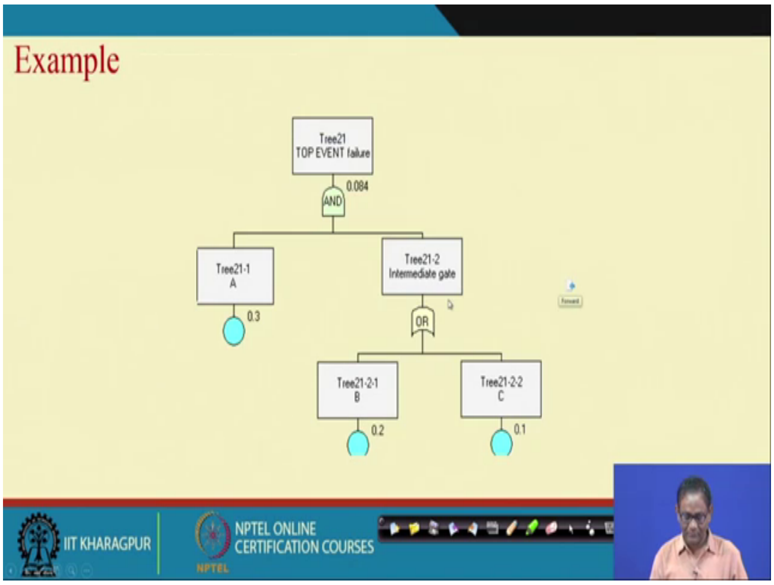

Anyhow so, let us see with an example. Now, let us concentrate on this I; it is example without any physical significant meaning I am giving you. What we are saying that there is a top event. And this top event will take place, top event will take place given 1 basic event A and another gate that we are basically saying intermediate gate. So, these 2 are input and it is there is an AND gate link to top event. Now again this intermediate gate this one this intermediate gate that is the OR gate, it has 2 inputs event B and event C. So that means, how many events have there, there are 3 basic events. So, with reference to this example we will explain the Brinbaum measure fine.

So, let assume that the probability of this event occur is 0.3 probability of B event occur is 0.2, probability of C event occur is 0.1. Then using gate by gate method or cut set method ultimately you will be able to find out the probability of the top event is this; what is this point 0.084, how this will be this will be that A time multiplied by B this one, here B plus C B will be there and C is there, but this gate probability OR gate probability you find out using the general normal calculation. And then AND gate is there these 2 will be multiplied you will be getting like this or you can use cut set method and you will find out this.

So, let us go by this example and let see what is happening.

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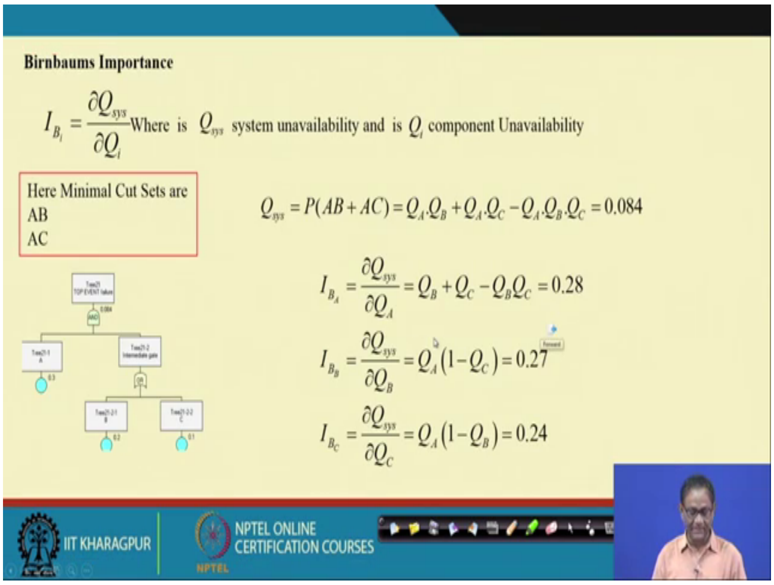

Now, what is the system level unavailability, system level unavailability is the system is under failed state when it will be under failed state if A failure occur, and B failure occur it will be failed. Similarly A and C occur it will be failed, because these two are the minimal cut set for the system. So, that mean the system will be unable way if this and this occur this occur or this occur. So, that mean the collectively what happen the union part, this union part this ultimately lead to talks about the system unavailability. So, we have 2 minimal cut set A B and A C, this with OR gate any one of them will ultimately lead to system unavailable. So, we have denoting by these and union is denoted by plus here.

Now, if you use the OR gate symbol you will find out what is A? What is the unavailability of A that is Q A which is nothing but 0.3 that is the probability of that event will occur and then Q B similarly then this for A B, this is fine for A C Q A into Q C Q C, because A B C they are independent. And minus we know that this into this so, A B into A intersection A B A will be A so, it will be A B C so, Q A Q B Q C ok.

So, what I mean to say; this P A B plus A C equal to A intersection B plus B intersection C minus that A B intersection A C. So, then A and A will be A intersection B intersection C. So, if you give probability here you put probability. So, then this one A and B independent P A into P B. And now P A is the probability that thus component A is unavailable that is Q A P B is component is B component unavailable that is Q b and probability of C is Q C. So, in that sense. So, this is your system probability, level failure probability it is known.

Now, we will use this equation so our equation is Q A is equal to this if we take derivative with reference to Q A what will happen this one will become this Q B only derivative of these will be this and derivative of this will be Q B into Q C. Now you know Q B Q C and Q B it is values are known; what is Q A Q A is 0.30, what is Q B 0.20, what is Q C 0.10. So, if you put the value here what happen 0.20 Q B plus 0.10] minus 0.20 into 0.1 so, that means, 0.30 minus 0.02 this result into this quantity. So, the Brinbaum importance measure the basic event A it is contribution is this, if it fails the top event failure will be something like this.

Now, if we go by B then again you take derivative del Q s by del B you will be getting this equation and you put the values like this, similarly I c like this. So, that mean importance wise B A B C 0.28 0.27 0.24 almost there equal kind of things with reference to read of increase in unavailability of the component increases that with leads to increase in unavailability of the system that is what we are talking about.

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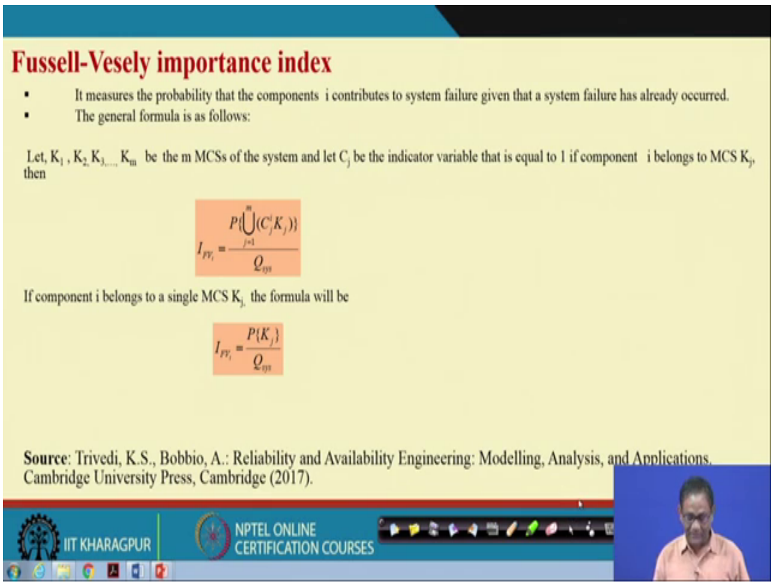

Second important measure is your fv that is Fussell-Vesely importance index. So, Fussell-Vesely important index it measures the probability. It measures the probability that component i contributes to the system failure, given that system failure has already occur, I know that system failure as occurred. So, you want to know what is the contribution of component i. So, general formula is suppose you have further system level fault tree that you have how many cut set m number of cut sets K 1 - K m and let the C j is an indicator variable, what does it says C j will be 1 equal to 1 if component i belong to M C S K j. So, you consider a K j M C S, which is K j.

Now in this M S C cut set whether the component i-th component that event is there or not, whether it is include the set if it is yes then it will be 1 otherwise it will be 0 so, if equal to 1 if component i. So, my means i belongs to K j. So, then that measure is like this so it equal to probability that union of indicator variable times that that particular M C S divided by system level unavailability.

Now, what will happen suppose if out of this m number of cut sets minimal cut sets suppose only 1 cut set content the component, then what will happen that out of these 1 to m only 1 is applicable the j-th one. So, this sum this will be probability of K j by this ok.

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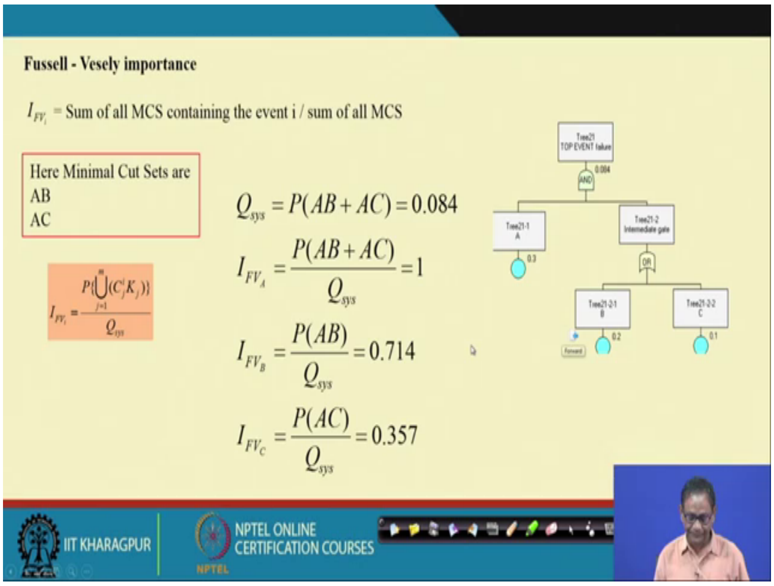

So, let us see with the reference to the example: now what is Fussell-Vesely importance sum of all M C S containing event i by some of all M C S. So, this is my system level unavailability we have seen it. Now what we will do that F V A is probability of this by this. Now, what we have required to know we are interested for A now you see how many cut sets are there 2 cut sets. So, A included in both cut sets yes so, the sum of all M C S containing i, what is this A B and A C by sum of all M C S then these probability and this is nothing, but this is nothing but Q s Q s system by Q system this is 1.

Now, if I go by the second one that is the B, then you see B is in the first cut set not in the second cut set. So, probability of these by system unavailability value is this similarly C in the second cut set not in the first set value is this so with reference to this example.

So, now what I can say that is the top event occur; which one is maximum top failure that system level failure occur machine contribution is given by this, followed by this, followed by this. So, this is your Fussell-Vesely importance.

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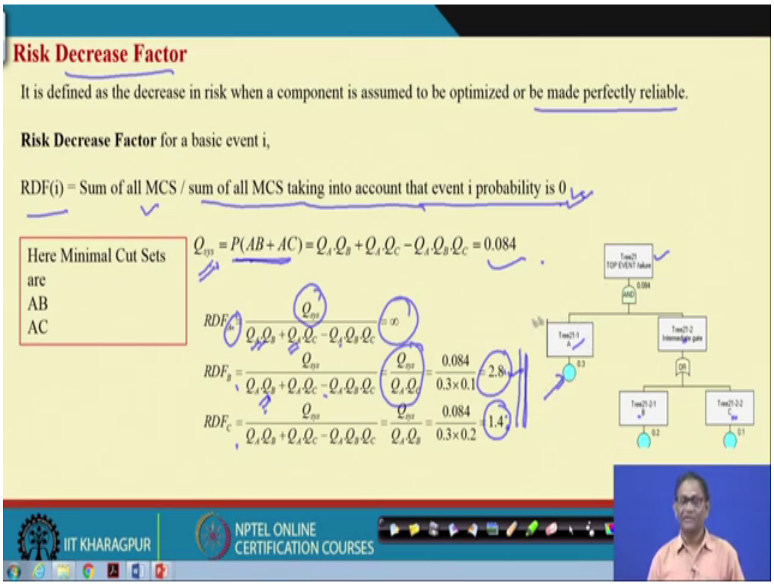

So, there are few more like risk reduction risk decrease factor, it is defined as the decrease in the risk when the component is assumed to be optimised or made perfectly reliable. Suppose for example, A, we will it will not fail so, that mean the event probability failure probability will be 0 or B it will not fail or C it will not fail. Then what happen if we can made some of the component should not fail. Then originally whatever the failure was there it will be reduced so, that risk is reduced failure risk is reduced.

So, then what is the formula here sum of all M C S divided by sum of all M C S taking into account that the event i probability is 0, with reference to these example some of all M C S is basically probability of this is nothing, but Q system this is this we know. Now what we want to do now? We want to find out for reason A so, what we have to do sum the numerator will be Q system, what will be the denominator? Denominator will be sum of all M S C taking into account i that event probability is 0; that means, what I mean to say that that Q A Q A this will be 0 because, you make it perfectly reliable.

Now, if I put Q A 0 it is becoming infinite, in the similar way if I put Q B 0 here then the this is the resultant and so, the value is 2.8. Similarly if we if you make C your component C completely reliable then it is 1.4. So, that mean from this measure we found that if you make the A complete reliable this will not happen because of an AND gate is also there, because it requires these as these two occur. But there other for B and C the value is low because even, if B will not occur suppose A and C occur top event will occur or A B occur top event will occur.

So, as a result there is decrease factor is B and C decrease factor is lower than A. Although, infinite is it is basically a theoretical value, but the physical meaning is that if you make it reliable because of and combination it will the top event will never occur if you can make it completely reliable.

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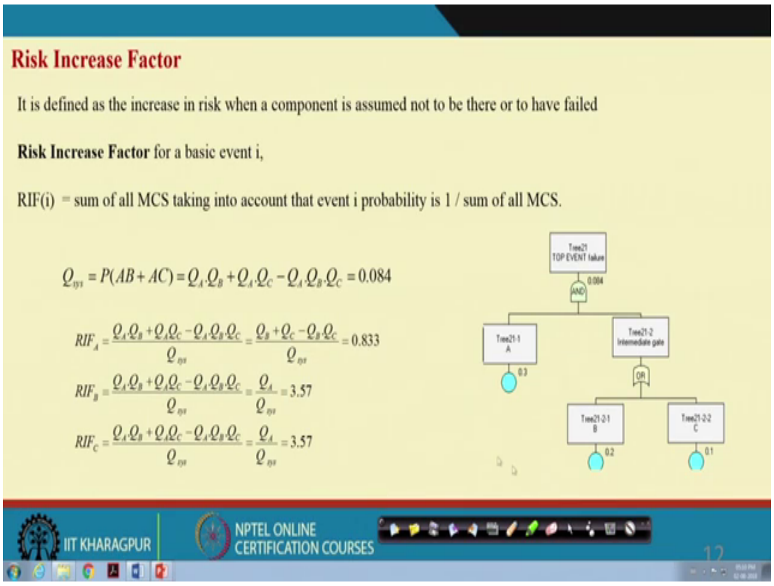

So, risk increase factor; that means, what happen in the risk decrease factor what we say it is the components are completely reliable so, if a component is completely reliable what is the reduction if you make reliable, in risk increase factor. Suppose 1 component is always under failed state so then; what is the increase. So, that one is sum of all M C S taking into account the event probability is 1 event i probability is 1, because it is in failed condition or it is not available by sum of all M C S. Now sum of all M C S is nothing but we are saying the Q system unavailability of the system.

Then what happen the in the in the in the numerator what you will do first you make the Q A equal to failed means Q A equal to 1. If you make Q A equal to 1, then this is this 1 1 that mean Q B then it is Q C minus Q B Q C by Q A is this value is 0.833. In the same manner B and C values are B 03.57 and C 3.57 there are these 2 are same. So, what it is saying; that means, actually it is basically we are saying that if any of the component unavailable or under failed state what is the risk increase had been probability of top event that will increase.

So, because of OR gate you will see the B and C's value B and C is value just what is QA value QA value is 0.30, what is top event value 0.084 so, it is almost this top event value is this. And again in both cases QA is coming why? Suppose QB equal to 1 then QA this QC then, it is QA and QC QC this equal to B equal to 1 or QC minus QC this QA correct.

Now, if we see C equal to 0 QA QB and that this is 1 that this is QA and QA QB this is correct. So, this is what is the way you will you just see that 1. And you are getting that rate of increase of the top level failure given the increase in the component level failure Brinbaum measure.

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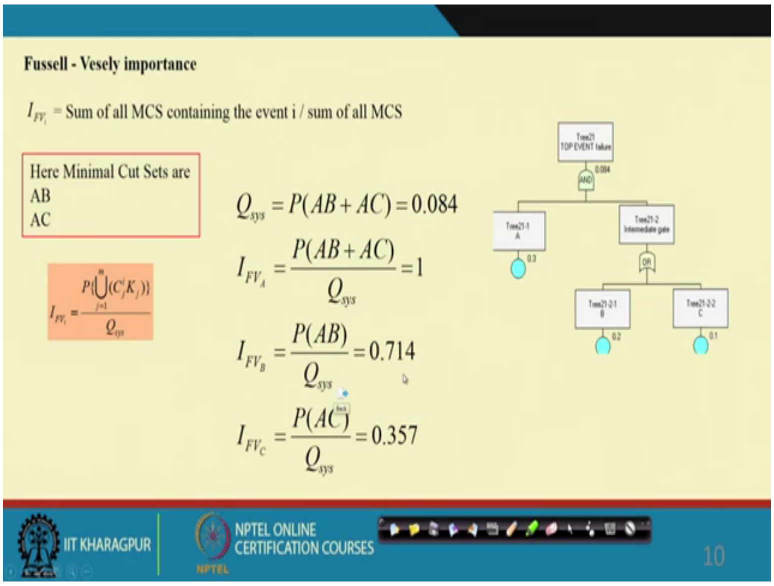

Then we have come to the Fussell-Vesely measure, what is what we have discussed M C S containing event by some of these so if. And the contribution of a particular event if it is in all the cut sets it says the maximum contribution. And someone which is having in one or more some of the cut set then it will be less contribution so, that importance measures giving you like this.

Then this is similar to your Brinbaum measure also, but risk decrease factor means you make one component perfectly reliable. And what will happen to the system level failure, and what is the contribution of this towards system level failure what will happen. And then when another one is basically suppose 1 is completely unavailable. So, these are the extremes basically we are talking about, but anyhow there are different measures, these measures will help you to understand the criticality of the parts and accordingly you can take decisions.

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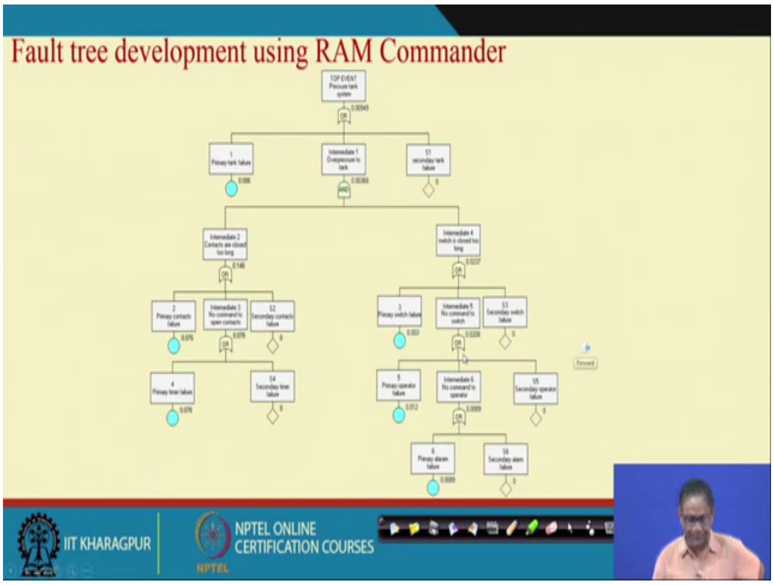

Now, here we are basically we have used RAM commander and we have developed this fault tree. And this fault tree can be manually developed also so that also we have seen. But thing is that we want to see all the that cut sets as well as the importance measures from this because manually computing those importance measures will be difficult in the sense that may not be possible also.

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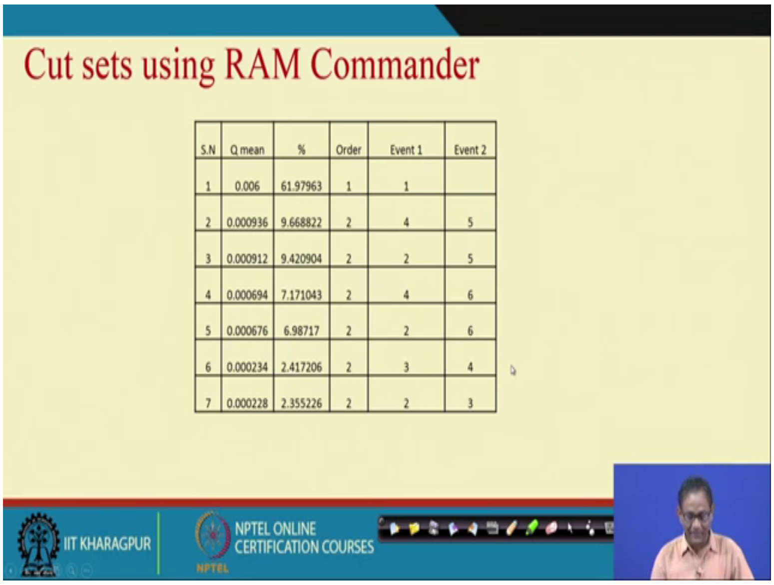

S.N	Q mean	%	Order	Event 1	Event 2
1	0.006	61.97963	1	1	
2	0.000936	9.668822	2	4	5
3	0.000912	9.420904	2	2	5
4	0.000694	7.171043	2	4	6
5	0.000676	6.98717	2	2	6
6	0.000234	2.417206	2	3	4
7	0.000228	2.355226	2	2	3

So, now see what happened the how many cut sets are there 1 is 4 5 then 2 5, 4 6 2 6, 3 4, 2 3 like this so how many 1 2 3 4 5 6 7, 7 cut sets have there. So, so that mean what will happen your if I want to know the Q system, then definitely you will say 1 plus this 4 5. So, if I say this is cut set 1, that means, we are saying that K K 1. So, that mean this K 1 plus K 2 like this the union part up to K 7 and also you know that they are AND gate so, ultimately probability that 1 plus 4 5 4 into 5 like this.

And then what you have to do; you have to find out the important measure. So, accordingly in case of the Brinbaum find out the derivative and you go on doing this one, but it is really laborious cumbersome. So, what we will do: we have used this software and we found out the values.

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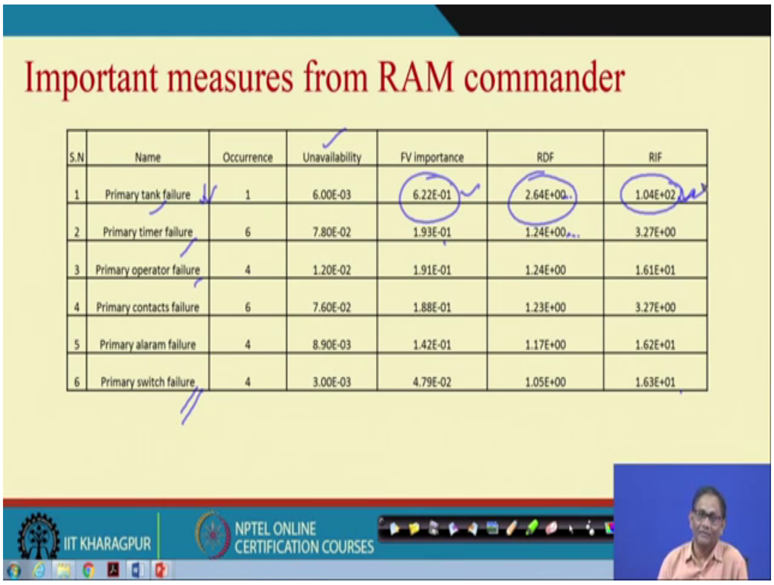

S.N	Name	Occurrence	Unavailability	FV importance	RDF	RIF
1	Primary tank failure	1	6.00E-03	6.22E-01	2.64E+00	1.04E+02
2	Primary timer failure	6	7.80E-02	1.93E-01	1.24E+00	3.27E+00
3	Primary operator failure	4	1.20E-02	1.91E-01	1.24E+00	1.61E+01
4	Primary contacts failure	6	7.60E-02	1.88E-01	1.23E+00	3.27E+00
5	Primary alaram failure	4	8.90E-03	1.42E-01	1.17E+00	1.62E+01
6	Primary switch failure	4	3.00E-03	4.79E-02	1.05E+00	1.63E+01

Now let us see, what are the values. So, the values unavailability for the 1st one 2nd one this say this 1 to this 6 basic events and then what happen that Fussell-Vesely measure and the risk reduction factor and risk increase factor we have computed.

Now, if I go by this measure so, which one is the maximum? Maximum is this one followed by this it is in order of in decreasing sequence. So, this is contributing maximum, when I go for R D F also, but all are 0 here, but maybe after some 0 some values will be there, but here if I go risk increase factor this one 10 to the power 2 ok, that mean this is also contributing obviously, the pressure tank failure is once it happen it completely the tank rupture will take place. So, it has definitely the maximum importance.

So, in by no time you should allow the wear and tear of the pressure tank to such level that it will happen and this tank rupture will take place ok. So, there is the most critical component of the system what we have discussed so far.

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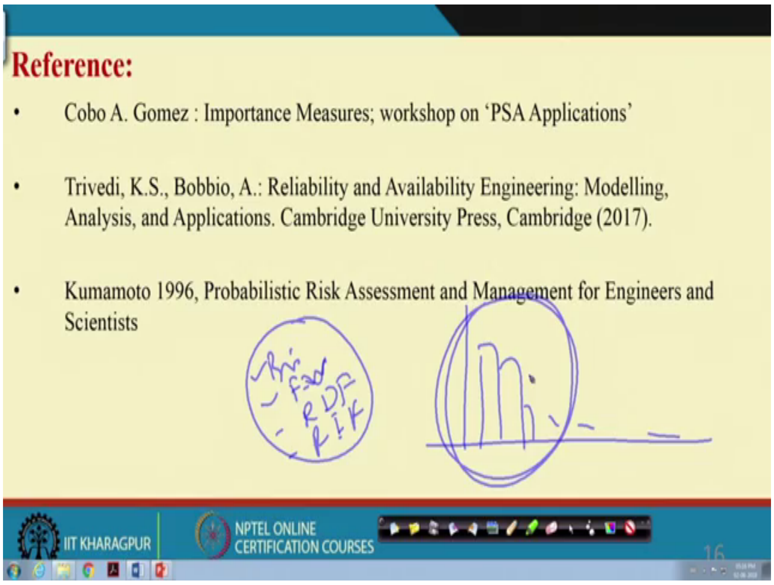

So, I hope you have you have understood the importance measures. So, there references 3 references are given from where we have taken the resource material. And I hope that you understand the importance of these importance measures. So, one is Brinbaum measure. Second one is Fussell-Vesely measure, third one is risk reduction factor, fourth one is risk increase factor; and these are all are basically to find out the importance relative importance of each of the cut sets or the basic events.

And primarily we have discussed from basic events point of view and accordingly if a the importance of the basic event or basic event will be ranked in terms of importance; when there are huge number of basic events, you can use the Pareto plot find out the find out the that this kind of things. And maybe few very important means 80 percent of the importance may be from few of the basic events, and definitely you try to make them as reliable as possible means, they are availability should be maximum unavailability should be near to 0.

Thank you very much. We will meet again in the next class.