Introduction to Reliability Engineering
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Lecture 26
Failure Data Analysis: Non- Parametric Approach

Hello everyone, in previous weeks, we discussed about various distributions, we discussed about system reliability. So, wherever we use the reliability values, unreliability values, failure rate, PDF, etcetera, we need to have known those values. So, these values we need to determine from the data. So, as you discussed earlier that for reliability our random variable is time to failure.

So, if we want to know the reliability, we have to collect the data for time to failure, once we have the instances for time to failure, then we can perform the statistical analysis and we are able to find out the probability that is reliability, unreliability, probability density function, failure rate, etcetera. So, now, we will start discussing that if we have the failure data, how do we find out the reliability or failure rate or the PDF or unreliability value.

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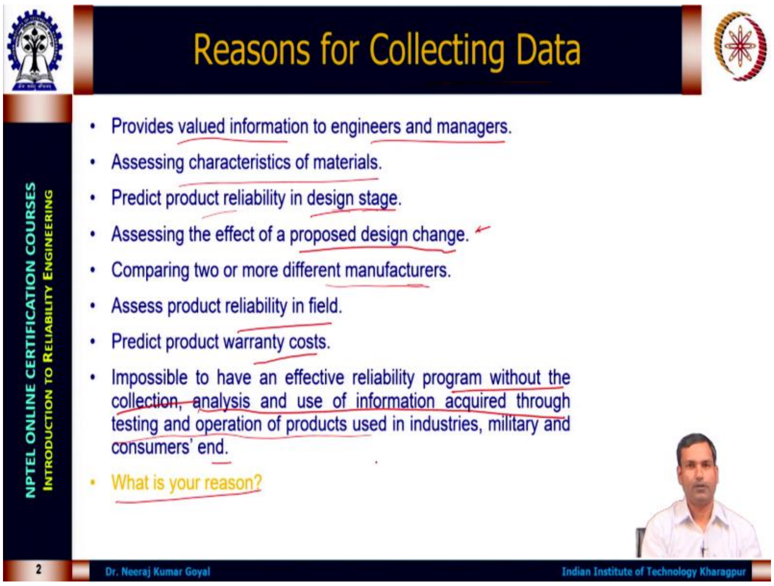

So, we need to have the data. So, for data we have to collect data. Data collection if we are able to do and if when then we can perform the analysis for the failure data then once we perform the analysis, this becomes some very useful information for us, it provides a valued information for engineers and managers. So, they are able to know from reliability data that what kind of reliability performance their systems are having and accordingly they can take other corrective actions or they can decide their policies for maintenance, policies for providing the failure corrections etcetera.

It also provides inputs for assessing characteristics of materials. So, we are able to understand that which materials are behaving better, which materials are not behaving so, well in the design therefore, so, every it is not necessary that all materials behave or provide good reliability in all scenarios. So, you are able to understand from the data, what kind of materials are better or for the particular use, you can predict product reliability and design phase as we discussed earlier when we were discussing about the system reliability that our aim of the because reliability we are able to achieve during the design phase, other phases like manufacturing or the uses generally reliability deteriorating.

So, maximum reliability which is achievable is determined by how well you have designed. So, design phase is the maximum influence of further reliability. Now, when we are designing the product, we may not have the data because it is supposed to be used in future and once it is used, you will have the failure data for that, but if we have the failure data from previous failures for the similar designs, then we can use the data like component reliability data we can use and we are able to find out the system reliability.

But, so, for the using the data and design stage we have to analyze the previous designs and find out their reliability and use them for the current design data. Whenever we are proposing a design change, then we should be able to know that whether this design change is effective or not. And what is the effect whether it is making the reliability poor or reliability better. So, it is not many times we are able to theorize and theoretically we feel that if you make the change your reliability will be better, but reliability is not just using better material not but it is also should be a good match.

So reliabilities for the system is that all should be helping each other or all the components are working together in a good way. So, whenever design changes are proposed then we can look into whether this design change is going to be effective or not. Or whether it the implemented design change is effective or not. We have many times suppliers, different manufacturers which are giving us the parts of life. Now if we have multiple suppliers two or more suppliers with us we can see the performance of their equipment's in our designs, whether they have been performing well or not so, well. And according to that, we can have the vendor selection.

Product reliability in field. So, generally nowadays, reliability can be used as a contextual parameter where the customer and the supplier both are having some agreement in reliability. So, once they have the values on which they have agreed, then from the field performance you can find out whether the reliability which you agreed similar reliabilities exhibited or not, or whether those criteria's are satisfied or not. So, field reliability data can be used and we can assess to find out whether how much is the reliability we can predict product warranty costs. So, what will happen once we know the reliability of our systems, we will know how many failures we are expecting during the uses.

So, over the time, and we will be able to understand that how much failures are we going to see and providing the warranty for those kinds of scenarios, how much it will cost if we do not have proper data collection. So, like many organizations may not focus on data collection, they want to use others data or they want to use the generic data or generic formulas, that is where the problem arises, because you will not be having your own inputs, you will not be able to understand that your design features or your way of designing or your applications, whether those are how they are influencing the reliability and how much reliability actually you are achieving.

So, using if you want to have a good reliability program, you should be able to use your own data. And for that you have to have a data collection and which should be analyzed and used for the, many times some pupil they make the procedures for data analysis some companies but they are not able to perform the analysis of the data and able to use that information for the design and decision making.

So, this information which are acquiring to testing operation and top products used during industry and military or customer end, we should be able to find this data we should be able to analyze this data and this information which you are gathering this information should be used in our decision making process, you may have your reason based on your role or based on whether your customer whether your manufacturer, or whether you are part of a team. So, based on that you may be having your own purpose one of these or maybe that can be separate from this, but most of the times one of these reasons would be applicable for you one or more of the reasons.

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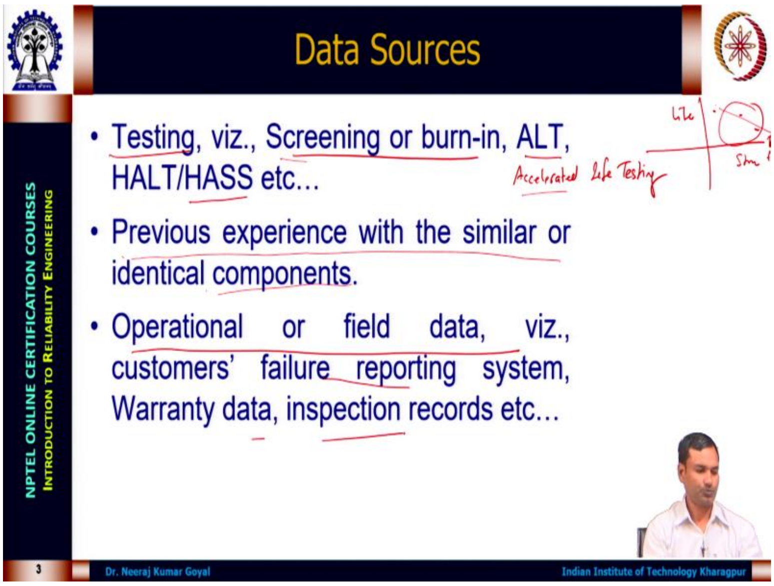

Generally if we want to do data analysis, then we need to have the data for reliability the data will come from testing. So, if we do if we perform in house testing, or if we perform testing at some third party sites, so, wherever we perform the testing, we will have certain data this data may be analyzed to get some reliability information like screening data, screening or burn-in as we discussed earlier, that many times after manufacturing due to manufacturing defects, some faults are part of the system.

So, these can be screened out by having a burn-in process or by having a HALT HASS process highly accelerated stress screening or ESS process that is environmental stress screening. This screening will also result in certain failures. So, this failure can also be analyzed to understand the infant mortality failures and that can give you a good idea that what can be the reasons for these failures, what kind of corrective actions you may be able to take either in design or in vendor site or in manufacturing sites. So that you are able to reduce these failures and you are able to eliminate the infant mortality failure in the future.

Similarly, you can perform accelerated life test ALT is accelerated life testing. So, here we try to find out the life of the product by performing the acceleration testing, this acceleration is generally achieved by applying the higher stresses. So we apply the multiple set of higher stresses and we use the life stress relationship like RNS relationship for temperature stress, or inverse power law for other kinds of stresses like voltage current, or mechanical load.

We use those formulas to establish the change in life due to the stress. So, once we are able to have a understanding by doing this life measurement, a different stresses, we know the pattern, the pattern in which the life versus stresses will fall. So, as the stress will increase generally life will decrease. So, we may have three points, three different stresses we can get through different life points, then we can fit a regression line through this and this regression line will be able to give us the relation of life with the stresses.

So, this regression life when because these are generally higher stresses, we may be extrapolating it to the lower stress level as the use level stress. So, by testing it higher stresses, we are able to complete the test in a smaller period of time, because, if product life is 10 years, 20 years, we cannot perform the test for 10 20 years. So, we apply the higher stresses, we try to finish the test in six months to eight months or nine months like that, and three tests will be conducted and with the three tests we will be having the life stress relationship and extrapolating the same will give the life at the normal use conditions.

So, stress at normal use condition and we will know the life and that same relationship we use for determining the reliability, again reliability failure rate etcetera under normal use conditions. So, this can be also used for the data analysis purpose. Another source of data can be the previous experiences with similar or identical components as we discussed earlier. No design comes from zero generally the design set or the modifications or the additional functionalities or additional features from earlier similar designs or maybe developed by the same company or maybe developed by some other companies.

So, if we have some previous data for those we can use that to understand that how much reliability can be achieved from the new designs. We can use the operational field data like customer failure reporting system, warranty data, inspection record, etcetera. This data is very useful in analyzing the system especially if that system is repairable, systems are costly bulky, repairable, because whenever they fail customer will report the failures and you your team, team of specialized technicians would address those failures and correct those failures.

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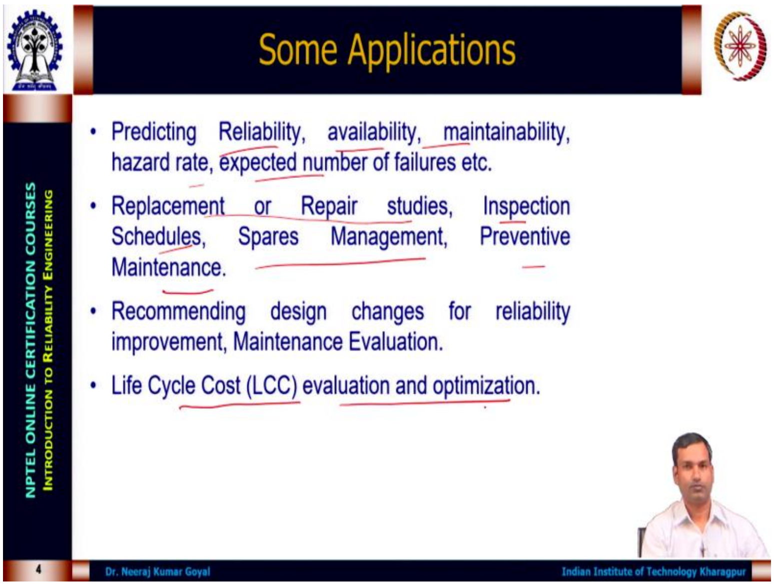

Some applications for this data would be predicting reliability, availability, maintainability hazard rate, expected number of failures, etcetera. So, then we can also find out whether we should do the replacement or repair. So, whenever a failure happens, there is a question arising that whether we should go with part replacement or we should do repair and reuse it. So, that can also be analyzed, we can decide the inspection schedules. So like for preventive maintenance purposes or to find out the hidden failures, we have to do periodically inspection.

So, when we perform the inspection, what should be the frequency which will allow us to have the good availability that also we can decide but again to deal all these decisions, we need the data and this data we need to collect and then only we can do that analysis, we can do the spare part management, we can do preventive maintenance, everything requires data and that data needs to be analyzed and used for the purposes we can recommend the design change for reliability improvement maintenance evolution etcetera.

We can if we want to do the lifecycle cost modeling, then also we require the data of it. So, based on the data, we can perform lifecycle cost and we can evaluate and lifecycle cost can be the rather than deciding based on the acquisition cost deciding based on the lifecycle costs would be much more proper it will give us that over the use of the product, how much cost would be total costs would be there for the equipment which you are going to use.

And that can be the criteria which can help us to know whether the equipment is whether sometimes costly equipment can actually be the having the lesser lifecycle costs, because if they are having the less failure rate and less failure probability, you will have to spend less time on repair.

Apart from that, there will be less downtime and because of that your productivity loss will not be there you will be able to use the function and because of less of loss of function, you will be not losing the money because of the failures. So there are we have to do the modeling and we can do the optimization and find out that what kind of product or what kind of option would be better for us.

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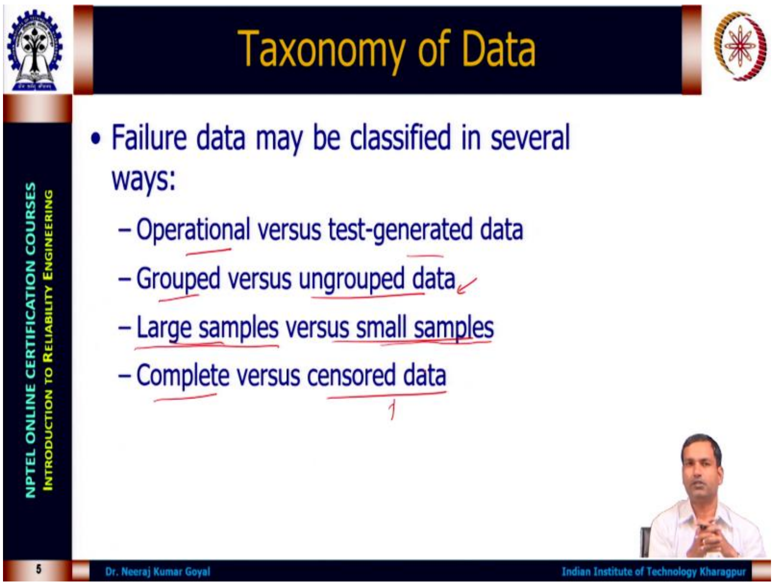

Generally the failure data, we would can divide in let us say operational data, which is coming from field or test generated data. So, operational data generally is less accurate, because people it depends on when failure occur and when people report it, and how we are operating it, whether operation time is recorded or not recorded, while test generated data is generally the test is generated in the lab environment.

So, it is supposed to be the accurate data, but here the conditions of tests would be varying, condition tests may not exactly represent the operational environment. So, because of that, the relation with the operational environment has to be established. So, that becomes a challenge when you are doing the testing.

Grouped versus ungrouped data. So, most of the time the data coming from operational side is the group data that we know how many failures occurs over a period of the time per day per week per month like that, ungrouped data is like, we have exact time to failure data that at what moment it failed, we are able to record it that kind of data can only be gathered generally when we are doing the testing. Large samples versus small samples.

So, number of samples which are collecting either from operational or test data. So, generally you make if you have the large time of the uses, you will have the large samples. So, large samples is definitely the desired one because the more the samples more accuracy you would have in the estimation, but many times we have to work with the small samples. So, if some samples numbers are small, then also we have to estimate but error would be high.

Complete versus censored data. Complete data is generally achievable in lab condition, but most of the time in lab also it is censored data, because all the equipment's which we are putting on tests or the all the equipment which we are giving to the customer for use, all equipment's are not going to fail. So, some equipment's is still keeps on working. So, those equipment's, which keeps on working, their failure times are not known to us, so, that becomes censored. So, that is censoring, our ability to see when the failure happens, but we know that till a certain time the failure has not happened.

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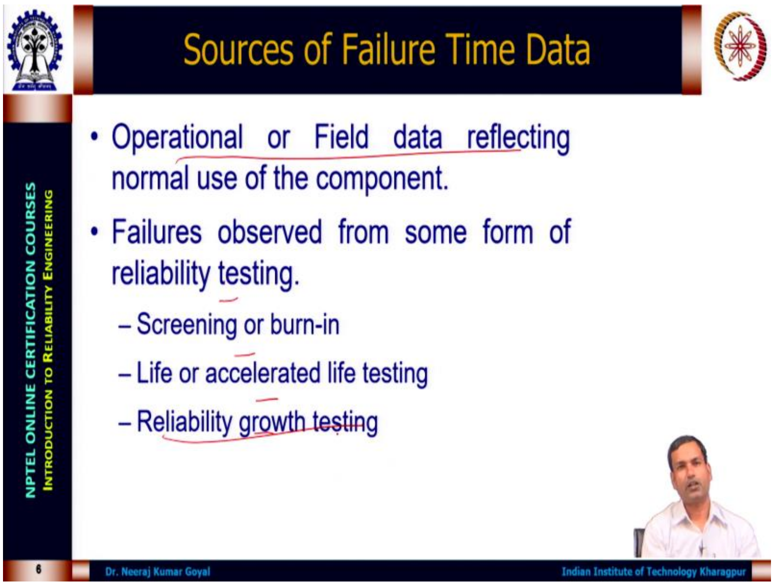

We will discuss these things in more detail, how we can get those failure time data, let us say we discussed that operational field data or we can do the reliability testing like this we have already discussed in detail like screening, burn-in, ALT or we have the growth testing. Reliability growth testing is another way of doing the test this is mostly done by the organization. So, developing organizations generally what they do, whatever you design, any product any software that product or software generally will not work, it will fail in the testing.

So, any product which you design initially is not reliable, because there are many weaknesses faults, it is theoretically looks good, but when you put it on to the qualification test, the product keeps on failing. So, when the product fails you test and when it fails, then you will be correcting the fault you will be improving the design and once you make the improvement, then next time same failure may not come but some other failure may come.

So, this testing fixing and again finding out the testing failure fix cycle once you do, then multiple cycles you do every time what happens you fix a failure fix a reason and what will happen the reliability of the product will grow. So, over the development period, main objective of development period is to make sure that system reliability laboratory grows by doing the test fix test fix. So, this growth data can also help in estimation.

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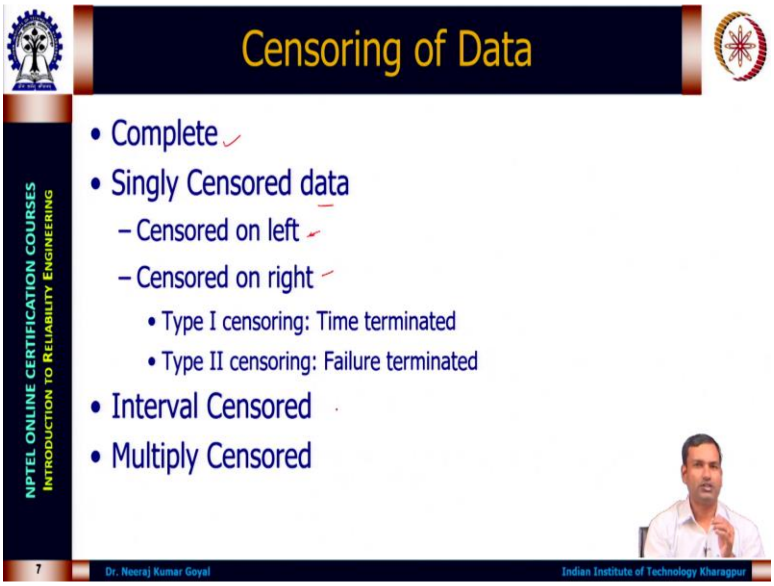

So, let us see that what kind of data we can have, complete data means, we have put all the all the equipment and all the equipment have failed, singly censored data means one side, so censored in left is uncensored on right. We will discuss this in by example in next slides. In censored in right there are two types of tests that the time terminated or failure terminated. Then there is interval censored and there is a multiply sensor. We will discuss these one by one.

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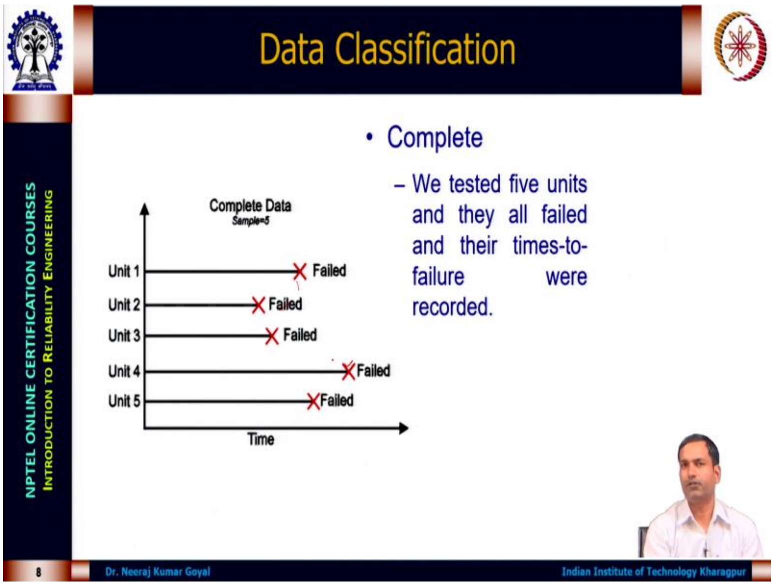

So, complete data means we have let us say put five units on test all are failed. So, we know the time to failure for each one, this is the time to failure 1, this is time to failure 2 3 4 5.

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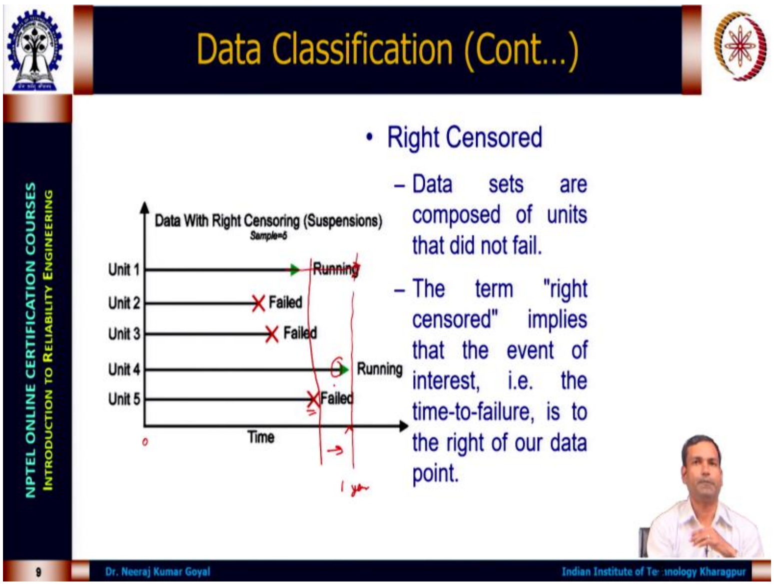

If we discuss about right censor data, right censor data means at some point of right this point should be up to here, let us say here, we have stopped testing, now this is testing we have stopped either due to the two reasons either we have decided that our testing will be or let us say we have given the data into further uses condition. So, when we give the data it falls here time t equal to 0, but now, let us say we have spent one year in the fields.

So, we have the only one year failed data. So, in one year whatever failure have happened that has happened here, but those which have not failed, they are still running at the end of the one year. So, this is time terminated data. Many times during tests what we decide we decide that we will run our tests up to a certain number of failures.

So, if you are putting let us say 30 units for the testing, you will say that our test will run till we observe 10 number of failures after the 10 number of failures, we will not continue our test. So, what will happen in that case, the last time where it is failing so, 10th failure will happen like here if you see here, if you look at here, the failure will last data would be on failure point and rest of the units which have not failed they will keep on running.

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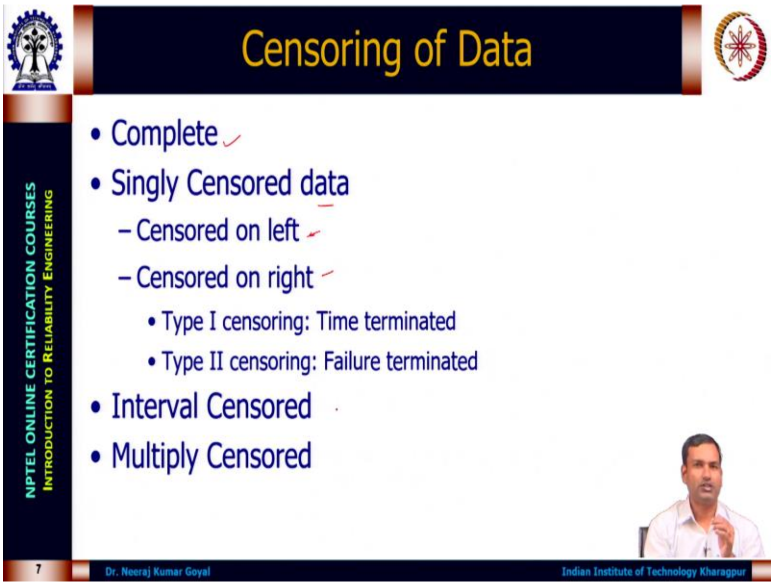

So, that is, so, this is where we have these two type of censored time terminated that means, you have decided that at a certain point of the time the test will terminate and failure terminate means, you have decided a number of failures for the termination point for the testing. So, in both the cases some equipment will keep on working, once the either time is reached or the number of failures is reached.

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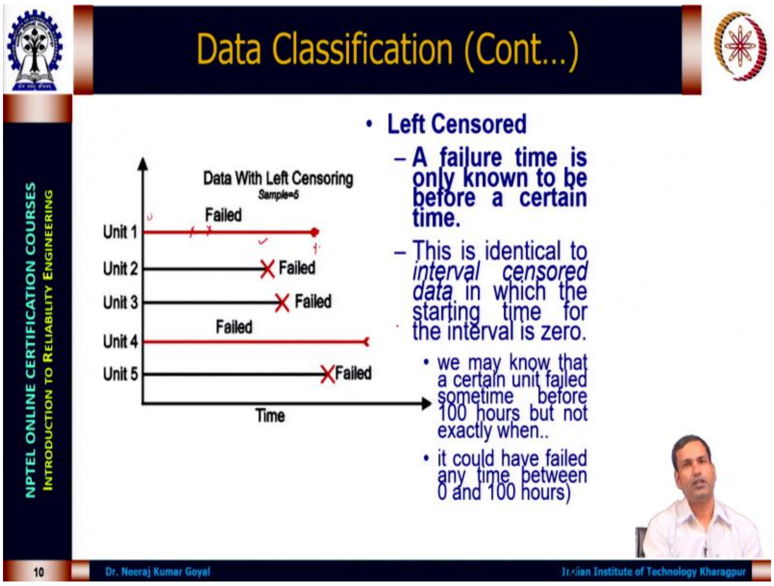

Then comes Left Censored, left censored is that we know that this is failed, like this equipment, I am checking here and I found it in fail condition, but I do not know when it failed. So, I know that it is failed from current before somewhere time before current time. So, somewhere from the start of the test till I observed now. So, this failure is kind of missed like we did not come to know when it happened. So, that is our left censored, because we do not know on the left-hand side when the failed because time to failure is on the left-hand side it may be here, it maybe here.

So, our ability is restricted towards left-hand left-hand side that we are not able to see towards left there the failure happened. In earlier case our ability to see was restricted on the right-hand side we were not able to see on the right-hand side where the failure because that will happen in the future. So here we are not able to record so that is why this becomes left. Left censor data is generally rare, we do not have much left censor data, we most of the time work with the either right sensor data or we have the multiply censor data.

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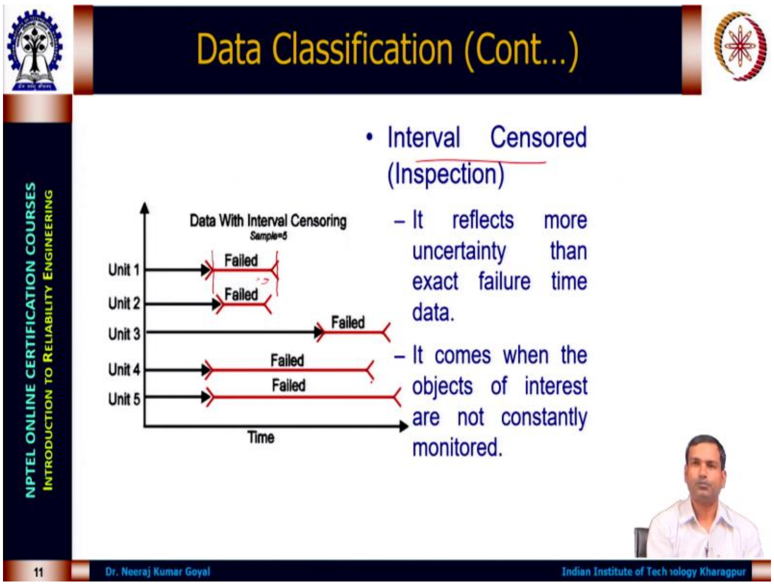

There is another kind of data, Interval sensor data. Interval sensor data is like a inspection data. So, what happens that we are not able to continuously monitor our the performance of the equipment. So, what we do, we will test time to time. So, we decide like every one hour we are going to go and check whether it is working or failed because to determine whether it is working or failed some tests need to be run and once you run that test setup you will come to know whether it is working or failed.

So, this working of failure information is limited in a interval. So, we know that it is failed within this interval but within the interval when it will, at the start of interval or end of the interval, or mid of the interval we do not know. So, our time to failure is restricted, we are not able to see it so, our censor has happened on the both somewhere in the interval. So, we try to find this is all interval failures.

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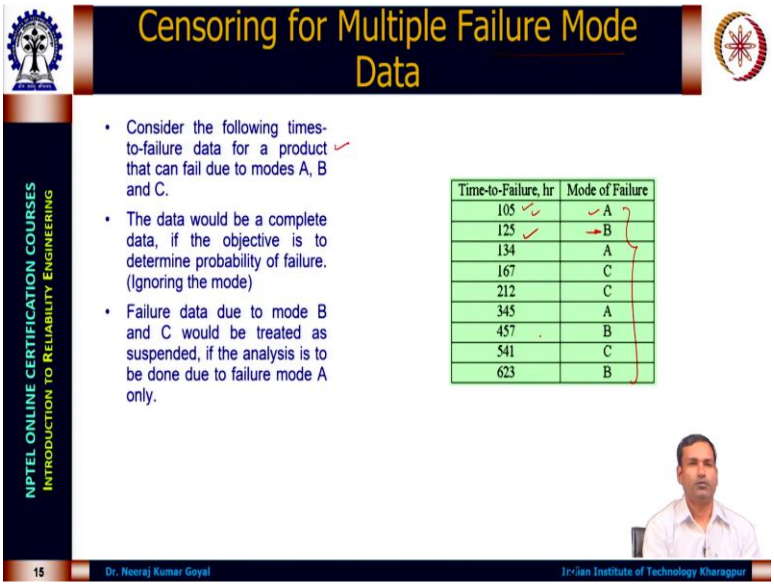

So, this we have discussed already, multiply censor data means that you are censoring is happening in between also. So this can be understood more by the one example here like let us say we have the multiple failure mode data. So, if you see that one product is there, let us say if you see and that can fail in three different modes A B and C and like here is the data which we have. So, at 105 the failure mode was failure due to the A now what happens when I am analyzing the failure mode B and for failure mode B 105 becomes the censor type because if it is not failed due to the failure mode A the system would have continued to work and in future somewhere it would have failed due to the failure mode B.

So, we are not this failure which has happened not because of the failure mode B it has become censored data for the failure mode B. Similarly, it has become censored data for failure mode C also because we are not. because this since been removed here because of the failure mode A, so, we do not know exactly when it is going to fail due to the failure mode B or C. Similarly, the data for failure mode B would be censored data for failure mode A and C. This becomes multiply sensor because this can happen anywhere left right interval. So, it becomes a multiply failure censor data.

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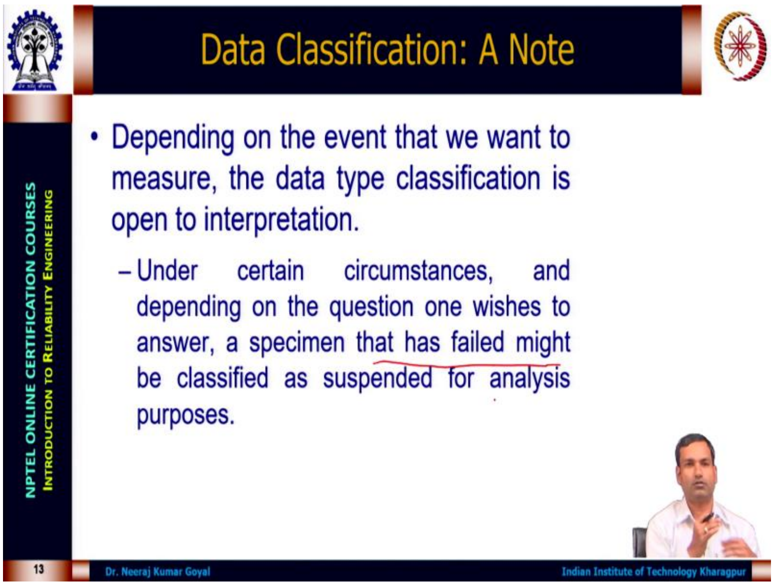

So, depending on what we want to measure data classification is open to interpretation. So, we want when, sometimes what happens that a device is failed, but it is failed due to a reason which is not of the concern for the testing. So, like let us say you are the testing device the supporting device is failed, testing device failed, then what will happen you will not be able to test the device further. So, it is recorded up to a certain period of time, but you do not know because the failure did not happen. So, that is again become suspended or censored.

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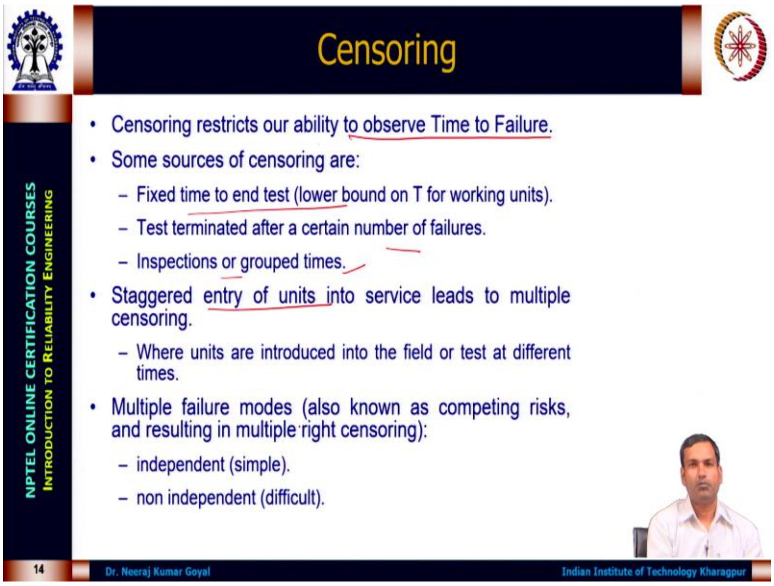

Censoring restricts our ability to see observe the time to failure we are not able to see time to failure, either right side means failure is on right side, left side means left left side, interval means in between and multiply means or sometimes here sometimes there so, failure time to failure is not seen. So, sources of test censoring are fixed time because tests cannot continue for long very very long periods or certain number of failures or grouped items or inspections which you are doing on group items.

Then a staggered entry of units like all the manufacturing units may not be manufactured in one day and sent to the service. So, different different time different units are going so, all the units will not record the same operational time. So, you will not have, you will have the censoring over there.

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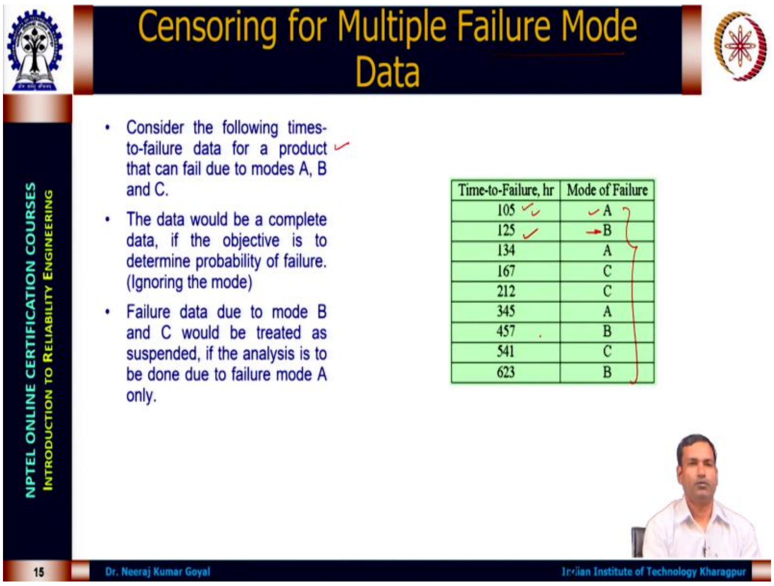

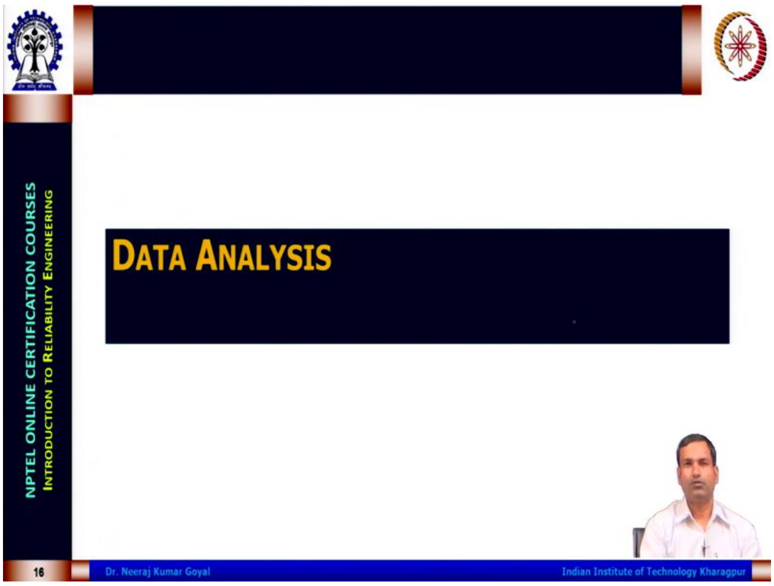

Multiple failure modes like we discussed here, that when you have multiple failure modes then for one failure mode, it will become the failure data for other failure modes it will become the censor data. So, here now, we will try to see and discuss that how this data can be analyzed. So, as we discussed the data can be in various categories, it can be complete data, it can be complete time to failure data, it can be complete group data, it can be censor data, it can be right censor data, it can be multiply censor data.

As we discussed lab sets data generally does not happen frequently. So, that scenario we are not, that is same as what we discuss in the multiply censor data, if we apply the same concept it is applicable to the left censor data also. So, we have the sense various types of censor data. So, we will discuss each and every category one by one and try to see that what kind of failure data analysis we are able to do.

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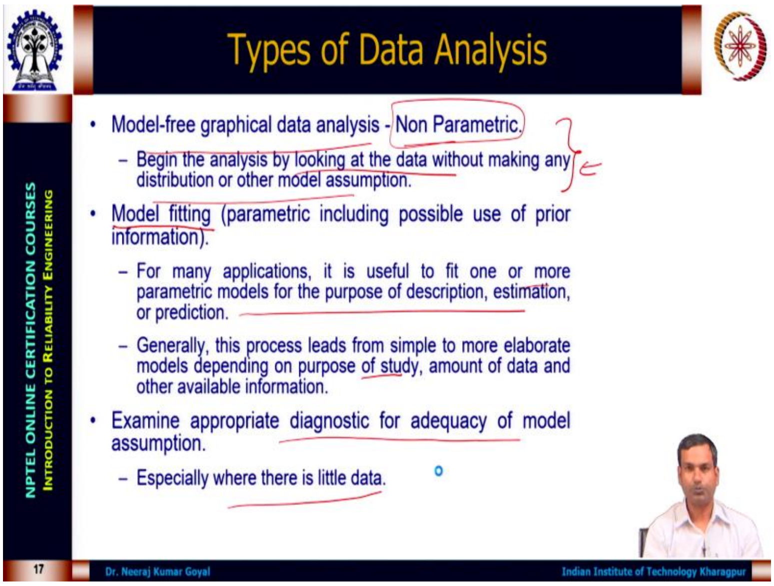

So, let us see the data analysis. So, first before going for distribution fitting etcetera, this data what we discussed, it can also be fit to the distributions which is called model fitting. But before doing that, we will discuss the model free graphical data analysis which is non parametric that means, it is not we are not fitting into this distribution or we are not trying to find out the parameters of the distribution, we are just looking at the data and from the data itself we are trying to see what data is saying from the reliability point of view.

So, we look at the data and we do not make any distribution or model assumption we simply see what is exactly is the value. But if we are able to do the model fitting it helps us but whenever we do nonparametric data, we know only how much the data is saying we are not able to extrapolate or interpolate or we are not able to consolidate that data because you are not trying to capture the pattern in the data here. you are simply trying to see that what is the meaning of the data, but when we fit the model, so, like we discuss the distributions, but different distributions give different failure pattern, exponential will have one pattern, viable with different beta parameters would have different patterns, than similarly long normal would have different patterns.

So different failure patterns we are trying to capture through the data. Once we are able to capture the failure pattern through sample data, we are able to understand the failure behavior of the whole population. And we can do little interpolation and extrapolation expecting that the same failure pattern will continue. And once we are able to do that, we are able to have more useful interpretations and the predictions we are able to do and those things we are able to to use for better decision making.

So, it is useful to fit one or more parameters distributions for the purpose of description estimation prediction. It leads from simple to more elaborate models depending on the purpose of study. So, we will discuss very brief like this maybe after a few lectures we will be discussing the this model fitting first we will discuss the nonparametric analysis, we will discuss the simpler ones so, that which you can understand you can quickly do the analysis.

Examine the appropriate diagnostic for adequacy of the model assumption. So, generally we try to use that whether so, whenever sample data is less than what can happen, it may not be correct representation of the population data and it may give the wrong interpretations also, but, whatever is data says we can only go with that we may not be able to unless we have the larger data sets from earlier historical data or somewhere from earlier experiences.

Without that it would be difficult to say which data is or what data saying is correct or incorrect. But, as we know more the data more higher the sample size, the estimation error will be less and that will be much more representative of the population. So, if you have larger data it will be always beneficial.

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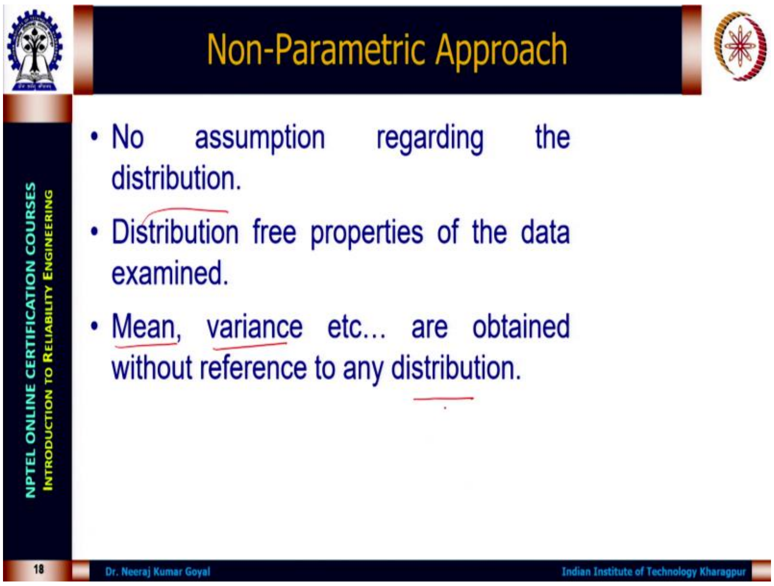

In nonparametric approach, we do not assume any distribution and we do distribution free analysis and what we focus on we try to find out mean variants etcetera, but without reference to any distribution and whenever we do censor data sometimes it becomes difficult.

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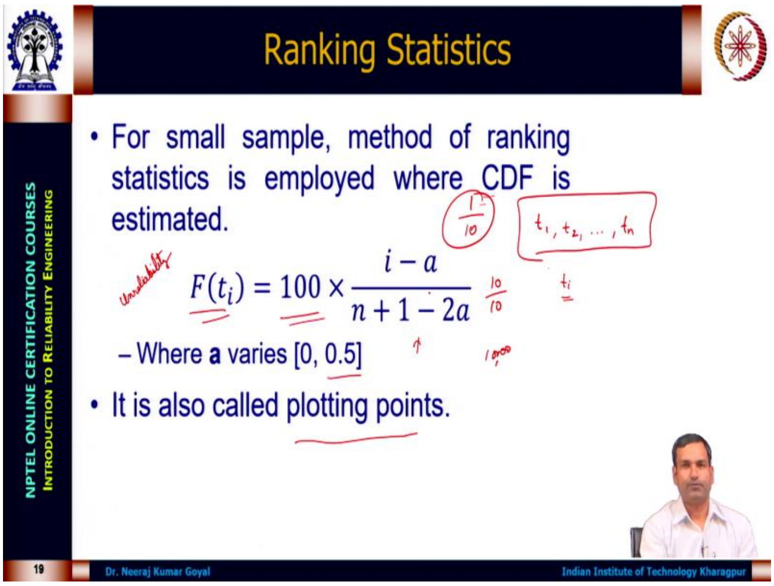

So, here, to do the data analysis like we, what kind of data we have? We generally have the data like T1, T1 is the time to failure for one unit, T2. So, if we have n number of failures, we have the time to failure data for n number of units. If it is the complete data generally it is arranged with the increasing order that means T1 is the smallest and Tn is the highest, when first failure occurs, second failure occurred like this nth failure occurred.

So, what happens if we have the this data So, Ti FEC, Ti is the data point. So, for Ti data points we can get the Fti value, what is the Fti, Fti is the unreliability. Unreliability or the failure probability. So, what is the failure probability? Failure probability is the number of failures divided by the total number of unit in time Ti. So, in Ti, Ti means when I say T1, T1 means one failure has occurred. T2 means second failure has occurred. So, whenever I am saying Ti means total I failures have occurred in time Ti but what happens this is a sample data.

So, it is not necessary that Ith failure whenever I say one failure so, whenever say one failure out of 10. So, that means 10 percent failure has occurred, but generally this is the sample data. So, in that case if I say 10 failures out of 10 failure let us say at 1000 hour it occurred then it will give us a misinterpretation it will say that unreliability is 1 at 10,000 hours, which is incorrect because if we take some more devices from the population that may work for 12,000 hours also 15,000 hours also.

So, what happens these data points which we have represented they are the they are not should not be taken at the end of the interval, whenever I am saying 1 out of 10 then it means that I am taking at the end of the interval first interval is taken at the end of the interval. So, we need to make certain corrections here so, that we are able to it should be a little less than 1 because first failure is occurring at some certain time which is less than that.

So, for doing that, we can use this formula that is median ranking formula that is 100 into I minus A upon n plus 1 minus 2a. So, generally this is called plotting points, because here FTi we plot it against the Ti. So, a varies from 0 to 0.5 whenever we do that, according to that, we will get the FTi.

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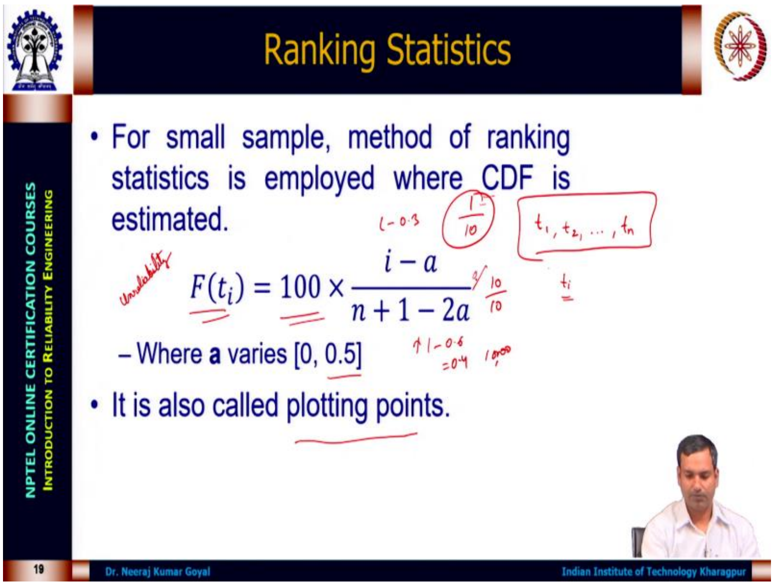

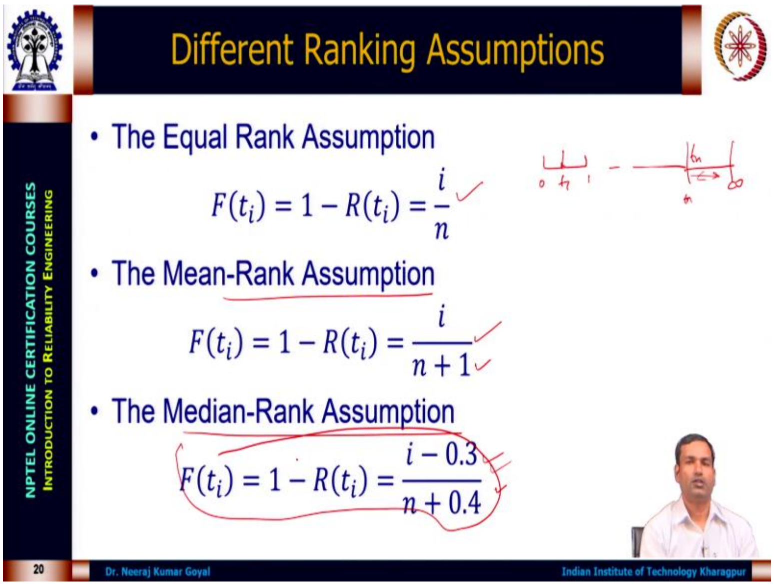

So, most appropriate value which you use is I minus 0.3, so, a value is 0.3. So, if I put a equal to 0.3, this will become I minus 0.3 and when I put equal to point this will become 1 minus 0.6 that is 0.4. So, I minus 0.3 divided by n plus 0.4 that is what we generally use for the FTi. So, we do not do percentage because we are working with probability. So this is in percentage. So, when we take probability that is the proportion so the same gives the proportion. So, this is the median rank assumption. Equal rank assumption means that data is assumed to be at the end of the interval.

So, we assume that exactly at this failure happen. So that is I opponent, but this can be generally when n is large, at that time, all three formulas will give you this almost similar values, but when n is small, that means number of sample are small, at that moment, this ranking will mat would matter that will give a little bit change. So, another most at mostly time used is the let us say first failure happens somewhere between 0 to first interval.

So, that is our T1. So, here what will happen nth failure, we will assume that there is one more failure at some other time infinity. So, that means that means nth failure is occurring in interval from n to n plus 1, which is somewhere in future. So, here what happens we assume that it is the interval point it is not the point at the, it is not single point it is the at some value at the interval. So, number of intervals becomes n plus1.

So, here we take an n plus 1 interval and for each interval we will have one failure. So that is how we try to we take the mean ranking assumption. So with this we will not get the failure rate 1 of failure probability 1 or reliability equal to 0, when last failure occurs. Similarly, we use the, so median rank assumptions is the most widely used assumption and whenever generally the data analysis is carried out by default, most of the methods are using this formula for the determining the FTi when Ti is given to you.

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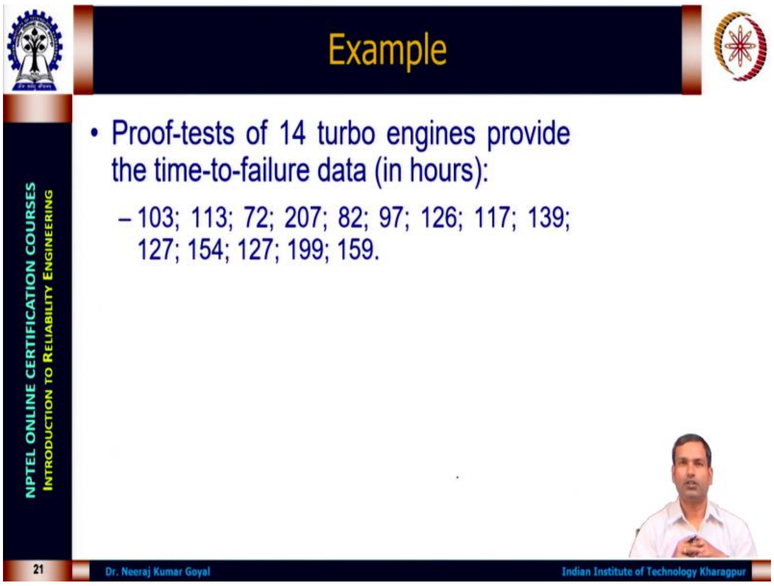

So, we will stop here today. We will continue our discussion with more examples and more patterns which we want to analyze. Thank you.