Six Sigma
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Lecture - 24
Process Capability Analysis : Key Concepts

Hello friends, hope you are enjoying the journey of Six Sigma and appreciating the various concepts I have covered as a part of our DMAIC cycle. I would like to remind you that we are discussing the various topics related to second phase of DMAIC cycle that is measure face and we are trying to appreciate the importance of measurement and the measure face issues. This lecture is 24 and we will talk about the process capability analysis some of the key concepts. We will continue our discussion on this very important topic and discuss couple of other aspects in the next lecture also. So, this lecture basically we will talk about the key concepts on process capability analysis.

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Now, let us begin with quite an inspiring quote if you cannot describe what you are doing as a process you do not know what you are doing and the quote is given by the renowned quality guru W Edwards Deming. So, here if I look at the word process capability then it says that what is the capability of my process? If my process is not at all capable then whatever I will do it will definitely produce the defective items.

So, if you cannot describe what you are doing as a process you are totally unaware ignorant you do not know what you are doing. So, here again its a noteworthy to say that you must understand the difference between efficiency and effectiveness. Effectiveness means doing right things and efficiency means doing the things correctly. So, if I am efficient, but not effective it has no value because I would be doing the thing correctly which is actually the thing itself is wrong. So, the first thing is to understand am I doing the correct thing right thing and then the question comes that how should I do it correctly.

Same applies to my processes and six sigma whether my processes really capable or not. If my process itself is not capable then whatever struggle I will do that all the struggle will be a wasteful effort and I cannot really conclude anything. So, my first attempt is to see that to what extent my process is capable to meet the specifications of the product or service and if it is not then what are the steps I can take to make my process capable.

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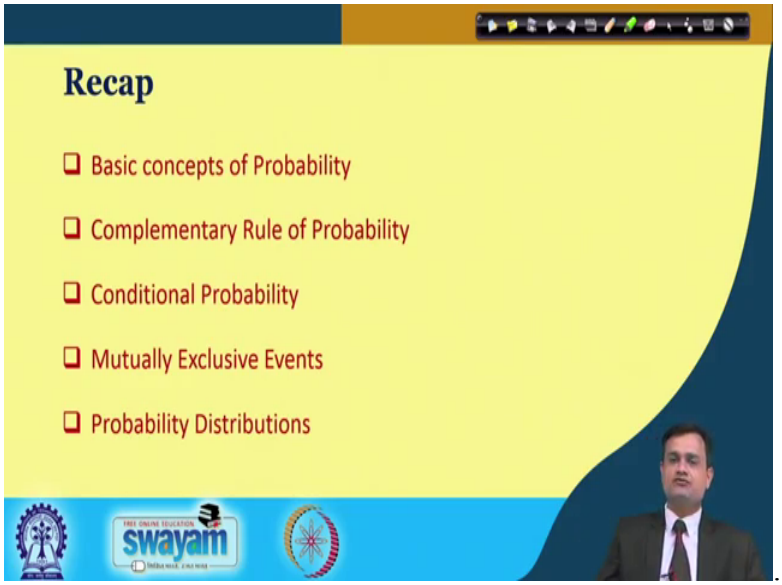

So, with this little understanding I can just give you the recap that we talked about some of the concepts of probability, which would now be extensively used in various topics, then we have seen the complementary rule, conditional probability, mutually exclusive events and some of the important probability distributions broadly in two categories one is continuous probability distribution like normal and I have said t-distribution and discreet distribution like binomial, hyper geometry, Poisson and so on.

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So, this particular lecture will focus on: first what is the need of process capability analysis? Natural process limits specification limits, control limits, tolerance limits, short term and long term process capability, difference between process performance metrics we have seen many like DPMO, DPU and others and if all those measures are there then, what is the need of some other measures like process capability indices. So, we will see some of the important issues in this lecture.

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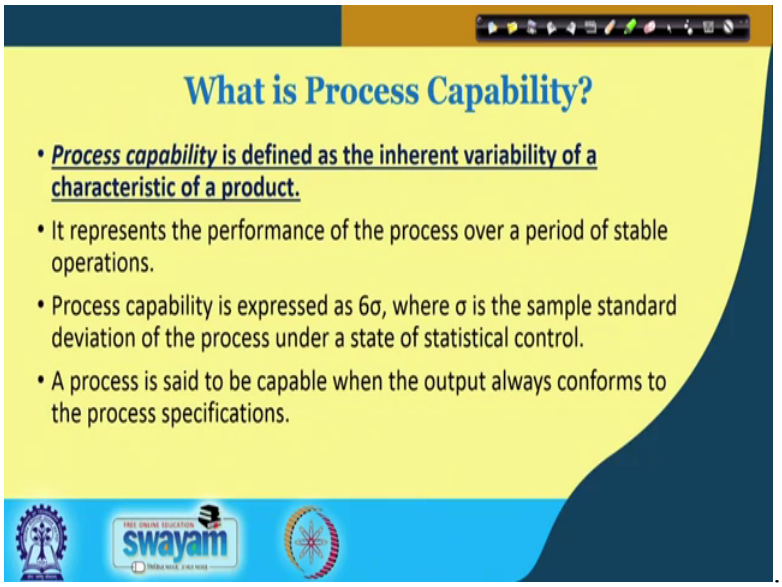

So, the first question what is process capability? So, you can see the line in bold underlined. Process capability is defined as the inherent variability of a characteristic of a product. So, when I am trying to analyze and capture this inherent variability of a characteristic of a product. So, characteristic maybe your diameter, thickness whatever is your interest of measurement then I am concerned about the process capability. So, typically it is expressed as six sigma and sigma is this sample standard deviation of the process which is under statistical control. So, it is very important to first check that whether my process is under statistical control or not if it is so, then only there is a point in conducting the process capability analysis.

If there are any assignable causes which can put my process out of the control and I am conducting the process capability analysis for such process it would be misleading. So, first I must bring my process under the statistical control and then I should see that yes what is my present process capability and how it can be improved. So, process is said to be capable when the output always conforms to the process specifications.

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Why to study the reasons are many just to summarize few predicting so as to hold tolerances. Many a times, designers they give the tolerances, but my processes are not capable enough to meet those tolerances. So, in this case I can have an idea that what is the capability of my process and to what extent it can meet the tolerances defined by the designer.

Assigning developers and designers in selecting and designing the processes because now you know what is the process capability? Establishing interval between sampling. So, this is also very important that I want to draw the sample to analyze, but I must see that what is the stability of my process and capability. So, this gives me a fair idea about deciding the interval between the samples. Specifying requirements for new equipment so, you want to purchase any equipment to meet certain standards produce a product with certain specification. So, it is important to see that what is the capability of this particular process basically an outcome of a particular instrument?

Selecting between vendors; here this is a very important point do not think that the final product if Maruthi is selling to consumer is just an outcome of Maruthi company itself. Maruthi purchases the components from various suppliers vendors and it is also important for a Maruthi to see that how capable their processes are. If their processes are not capable then they are producing more number of defectives parts are costly or the parts are of lower grade and when this is passed on in terms of cost in terms of quality to the Maruthi either it will have an impact on the final product price or the quality.

6th planning production sequence with interactive effects of process on the tolerances and reducing variability in the manufacturing process. So, there are various reasons that why should I conduct the process capability study?

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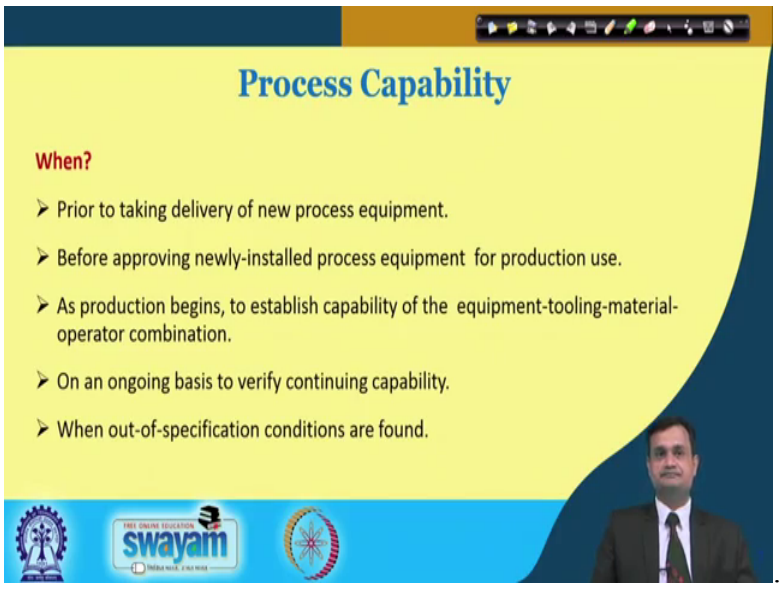

So, when there is a trigger that I should really go for process capability. So, prior to taking delivery of any no process equipment this is the first prerequisite requirement that I should conduct the process capability study. Second, before approving newly installed process equipment for production use. Let me first see the process capability and then let me go for the full fledged production. As production begins to establish capability of the equipment tooling material operator combination this study is required on an ongoing basis to verify continuity or continuing capability process capability analysis is necessary and when out of specification conditions are found.

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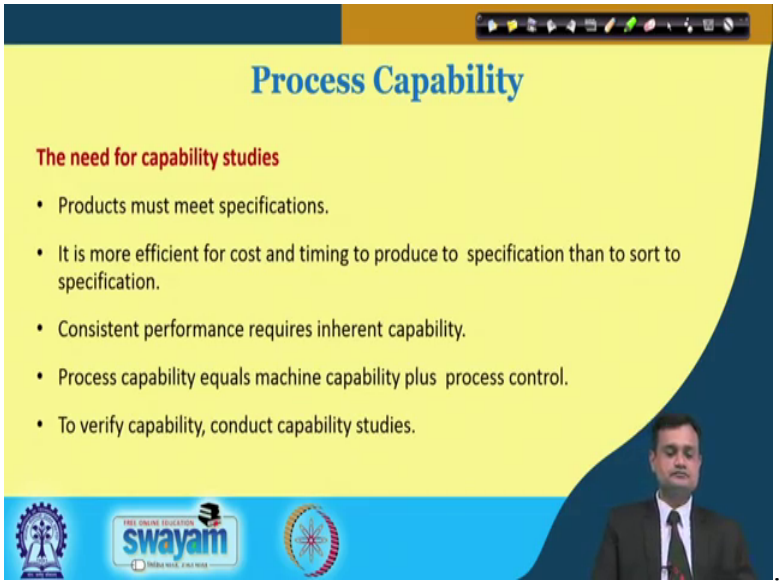

So, we have seen what is the need of process capability, basically to understand better how my processes are capable to meet the specifications and if there is any shift in the process mean then what will happen we will see through figures on my defect rate or the generation of the defective items.

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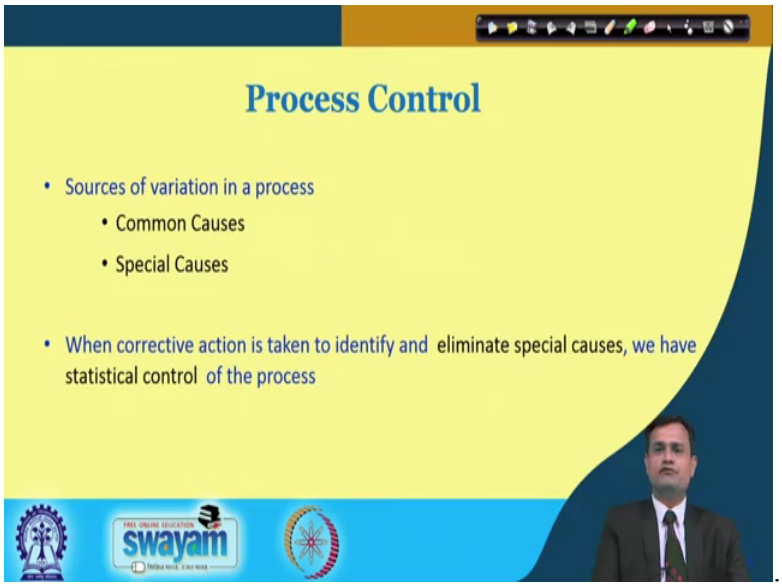

Now, before we extend our discussion there are some basic concepts to be appreciated. When we say statistical control or process control always remember that you cannot avoid all the variations and typically the variations are primarily because of common causes and special causes. If there are variances because of common or chance causes such variations are within the control and I do not much bother about the chance or common causes. But if there are special or assignable causes then some corrective action is required process need to be readjusted corrected and then only I can go for the process capability analysis.

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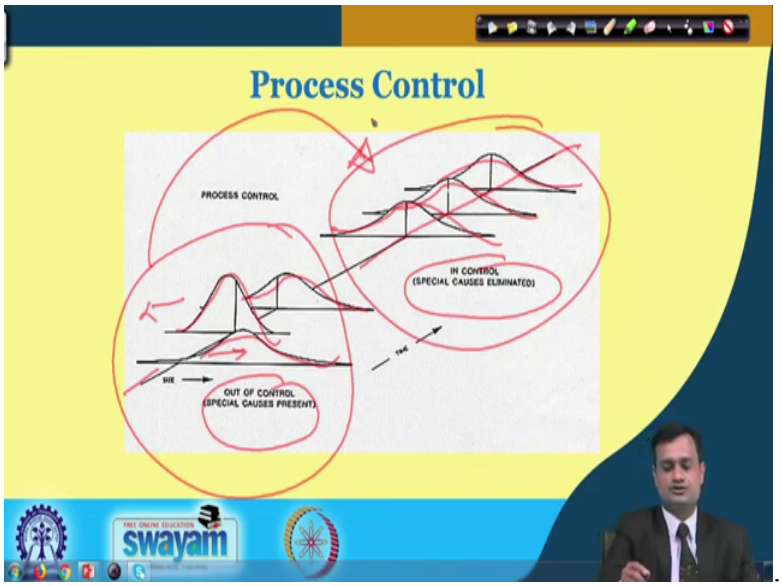

This is very interesting to appreciate just see that you have the process typically out of control. So, this indicates that there is a special cause present and why this is out of control? You just see that there is a mean value, mean line and this process is drifting from this side to this side and also there is a huge variation in terms of process variability. If you look at the processing control then more or less you will find that process variability remains same and your process is centered at a particular desired value. So, you have the process which is in control you have a process which is out of control and it is necessary that first you bring your process in control and then only you go for the process capability analysis.

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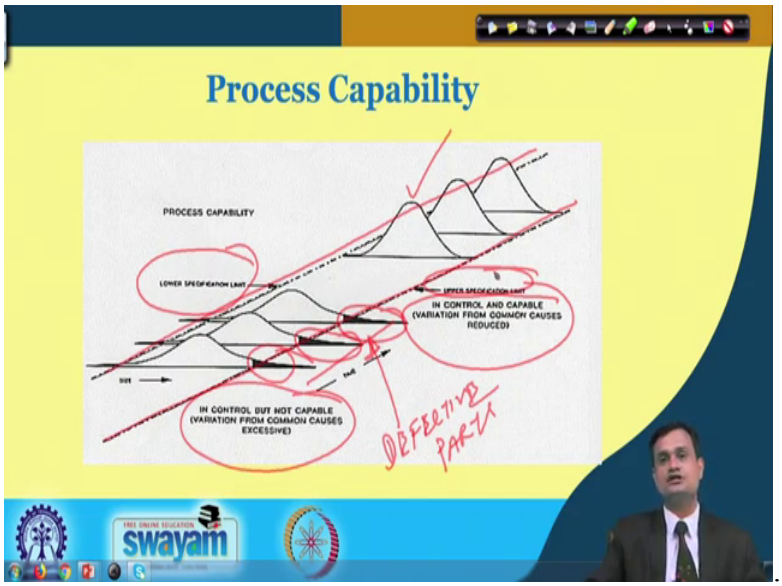

If you see this figure process capability then, you will find here that you have lower specification limit typically this one, you have upper specification limit typically this one and when you look at the process which is in control, but not capable. So, variation from common causes excessive what you will find that some of the portion which is shown in dark is falling outside the specification limit, this is basically an indication of defective parts. But when I look at this particular process which is in control and capable so, in this case I am not producing any defective component.

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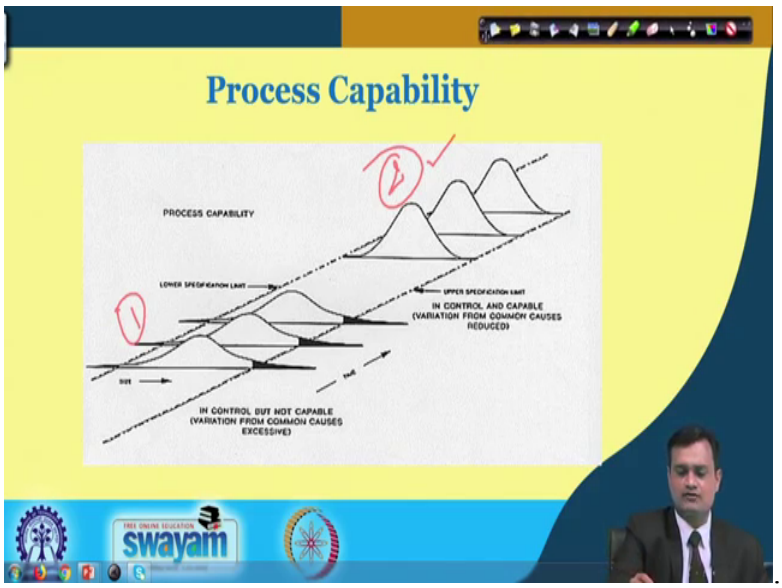

So, here both the processes they are number 1 and number 2 they are in statistical control, but one process because of common causes variability is excessive and producing the defective part and it is not capable wherein in case of 2 the process is in control as well as it is capable. So, I hope this would have cleared your understanding on what is the process which is in control statistical control and it is capable or not capable.

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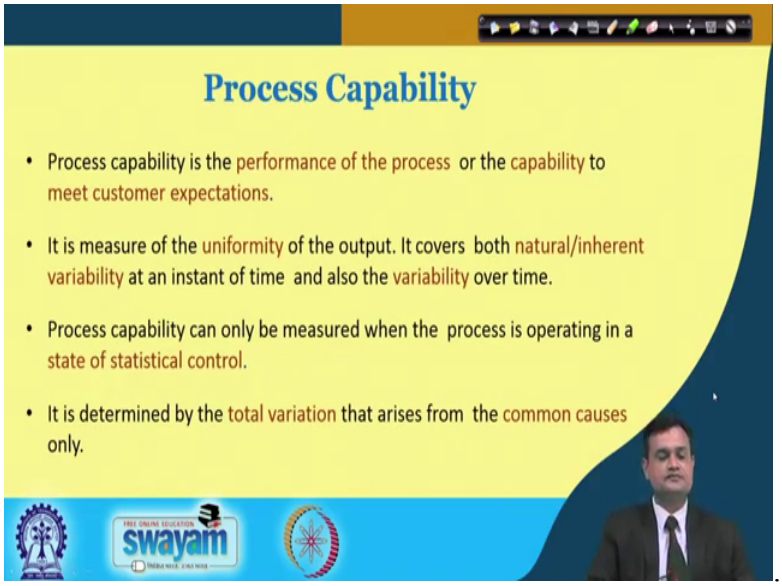

So, process capability is basically for indicates the performance of the process or the capability to meet the customer expectations and it measures the uniformity of the output covers both natural inherent variability at an instant of time and variability over a period of time.

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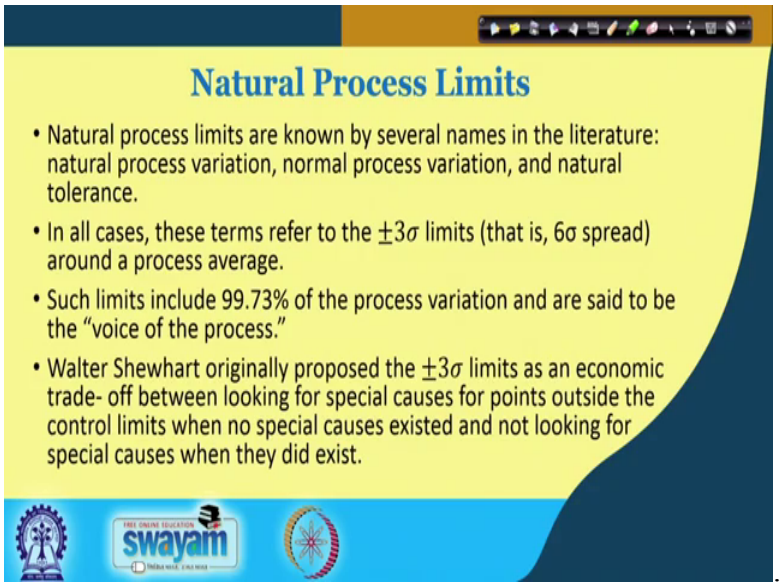

Now, I would like to introduce couple of important terms natural process limit one of them. So, natural process limits are known by several names and typically it could be natural process variation, normal process, variation normal tolerance, but basically they convey the same thing.

So, typically in all cases plus or minus 3 sigma limit sigma six sigma is the spread total spread on either side of the mean around the process average and such limit basically include 99.73 percent of the process variation and typically are said to be voice of the process. So, if you recall we have discussed about voice of the customer. So, that is customer can speak and he can have a voice, but yes your process also speaks and it is in terms of control rejections defectives and we need to capture this voice also.

So, the Shewhart the godfather of statistical process control quality control proposed plus or minus 3 sigma limits as an economic tradeoff between looking for special causes for points outside the control limit when no special causes existed and not looking for special causes when they did exist. So, typically this kind of phenomena is called type one and type two error. When I conduct the analysis there is a likely possibility that I may say that my component is defective, but actually it is not or I may say that my component is acceptable, but it is actually defective.

So, when we have to see the tradeoff between this type one and type two error the most economical tradeoff you get at plus or minus 3 sigma because when you increase the try

to reduce the type one error, type two error increases in same way when you try to reduce the type two error, type one error increases.

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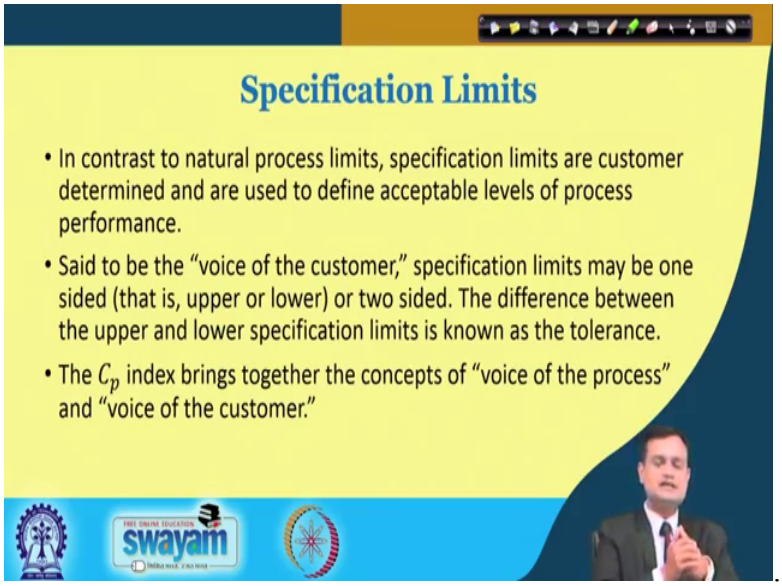

Now, you have the another term that is specification limits. So, specification limits basically they are determined by the customer given by the customer and these are used to define the acceptable levels of the process performance. So, my process should deliver the product which is acceptable to my customer and my customer believes in this specifications. So, I must have the process voice of the process which is capable enough to meet this voice of the customer that is the specification.

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So, there is a one to one relationship between vop voice of process and voc voice of customer. So, just see the example to clarify specification limit. There are limits on a product characteristics of individual units put by the designer for proper product function and suppose I say that is a diameter of the pipe 20 or minus 0.5 mm I will say upper specification limit is 20.5 mm lower specification limit is 19.5 mm. My process must be capable enough to produce the pipes in this case of such a specification.

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Now, there is another say issue that you talk about sometimes control limits, sometimes specification limit what is the difference. So, specification limits relate to the need of the customer given by the customer and which are analyzed and built into the design. So, these are limits on a product characteristic for individual units put by designer for proper product function. Now, if you see the control limit they are identify they identify the variations that exist between sample or subgroups of the measurement and they do not apply to individual unit unless the control chart is for individual measurement.

So, in summary control limits reflects the variability of the process I must try to control the variability of the process and have no relationship to the specification limit with relate to the need of the customer.

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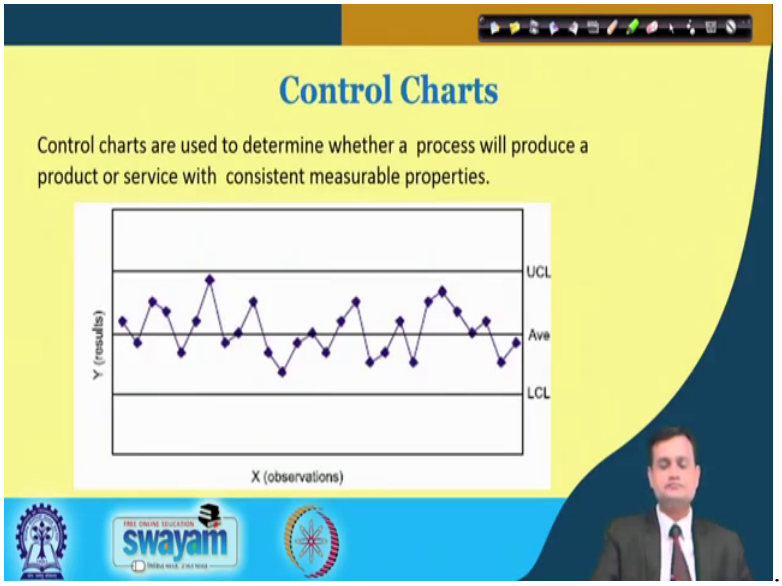

We will see in detail the control charts, but because we are discussing about the control limits I will just try to say that this is a typical process where you are taking X observation and you have Y results. So, I would like to say set upper control limit lower control limit and average and so long the variability means you can see the plot and you can see the data point. So, long they are within this particular limit not even depicting a particular pattern then, I can say my processes within statistical control.

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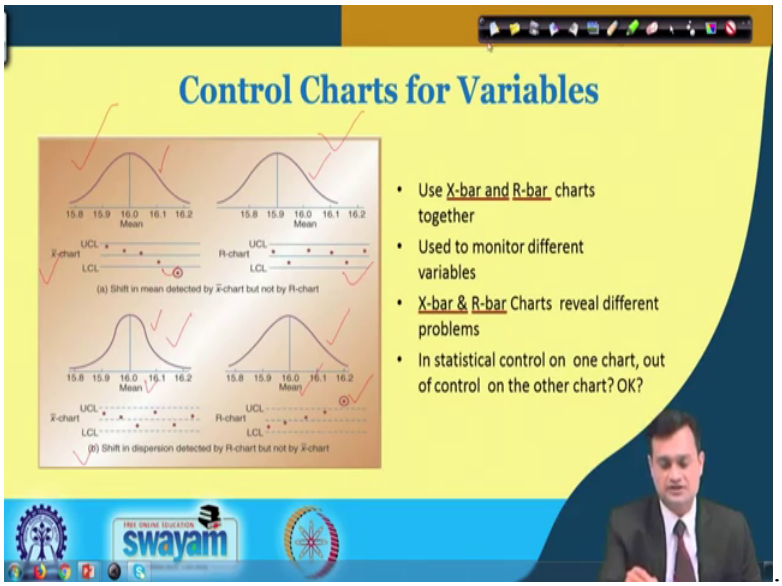

So, you have control charts for variables we have a session on this. So, X bar chart R chart for variables and used to monitor the different variables. You have X bar and R chart reveal different problems and in statistical control on one chart out of control on the other chart. So, just see the figure here what you can see here that this particular figure has a particular process typically depicted by bell shape curve and it has a mean 16. I have another process it has a mean 15.9 and when I put X bar chart and R chart I can see that on R chart the measurements are within the limit on X bar chart this particular measurement is falling outside the lower control limit.

So, there is shifting mean detected by X bar chart not by the R chart. So, as we know R is related to variability X bar is related to the mean of the process. So, this indicates that there is a shifting mean. If you see the b part then, I have a process described by bell shaped curve mean 16 again mean 16 there is no shift in mean and you will see that the point is falling outside the control chart on R bar and this says shift in dispersion means my mean remain same, but because of some reason the variability has increased. So, you can see in this variability graph is same here the variability is less variability as increased. So, this figure can help you very much to understand and differentiate the difference between an utility of X bar and R chart.

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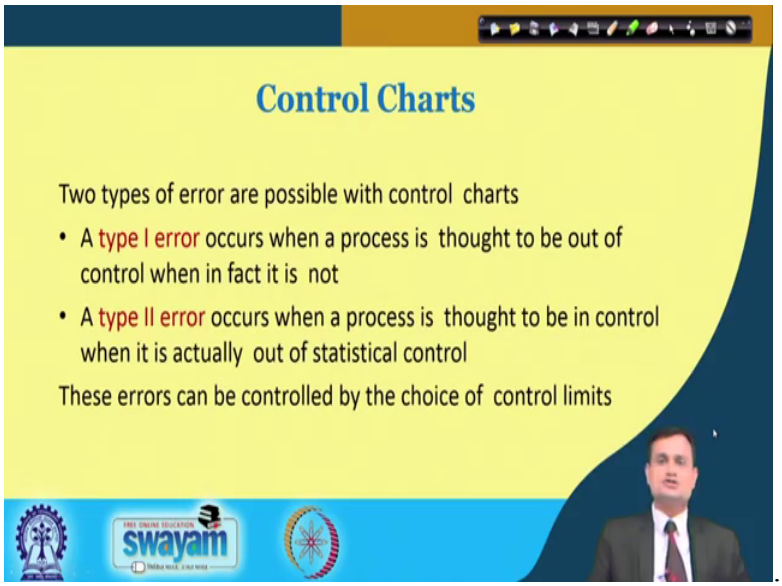

So, control charts as I mentioned typically we deal with type I error and type II error and type I error occurs when a process is thought to be out of control when typically it is in the control and type II error then process is thought to be in control where it is actually out of statistical control. Just think more practically to appreciate the importance of this type I and type II error suppose there is a judiciary system and innocent person is funniest declared guilty. This error clearly indicates that it is a type I error because you are rejecting the part when it is of acceptable quality, you are punishing the innocent when he is actually not and this is type I error.

Type II error is the reverse case when you are say exempting the person giving no punishment when actually he is guilty. So, many a times say it is difficult to see the tradeoff between type I and type II and it is quite say dependent on the context if you see in the judiciary system then should I accept the higher type I error or a type II error. So, if you look at the type I error I am punishing an innocent person when he is not guilty the societal cost is very high moral ethics will be diluted.

But if you see the second case fine my judiciary system has made the mistake not punished the guilty one, but because of his attitude nature and habit if not today tomorrow he will be captured and in this kind of case it is always better to have a statistical system which can have less type I error and I can afford to make type II error.

So, this is a trade off and contextual as I mentioned squad suggested the most economic trade off you can have by having plus or minus 3 sigma limit.

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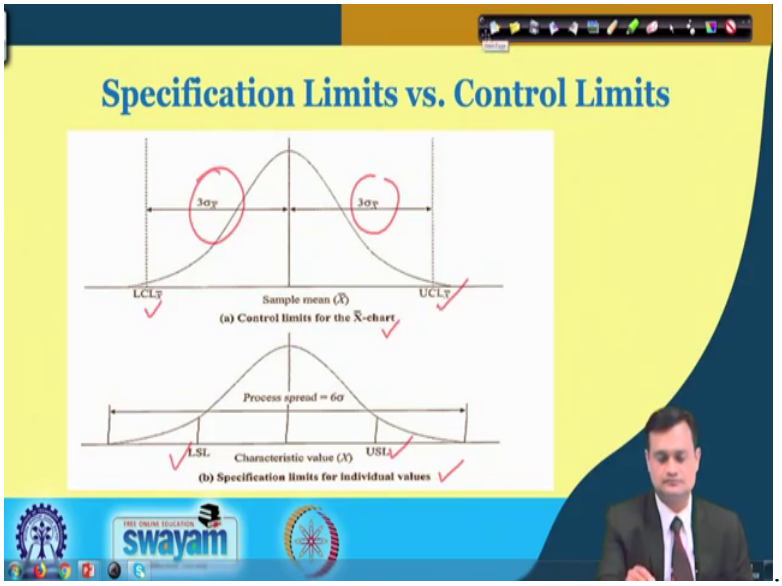

So, here we have compared specification limits versus control limits and you can see that you have the lower control limit upper control limit placed at plus or minus 3 sigma X bar specific store spam sample and here you have lower specification limit and upper specification limit. So, please try to appreciate that you are the control limits for X bar chart specification for individual value. So, these two are different things do not get confused control limits which are specific to process, the objective is to control the process and the specification limit the objective is to see that the parts I am producing meets satisfies this specification which are basically obtained from voc voice of customer and given by the customer.

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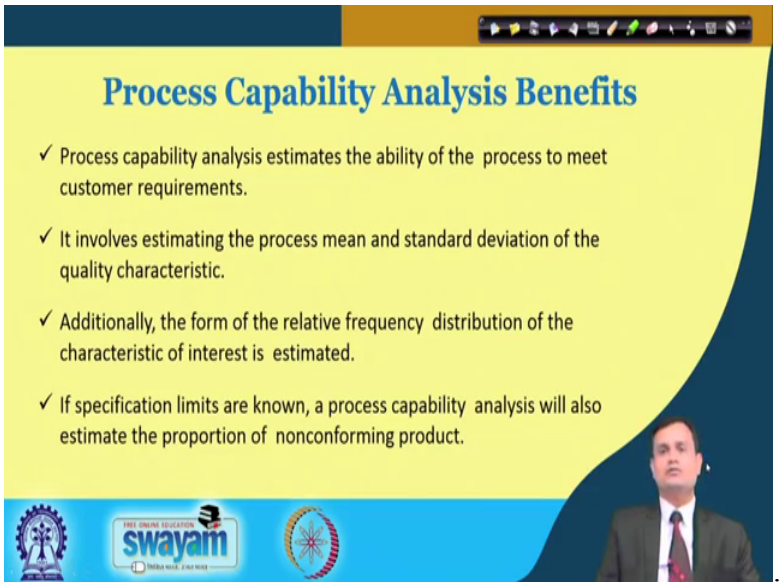

Now, the benefits we have seen that we can be more confident in our process. We can commit to our vendors and customers that to what extent our processes are capable in meeting the requirement and also if we have the fair analysis of process capability then, we can take the corrective action rightly because the cost of scrap is much higher than says cost of rework. So, many a times say if all together my components are going outside the control limit and I have to reject it then, it is better to take corrective action and put my process under the appropriate capability zone.

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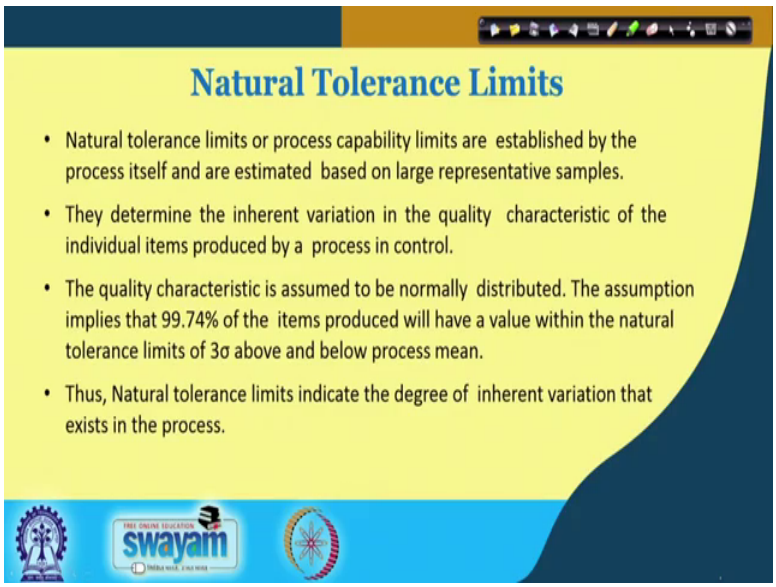

There is another term which is called natural tolerance limit. So, natural tolerance limit or process capability limits same thing are established by the process itself and are estimated based on the large representative sample. So, typically the assumption 99.74 percent of the item produce will have within the natural tolerance limit of plus or minus 3 sigma and this gives me more or less a good economic tradeoff. So, natural tolerance limits indicate the degree of inherent variants variation that exist in the process.

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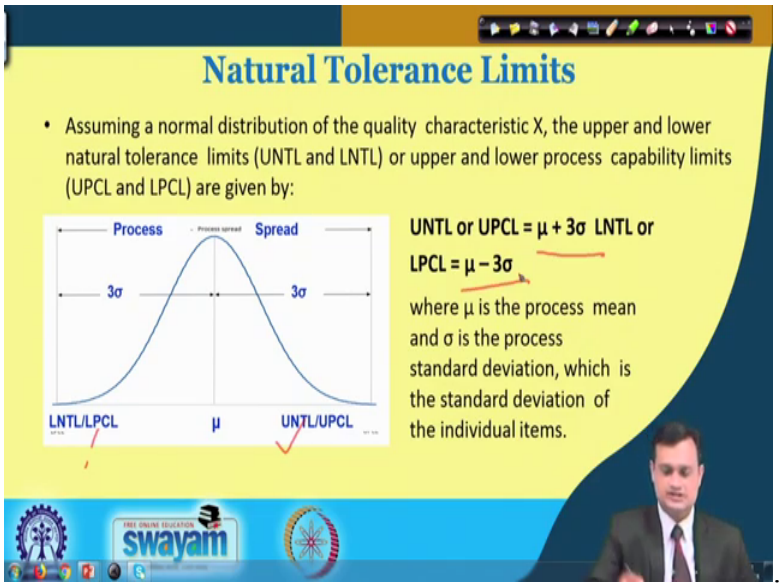

So, now here you can see very well. So, upper natural tolerance limit or upper process capability limit, lower natural tolerance limit or lower natural lower process capability limit and mu plus 3 sigma or mu minus 3 sigma is good enough to set my natural tolerance limit or the capability limit.

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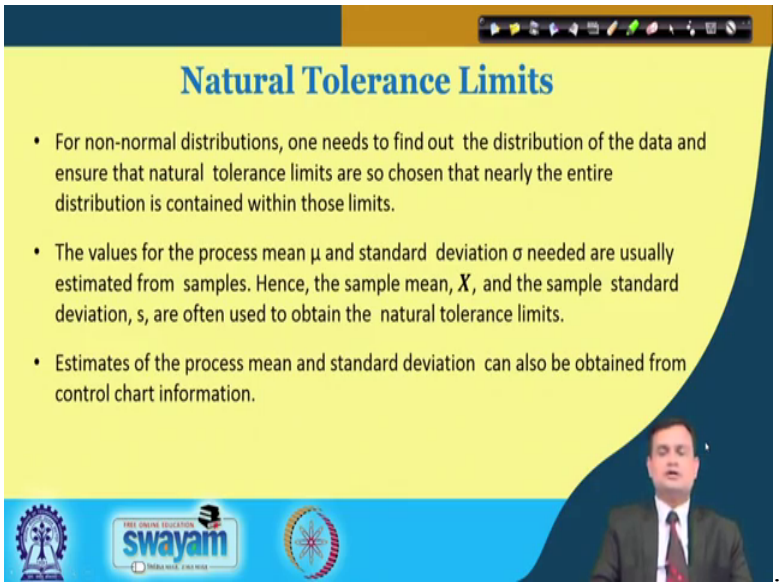

So, we may have whatever we have seen is mainly we have checked our understanding with the bell shaped curve normal distribution, but you can have non normal distribution. And in this case you need to find out the distribution of the data and ensure that the natural tolerable limits are so, chosen that nearly the entire distribution is contained within those limits just I would like to remind you that we have already discussed the relationship between mu and sigma through two different approaches one is Chebyshevs theorem other is the empirical rule.

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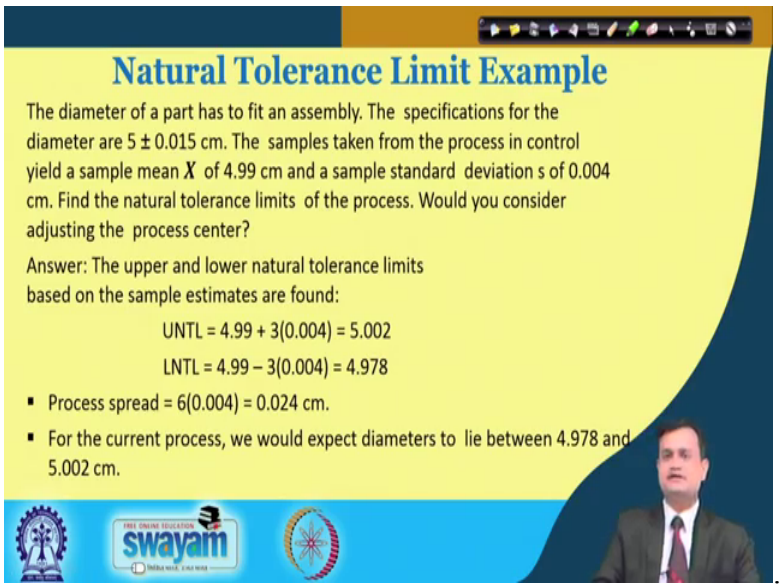

So, natural tolerance limit you can appreciate better through this example that let us say the diameter of a part has to fit and assembly and the specification for the diameter are 5 plus or minus 0.015 samples are taken from the process in control yield a sample mean X of 4.99 and a sample standard deviation of 0.004.

Now, find the natural tolerance limit of the process and would you consider adjusting the process center there is the question. So, I have plus or minus 3 sigma as a rule of thumb so, 4.99 is my say mean of my sample and 3 sigma, sigma is 0.004. So, what I get is 5.002 and 4.978. So, you have a process spread 0.024. So, for the current process we would expect diameter to lie fall between 4.978 and 5.002.

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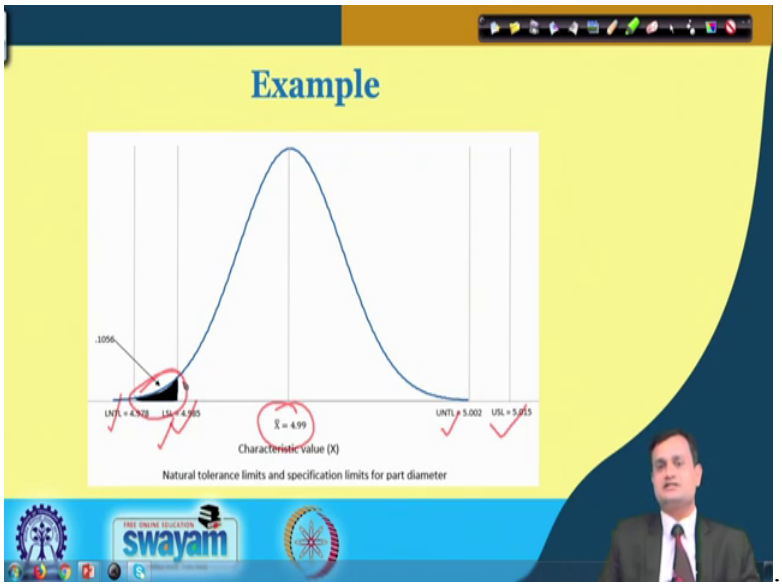

Now, just see here it is interesting, I have upper specification limit 5.015, I have lower specification limit 4.985, I have upper natural tolerance limit 5.002 and lower natural tolerance limit 4.978.

Now, if an and the mean is 4.099 if this is the case and presence status of my process you will see that this portion highlighted portion in black basically is an indicative of defectives I am producing which are not meeting the lower specification limit. So, this kind of process will have some defectives to be produced and I should try to see that this can be avoided because even if I go for the rework the cost is high and if I scrap the entire value addition is lost.

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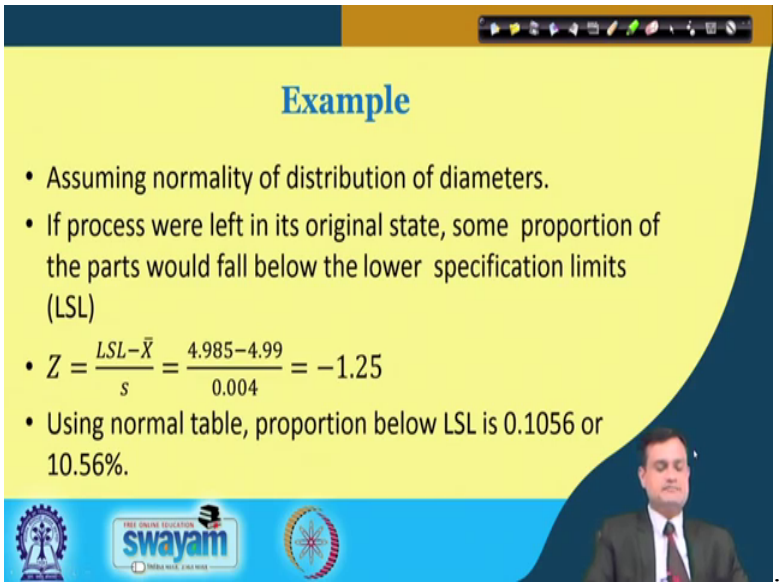

So, now I can take the example further Z is equal to LSL minus X bar divided by s. I am just plugging in the values 4.985 minus 4.99 divided by 0.004 which comes out to be minus 1.25 and I can use the normal table and find that what is the proportion or probability. So, 10.56 percent will fall below LSL and that I have to reject.

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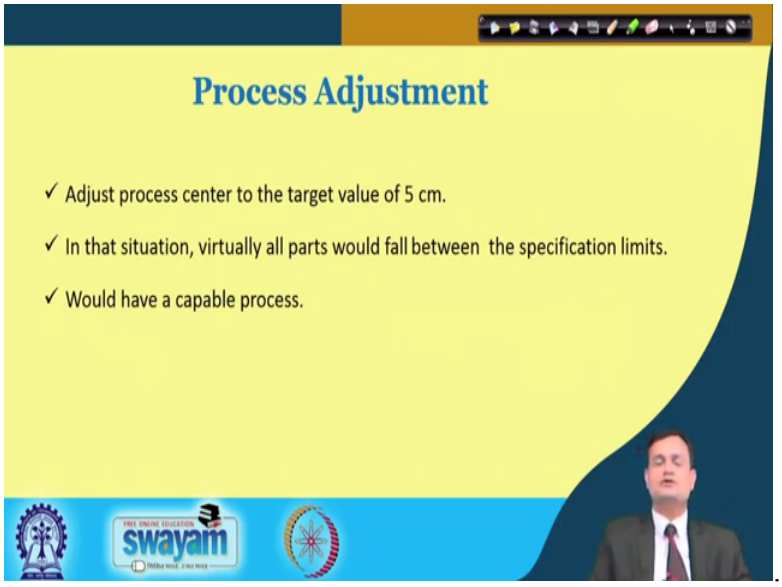

So, what to do now in this situation fine? I have measured, I have checked now what to do. So, you have couple of options number one adjust the process center to the target value of 5. So, you shift the process center. So, that automatically your entire process

will get shifted and probability of getting more number of parts outside the lower specification limit will reduce. In this situation, virtually all parts would fall between the specification limit and would have a capable process.

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So, we can just put it in a simple way that, I have a case I process spread less than specification spread. So, UNTL Upper Natural Tolerance Limit minus LNTL is equal to 6 sigma if this is less than specification spread USL minus LSL then the processes quite capable.

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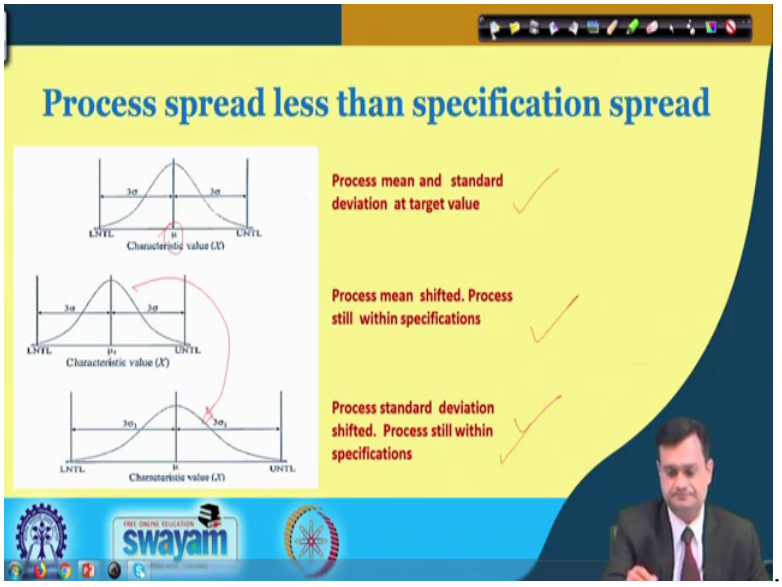

So, we can see it further just see that process spread less than specification spread in all the cases and first case process mean in standard deviation at target value, process mean in standard deviation they are at the target value, process mean little bit got shifted with respect to this and process still within specification because it is within the a your LNTL and UNTL and here process standard deviation shifted. So, you can see that there is a spread increasing spread so, standard deviation shifted still processes within the specification. So, fine this is the case where even shifting is taking place my shifting in terms of means shifting in terms of variability my process is still within the control.

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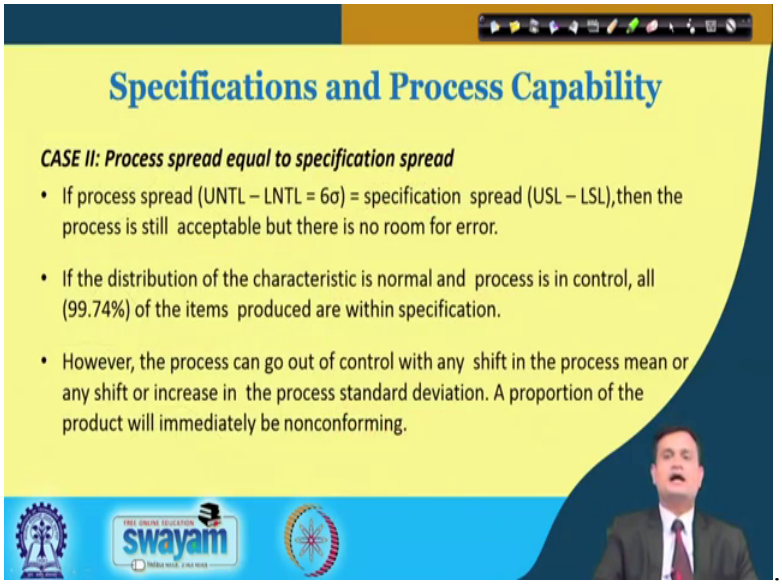

Now, I would try to describe the case II where process spread equal to specification spread. So, you have UNTL minus LNTL is equal to 6 sigma and exactly this interval equals to USL minus LSL. So, I will say that my process is barely capable enough to meet the requirement, but it can go at any point in time out of control.

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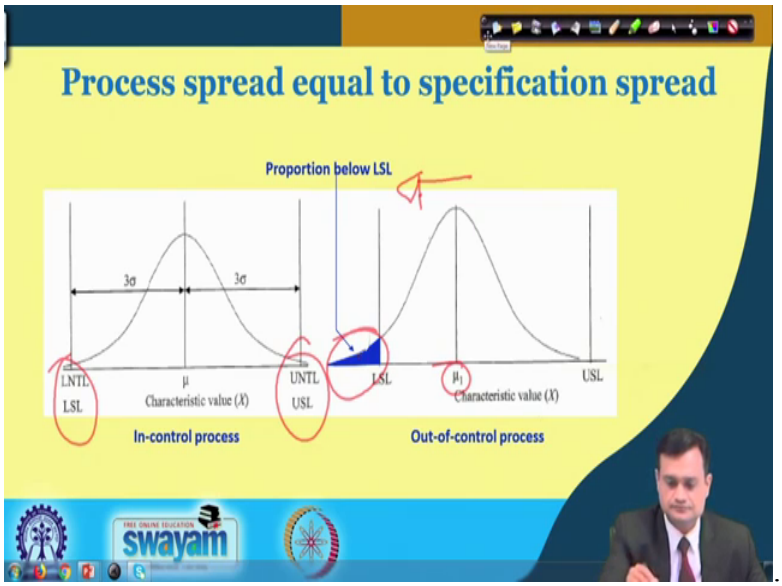

So, typically you can see here that you have LNTL and LSL matching UNTL and USL matching and my process is in control, but barely meeting the requirement the moment there is a shift mu 1 becomes mu; mu becomes mu 1 that is some shift on this side and because of this shift you would be producing this much of portion which is highlighted in blue as the defective. So, process is just capable.

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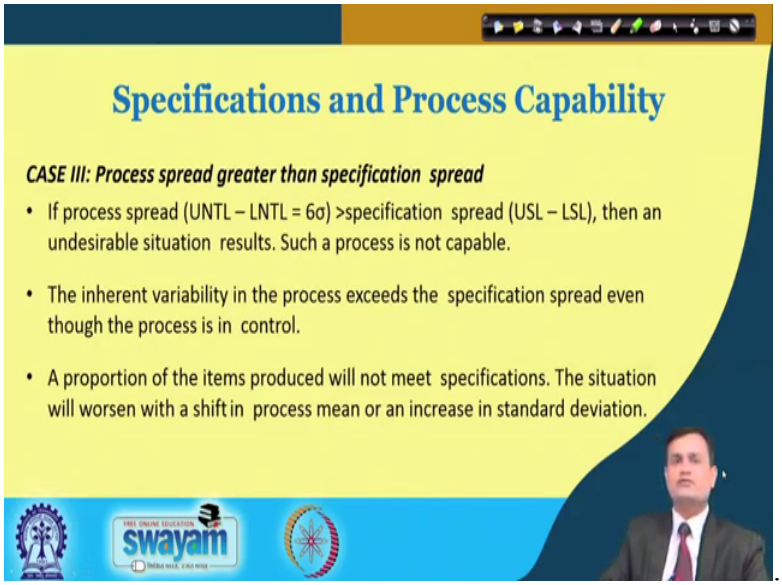

Now, you have case three were; obviously, you can understand that my UNTL minus LNTL is greater than specification spread then it is an undesirable situation.

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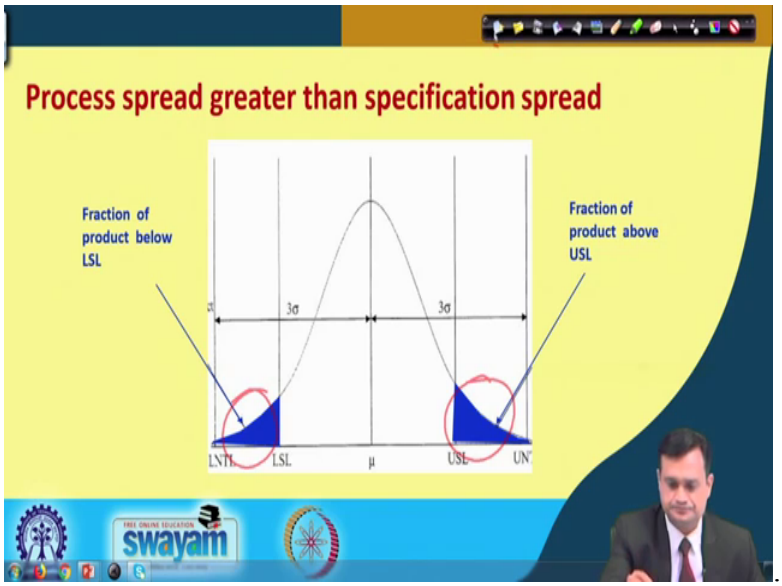

So, here I will have something like this specifications limits are closer and your natural tolerance limits they are wider. So, whatever you do your process is not capable and it will produce and the defective because your specification limits are closer. So, now the question comes what to do?

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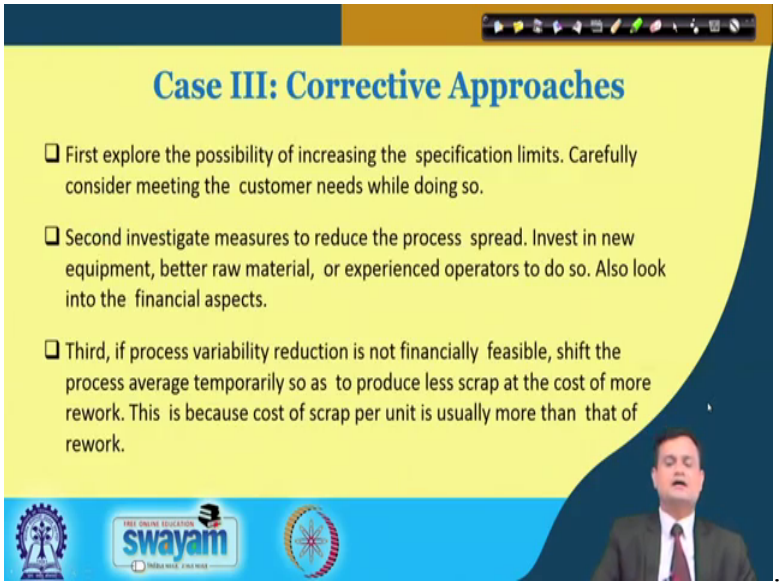

If this is the situation then what are the corrective approaches when my process is neither capable or barely capable it is not capable, you have three options or approaches available number one explore the possibility of increasing the specification limits. Many

a times, designer customers they are fascinated by some specification limit which are actually not realistic or required. So, can you really change or increase the specification limit so, that it can meet your process capability.

If not second investigate the measures to reduce the process speed. You try to make your process more centric towards the mean value so automatically your upper natural tolerance limit and lower nature transfer limit will come as a within and you would be able to meet the requirement. Third if the process variability reduction is not financially feasible shift the process average temporarily this is a temporary measure just shift. So, that you can at least correct because the cost of rework is less than cost of scrap.

So, suppose let us say in this case if you have produce the components on higher site this particular side let us say then, you have the possibility suppose it is a diameter you have produce oversized diameter extra material you can rework it and reduce it. So, it is the rework cost is there, but suppose it is like this now you cannot add the material you have to simply scrap it. So, in this situation you shift the mean on the desirable side and try to see temporarily that you can reduce the amount of scrap and you can at least have some reasonable situation where cost of rework is affordable. So, these are couple of issues that is specific to process capability.

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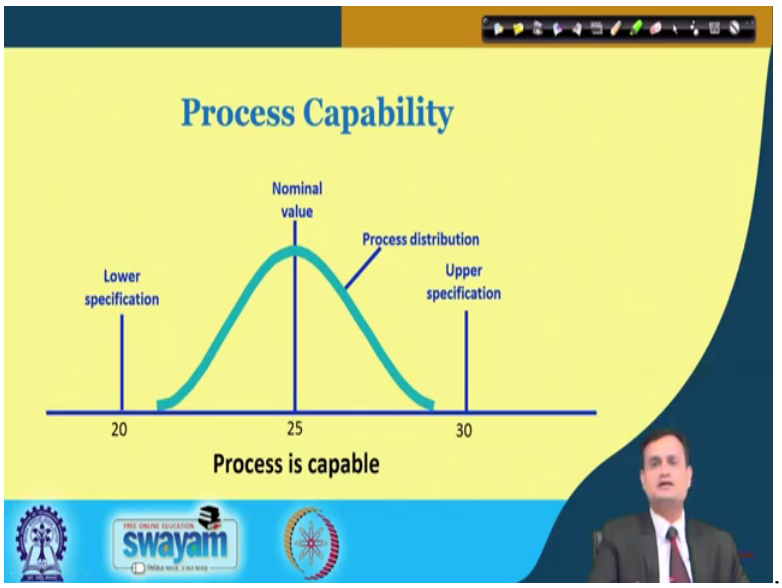

You can see processes capable specification, limits are wider, variability is very less even if your process will dance in between drift in between you are in a comfortable zone.

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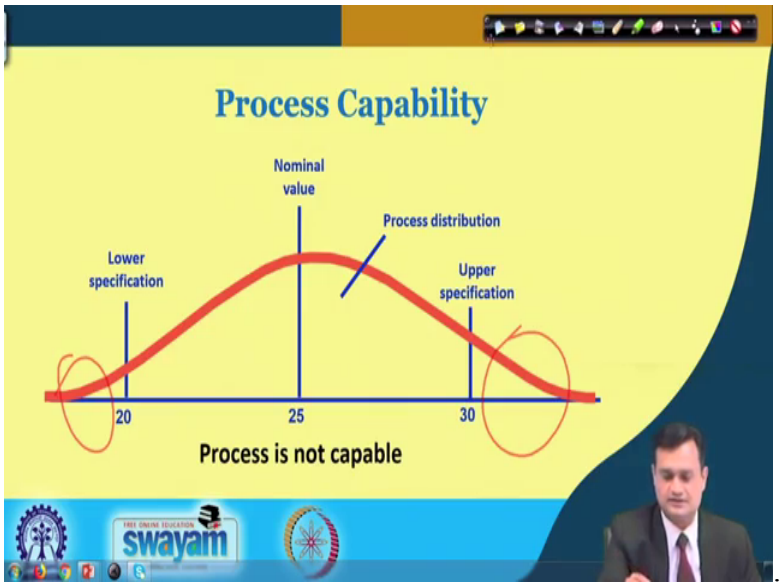

You have a process which is not capable it will be producing; it will be producing defective here and it is not capable process.

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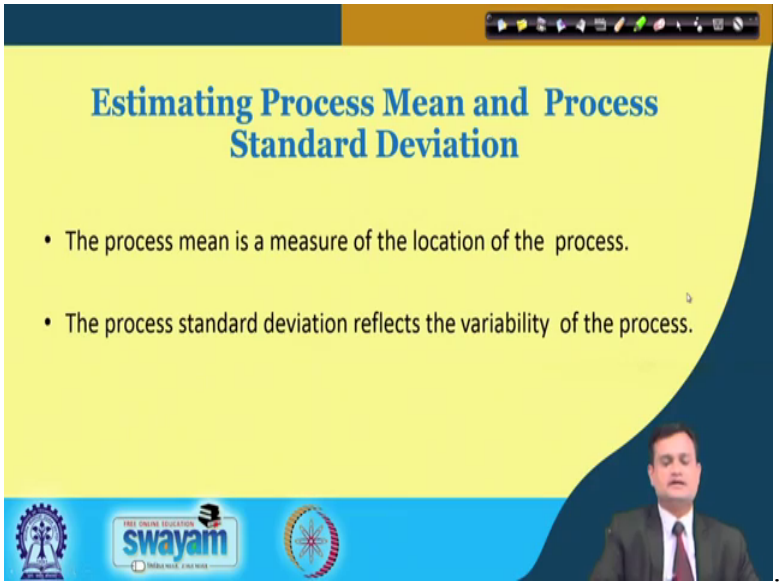

We can just see that how to estimate the process mean and process standard deviation. So, process mean is a measure of location of the process and standard deviation reflects the variability of the process.

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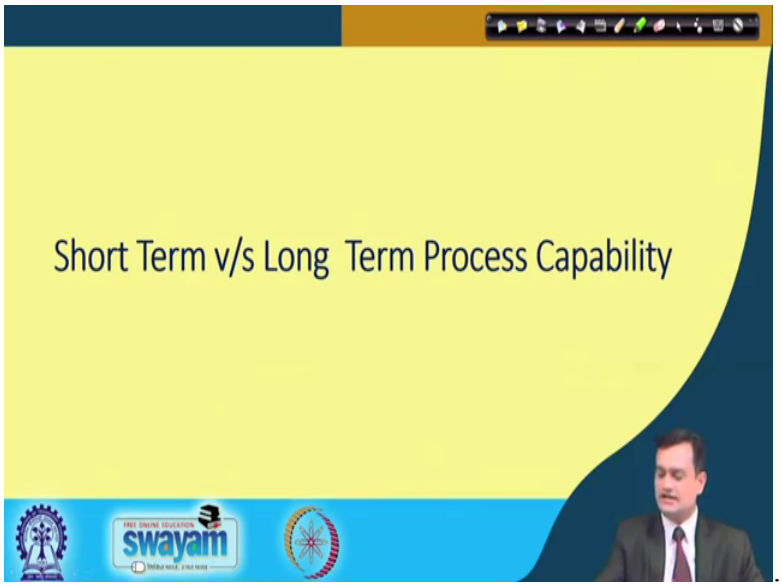

Now, there is something interesting to appreciate here, when we talk about process capability it is short term versus long term.

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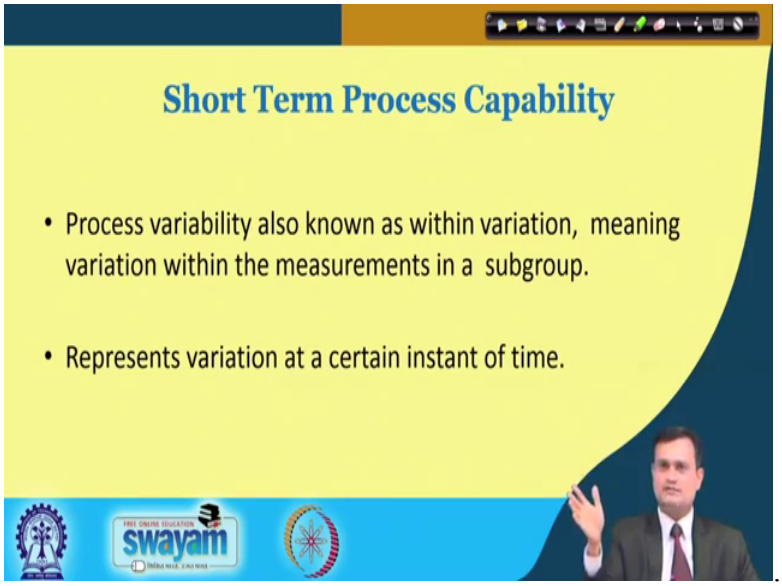

So, where is the short term it is basically within variation you have various subgroups samples when you try to study for that it is short term process capability for a particular instant of time.

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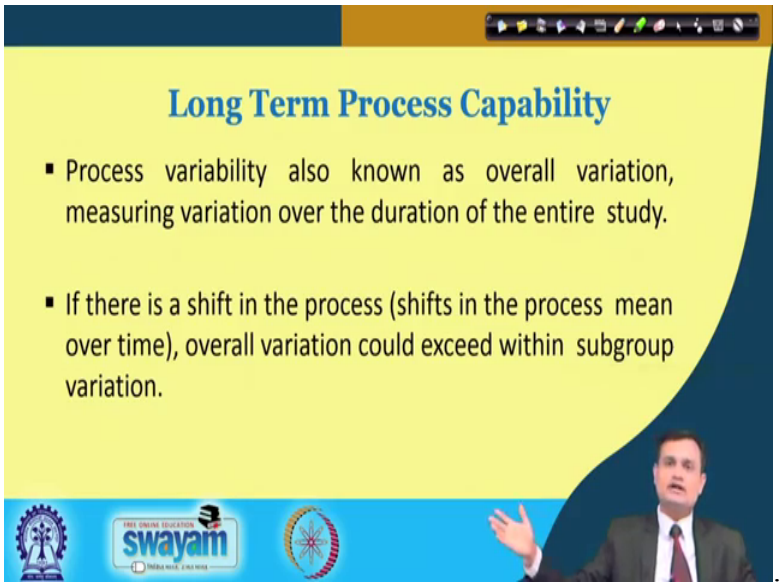

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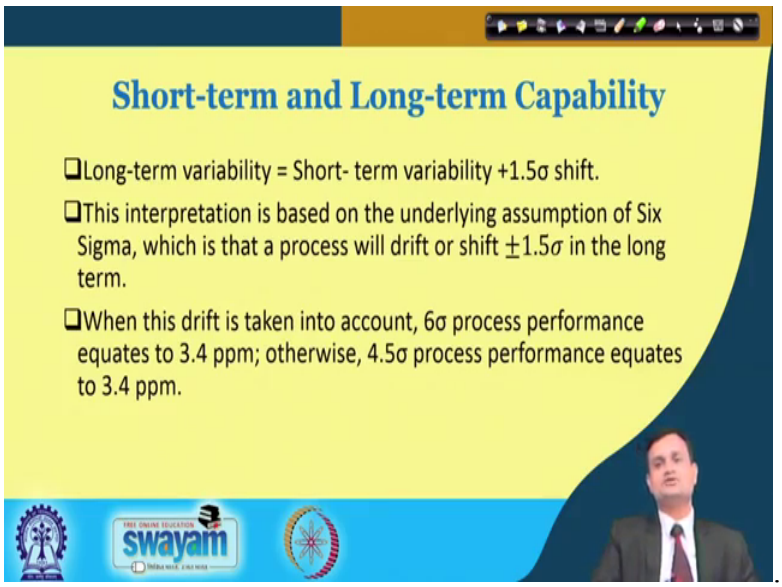

But when you study it over a an extended period of time large time then this process or entire process range, this is called long term process capability. So, long term process capability typically will be short term plus 1.5 sigma shift and this interpretation is based on my six sigma understanding we discuss in the basics that even if there is a shift in 1.5 sigma, my process should not produce anything more than 3.4 ppm say parts per million as defective.

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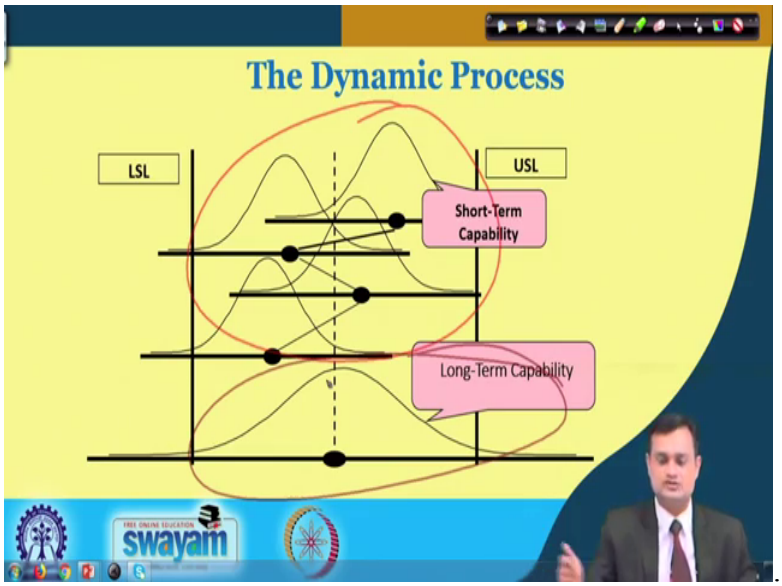

You can see the dynamic process and when I say short term process capability it is specific to this particular domain where subgroups or samples they are analyzed in terms of process capability when I typically say the process capability for long term then it is basically this long term process capability over the entire zone of the process.

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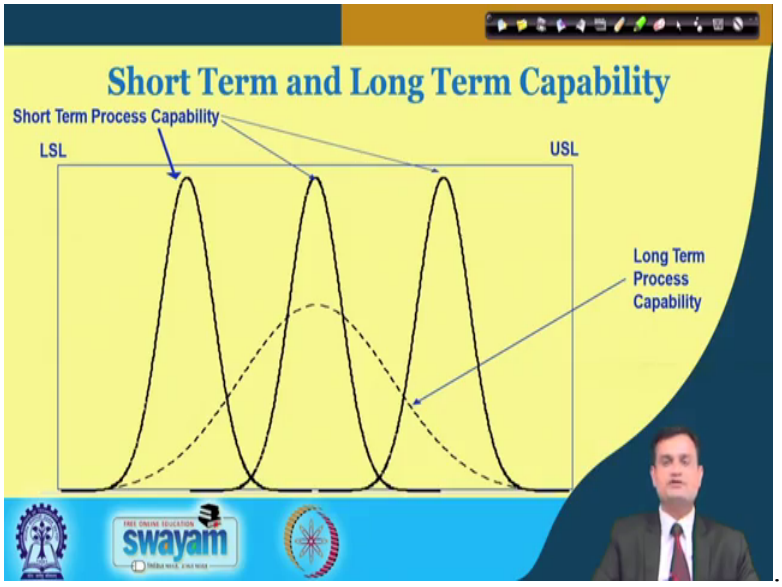

You can also see in a very simplified version here same thing this is your long term process capability this is your short term process capability specific to particular sub group or samples.

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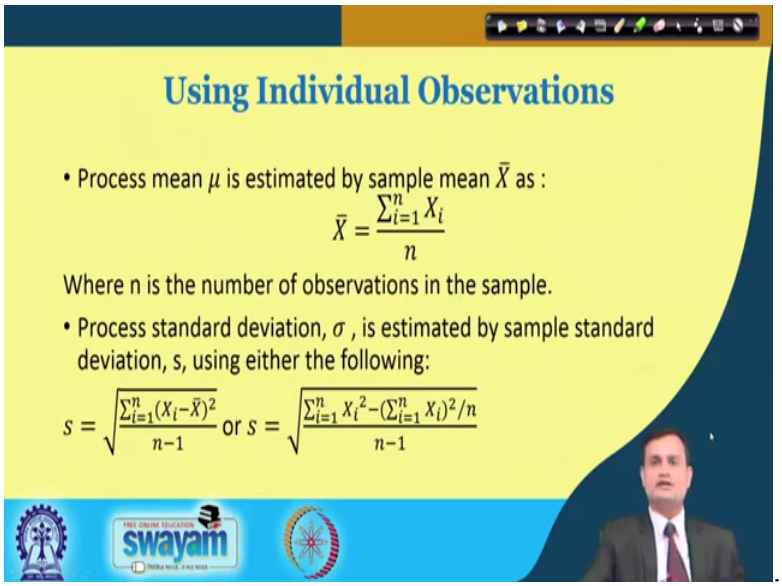

So, you can use this formulas for individual observation X bar you can estimate the value of sigma process standard deviation by sample standard deviation s using this expression which we have discussed.

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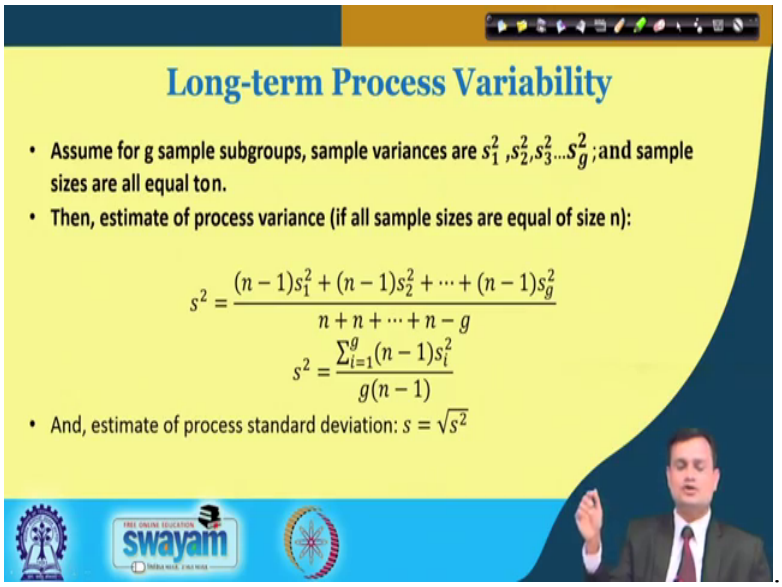

So, long term process capability or variability is captured through s square n minus 1 s 1 square n minus 1 s 2 square because you have different sample and hence the sample variability is different and then you can put n plus n if it is equal, if it is separate you

consider n 1, n 2 into and so on and this way you can consider the s square and square root of s square is processed under deviation s estimate of the process standard deviation.

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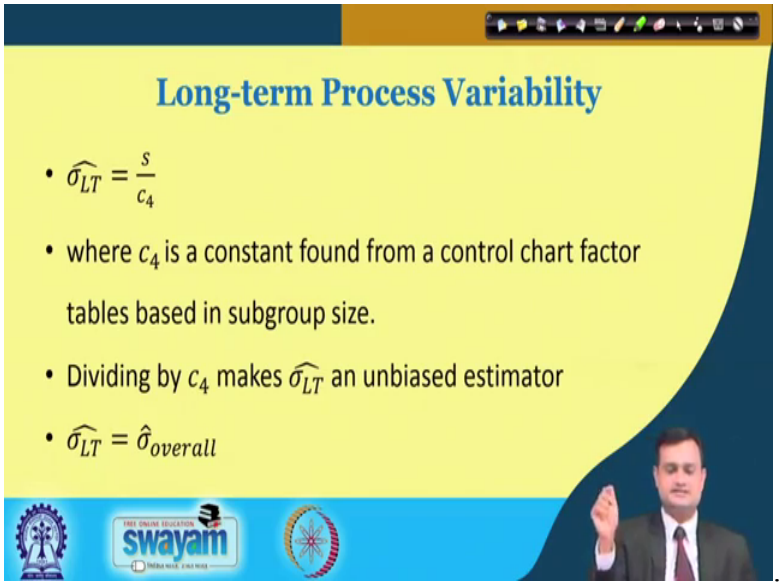

Long term process capability the h is basically a symbol for estimation I can make use of standard tables available in majority of the black belt quality control book and they give some of the standardized values of the constants like d 2 we have seen last two last time c 4. So, here s divided by c 4 constant you can find the standard deviation for long term process capability study.

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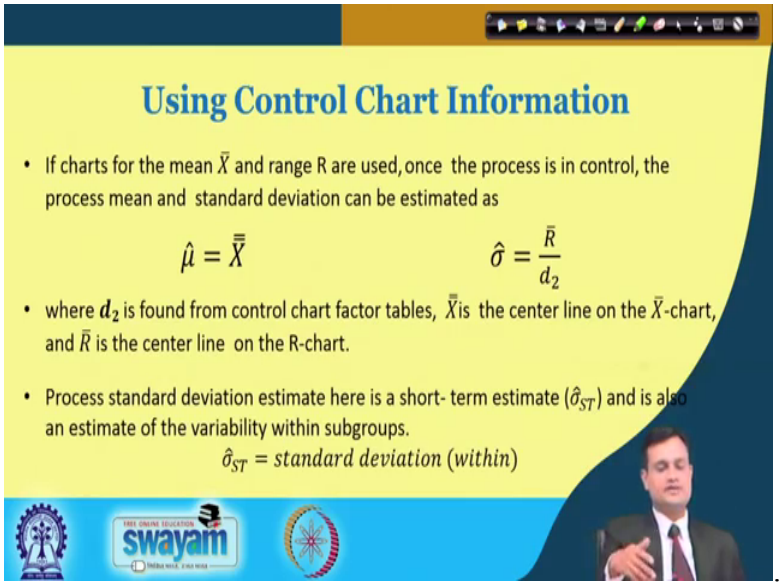

Similar way mu is X double bar R sigma estimate can be determined through R bar divided by d 2.

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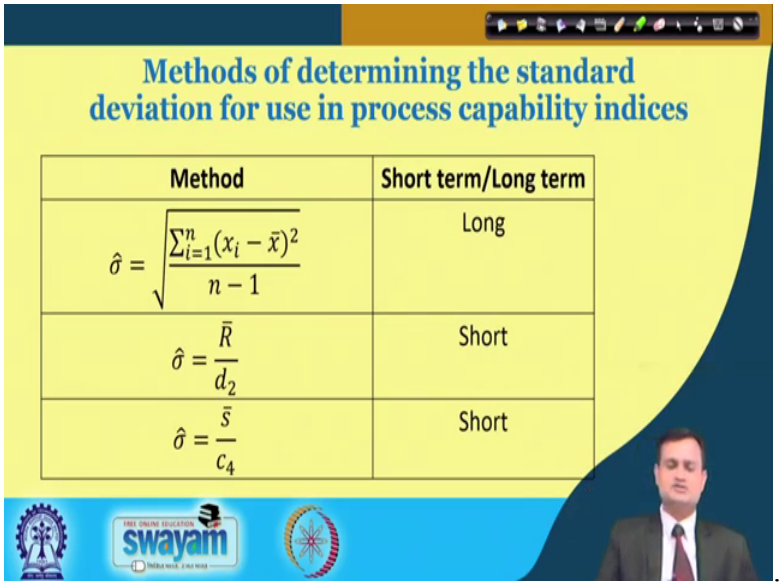

And your various methods of determining the standard deviation for using process capability indices it could be for long term and short term.

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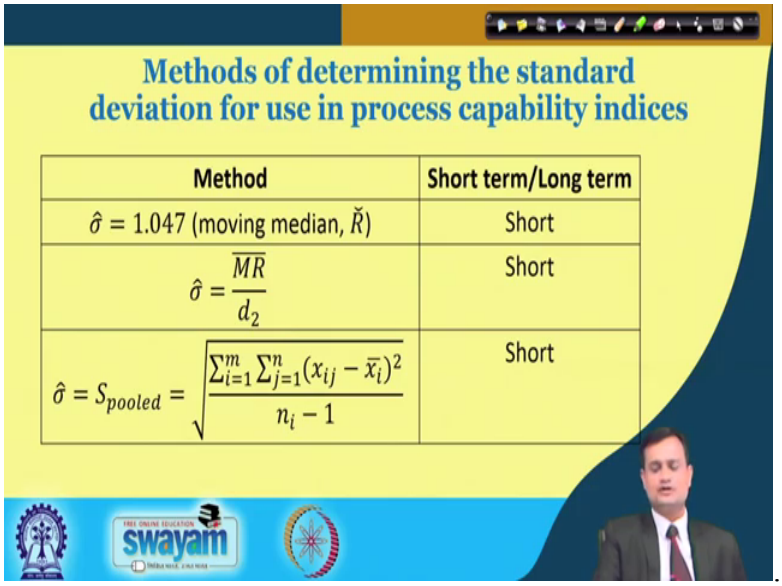

So, and this expressions we can easily use.

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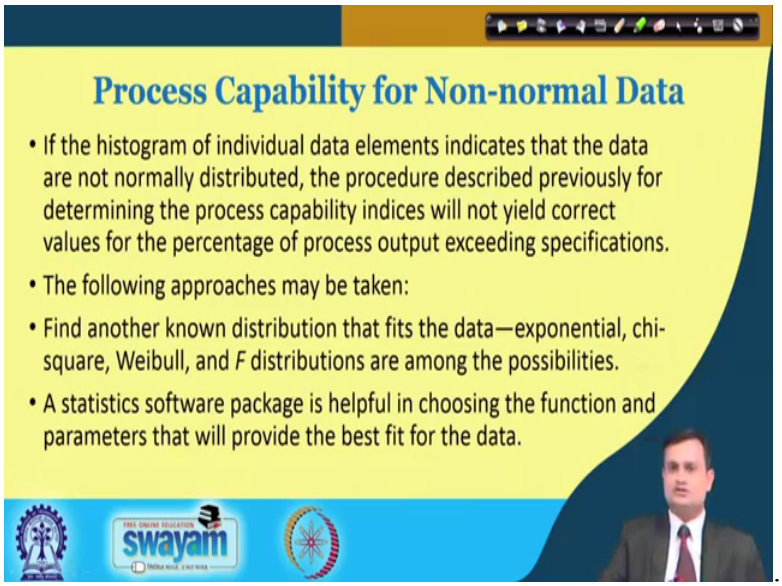

We can also conduct the process capability analysis for non normal data, but first we should apply some transformation to convert my non normal data either into normal or directly I can use some mathematical equations transformations to conduct the non normal process capability that we will see in the coming lecture.

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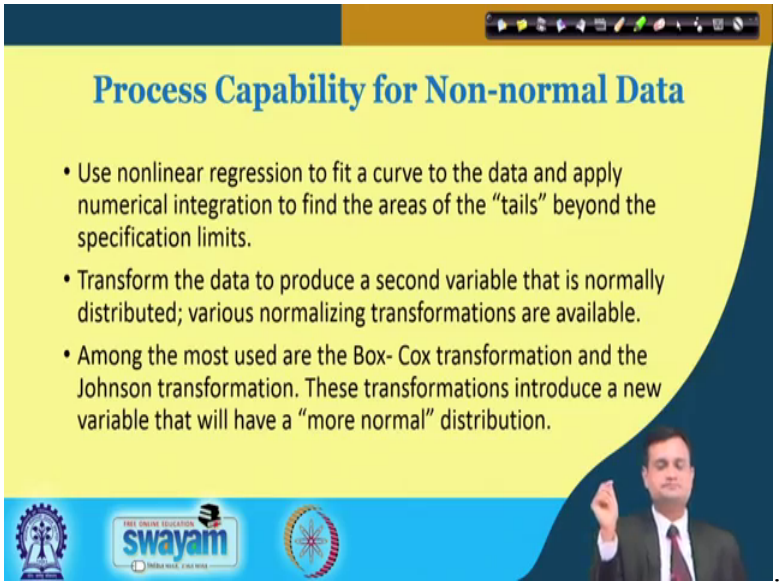

So, process capability Box and Cox transformation Johnson's transformation these are. So, they try to live the data using some transformation from the present non normal state

to normal state and then you can conduct the non normal process normal process capability.

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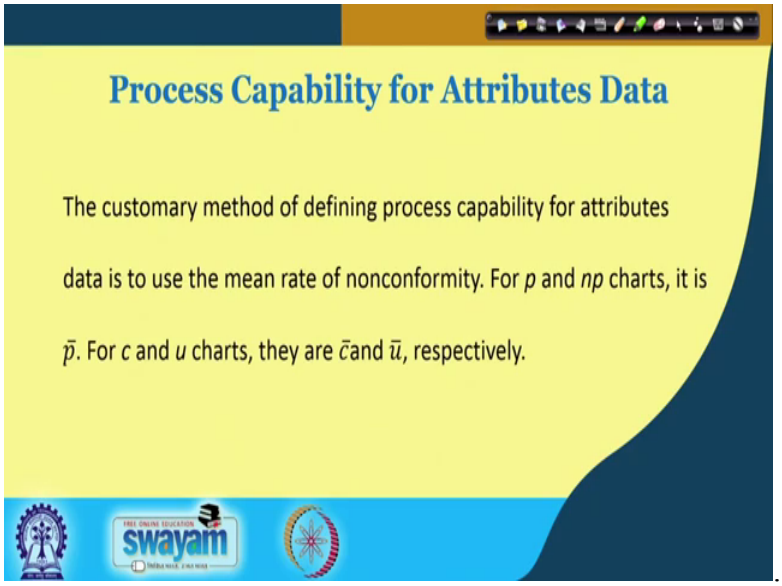

You can have process capability for attribute data typically the various charts we would be discussing later on c u c bar u bar that will help us to conduct the process capability for non normal

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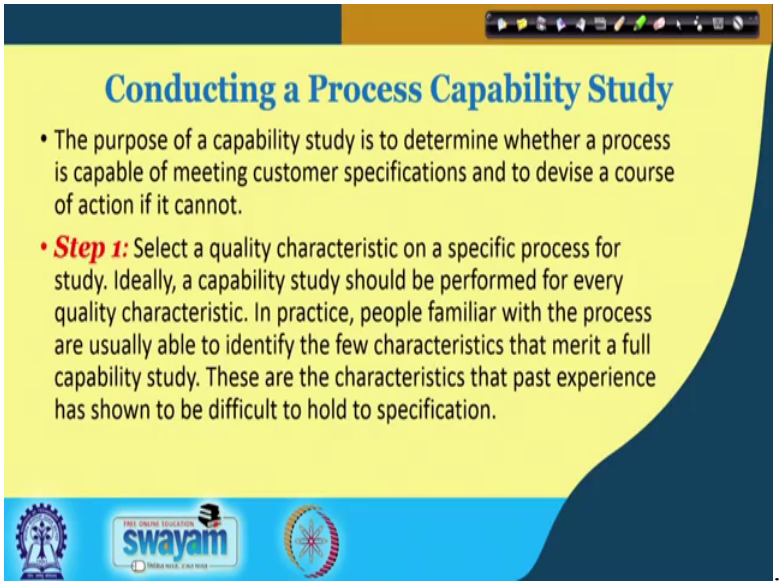

. So, I am just summarizing the various steps conducting a process capability study select the quality characteristic.

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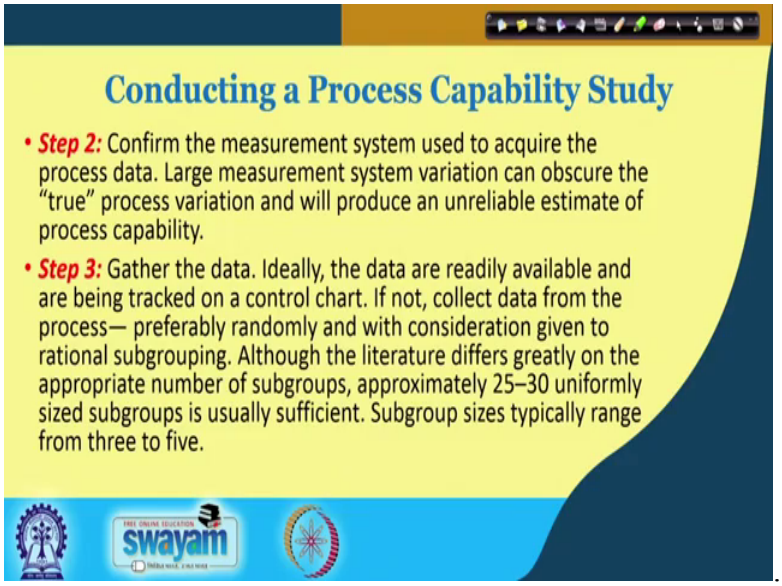

Confirm the measurement system, gather the data, verify the process stability it should be in the statistical control.

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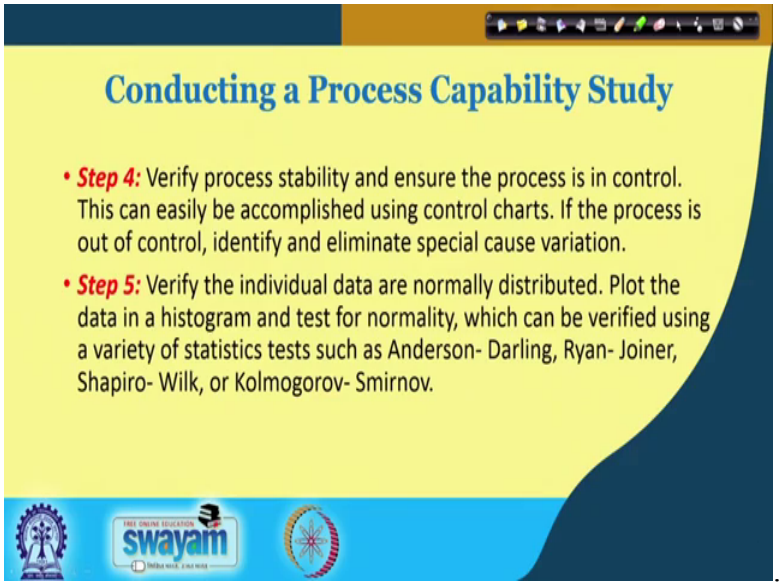

Verify the individual data and using a various statistics Ander-Darling then Ryan Joiner another you can also try to study the histogram and check the normality of the data.

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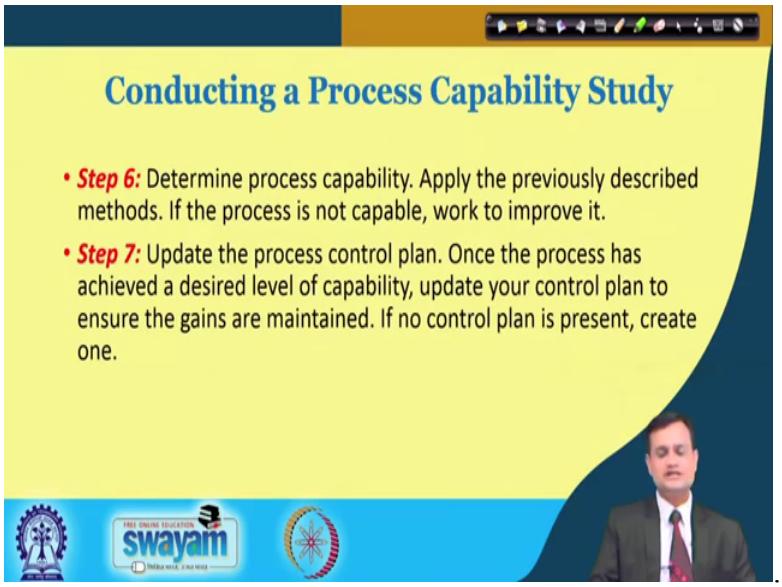

Determine the process capability apply the previously described method and update the process control plan.

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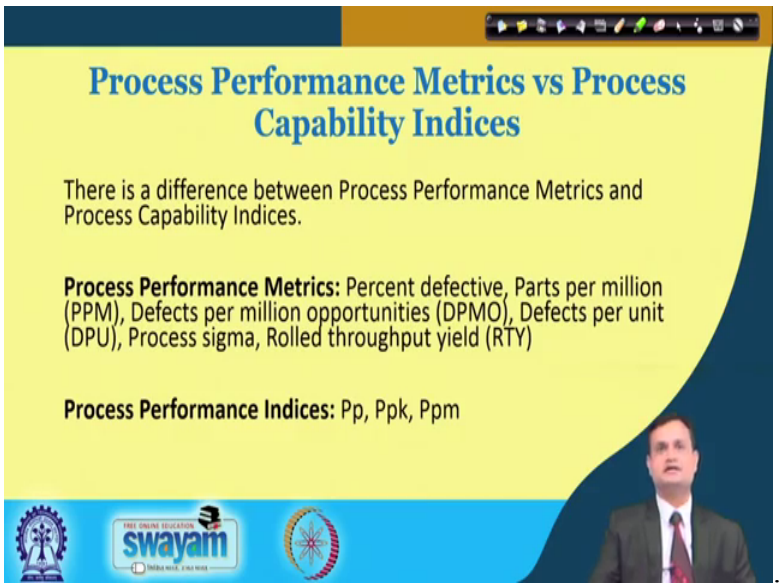

So, there are various measures related to process performance and your process capability what we have studied previously is for prep say person defective DPMO, RTY they all are basically process performance metrics process performer indices we will discuss in the next class Pp, Ppk, Ppm and so on.

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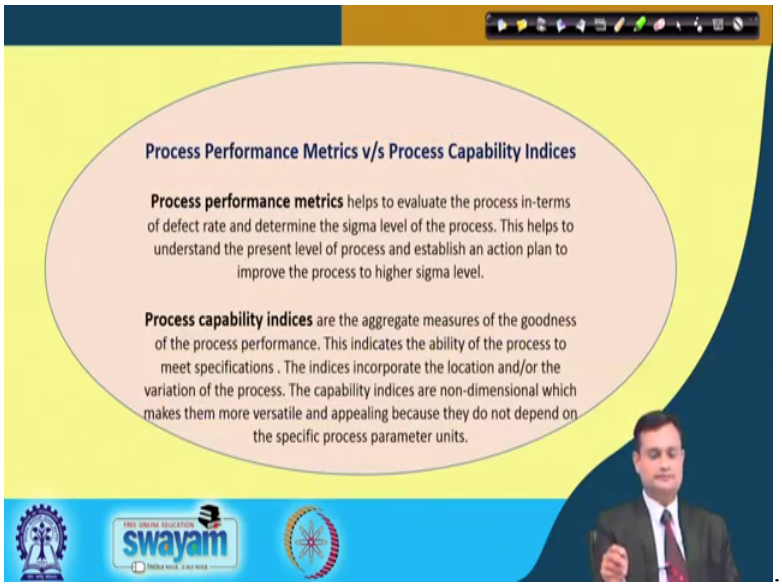

So, the difference between these two is very simple, process performance metrics helps you evaluate the process in terms of defect rate where in the process capability measures check the goodness of the process performance how capabilities.

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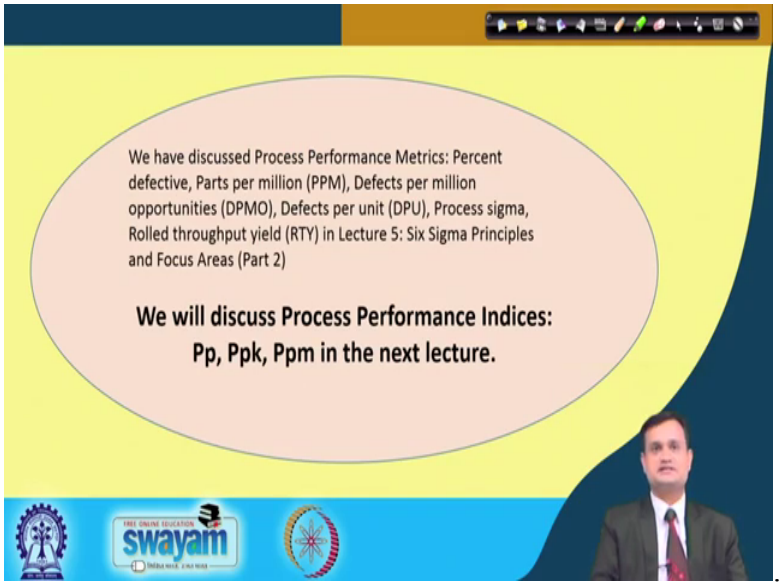

So, we will discuss the various measures related to process capability subsequently just think it.

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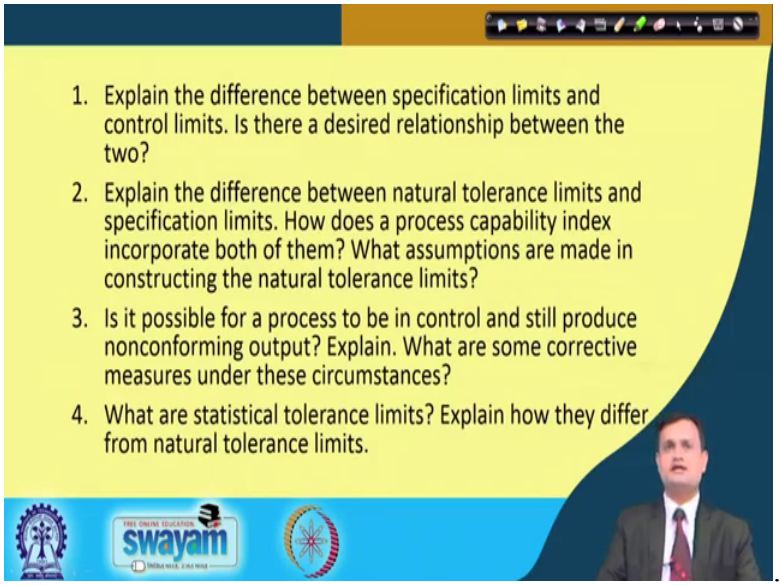

That explain the difference between specification limits and control limit. Explain the difference between natural tolerance limit specification limits. How does the process capability index incorporate both of them. Is it possible for a process to be in control and still produce non conforming outcome just try to comment. What are the statistical tolerance limits and how do that differ from the natural tolerance limits?

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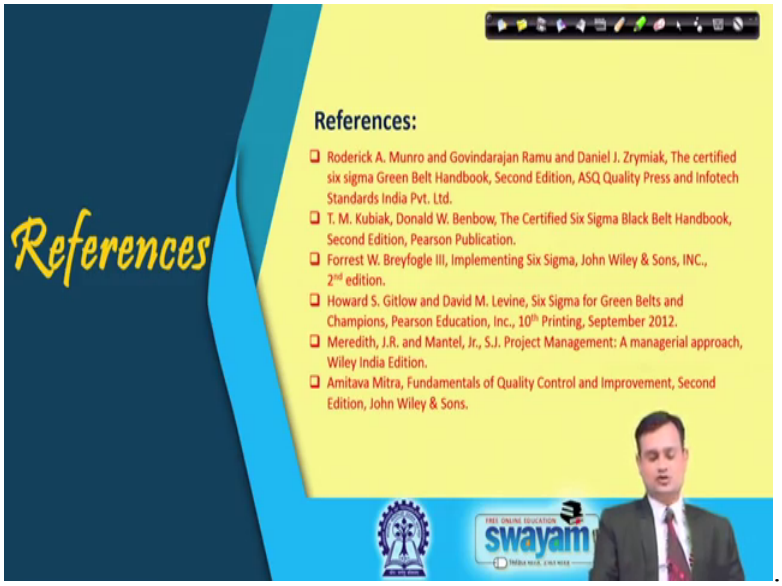

Use this references to understand this very important topic.

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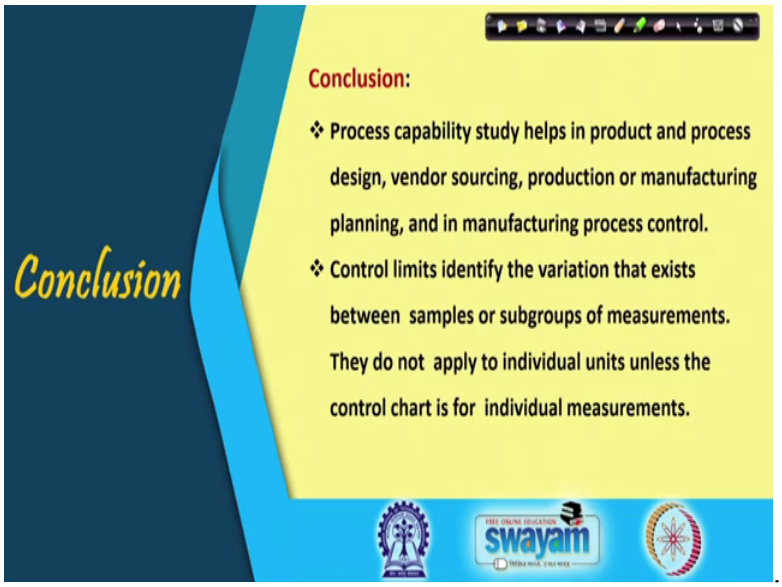

And typically this capability analysis helps me to judge the capability of the process and then after only I can go for the execution of the process and ensure that my process will produce the good quality components.

So, with this thank you very much keep revising, keep introspecting go in to detail of the concepts covered, be with me enjoy.