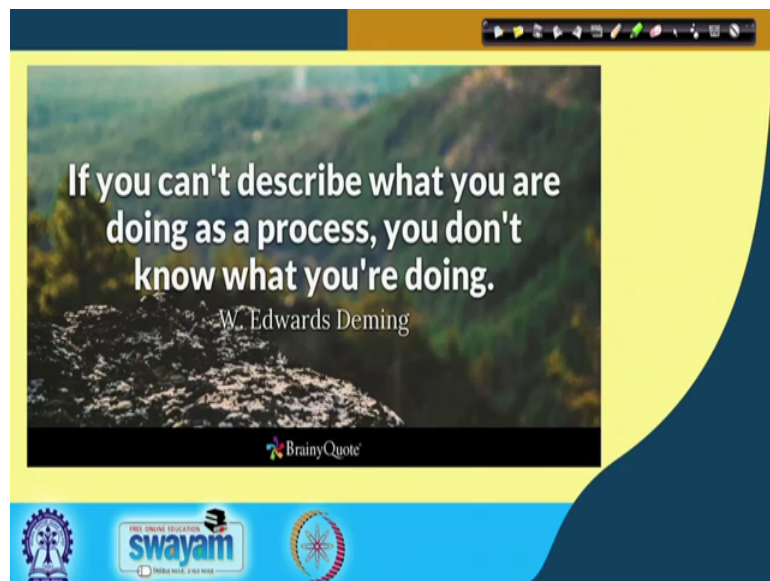


Six Sigma
Prof. Jitesh J Thakkar
Department of Industrial and Systems Engineering
Indian Institute of Technology, Kharagpur

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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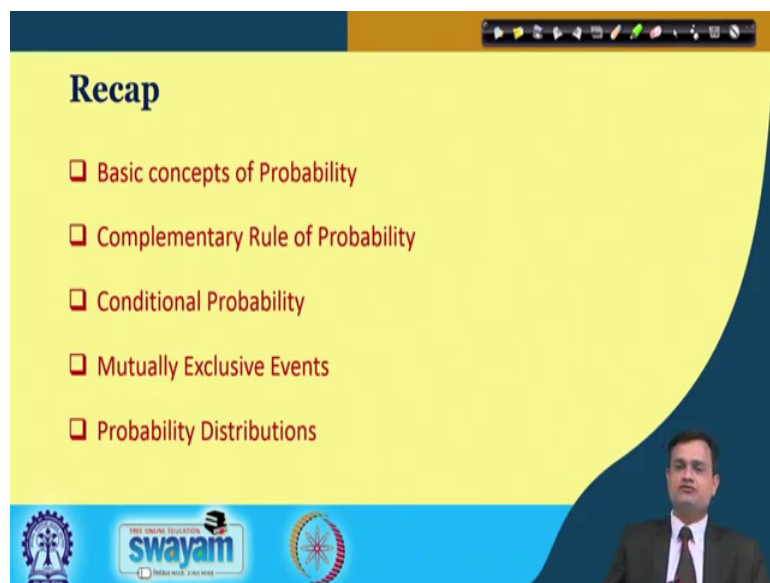


Now, let us begin with quite an inspiring quote if you cannot describe what you are doing as a process you do not know what you are doing and the quote is given by the renowned quality guru W Edwards Deming. So, here if I look at the word process capability then it says that what is the capability of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

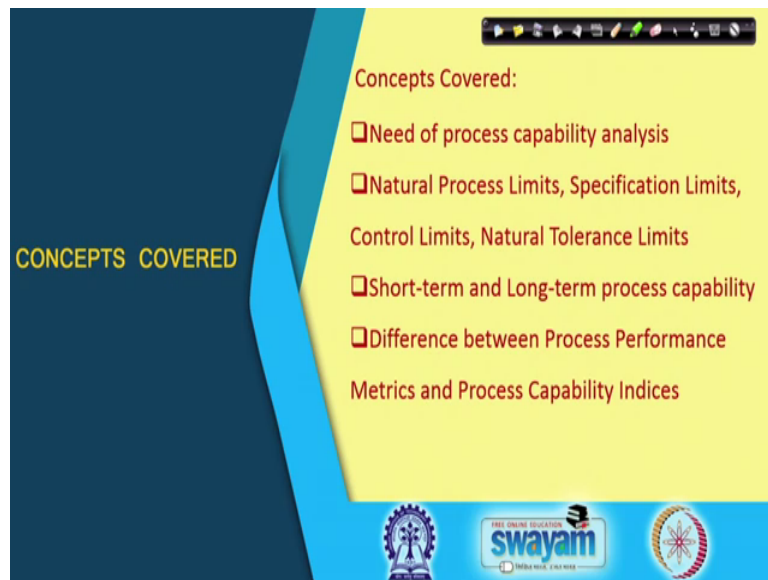
Same applies to my processes and six sigma whether my processes really capable or not. If my process itself is not capable then whatever struggle I will do that all the struggle will be a wasteful effort and I cannot really conclude anything. So, my first attempt is to see that to what extent my process 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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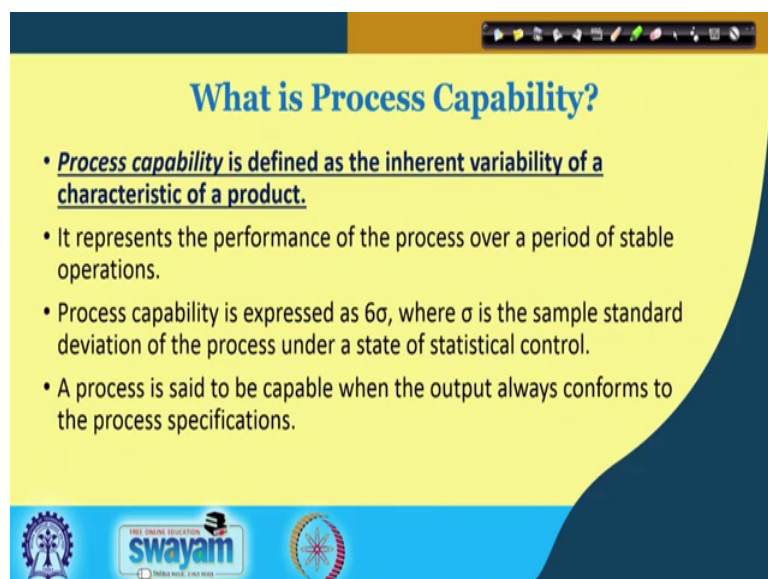
So, with this little understanding I can just give you the recap that we talked about some of the concepts of probability, which would now be extensively used in various topics, then we have seen the complementary rule, conditional probability, mutually exclusive events and some of the important probability distributions broadly in two categories one is continuous probability distribution like normal and I have said t-distribution and discrete 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.

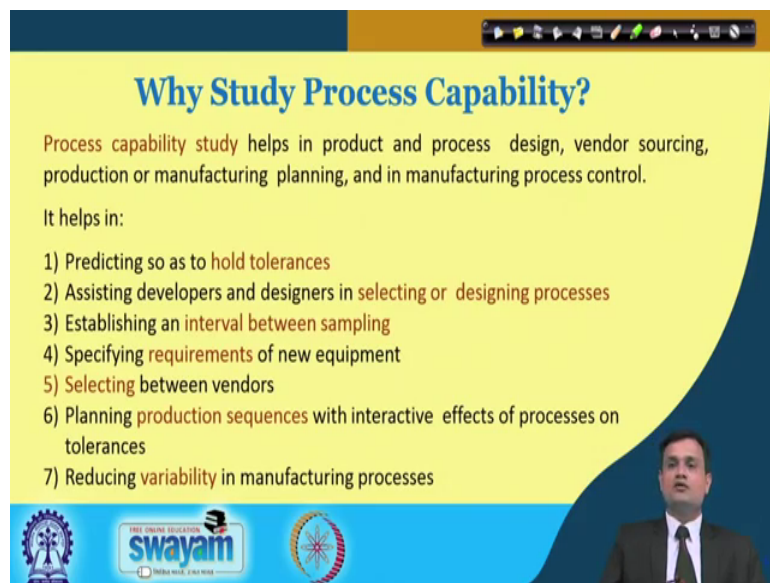
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So, the first question what is process capability? So, you can see the line in bold underlined. Process capability is defined as the inherent variability of a characteristic of a product. So, when I am trying to analyze and capture this inherent variability 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 Study Process Capability?

Process capability study helps in product and process design, vendor sourcing, production or manufacturing planning, and in manufacturing process control.

It helps in:

- 1) Predicting so as to hold tolerances
- 2) Assisting developers and designers in selecting or designing processes
- 3) Establishing an interval between sampling
- 4) Specifying requirements of new equipment
- 5) Selecting between vendors
- 6) Planning production sequences with interactive effects of processes on tolerances
- 7) Reducing variability in manufacturing processes

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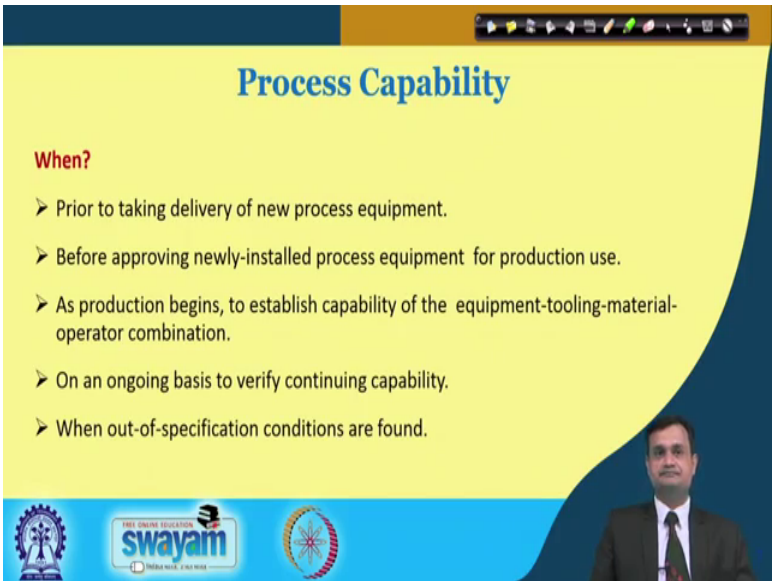
Why to study the reasons are many just to summarize few predicting so as to hold tolerances. Many a times, designers they give the tolerances, but my processes are not capable enough to meet those tolerances. So, in this case I can have an idea that what is the capability of my process and to what extent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

When?

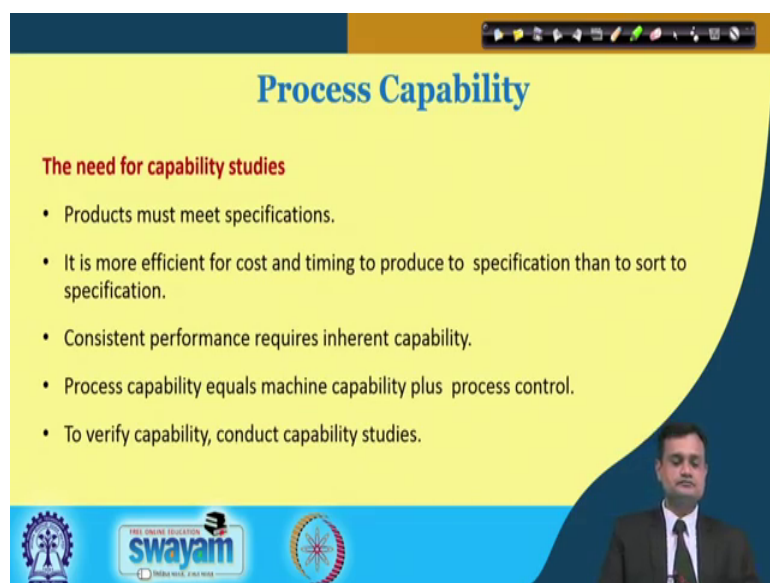
- Prior to taking delivery of new process equipment.
- Before approving newly-installed process equipment for production use.
- As production begins, to establish capability of the equipment-tooling-material-operator combination.
- On an ongoing basis to verify continuing capability.
- When out-of-specification conditions are found.



So, when there is a trigger that I should really go for process capability. So, prior to taking delivery of any new 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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Process Capability

The need for capability studies

- Products must meet specifications.
- It is more efficient for cost and timing to produce to specification than to sort to specification.
- Consistent performance requires inherent capability.
- Process capability equals machine capability plus process control.
- To verify capability, conduct capability studies.

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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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Process Control

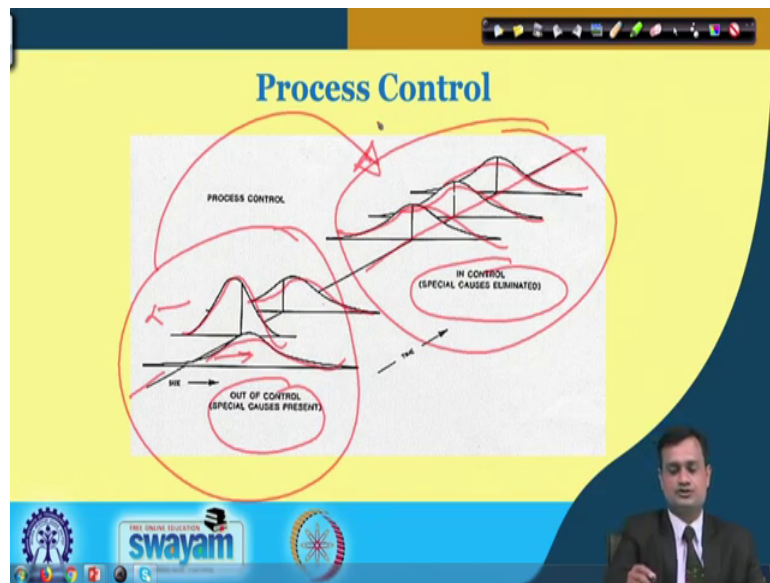
- Sources of variation in a process
 - Common Causes
 - Special Causes
- When corrective action is taken to identify and eliminate special causes, we have statistical control of the process

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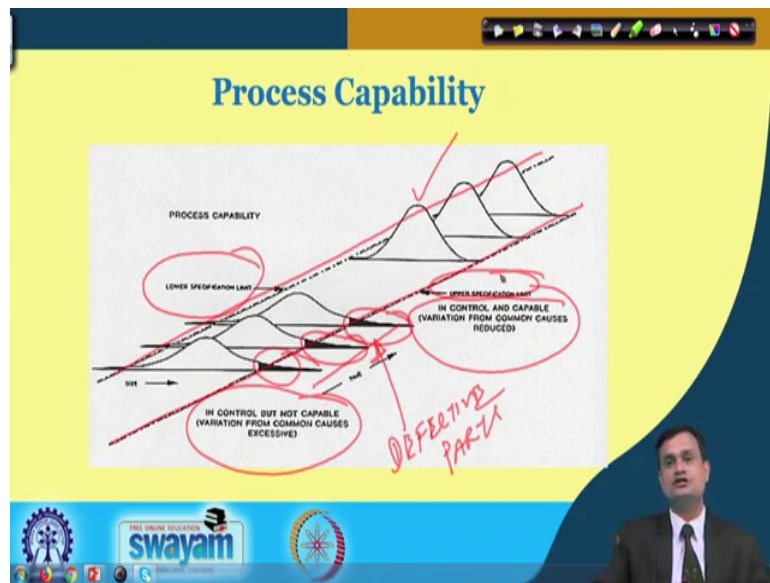
Now, before we extend our discussion there are some basic concepts to be appreciated. When we say statistical control or process control always remember that you cannot avoid all the variations and typically the variations are primarily because of common causes and special causes. If there are variances 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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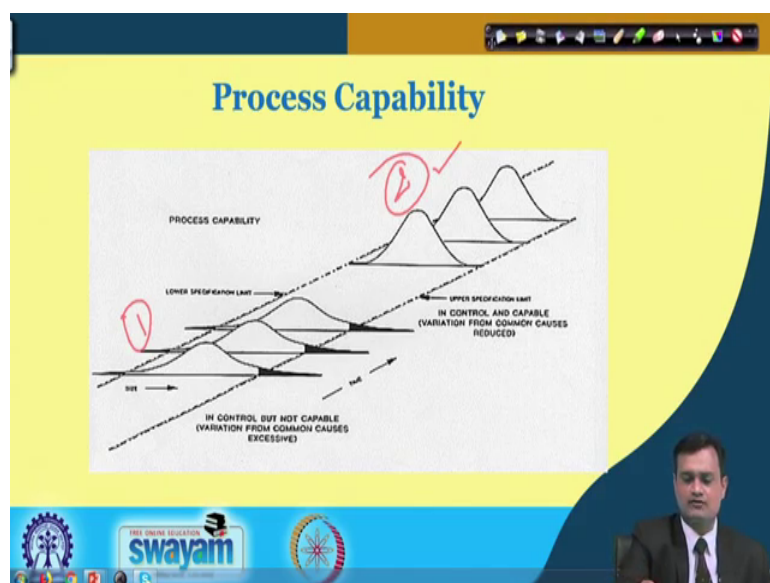
This is very interesting to appreciate just see that you have the process typically out of control. So, this indicates that there is a special cause present and why this is out of control? You just see that there is a mean value, mean line and this process is drifting from this side to this side and 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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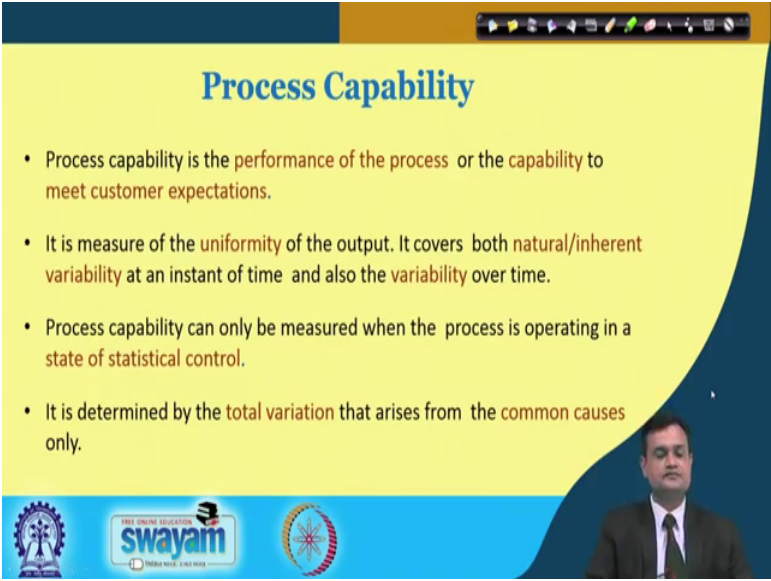
If you see this figure process capability then, you will find here that you have lower specification limit typically this one, you have upper specification limit typically this one and when you look at the process which is in control, but not capable. So, variation from common causes excessive what you 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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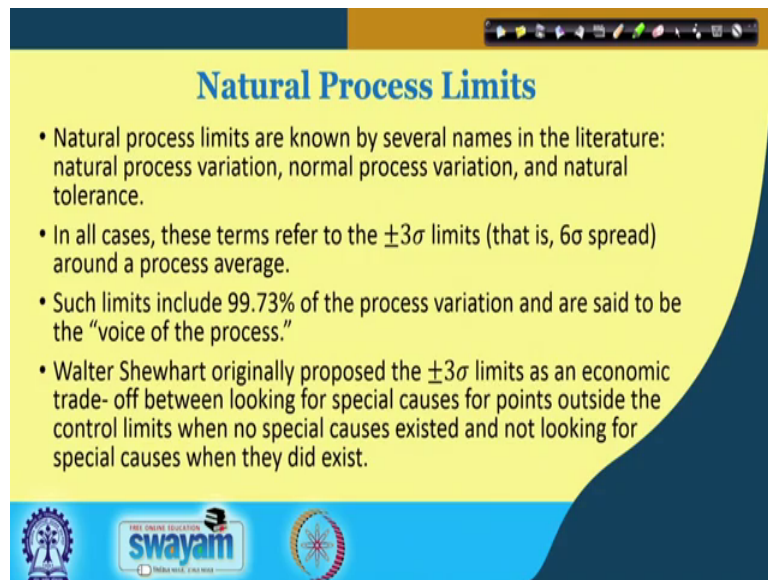
Process Capability

- Process capability is the performance of the process or the capability to meet customer expectations.
- It is measure of the uniformity of the output. It covers both natural/inherent variability at an instant of time and also the variability over time.
- Process capability can only be measured when the process is operating in a state of statistical control.
- It is determined by the total variation that arises from the common causes only.

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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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Natural Process Limits

- Natural process limits are known by several names in the literature: natural process variation, normal process variation, and natural tolerance.
- In all cases, these terms refer to the $\pm 3\sigma$ limits (that is, 6σ spread) around a process average.
- Such limits include 99.73% of the process variation and are said to be the “voice of the process.”
- Walter Shewhart originally proposed the $\pm 3\sigma$ limits as an economic trade-off between looking for special causes for points outside the control limits when no special causes existed and not looking for special causes when they did exist.

Logos at the bottom: Indian Institute of Technology, Swayam, and a circular emblem.

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.

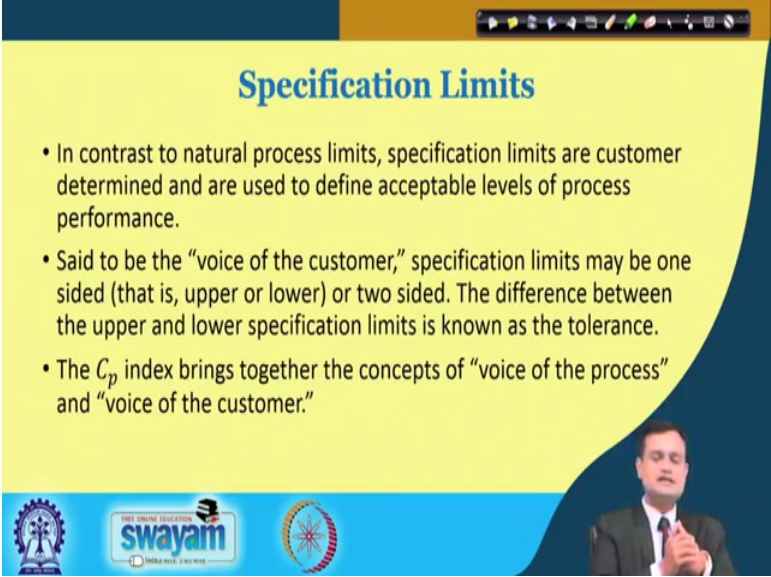
So, typically in all cases plus or minus 3 sigma limit sigma six sigma is the spread total spread on either side of the mean around the process average and such limit basically include 99.73 percent of the process variation and typically are said to be voice of the process. So, if you recall we have 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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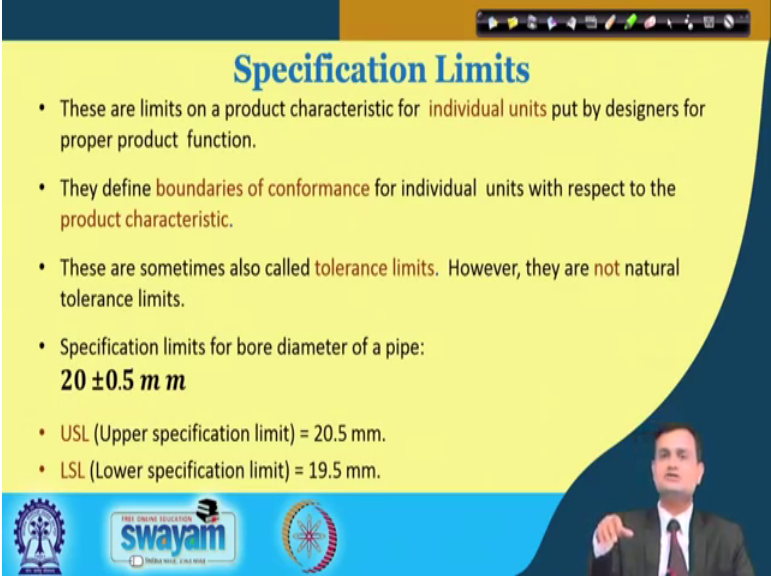
The slide is titled "Specification Limits" in blue text on a yellow background. It contains three bullet points. The first bullet point states that specification limits are customer-determined and used to define acceptable levels of process performance. The second bullet point explains that specification limits can be one-sided (upper or lower) or two-sided, with the difference between upper and lower limits being the tolerance. The third bullet point mentions that the C_p index combines the concepts of "voice of the process" and "voice of the customer." The slide features a blue header bar with a navigation menu, a blue footer bar with logos for IIT Bombay, Swayam, and the Ministry of Education, and a small video inset of a man in a suit in the bottom right corner.

Specification Limits

- In contrast to natural process limits, specification limits are customer determined and are used to define acceptable levels of process performance.
- Said to be the "voice of the customer," specification limits may be one sided (that is, upper or lower) or two sided. The difference between the upper and lower specification limits is known as the tolerance.
- The C_p index brings together the concepts of "voice of the process" and "voice of the customer."

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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Specification Limits

- These are limits on a product characteristic for individual units put by designers for proper product function.
- They define boundaries of conformance for individual units with respect to the product characteristic.
- These are sometimes also called tolerance limits. However, they are not natural tolerance limits.
- Specification limits for bore diameter of a pipe:
 $20 \pm 0.5 \text{ mm}$
- USL (Upper specification limit) = 20.5 mm.
- LSL (Lower specification limit) = 19.5 mm.

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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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Specification Limits vs. Control Limits

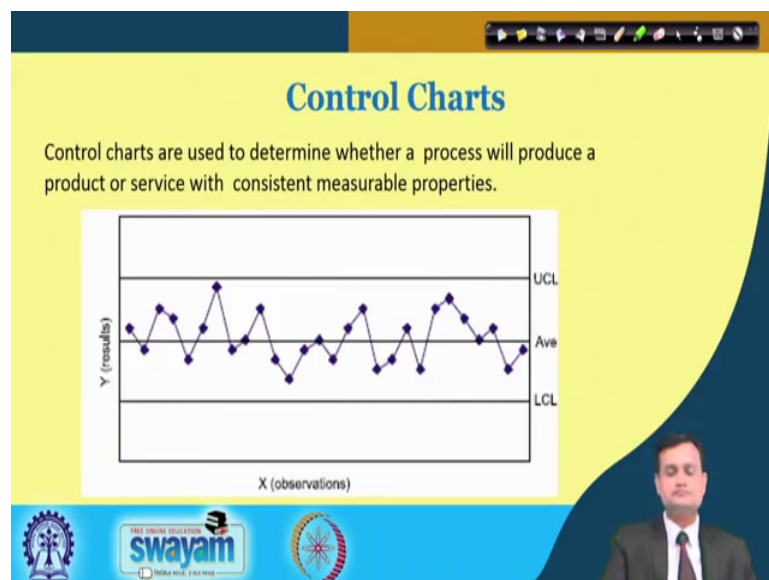
- Specification limits relate to needs of the customer, which are analyzed and are built into design. These are limits on a product characteristic for individual units put by designers for proper product function.
- Control limits identify the variation that exists between samples or subgroups of measurements. They do not apply to individual units unless the control chart is for individual measurements.
- Control limits reflect the variability of the process and have no relationship to specification limits, which relate to the needs of the customer.

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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.

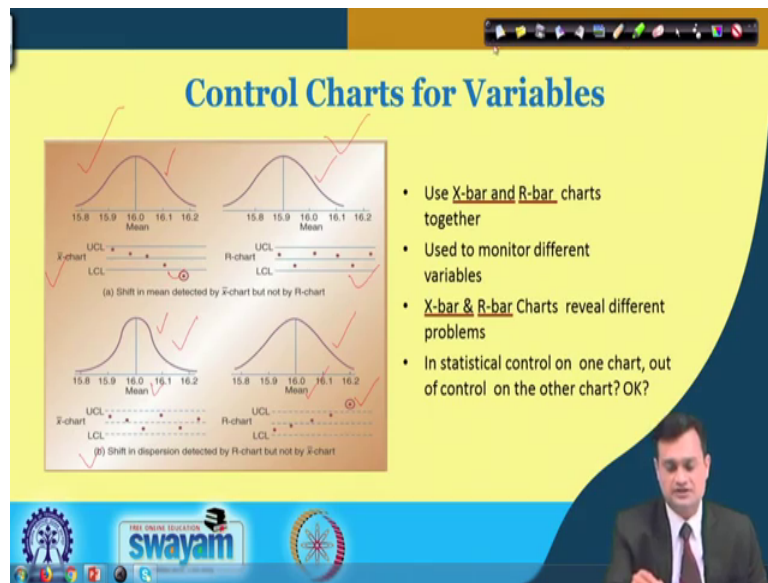
So, in summary control limits reflects the variability of the process I must try to control the variability of the process and have no relationship to the specification limit with relate to the need of the customer.

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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, \bar{X} bar chart R chart for variables and used to monitor the different variables. You have \bar{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 \bar{X} bar chart and R chart I can see that on R chart the measurements are within the limit on \bar{X} bar chart this particular measurement is falling outside the lower control limit.

So, there is shifting mean detected by \bar{X} bar chart not by the R chart. So, as we know R is related to variability \bar{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 \bar{X} bar and R chart.

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Control Charts

Two types of error are possible with control charts

- A **type I error** occurs when a process is thought to be out of control when in fact it is not
- A **type II error** occurs when a process is thought to be in control when it is actually out of statistical control

These errors can be controlled by the choice of control limits

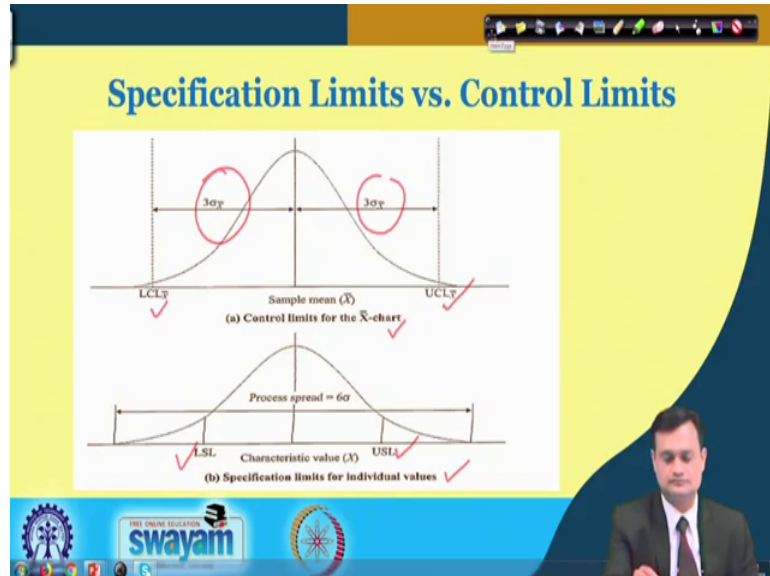
So, control charts as I mentioned typically we deal with type I error and type II error and type I error occurs when a process is thought to be out of control when typically it is in the control and type II error then process is thought to be in control where it is actually out of statistical control. 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.

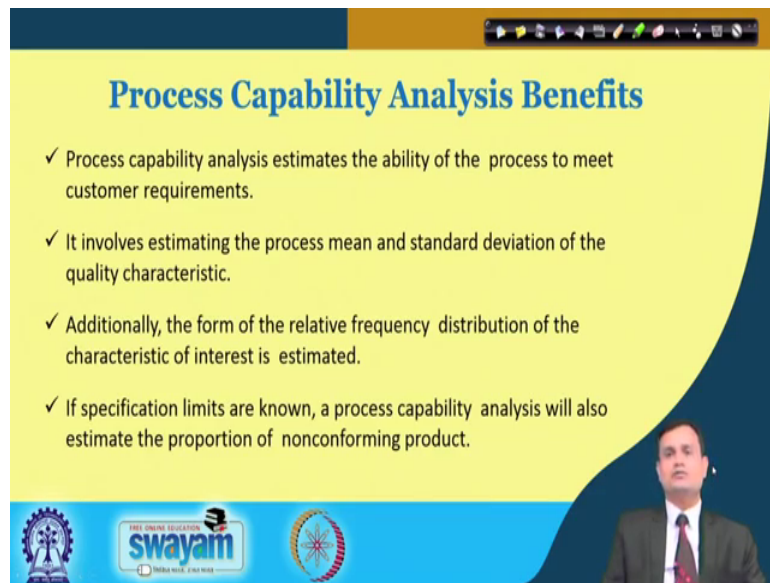
So, this is a trade off and contextual as I mentioned squad suggested the most economic trade off you can have by having plus or minus 3 sigma limit.

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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 \bar{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 \bar{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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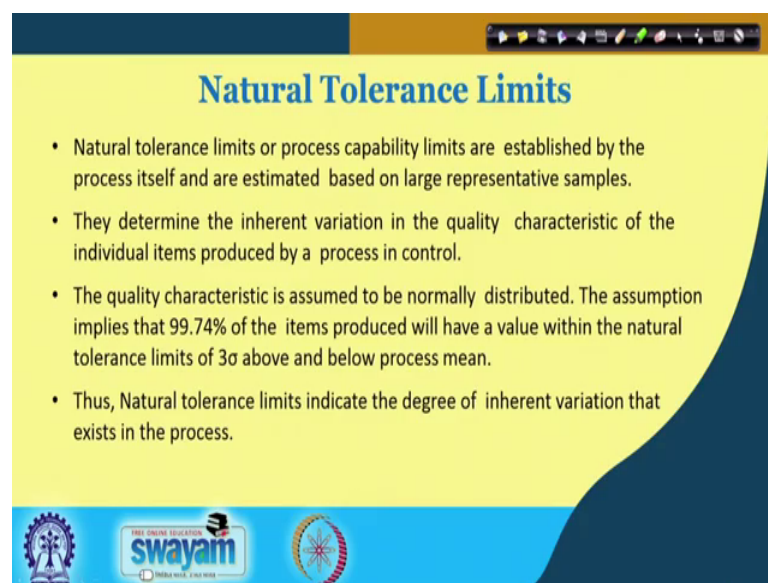
Process Capability Analysis Benefits

- ✓ Process capability analysis estimates the ability of the process to meet customer requirements.
- ✓ It involves estimating the process mean and standard deviation of the quality characteristic.
- ✓ Additionally, the form of the relative frequency distribution of the characteristic of interest is estimated.
- ✓ If specification limits are known, a process capability analysis will also estimate the proportion of nonconforming product.

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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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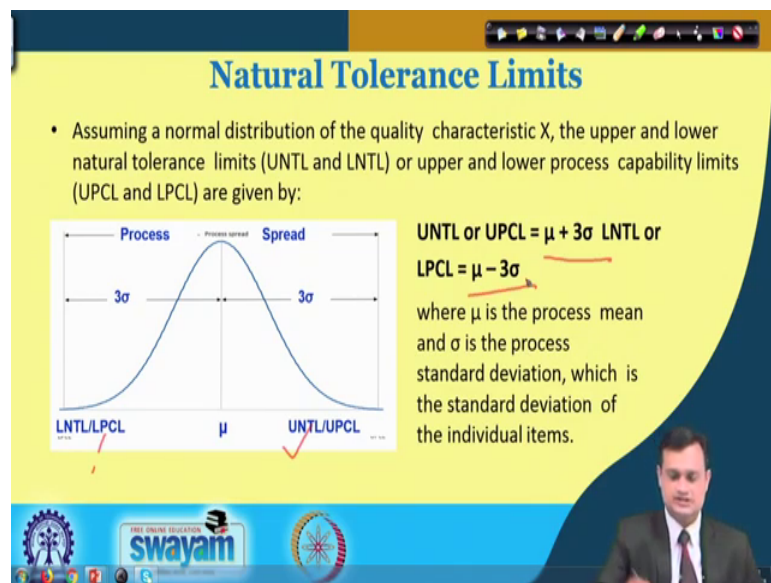
Natural Tolerance Limits

- Natural tolerance limits or process capability limits are established by the process itself and are estimated based on large representative samples.
- They determine the inherent variation in the quality characteristic of the individual items produced by a process in control.
- The quality characteristic is assumed to be normally distributed. The assumption implies that 99.74% of the items produced will have a value within the natural tolerance limits of 3σ above and below process mean.
- Thus, Natural tolerance limits indicate the degree of inherent variation that exists in the process.

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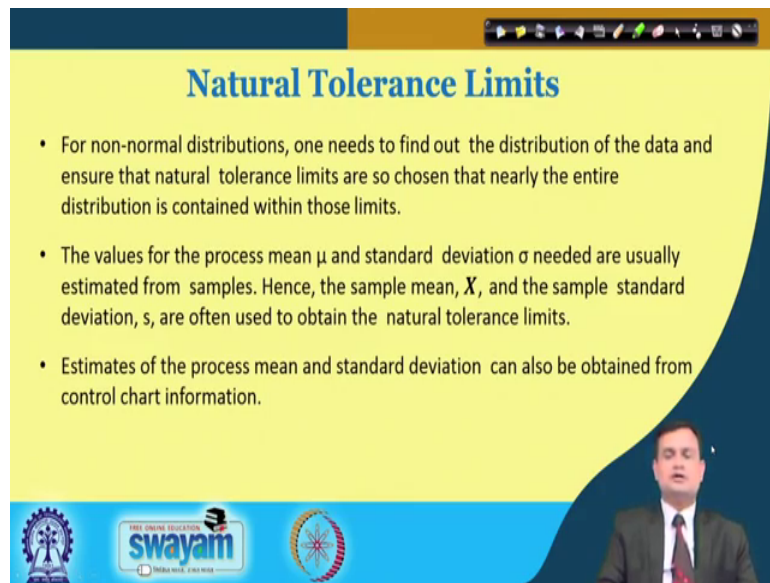
There is another term which is called natural tolerance limit. So, natural tolerance limit or process capability limits same thing are established by the process itself and are estimated based on the large representative sample. So, typically the assumption 99.74 percent of the item produce will have 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 $\mu + 3\sigma$ or $\mu - 3\sigma$ is good enough to set my natural tolerance limit or the capability limit.

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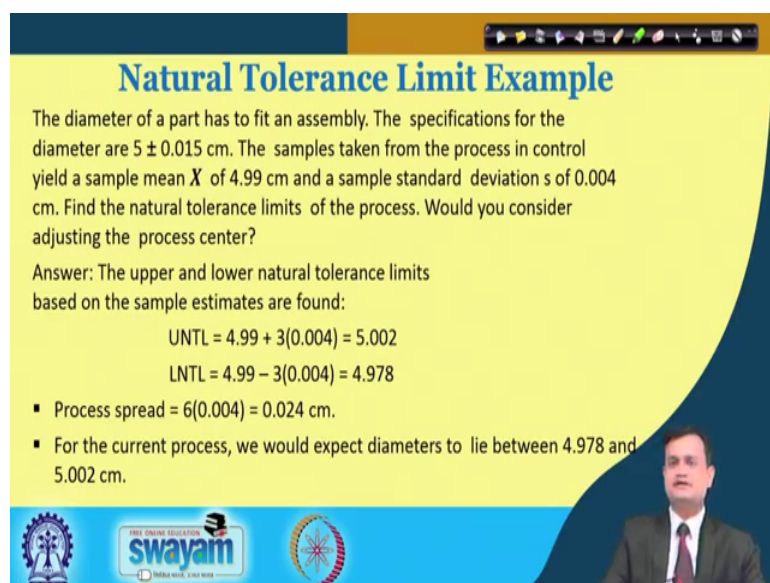
Natural Tolerance Limits

- For non-normal distributions, one needs to find out the distribution of the data and ensure that natural tolerance limits are so chosen that nearly the entire distribution is contained within those limits.
- The values for the process mean μ and standard deviation σ needed are usually estimated from samples. Hence, the sample mean, \bar{X} , and the sample standard deviation, s , are often used to obtain the natural tolerance limits.
- Estimates of the process mean and standard deviation can also be obtained from control chart information.

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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 μ and σ through two different approaches one is Chebyshevs theorem other is the empirical rule.

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Natural Tolerance Limit Example

The diameter of a part has to fit an assembly. The specifications for the diameter are 5 ± 0.015 cm. The samples taken from the process in control yield a sample mean \bar{X} of 4.99 cm and a sample standard deviation s of 0.004 cm. Find the natural tolerance limits of the process. Would you consider adjusting the process center?

Answer: The upper and lower natural tolerance limits based on the sample estimates are found:

$$\text{UNTL} = 4.99 + 3(0.004) = 5.002$$
$$\text{LNLT} = 4.99 - 3(0.004) = 4.978$$

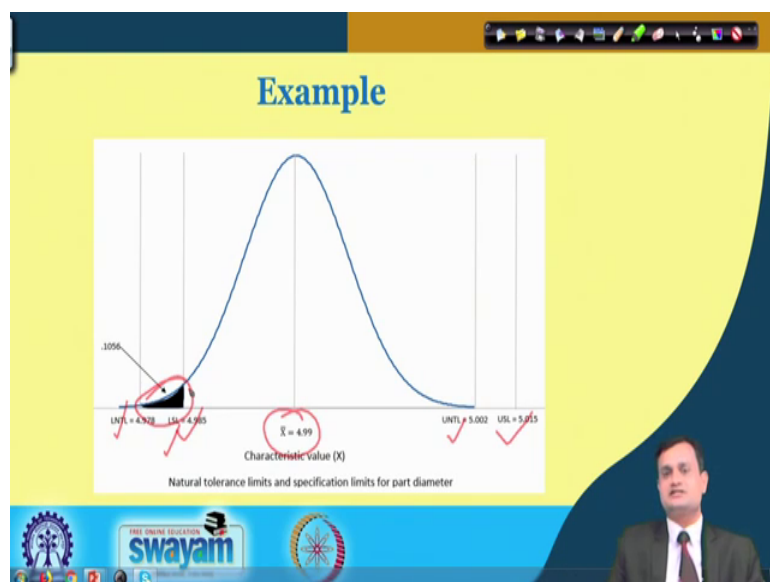
- Process spread = $6(0.004) = 0.024$ cm.
- For the current process, we would expect diameters to lie between 4.978 and 5.002 cm.

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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 \bar{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.

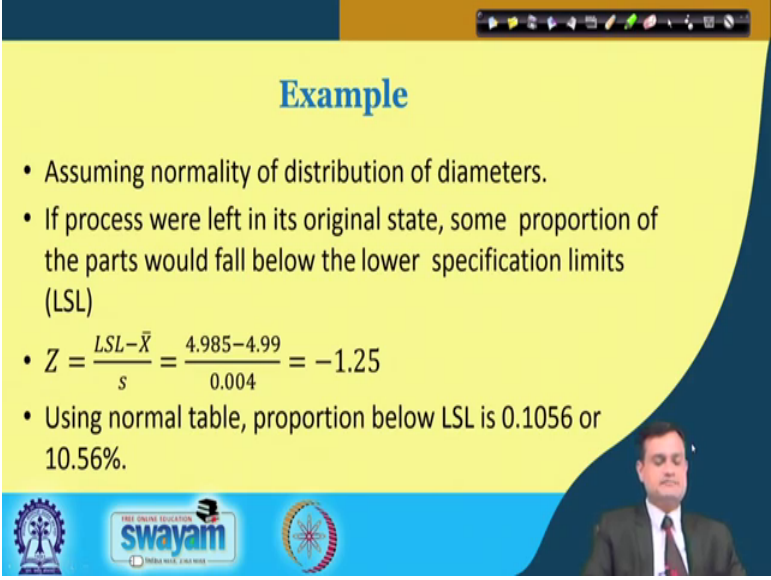
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Now, just see here it is interesting, I have upper specification limit 5.015, I have lower specification limit 4.985, I have upper natural tolerance limit 5.002 and lower natural tolerance limit 4.978.

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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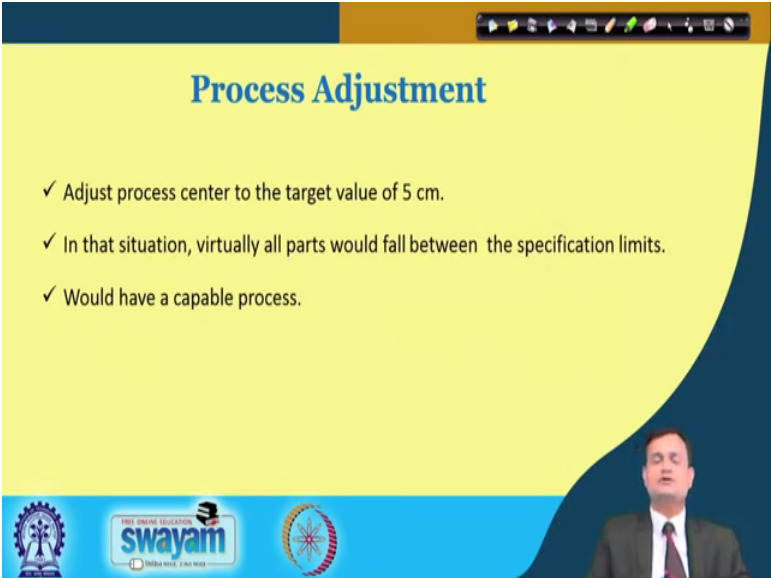
Example

- Assuming normality of distribution of diameters.
- If process were left in its original state, some proportion of the parts would fall below the lower specification limits (LSL)
- $Z = \frac{LSL - \bar{X}}{s} = \frac{4.985 - 4.99}{0.004} = -1.25$
- Using normal table, proportion below LSL is 0.1056 or 10.56%.

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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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Process Adjustment

- ✓ Adjust process center to the target value of 5 cm.
- ✓ In that situation, virtually all parts would fall between the specification limits.
- ✓ Would have a capable process.

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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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Specifications and Process Capability

CASE I: Process spread less than specification spread

- If process spread ($UNTL - LNTL = 6\sigma$) < specification spread ($USL - LSL$), then the process is quite capable.
- If the process mean μ is at the target value (midway between the specification limits), all items produced are well within specifications.
- In fact, there is some flexibility for the process to go out of control and still produce items within specifications.
- If control chart is kept, action can be initiated to bring the process back to control with any out-of-control signal.

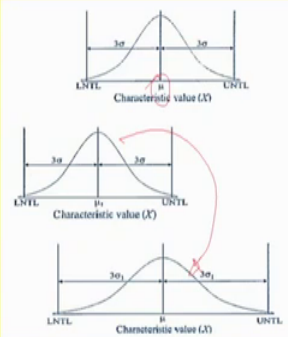


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So, we can just put it in a simple way that, I have a case I process spread less than specification spread. So, UNTL Upper Natural Tolerance Limit minus LNTL is equal to 6 sigma if this is less than specification spread USL minus LSL then the processes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

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Process spread less than specification spread



Process mean and standard deviation at target value ✓

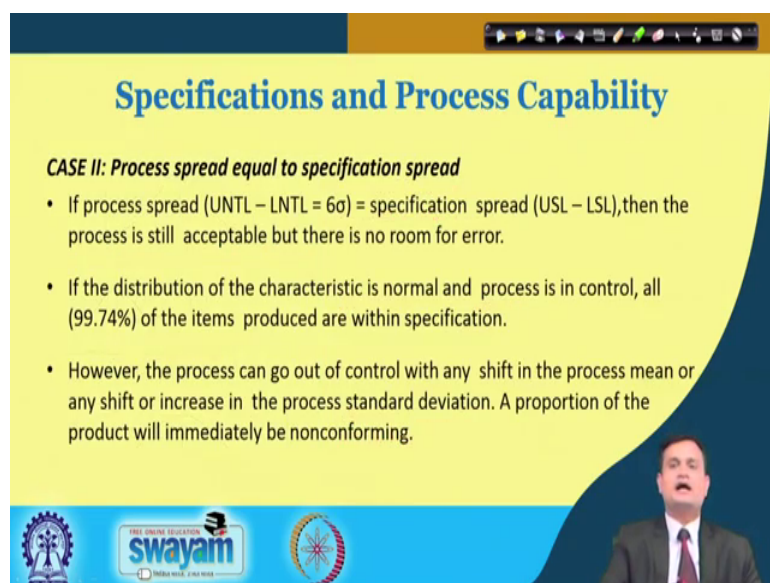
Process mean shifted. Process still within specifications ✓

Process standard deviation shifted. Process still within specifications ✓

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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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Specifications and Process Capability

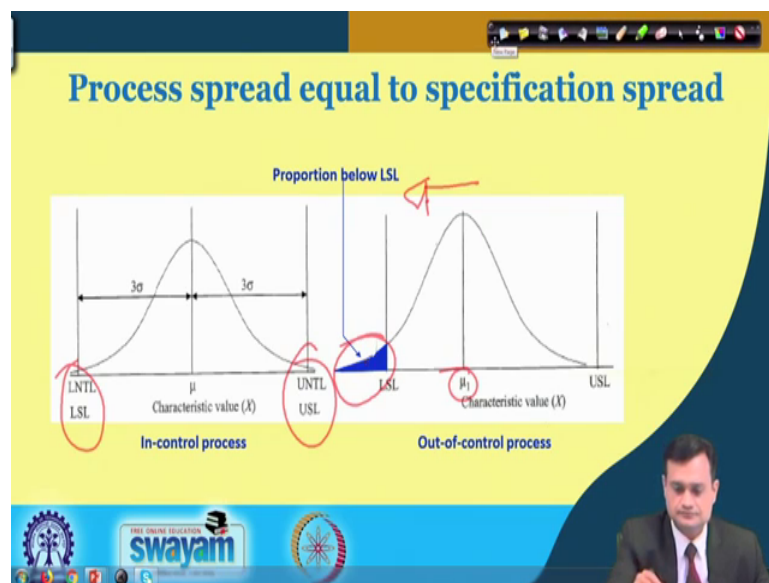
CASE II: Process spread equal to specification spread

- If process spread ($UNTL - LNTL = 6\sigma$) = specification spread ($USL - LSL$), then the process is still acceptable but there is no room for error.
- If the distribution of the characteristic is normal and process is in control, all (99.74%) of the items produced are within specification.
- However, the process can go out of control with any shift in the process mean or any shift or increase in the process standard deviation. A proportion of the product will immediately be nonconforming.

The slide features a video inset of a man in a suit speaking in the bottom right corner. At the bottom, there are logos for the Indian Institute of Technology (IIT) and the Swamyam initiative.

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 μ_1 becomes μ ; μ becomes μ_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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Specifications and Process Capability

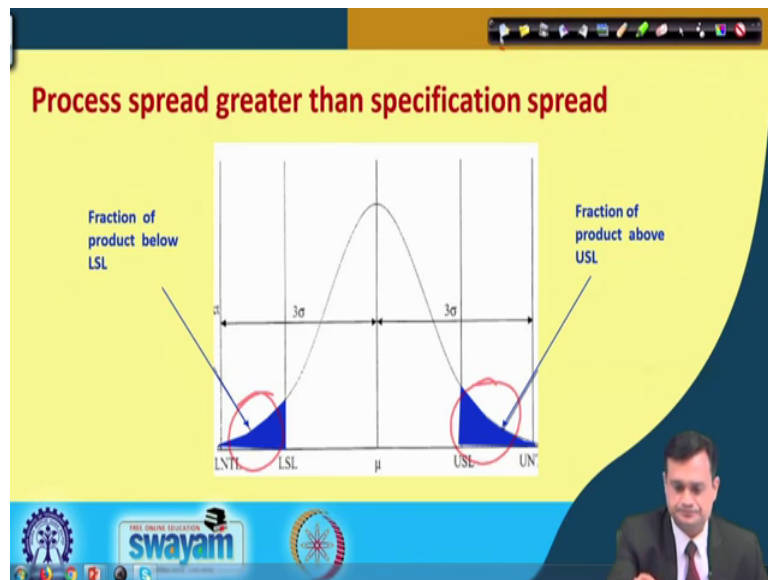
CASE III: Process spread greater than specification spread

- If process spread ($UNTL - LNTL = 6\sigma$) > specification spread ($USL - LSL$), then an undesirable situation results. Such a process is not capable.
- The inherent variability in the process exceeds the specification spread even though the process is in control.
- A proportion of the items produced will not meet specifications. The situation will worsen with a shift in process mean or an increase in standard deviation.

The slide includes logos for Swamyam and a speaker in the bottom right corner.

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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Case III: Corrective Approaches

- ❑ First explore the possibility of increasing the specification limits. Carefully consider meeting the customer needs while doing so.
- ❑ Second investigate measures to reduce the process spread. Invest in new equipment, better raw material, or experienced operators to do so. Also look into the financial aspects.
- ❑ Third, if process variability reduction is not financially feasible, shift the process average temporarily so as to produce less scrap at the cost of more rework. This is because cost of scrap per unit is usually more than that of rework.

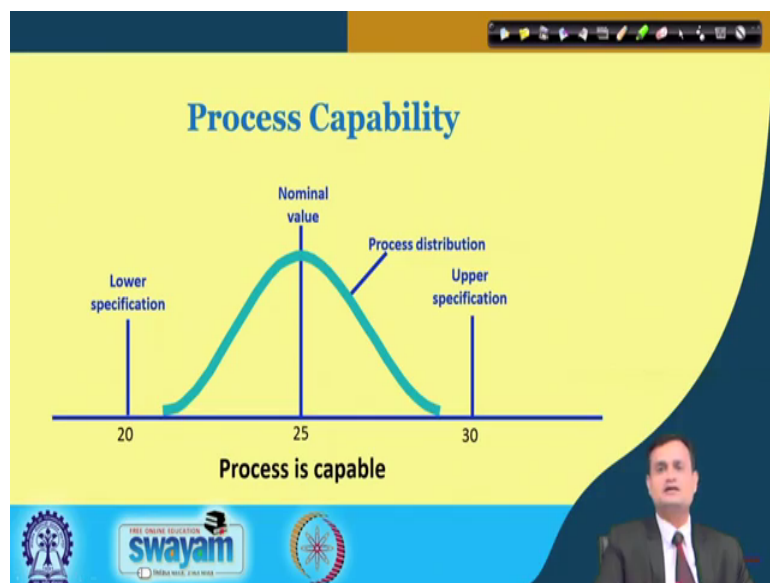
If this is the situation then what are the corrective approaches when my process is neither capable or barely capable it is not capable, you have three options or approaches available number one explore the possibility of increasing the specification limits. Many

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.

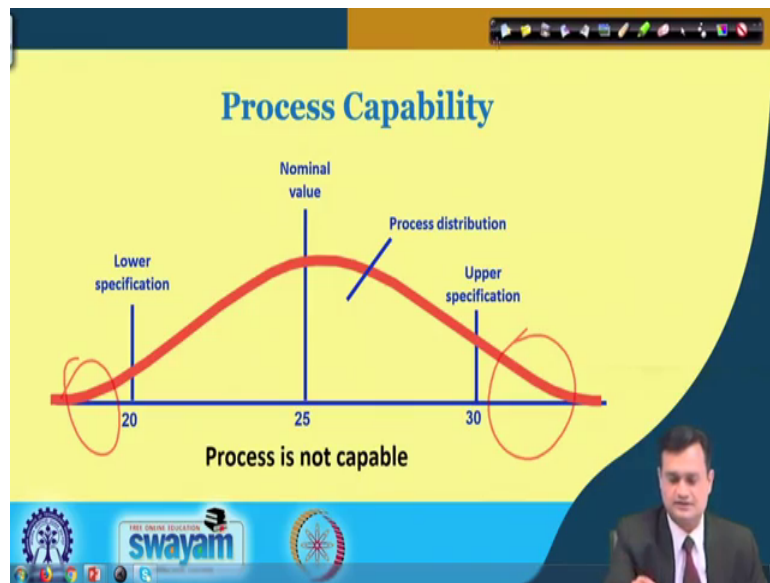
So, suppose let us say in this case if you have produce the components on higher site this particular side let us say then, you have the possibility suppose it is a diameter you have produce oversized diameter extra material you can rework it and reduce it. So, it is the rework cost is there, but suppose 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.

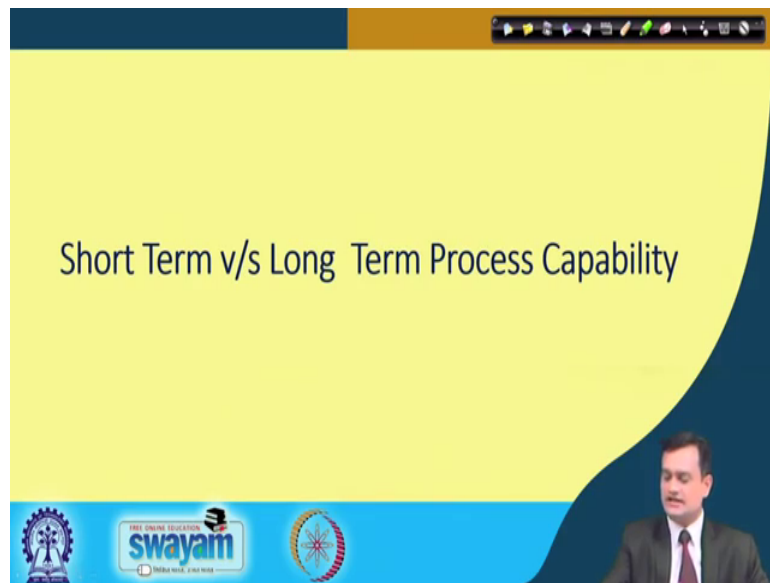
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Estimating Process Mean and Process Standard Deviation

- The process mean is a measure of the location of the process.
- The process standard deviation reflects the variability of the process.

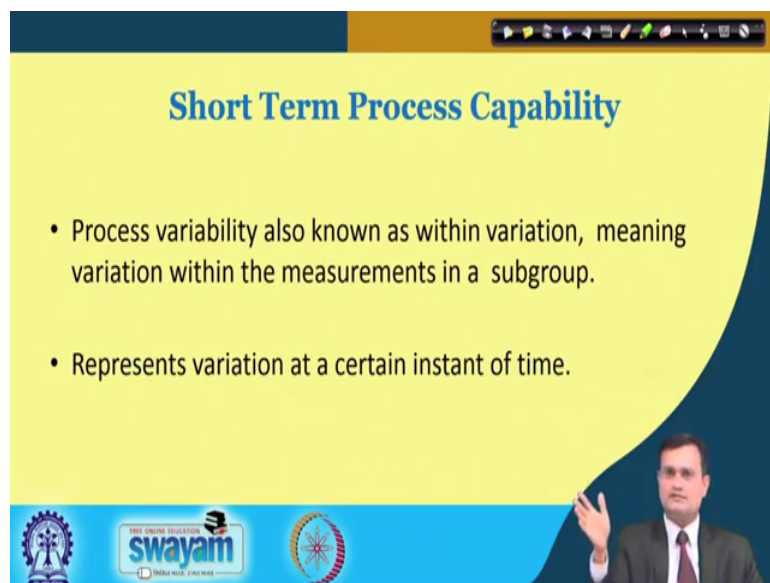
We can just see that how to estimate the process mean and process standard deviation. So, process mean is a measure of location of the process and standard deviation reflects the variability of the process.

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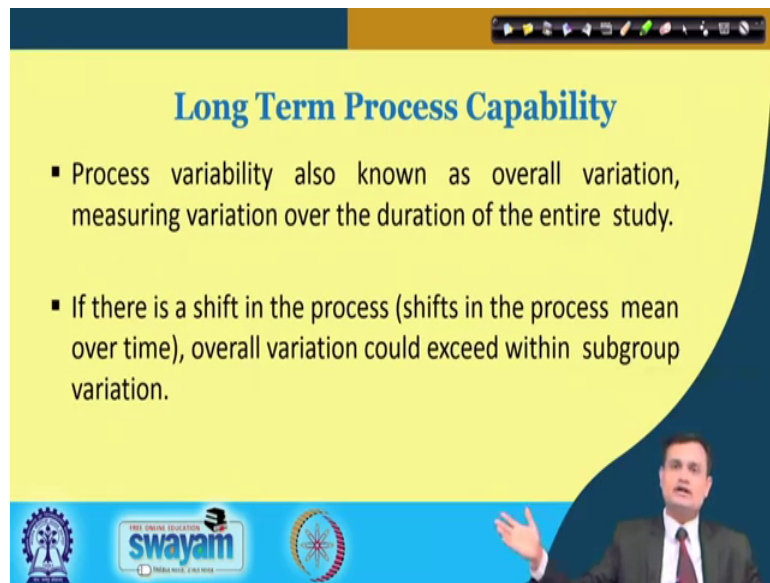
Now, there is something interesting to appreciate here, when we talk about process capability it is short term versus long term.

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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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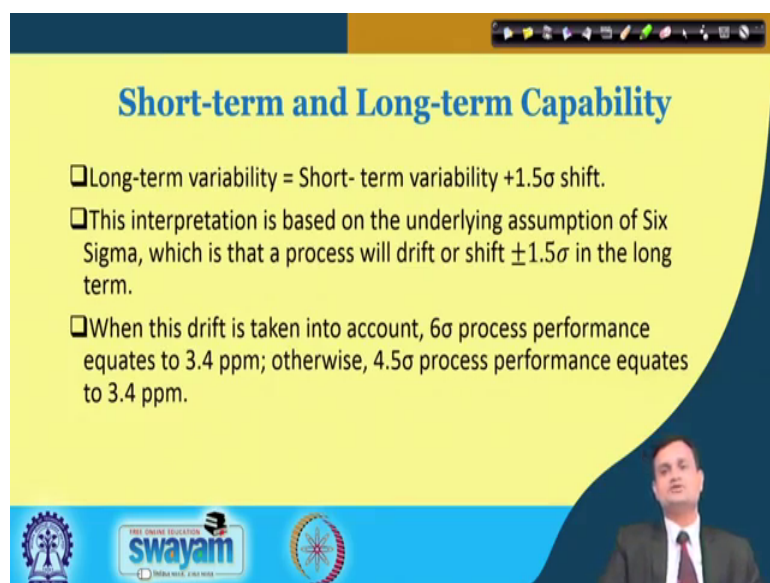


Long Term Process Capability

- Process variability also known as overall variation, measuring variation over the duration of the entire study.
- If there is a shift in the process (shifts in the process mean over time), overall variation could exceed within subgroup variation.

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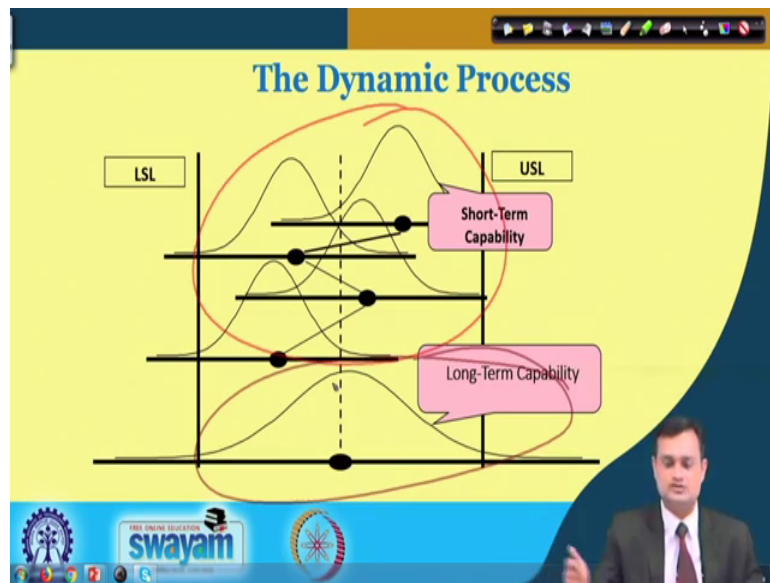
Short-term and Long-term Capability

- Long-term variability = Short-term variability + 1.5σ shift.
- This interpretation is based on the underlying assumption of Six Sigma, which is that a process will drift or shift $\pm 1.5\sigma$ in the long term.
- When this drift is taken into account, 6σ process performance equates to 3.4 ppm; otherwise, 4.5σ process performance equates to 3.4 ppm.

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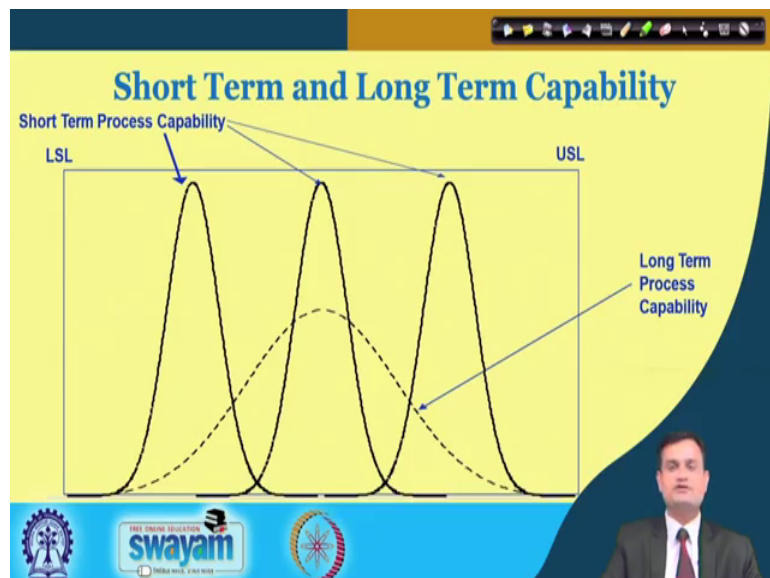
But when you study it over a an extended period of time large time then this process or entire process range, this is called long term process capability. So, long term process capability typically will be short term plus 1.5 sigma shift and this interpretation is based on my six sigma understanding 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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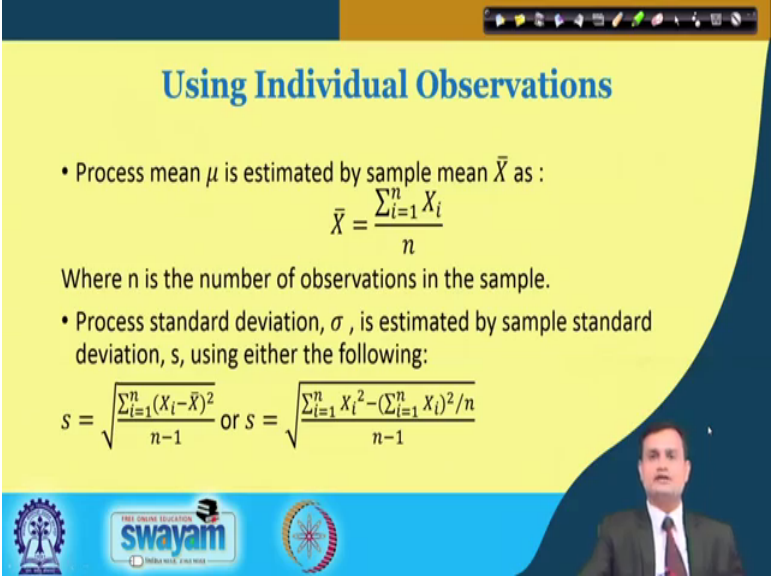
You can see the dynamic process and when I say short term process capability it is specific to this particular domain where subgroups or samples they are analyzed in terms of process capability when I typically say the process capability for long term then it is basically this long term process capability 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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Using Individual Observations

- Process mean μ is estimated by sample mean \bar{X} as :
$$\bar{X} = \frac{\sum_{i=1}^n X_i}{n}$$

Where n is the number of observations in the sample.

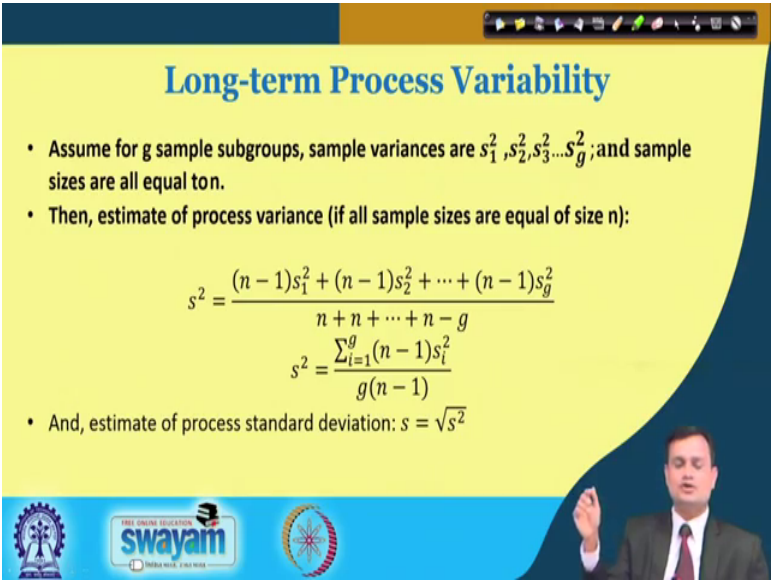
- Process standard deviation, σ , is estimated by sample standard deviation, s, using either the following:

$$s = \sqrt{\frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n-1}} \text{ or } s = \sqrt{\frac{\sum_{i=1}^n X_i^2 - (\sum_{i=1}^n X_i)^2 / n}{n-1}}$$

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So, you can use this formulas for individual observation \bar{X} 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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Long-term Process Variability

- Assume for g sample subgroups, sample variances are $s_1^2, s_2^2, s_3^2, \dots, s_g^2$; and sample sizes are all equal to n.
- Then, estimate of process variance (if all sample sizes are equal of size n):
$$s^2 = \frac{(n-1)s_1^2 + (n-1)s_2^2 + \dots + (n-1)s_g^2}{n + n + \dots + n - g}$$
$$s^2 = \frac{\sum_{i=1}^g (n-1)s_i^2}{g(n-1)}$$

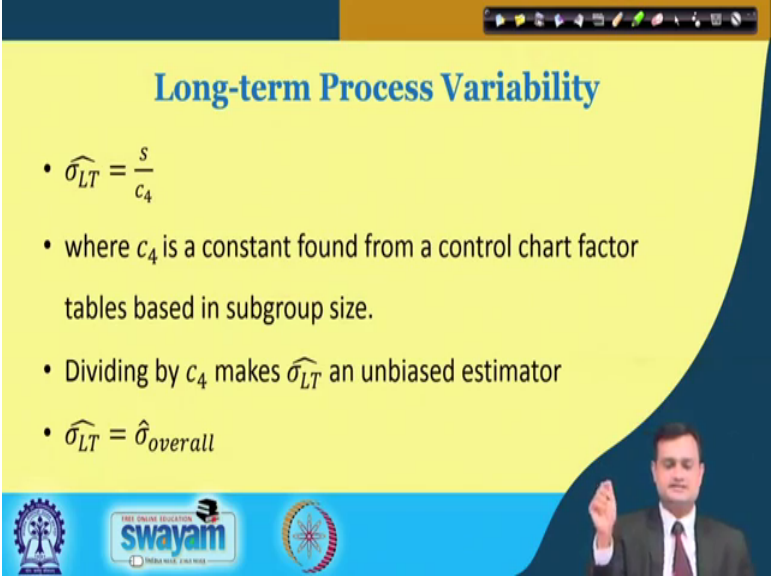
- And, estimate of process standard deviation: $s = \sqrt{s^2}$

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So, long term process capability or variability is captured through s^2 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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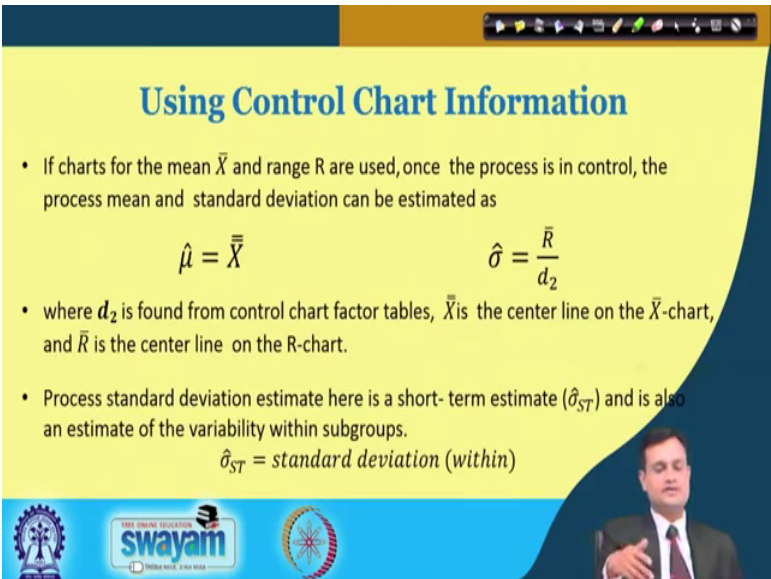


Long-term Process Variability

- $\hat{\sigma}_{LT} = \frac{s}{c_4}$
- where c_4 is a constant found from a control chart factor tables based in subgroup size.
- Dividing by c_4 makes $\hat{\sigma}_{LT}$ an unbiased estimator
- $\hat{\sigma}_{LT} = \hat{\sigma}_{overall}$

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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Using Control Chart Information

- If charts for the mean \bar{X} and range R are used, once the process is in control, the process mean and standard deviation can be estimated as

$$\hat{\mu} = \bar{\bar{X}} \qquad \hat{\sigma} = \frac{\bar{R}}{d_2}$$

- where d_2 is found from control chart factor tables, $\bar{\bar{X}}$ is the center line on the \bar{X} -chart, and \bar{R} is the center line on the R -chart.
- Process standard deviation estimate here is a short-term estimate ($\hat{\sigma}_{ST}$) and is also an estimate of the variability within subgroups.

$$\hat{\sigma}_{ST} = \text{standard deviation (within)}$$

Similar way μ is \bar{X} σ estimate can be determined through \bar{R} divided by d_2 .

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Methods of determining the standard deviation for use in process capability indices	
Method	Short term/Long term
$\hat{\sigma} = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}}$	Long
$\hat{\sigma} = \frac{\bar{R}}{d_2}$	Short
$\hat{\sigma} = \frac{\bar{s}}{c_4}$	Short

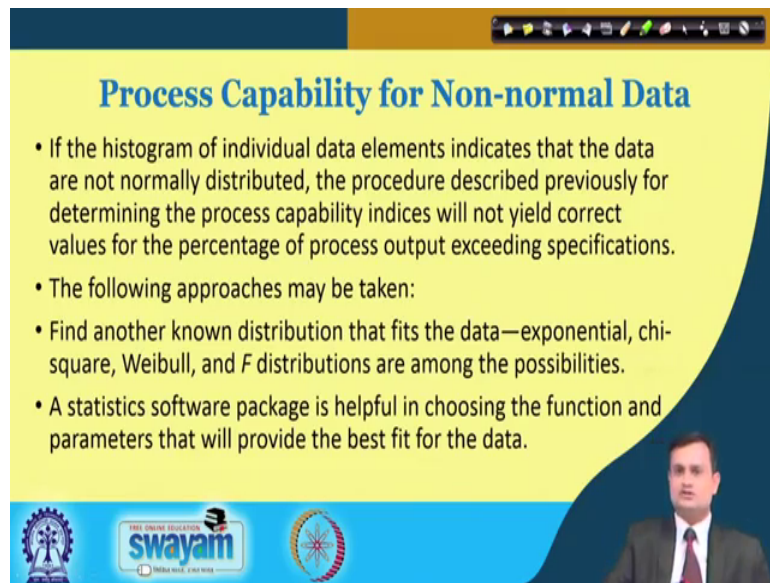
And your various methods of determining the standard deviation for using process capability indices it could be for long term and short term.

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Methods of determining the standard deviation for use in process capability indices	
Method	Short term/Long term
$\hat{\sigma} = 1.047 (\text{moving median, } \check{R})$	Short
$\hat{\sigma} = \frac{\overline{MR}}{d_2}$	Short
$\hat{\sigma} = S_{pooled} = \sqrt{\frac{\sum_{i=1}^m \sum_{j=1}^n (x_{ij} - \bar{x}_i)^2}{n_i - 1}}$	Short

So, and this expressions we can easily use.

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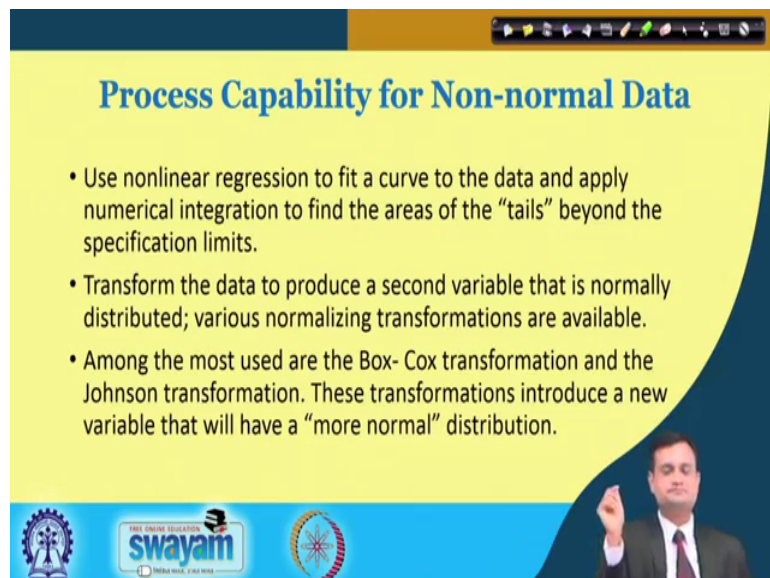
Process Capability for Non-normal Data

- If the histogram of individual data elements indicates that the data are not normally distributed, the procedure described previously for determining the process capability indices will not yield correct values for the percentage of process output exceeding specifications.
- The following approaches may be taken:
- Find another known distribution that fits the data—exponential, chi-square, Weibull, and F distributions are among the possibilities.
- A statistics software package is helpful in choosing the function and parameters that will provide the best fit for the data.

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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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Process Capability for Non-normal Data

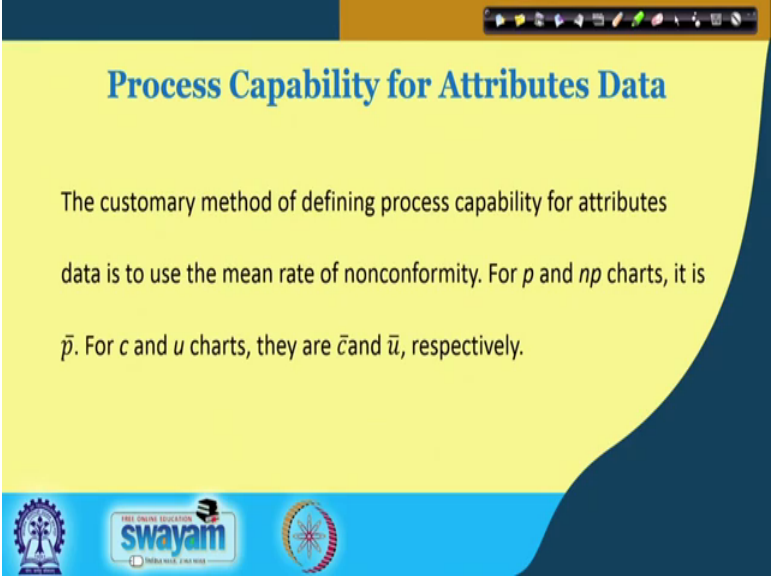
- Use nonlinear regression to fit a curve to the data and apply numerical integration to find the areas of the “tails” beyond the specification limits.
- Transform the data to produce a second variable that is normally distributed; various normalizing transformations are available.
- Among the most used are the Box- Cox transformation and the Johnson transformation. These transformations introduce a new variable that will have a “more normal” distribution.

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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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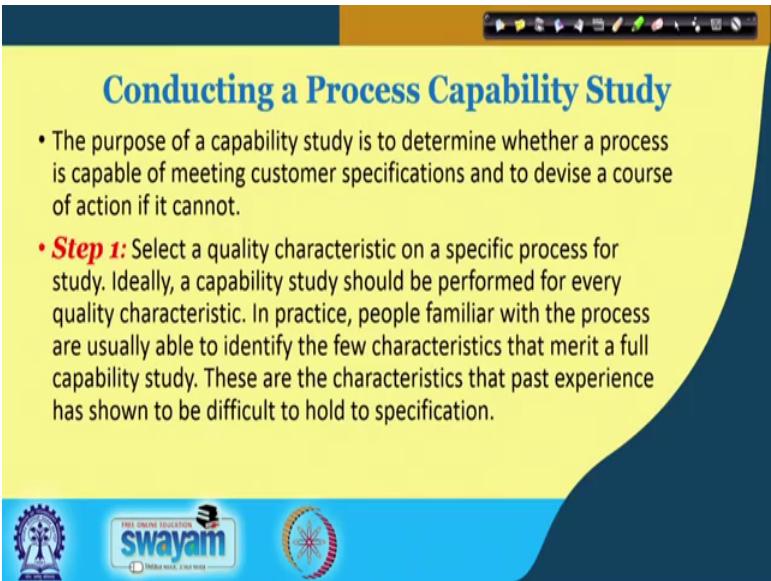
Process Capability for Attributes Data

The customary method of defining process capability for attributes data is to use the mean rate of nonconformity. For p and np charts, it is \bar{p} . For c and u charts, they are \bar{c} and \bar{u} , respectively.

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

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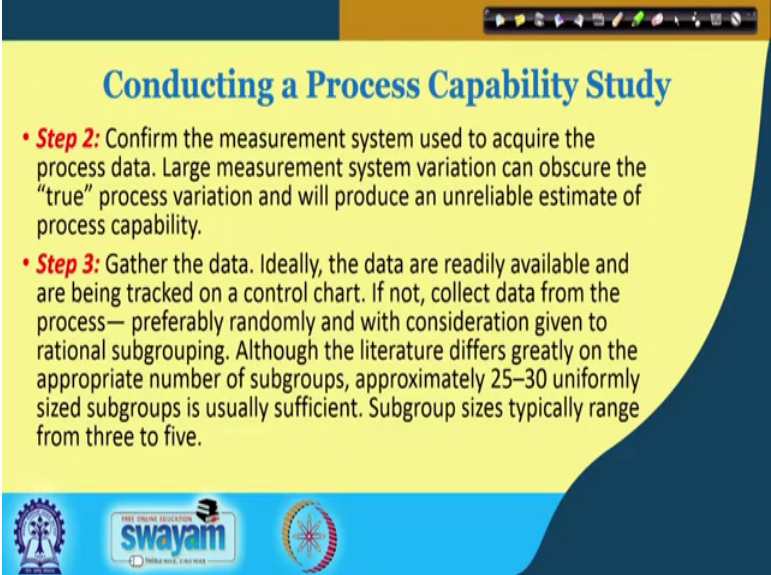
Conducting a Process Capability Study

- The purpose of a capability study is to determine whether a process is capable of meeting customer specifications and to devise a course of action if it cannot.
- **Step 1:** Select a quality characteristic on a specific process for study. Ideally, a capability study should be performed for every quality characteristic. In practice, people familiar with the process are usually able to identify the few characteristics that merit a full capability study. These are the characteristics that past experience has shown to be difficult to hold to specification.

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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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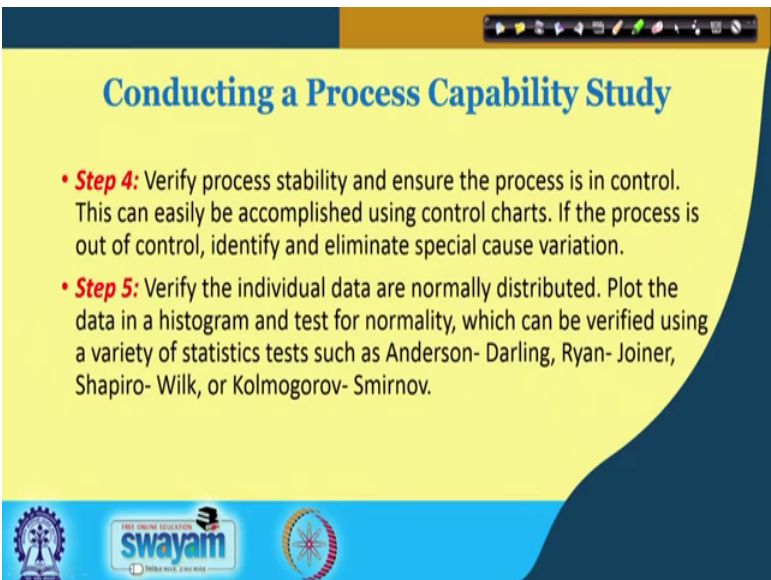
Conducting a Process Capability Study

- **Step 2:** Confirm the measurement system used to acquire the process data. Large measurement system variation can obscure the “true” process variation and will produce an unreliable estimate of process capability.
- **Step 3:** Gather the data. Ideally, the data are readily available and are being tracked on a control chart. If not, collect data from the process— preferably randomly and with consideration given to rational subgrouping. Although the literature differs greatly on the appropriate number of subgroups, approximately 25–30 uniformly sized subgroups is usually sufficient. Subgroup sizes typically range from three to five.

Logos at the bottom: Indian Institute of Technology, swayam, and a circular emblem.

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

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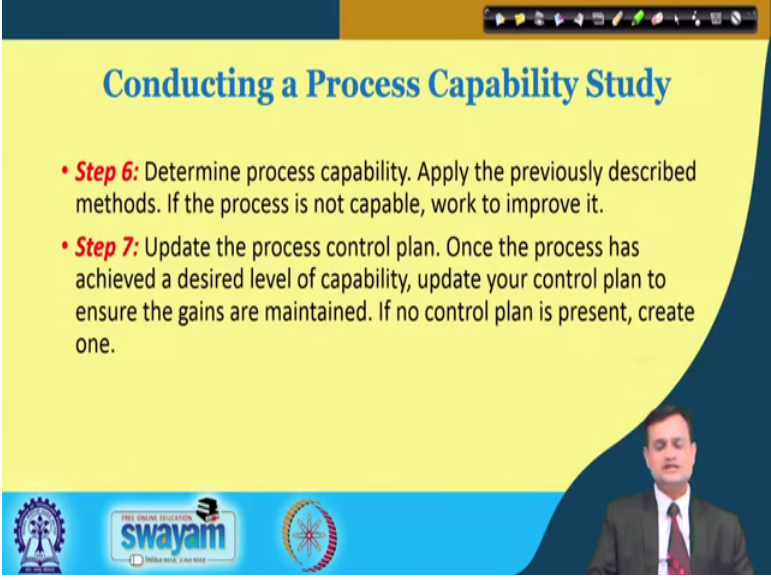
Conducting a Process Capability Study

- **Step 4:** Verify process stability and ensure the process is in control. This can easily be accomplished using control charts. If the process is out of control, identify and eliminate special cause variation.
- **Step 5:** Verify the individual data are normally distributed. Plot the data in a histogram and test for normality, which can be verified using a variety of statistics tests such as Anderson- Darling, Ryan- Joiner, Shapiro- Wilk, or Kolmogorov- Smirnov.

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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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Conducting a Process Capability Study

- **Step 6:** Determine process capability. Apply the previously described methods. If the process is not capable, work to improve it.
- **Step 7:** Update the process control plan. Once the process has achieved a desired level of capability, update your control plan to ensure the gains are maintained. If no control plan is present, create one.

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

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Process Performance Metrics vs Process Capability Indices

There is a difference between Process Performance Metrics and Process Capability Indices.

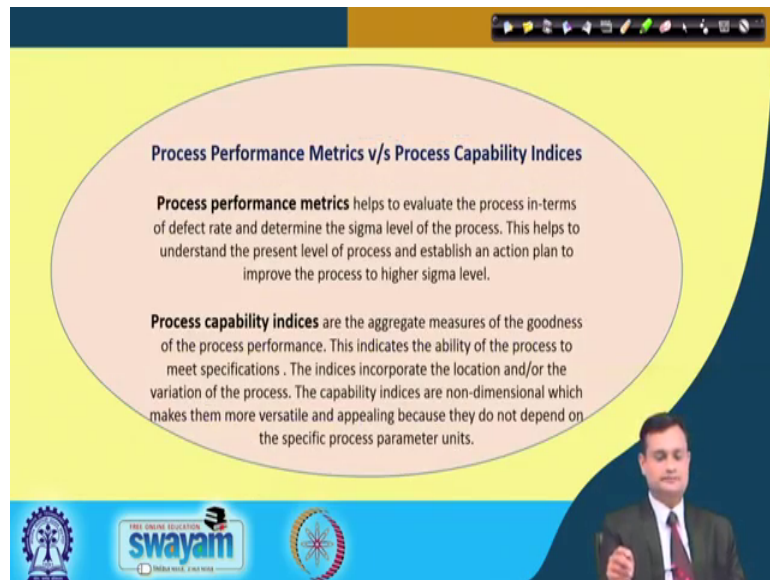
Process Performance Metrics: Percent defective, Parts per million (PPM), Defects per million opportunities (DPMO), Defects per unit (DPU), Process sigma, Rolled throughput yield (RTY)

Process Performance Indices: Pp, Ppk, Ppm

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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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Process Performance Metrics v/s Process Capability Indices

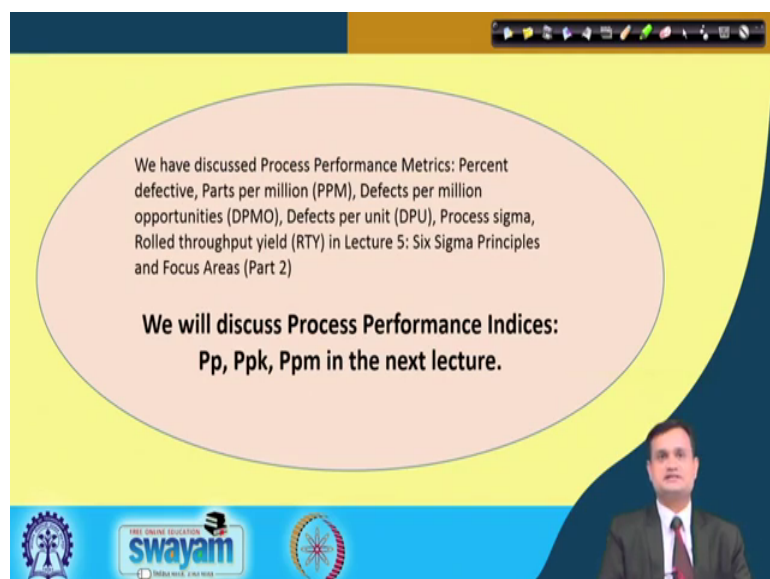
Process performance metrics helps to evaluate the process in-terms of defect rate and determine the sigma level of the process. This helps to understand the present level of process and establish an action plan to improve the process to higher sigma level.

Process capability indices are the aggregate measures of the goodness of the process performance. This indicates the ability of the process to meet specifications. The indices incorporate the location and/or the variation of the process. The capability indices are non-dimensional which makes them more versatile and appealing because they do not depend on the specific process parameter units.

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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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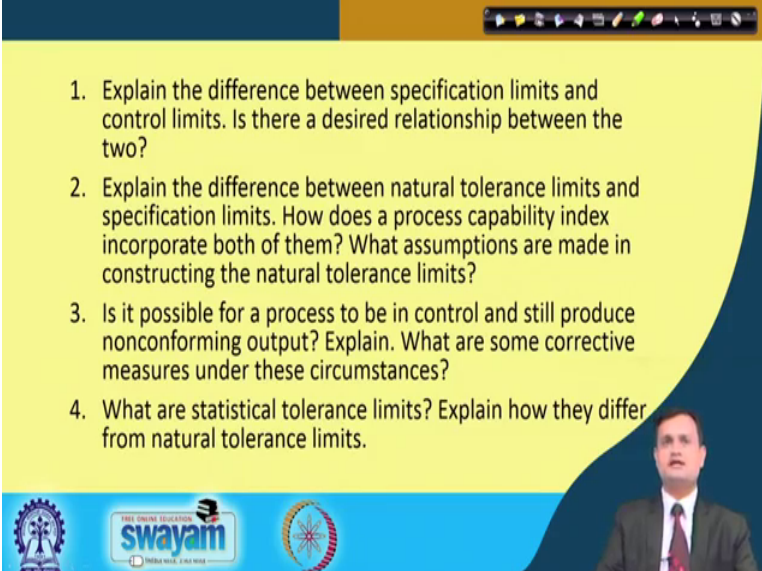
We have discussed Process Performance Metrics: Percent defective, Parts per million (PPM), Defects per million opportunities (DPMO), Defects per unit (DPU), Process sigma, Rolled throughput yield (RTY) in Lecture 5: Six Sigma Principles and Focus Areas (Part 2)

**We will discuss Process Performance Indices:
Pp, Ppk, Ppm in the next lecture.**

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

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1. Explain the difference between specification limits and control limits. Is there a desired relationship between the two?

2. Explain the difference between natural tolerance limits and specification limits. How does a process capability index incorporate both of them? What assumptions are made in constructing the natural tolerance limits?

3. Is it possible for a process to be in control and still produce nonconforming output? Explain. What are some corrective measures under these circumstances?

4. What are statistical tolerance limits? Explain how they differ from natural tolerance limits.

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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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References:

- ❑ Roderick A. Munro and Govindarajan Ramu and Daniel J. Zrymiak, The certified six sigma Green Belt Handbook, Second Edition, ASQ Quality Press and Infotech Standards India Pvt. Ltd.
- ❑ T. M. Kubiak, Donald W. Benbow, The Certified Six Sigma Black Belt Handbook, Second Edition, Pearson Publication.
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Use this references to understand this very important topic.

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Conclusion:

- ❖ Process capability study helps in product and process design, vendor sourcing, production or manufacturing planning, and in manufacturing process control.
- ❖ Control limits identify the variation that exists between samples or subgroups of measurements. They do not apply to individual units unless the control chart is for individual measurements.

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.