

Design Practice
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Lecture – 09
Concurrent Engineering

Hello and welcome to this course design practice module 9 we would talking about the concurrent engineering philosophy and how to understand this in real practice.

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So, I had already illustrated this that the philosophy of engineering design in consultation with all stakeholders associated with the whole lifecycle of a product. You know at the very beginning involving everybody together to emerge the engineering design is called the concurrent cons concept of engineering design; it is a highly multidisciplinary cross functional approach of designing products.

Particularly in an environment which is driven by all stakeholders, together from the very beginning and there are a lot of benefits which happen when we talk about such an approach of engineering design and.

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Why concurrent engineering?

- Increasing product variety and technical complexity that prolong the product development process and make it more difficult to predict the impact of design decisions on the functionality and performance of the final product.
- Increasing global competitive pressure that results from the emerging concept of reengineering.
- The need for rapid response to fast-changing consumer demand.
- The need for shorter product life cycle.
- Large organizations with several departments working on developing numerous products at the same time.
- New and innovative technologies emerging at a very high rate, thus causing the new product to be technological obsolete within a short period.

Some of the reasons why concurrent engineering is really the need of the day or need of the hour is that ah. You know first of all there is an increased amount of a product variety because of customization aspects and demands almost rocketing demands on the part of the consumers about the exact fitting of their needs and

So, therefore, you know because of the product variety and the associated technical complexity involving a single manufacturing setup, being able to flexibly manufacture in a customized manner ah. It generally prolongs you know the development process because any product which you may envision today and design today based on the manufacturing setup that you already have with probably very less capital investment and you know, very flexible overall production environment it is very complex to build such a design are it is very complex to develop such a product design. So, therefore, because of the product variety and technical complexity generally the development process gets highly prolonged and more difficult ok.

So, typically the predictability of what would be the impact of a small design change in the product or maybe a certain design decision on the overall functionality may become increasingly very complex to figure out. And therefore, the performance of the final product sometimes may get jupatise because of this exodus of customized needs associated with the different markets which are in play and which actually create those forces which are responsible for the realization of engineering products. So, increasing

global competitive pressure that is another reason why concurrent engineering is very important.

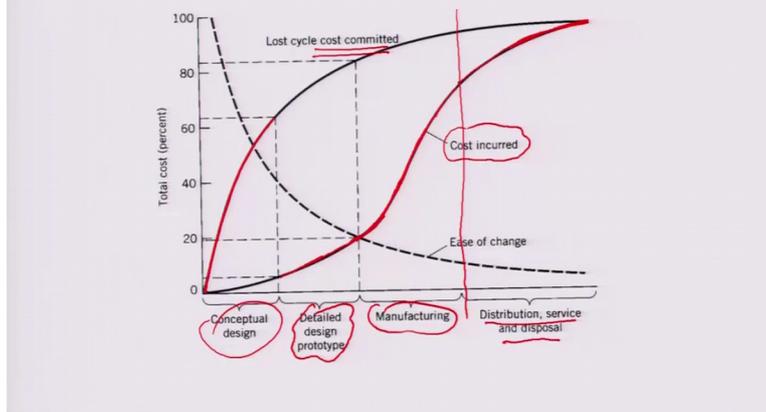
Ah. So, basically the pressure is from the emerging concept of a reengineering of products ok. So, you do not know what part of the world what is being manufactured and that may fall in place with certain segments wishes or aspirations and. So, in order to map that product you need to be able to flexibly change everything including the realization setup etcetera in a very small time ah. So, that you could re engineer anything which is felt to be the need of the hour and available globally as such on a local basis, the need for rapid response to fast changing consumer demands is again one of the reasons why contract engineering should be practiced, need for shorter product life cycles.

Today's products you know are basically shrinking as far as their lifecycle goals because there is new technology which is emergent and there is a consumer behavior which is actually geared by an addiction to more and more complexity in the technology. So, therefore; obviously, the product life cycle of some products have become very very short and that is again one of the reasons why the concurrent engineering helps you to go with psyche of the exact market segment built in the product from the very beginning.

So, large organizations with several departments, they work on developing numerous products at the same time. So, if they do it in a concurrent manner their efforts can be more focused and; obviously, new and innovative technologies emerging at a very high rate causing new products to be technologically obsolete within a very short period. As I told you about the short life cycle of the product is another reason why concurrent engineering helps to beat the competition in this kind of a complex environment.

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A characteristic curve representing cost incurred and committed during the product life cycle



So, these are some of the reasons why concurrent engineering is the need of the day basically if I looked at the characteristic curve which would represent the incurred cost on the product development process as opposed to the committed cost during the whole product lifecycle from the conceptual design state to the detailed design prototype stage or maybe the manufacturing and the post manufacturing distribution service and disposal state.

So, let us look at this curve behavior how what are the different costs. So, at the planning and design state of course, is going to be a research and development costs and cost of product design etcetera which is going to be the bulk of the committed cost and. In fact, if you commit this cost as you can see the total amount of course, that is actually incurred in you know the conceptual design phase actually falls down as a percentage because and then it actually also gives you a very smooth rise all the way to the manufacturing phase, because you have involved a lot of investment in the in the design itself of product.

Then of course, there is a manufacturing phase where the stage witnesses are sort of growth and maturity in the sales and all the manufacturing marketing selling and distribution costs are incurred at this particular phase and that is one of the reasons why there is a sort of a rise a gradual rise in this particular phase of the actual cost incurred.

And then there is a service and abandonment stage and those typically the last stage of the product will it is all post distribution and in the market. So, at this stage the product

this lifecycle is signified by a decline in the sales volume. So, the demand for the product declines at this stage, on the other hand the producers may be required to provide sort of after sales service and already to already sold products and there are costs incurred various costs incurred at this stage which kind of plateaus down. You know because of the certain level of constancy in the, on the size of the market ok. So, that is how the cost incurred goes and this kind of shows, what is the committed cost ok.

So, most of the committed costs about almost 80 percent is actually at the design stage of any product beyond which you know it kind of determines what is the cost that would be involved in the manufacturing. So, if you are investing more amount of money in the design phase typically you know it kind of leads to a quick constancy in the overall committed cost plan there is associated with the product. So, this is a sort of a curve which signifies what are the various aspects related to the actual commitments of the cost being made and the cost that are being incurred, the various stages of design and manufacturing and abandonment or distribution or sales service phase of product life cycle.

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Results of a survey that include the following improvements to specific product lines by the applications of concurrent engineering

1. Development and production lead times

- Product development time reduced up to 60%.
- Production spans reduced 10%.
- AT&T reduced the total process time for the ESS programmed digital switch by 46% in 3 years.
- Deere reduced product development time for construction equipment by 60%.
- JTI reduced the design cycle for an electronic countermeasures system by 33% and its transition-to-production time by 22%.

2. Measurable quality improvements

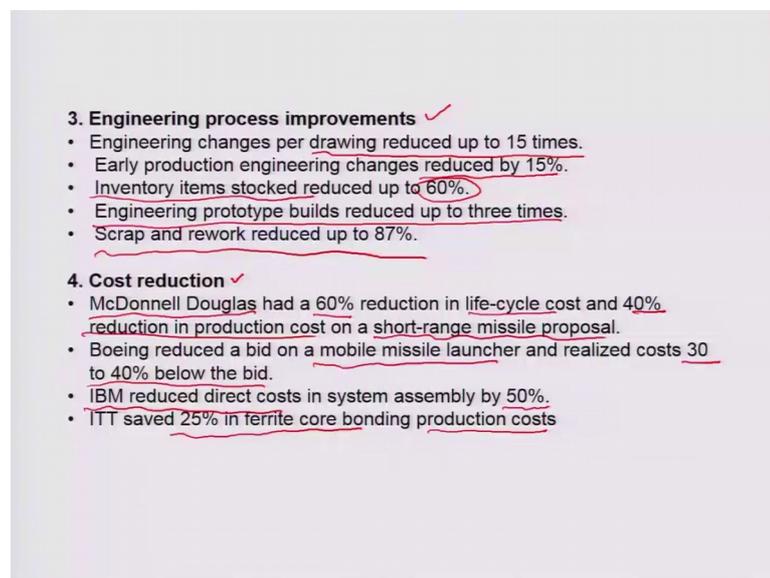
- Yield improvements of up to four times.
- Field failure rates reduced up to 83%.
- AT&T achieved a fourfold reduction in variability in a polysilicon deposition process for very large scale integrated circuits and achieved nearly two orders of magnitude reduction in surface defects.
- AT&T reduced defects in the ESS programmed digital switch up to 87% through a coordinated quality improvement program that included product and process design.
- Deere reduced the number of inspectors by two-thirds through emphasis on process control and linking the design and manufacturing processes.

So, there are some results that I would like to share of a survey which includes an improvement of 2 specific product lines by application of concurrent engineering philosophy there are various concerns or companies which are which are involved in showing such a reduction and you will get to know from these statistics that I am sharing

with you how important the concurrent philosophy of engineering design can be in terms of overall improvement in product lines. So, when we talk about development and production lead times, product development time has been shown to reduce almost up to 60 percent with the concurrent engineering philosophy being implemented and the production spans have reduced by almost 10 percent.

So, if we looked at in specifics related to certain companies at and t for example, reduce the total process time for the ESS programmed digital switch manufactured by them by almost 46 percent in a 3 years time phase using concurrent engineering philosophy. Similarly, John deere reduced product development time for construction equipments by almost 60 percent again using the concurrent engineering philosophy there are other companies like ITT for example, which will use the design cycle for an electronic countermeasures system by almost 33 percent and its transition to the production time by almost 22 percent again by utilization of the concurrent enduring philosophy.

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3. Engineering process improvements ✓

- Engineering changes per drawing reduced up to 15 times.
- Early production engineering changes reduced by 15%.
- Inventory items stocked reduced up to 60%.
- Engineering prototype builds reduced up to three times.
- Scrap and rework reduced up to 87%.

4. Cost reduction ✓

- McDonnell Douglas had a 60% reduction in life-cycle cost and 40% reduction in production cost on a short-range missile proposal.
- Boeing reduced a bid on a mobile missile launcher and realized costs 30 to 40% below the bid.
- IBM reduced direct costs in system assembly by 50%.
- ITT saved 25% in ferrite core bonding production costs.

So, there are numerous such examples in terms of measurable quality improvements, in terms of engineering process improvements and overall cost reduction where a lot of concerns have shown, a lot of companies have shown a reduction in the overall cost or increase in overall process improvement through confident engineering philosophy. For example, if we looked at quality improvement almost yield improvements to the level of almost up to four times have been recorded field failures.

For example reduce up to 83 percent by you know in case of AT and T which achieved almost a fourfold reduction in variability in a polysilicon deposition process on a microchipped production line. For very large scale integrated circuits typically also known as VLSI circuits and it also achieved nearly 2 orders of magnitude reduction in the surface defects associated with such polysilicon deposits, because of the utilization of the concurrent engineering philosophy with the involvement of everybody.

Similarly, in the ESS program digital switch manufactured by at and t again which is actually known to be a company which is quite conversant with this implementation of the concrete engineering approach. they reduce almost defects almost about 87 percent through a coordinated q I p that in included product and process design improvements being suggested by a team of professionals working in a concrete manner. Similarly, john deere reduced the number of inspectors on their production lines by almost two thirds through emphasis on process control and linking design and manufacturing processes closely so, that they could have measurable quality improvement again as results because of the content engineering applications.

There are other examples also for engineering process improvement for example, engineering changes per drawing have been seen to reduce almost 15 times sometimes early production engineering changes got reduced by about 15 percent. Inventory items stocked and essentially blocked capital reduced to almost 60 percent by use of a concurrent engineering philosophy, just because there was a stake holding from all associated people with a product development or manufacturing or even sales and service process or let us say associated with the whole product lifecycle of a product.

Again engineering prototype builds reduced by almost up to 3 times. if certain number of iterative prototypes were planned with the serial engineering with the concrete engineering it probably could be accomplished by almost one third of the numbers that was there in the serial engineering approach scrapped and reworked will be used almost up to 87 percent because of confident philosophy again.

If we talk about cost reduction again the famous McDonnell Douglas airplanes manufacturer had a 60 percent reduction in lifecycle cost almost a 40 percent reduction in production cost particularly on a difference program related to missiles. Again a Boeing reduced a bid on a mobile design launcher realize the cost almost about 30 to 40

percent below the bided price just by applying the concurrent approach in their overall philosophy similarly IBM could reduce direct costs and systems system assemblies by almost 50 percent or ITT saved about 25 percent in the ferrite core bonding production costs by using confident in doing. So, there are numerous examples cited in literature where you see how important it is to design with the concurrent philosophy ok.

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Example for Serial Engineering vs. Concurrent Engineering:

Case Study I

ABC Company requires 1000 units of a turned cylindrical part (shaft). The design department of ABC company defines a need for a cylindrical part to be finished to 1 ± 0.003 inch. A serial engineering approach and a concurrent engineering solution are presented in the two scenarios that follow. We compare two situations that emerge from these strategies.

- **Serial Engineering Approach**
- The design department of ABC recommends a shaft dimension and tolerance of 1 ± 0.003 inch; this information is transmitted to the manufacturing engineering department.
- In the serial engineering approach, manufacturing engineering accepts these specifications and attempts to find the best manufacturing technology to accommodate the request made by design.
- Manufacturing engineering will challenge the specification only if the design is not producible.
- Drawing on the preceding analysis, manufacturing engineering decides to produce the parts on a turret lathe because the desired tolerances can be obtained. The process average and the standard deviation are estimated to be 1.00 and 0.003 inch, respectively.

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So, we will now like to investigate a small model based problem, it is case study of a company which requires about thousand units of turned cylindrical part to be produced, a shaft needs to be produced on a turning machine and the design department of this company defines a need for a cylindrical part to be finished to an extent of about 1 plus minus 0.003 inches.

That means the overall die of this part or diameter of this part varies between as acceptable limits between 0.997 inches on one side and 1.003 inches on another side. So, here the idea is to use first the serial engineering approach to see what is going to be the overall cost per piece in order to bring out this through the process of the design and the manufacturing improvement and then using a concurrent engineering solution in another scenario and then there can be a cost comparative drawn in terms of the final produced product being manufactured.

So, you will see how this concurrent engineering philosophy as applied to a sequential otherwise a standard sequential engineering activity can bring down costs significantly of

the pieces which have been produced through this trees approach. So, I will just highlight what the serial engineering approach had to face as challenges and what the concurrent engineering approach had to face and then we will work on developing a mathematical model to understand how the cost can be optimized to the best possible value through both the approaches.

So, in the serial engineering approach the design department of this company recommends a overall shaft dimension and tolerance in the range of one plus minus 0.003 inches and this information is transmitted to manufacturing. And; obviously, in this particular serial engineering approach the manufacturing engineering accepts these specific tries to attempt to build the part tries to find out the best manufacturing technology that they may have to accommodate the requests made and they can only challenge the specification as set up by the design department if the design is not compatible and producible in one of the machines which they may be having.

And so drawing on the proceeding analysis the manufacturing engineering decides in this particular case to produce the parts and it uses a turret lathe which is there already with the manufacturing engine department. Because whatever tolerances have been desired by the design can be easily implemented the process average and the standard deviation of the turret lathe that is there with the manufacturing engineering happens to be about 1 inch and it also happens to be the deviation happens to be about 0.003 inches.

So, this is a good match between what needs to be produced and what has to be delivered ah, but essentially this may not be all the information that is needed to find calculate what is going to be the cost related to such a product because the question that may be asked is whether really we need this kind of a closed tolerance in the finish and that can be best adjust by a person who works.

Let us say in the post sales service which talks about what is going to be the reliability aspect or what is going to be the warranty failure or what is going to be the cost associated with such failures what is the criteria of the failure and also the quality person who is in house and working on a problem and tries to implement this particular specification within engineering assembly.

So, from his learning somehow the overall needs statement which came up to the design department can get influenced and therefore, there may be a much broader specification

range in which the piece can be turned and produced at a much lower cost because it may not be necessary that the tight tolerances given by the design are really the ones which are required by the whole process. So, we will slightly change the connotation when it comes to a concurrent engineering approach.

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Concurrent Engineering Approach
Various issues to be addressed by multidisciplinary team:

- The marketing services of ABC found that the tolerance range of 1 ± 0.003 inch may be too tight.
- The quality department did not like the number of rejections.
- The manufacturing planning department wants to use machine tools with better process capabilities.
- The purchasing department cannot buy so many raw shafts because of the restricted availability of such steel.

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And there will be various issues which need to be addressed by again CFTS or cross functional teams in this particular case for example, the marketing services for this company finds that the tolerance range 1 plus minus 0.003 inches may be too tight and it is really not needed I mean you can work with a better specification, a much wider specification where process control of that level may not be really needed.

The quality department; however, did not like the number of rejections because; obviously, if there is a process in place and there is going to be some feedstock given to the process and it produces some output they are going to be rejects and. So, if the process capability of a machine is not very well defined then; obviously, there may be rejects and costs related to the rejects.

So, we need to build a mathematical model around all this to approach this problem. So, that we can actually bring the specifics of the cost, we will make some assumptions about the different costs related to the raw materials or that related to the rejected materials all that related to the material which comes out and then we will finally, try to do both the philosophies in place and try to calculate what is the overall cost ok.

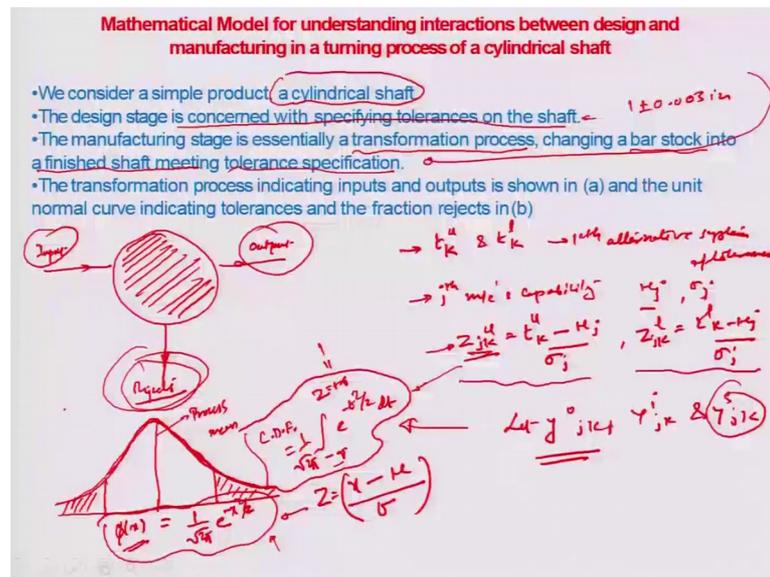
Similarly, in the concurrent case the manufacturing planning department it wants use machine tools with better process capabilities. So, that they can work on closer tolerances, but this is a conflicting interest with the marketing which says that the tonal range given is too tight and it may not be necessary really for the product and similarly the purchasing department cannot buy so many raw shops because of the restricted availability of such steels. So, they would also look at what quality is saying in this particular case about lower number of rejects.

So, it is some conflicts which are there at the very beginning and if they can be involved at the outset the design which will emerge will be making everybody else happy about their requirements and then that the goals of an organization to design something in concurrence.

Ok with everybody who is a stakeholder would be the best possible alternative in this kind of a conflicting situation, in the serial approach if we had introduced this design specification there would be checks and balances at every stage and it needs to eater it probably many times before the final design can come through. Whereas, in the concurrent you can do one short with all opinions together and make a design which may not need to be prototype for more than 1 probably, for more than 1 or 2 times probably a prototyping for a second time may be needed because of some functional aspect associated with the product as we will find out later which may get emerged in the concurrent engineering case.

So, let us look at how we will develop a process model for this.

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So, you know in this particular case we consider a very very simple product that is a cylindrical shaft and you know at the design stage we concerned with specifying the tolerances on the shaft which has already been done to be 1 plus minus 0.003 inches and the manufacturing state again it is sort of a transformation process that whatever you know raw material we have in terms of rods or feedstocks which we are giving to the system they would like to turn the the rod into a smaller diameter rod. So, a bar stock for example, would be converted into a finished shaft to meeting the necessary tolerance specifications as specified by the initial design and the transformation process would indicate inputs and outputs in the following manner. So, let us say this circle here represents the transformation method and there is some kind of a input material which is given to a transformation process and it generates an output material..

So, obviously, such a transformation would also be responsible for generating many process rejects because it may not fully comply to the tolerance specification is indicated. The capability of the process may be lower in comparison to the tight tight tolerances which are being specified by the design and therefore, there may be some cases where there are non confirming parts or you know spots not meeting specification.

So, we would like to sort of look at it from the standpoint of a normal distribution where we have a process mean and a sort of an avere you know a standard deviation and as you

know that such distributions are signified by a inverted bell shaped curve as is represented here and this is the process mean around which this curve is centered.

So, the the normal distribution function is typically represented through $\frac{1}{\sigma\sqrt{2\pi}}$. So, this is the standard normal distribution function. So, $\frac{1}{\sigma\sqrt{2\pi}}$ times of e to the power of minus t square by 2 sorry this is x ok. So, a minus x square by 2 and. In fact, if I wanted to see what is the area under this curve and also the area under the contents of more important significance when you typically do a scaled normal distribution with $\frac{1}{\sigma}$ or $\frac{1}{\text{standard deviation}}$ in place for the whole whole function here.

So, the cumulative density function $c d f$ which signifies the area under the curve here would be represented then by $\frac{1}{\sigma\sqrt{2\pi}}$ with t varying between minus infinity to the value z e to the power of minus t square by 2 $d t$ where z typically is the scaled variable which is actually the x minus the mean for the process divided by the sigma for the process. So, that is how you scale the distribution the standard normal distribution and obtain the area under the curve. So, having said that and this is all very commonly available information as far as statistical process control goes I am just going to apply this to the concurrent engineering philosophy that we are talking about when we mentioned about this as a as a as an engineering design tool.

So, here there are going to be upper specifications and lower specific given by the design department which have to be overlapped, with this process this you know characterization or process characteristics of a mean and a variance which is related to a certain process. So, for example, if the process is a turret lathe which has been seen here, the turret lathe in question may have a certain capability in terms of giving a certain mean dimension and a certain variation you know in production of parts and. So, that mean and standard deviation would then be the process mean and the process standard deviation which we have to overlay on the design requirement which is the upper and the lower specification given by the design department remember, it was given us 1 ± 0.003 inches on one side and 1 ± 0.003 inches on another side.

So, supposing let us say the design department specifies a tolerance limit you know corresponding to the k th alternative system of tolerances that you know the whole engineering assembly has and there is an upper side of the tolerance and then there is a lower side of the tolerance that has been specified and let us say. So, this is

corresponding to the k th alternative system of tolerances and let us say we are evaluating j machines in place which are there with the manufacturing wing and all these j machines would have different process capabilities and when we talk about the j th machine that we want to mix and match for example, in this case the turret lathe may be the such a machine you know such. So, we just number them we have as different processes.

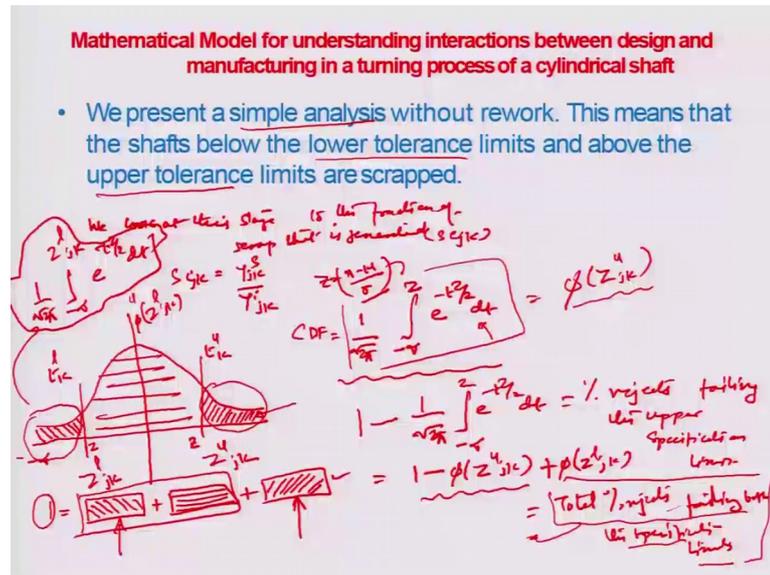
So, the j th machines capability is illustrated in terms of process mean and a process standard deviation let us call it μ_j and σ_j . So, then in this case the scaled variable that we are talking about for this building up this you know cumulative distribution function which is otherwise actually the the scaled variable if we look at here the c d f corresponding to the whole area under the curve varying from minus infinity to z equal to plus infinity happens to be unity ok. So, that is how so it is like more like 100 percent of the parts qualify to lie within that distribution when we go from minus infinity to plus infinity of the scaled variable.

So, the scaled variable in this particular case for overlapping the tolerance or overlaying the tolerance on our process capability for the j th machining system is given through an upper scaled variable and a lower scaled variable. The upper scaled variable is nothing, but the tolerance given the k th tolerance which is being manufactured on the j th machine you know which has capabilities μ_j and σ_j and similarly there is a lower scaled based on the lower tolerance given on the same machine of the j th alternative machine which has μ_j and σ_j as the process mean and the process standard deviation.

So, these are the standard normal variates and these are very important because such scaled variates would get into such a distribution function here as shown here which corresponds to you know 100 percent inclusion of whatever parts are being produced to fall under the whole normal distribution curve as mentioned here.

So, let us now look at some numbers in terms of number of inputs and number of outputs and see how the input output behavior or flow would happen in this particular case. So, that y_{0jk} and y_{Ijk} and y_{sjk} signify the output coming out here in this particular figure, the input you know which is being fed inside the figure and the scraped the rework or the rejects which are coming out as a result of this transformation matrix ok.

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So, let us say this kind of simplifies the analysis that anything above the lower tolerance or below the anything below the lower tolerance or above the upper tolerance are sort of rejected together and we look at at this stage to the fraction of scrap that is generated ok. So, the you know we call it the scrap for the fraction of the scrap as s_{jk} and this s_{jk} is nothing, but the the percentage scrap units per unit or the number of scrap units per unit the number of inputs. So, basically it is about how much of material is actually not getting transformed and being sent out by the transformation processes scrap.

So, if I looked at again the normal distribution and the way that rejects are being done, you know that there is a process mean and; obviously, there is upper tolerance and lower tolerance corresponding to which there is a z variate which has been plotted. So, there is a z variate lower and that variate upper. So, if so, this is corresponding to let us say the upper specification limit of the gate specification system and the lower specification limit of the gate specification system. So, everything which falls outside this domain; that means, the the shaded area represented here and you know everything which falls outside this domain would correspond to let me just shade this in a little different manner. So, that it is better for us to understand. So, let us say this is shaded in this manner ah. So, everything falling above the upper specification or below the lower specification this way are being rejected and everything which is actually in between here qualifiers to the design specs are being accepted.

So, we know that in this particular distribution because it is a scale distribution and you know 100 percent components correspond to the value 1 which is the area under the curve. So, I would say that 1 is basically a summation of all these different areas. So, you have an area shaded like this, you have an area shaded like this and then again an area shaded in this manner. So, these are sort of cumulatively all these areas together mean that 100 percent lie within this particular zone; however, out of this 100 percent these 2 are the areas which would be needed or which would need to be taken off from the cumulative distribution function which we had earlier provided in the last slide . In which we talked about $1 - \frac{1}{\sqrt{2\pi}} \int_{-\infty}^z e^{-\frac{t^2}{2}} dt$ this value of the integral or area under the curve when the z here is a distribution $\frac{x - \mu}{\sigma}$ so a scale distribution.

So, so; obviously, we can find out you know the values of this numerical integral and record these and these are also available at standard tables from which we can find out what is the percentage which is being rejected on either side of the upper and lower specification limits. So, for example, if I wanted to find out what is the rejects above the upper tolerance limit in this case I would look at the whole distribution as one and just simply subtract the numerical integral $1 - \frac{1}{\sqrt{2\pi}} \int_{-\infty}^z e^{-\frac{t^2}{2}} dt$ to the point z here $e^{-\frac{t^2}{2}}$.

So, the area under the curve corresponding to these 2 values would have to be subtracted from 1 in order to get this particular value. So, this corresponds to percentage rejects failing the upper specification limit similarly . So, I call this $1 - \Phi(z_{ujk})$ remember we are representing this function through a function Φ if the variable here z in this case it is z_{upper} while choosing the k th specification and trying to process it through the j th machine ok.

Similarly, I would like to get a value on this side of the normal distribution which is actually $\frac{1}{\sqrt{2\pi}} \int_{-\infty}^z e^{-\frac{t^2}{2}} dt$ again varying between minus infinity all the way to this value z here which is z_{lower} $e^{-\frac{t^2}{2}}$. So, this is another numerical value that I would like to get from the normal distribution I call this value as such $\Phi(z_{lj k})$. So, if I add the $\Phi(z_{lj k})$ to the one minus $\Phi(z_{uj k})$ this is typically what we are talking about as the total percentage rejects failing both the specification limits, both the specification limits.

So, that is how we try to analyze the the total percentage projects in this particular case or category and the idea is that once we get this value estimated from a simple normal table I should be able to put this in terms of cost calculation which I will probably do in the next lecture. So, thank you very much for being with us here and in the next lecture I will show you how the overall cost gets influenced because of this many percentage of projects which gets generated because of force fitting a certain specification limit on a process capability associated to the machine.

Thank you very much again.