Six Sigma
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Lecture - 45
Taguchi Method: Key Concepts

Hello friends, welcome to our journey on Six Sigma. And one by one, we are have trying to appreciate the various concepts in detail. And I would like to remind you that we are through with define, measure, analyze; and at present, we are discussing the improve phase of six sigma cycle. As a power of improved phase, we have talked about design of experiments, randomized complete blog design, factorial design, fractional factorial design with its Minitab application.

And now today as a part of lecture 45, I want to discuss a very very important topic, and very much useful methodology that is Taguchi method. I will discuss the key concepts in this lecture. And subsequently in the next lecture, we will see some illustrative application of this method.

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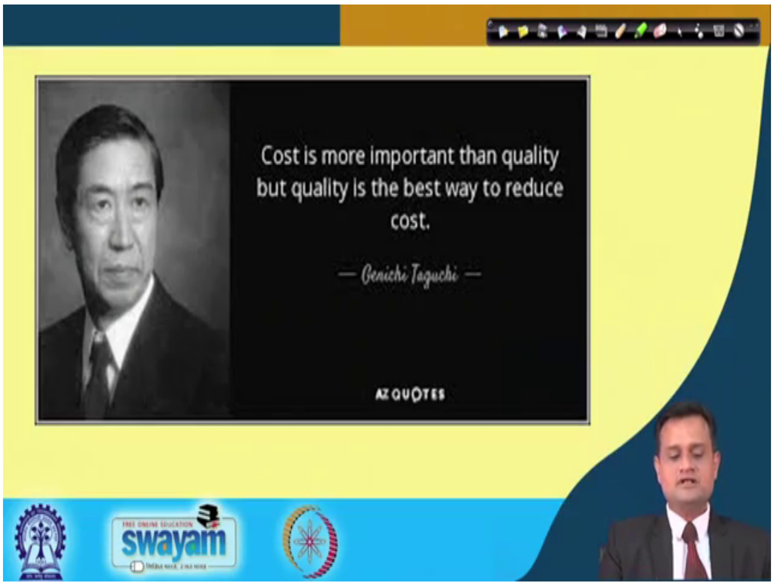

So, let us appreciate that what is the concept of Taguchi or what is his ideology, and basically it is Genichi Taguchi. So, cost is more important than quantity, but quality is the best way to reduce cost ok. So, this is what Taguchi says, can you think what is the importance of this statement, you may get an idea that cost is more important than the quality fine. Sometimes we think like that, but quality is the best way to reduce cost.

Now, the logic is very simple. If you produce the product by employing your all resources, processes, manpower, energy, material, and finally if this product is not accepted by the customer, because of poor performance or too much deviation from the targeted performance, that is what we try to address in this lecture. Then your product will not be sold, you have to throw away, just sell it at a throwaway price, then there is a loss.

If you produce the product, which does not meet the desired specific essence, that is a loss, because you will end up with the rework and rejection. So, the second part is really true that quality is the best way to reduce cost. If you want to reduce any kind of cost, rework, rejection, failure at the customer and or market or unsold product, then try to address the quality, all other things will be taken care.

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So, recap we had a detailed discussion on Minitab application for fractional factorial design.

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And now in this, I would like to focus on couple of important aspects of Taguchi, experimental strategy that is goal-post philosophy, Taguchi method, signal and noise, and then Taguchi's parameter design steps.

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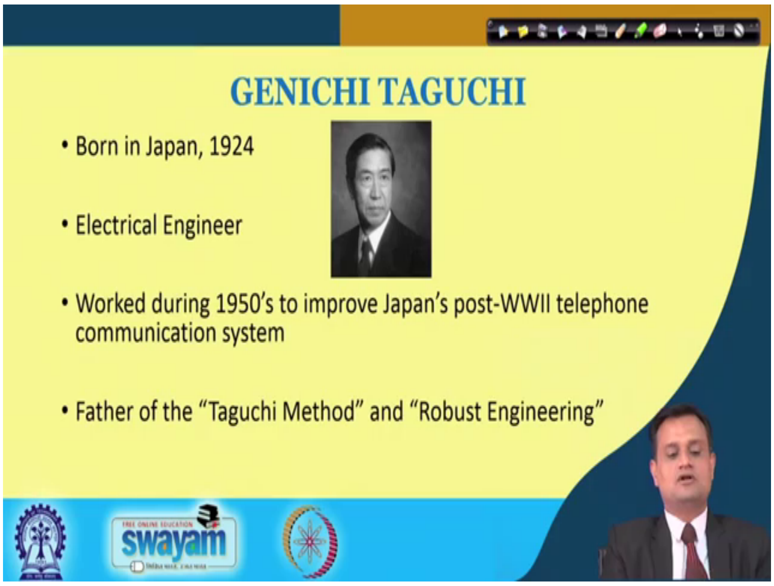

So, let us see what is the contribution of Genichi Taguchi, he was born in Japan 1924, basically an electrical engineer and worked during nineteen 1950's to improve Japan's post-World War 2 telephone communication system. And he is the father of Taguchi method, typically robust design. So, you all understand the meaning of robustness, less sensitive to the other factors, external factors, and performs to the targeted value gives the desirable performance. And this is something we call as robustness, so Taguchi emphasize on robustness of the design, and that is where he brought his concept in the domain of design of experiment.

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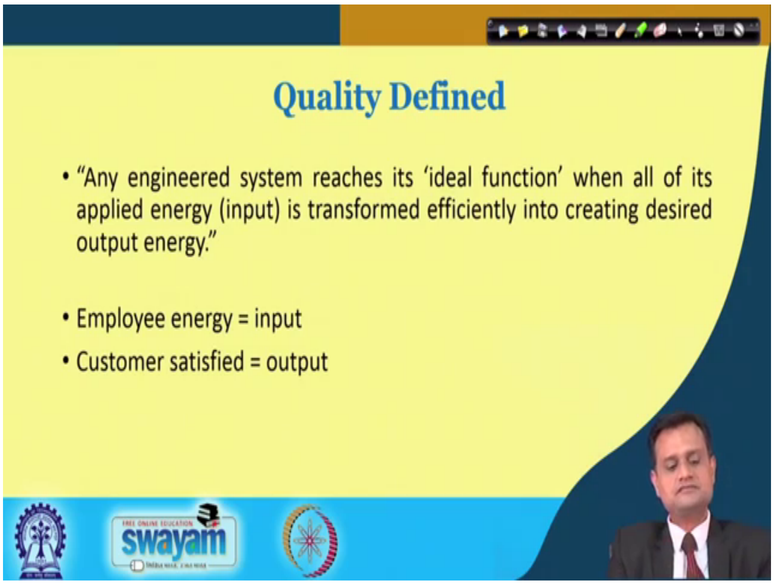

So, let us see, how he defines the quality, and what is it is understanding. So, any engineered system reaches its ideal function, when all of its applied energy that is the input is transformed efficiently into creating desired output energy. So, this is something that ideal function means, if you input some energy or material or whatever, then this needs to be efficiently transformed in creating the desired output.

Suppose, you take the example of automobile, then suppose your input energy is petrol, then what is the efficiency, you get in terms of mileage. So, you have the input energy in a typical system, maybe your employee energy, you may be your equipment machinery, customer satisfied is the final output that is the expected desirable outcome.

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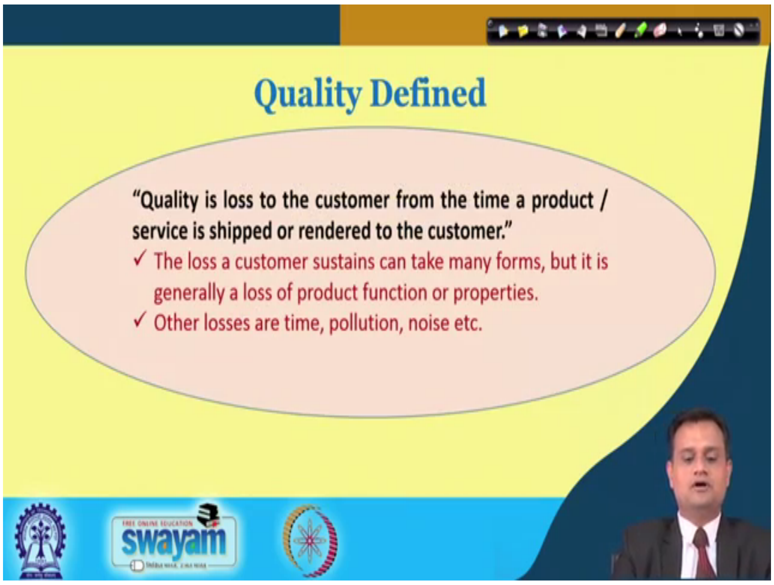

Now, quality is defined in Taguchi's language as loss to customer from the time a product or service is shipped to or rendered to the customer. So, now just take the example, I am giving this video to the student through an online mechanism. Now, by chance if the recording quality is not good, then the final delivery will be affected, and you would not be happy in understanding the concepts.

So, the moment we deviate from the targeted value, then our quality gets affected, and that is where the loss to society is important. So, this is a very very important in beautiful concept. The loss a customer sustained can make take many forms, but generally the laws of product function or properties. And this could be in terms of time, money, pollution, noise etcetera.

Today, we talk about sustainability. You download the product, but that has a very huge impact on the environment, then the sustainability is damaged, and that is the loss to society. You produce the product in which your products totally produced A grade products are very less, B grade products are more, C grade products are too much, then your conversion process is not affect you. And if this products are delivered to the market, there is likely possibility, that they will not solve the intended purpose.

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So, loss imparted to society from the time of product is shipped, whether it creates the bad performance, whether it is not convenient in use, whether it confuses my customer, it damages the environment, and what not. So, all these is counted as loss to society, the moment product is shipped to the customer.

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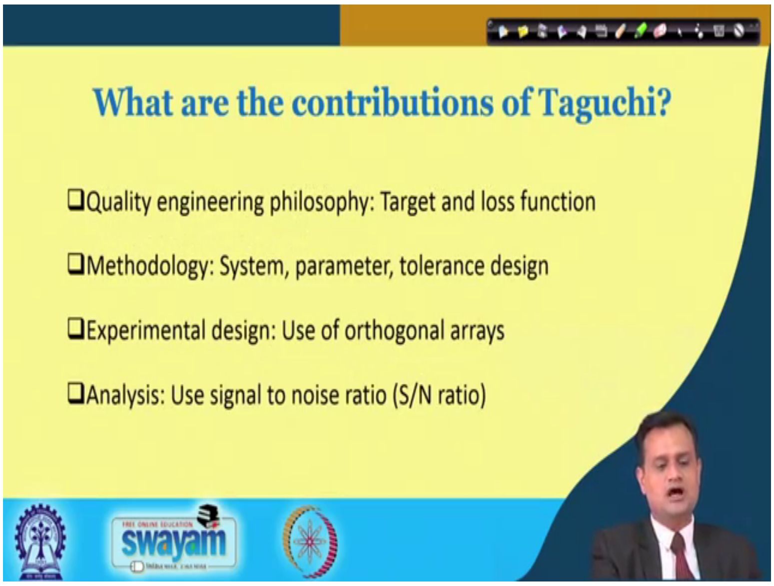

So, now what are the key contributions? So, philosophy is target is the best. And when you deviate from the target, you need to look at the loss function. Methodology is system, parameter, tolerance design. And typically, he has used the mathematical concept that is the orthogonal arrays.

So, now here how to conduct the experimentation by considering the concept of robustness, he tried to capture the randomness of conducting the experimentation by adopting the concept of orthogonal array, which is a mathematical concept. And then he developed a strategy by which you conduct the experimentation easily, by avoiding many higher level interaction, which reduces your say size of the experimentation.

And you use the concept robustness concept delivered by Taguchi that is S by N ratio. So, S stands for signal, N stands for noise. We should try to maximize this ratio signal to noise, because noise is something, which makes the product less robust, and more sensitive to some of the factors, under which the performance may deteriorated.

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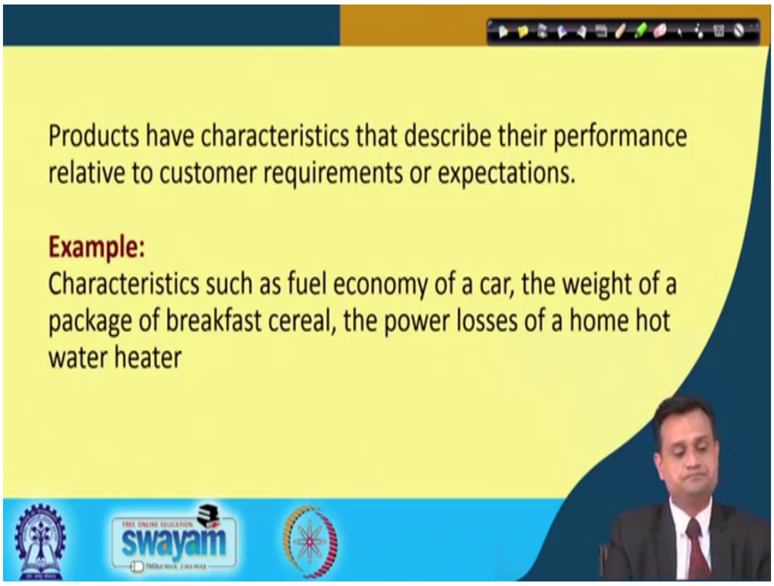

So, this is just a small example that characteristics such as fuel economy of a car as I said, the weight of a package of breakfast cereal, you are purchasing. Let us say, you purchased let us say cornflakes, now you paid for 500 gram. Usually, for your family you see that you consume 500 gram in 10 days by taking some amount every day, now this time you found that your cereal packet is just consumed in 7 days. So, you have a suspicion that whether I consumed it more or now this packet has the less weight. So, you say that no, I exactly consume the same quantity, it means the weightage of this particular cereal in the packet is less that makes you dissatisfied power losses of a home hot water heater, so this is again the loss of energy.

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And likewise, there could be many examples where loss occurs. So, you cannot achieve the competitiveness, unless you deliver the robust services and robust products, and this is where the concept of Taguchi is useful.

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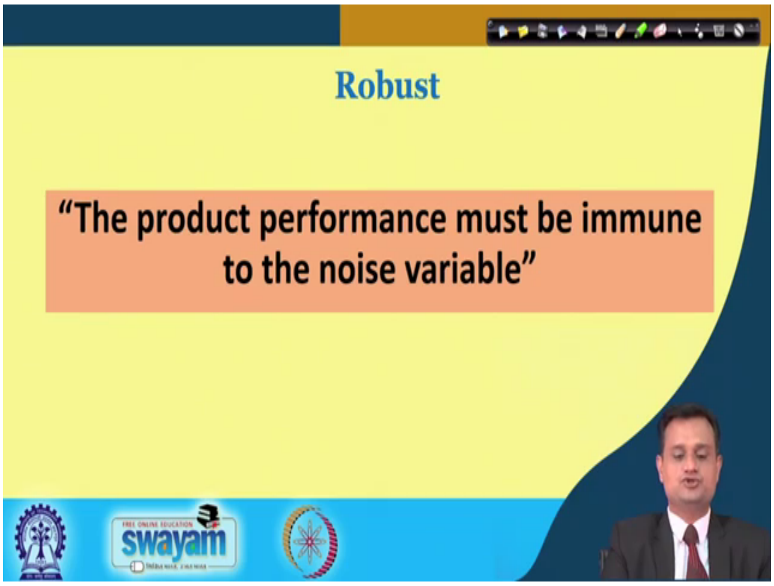

So, robustness as I mentioned, the product performance must be immune to the noise variable. Just take your body, thousands of say viruses; they are welcoming us, surrounding us. Now, I do not really have control to have any restriction on these viruses, bacteria, maybe insects, what I can have is my own system immunity which make my body robust, so that I do not get affected immediately. So, this is where the robustness lies, and you need to make your system more immune, more robust rather than say too much bothering about controlling the noise or the actual external factors, which are beyond your control.

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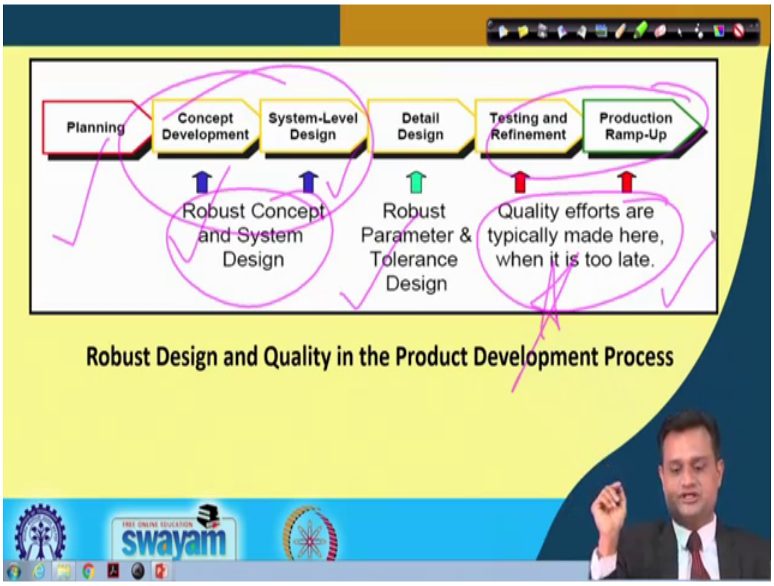

So, this is typically what you can see here that you do the planning, then you have the concept development that is robust concept and system design, then system level design comes in picture. So, this is what you try to address at the system level. Then detailed design, where robust parameter and tolerance design you take into account, then testing and refinement production ramp-up. So, quality efforts are typically made here, when it is too late.

So, please understand that this is where if you are really targeting, it is too late. So, again I would repeat, you are taking a good quality, nutritional powder, you are taking fruits, milk, you are taking chavanpras or some other kind of say good food. And you are obviously, daily food schedule, this all makes you robust immune. And then you are doing these, basically you are trying to address these at this stage early stage. The moment you go here, it means now you are affected by let us say some viruses, you got viral fever tuberculosis, you are going to the doctor, doctor will prescribe the medication and try to control.

So, this is the too late stage, where you have to do rework or rejection in a typical system, customer is visiting your restaurant. And suppose your delivery time is too high, now this customer will not come again, will not show again, and then there is a total loss of business. So, if you are trying to control at the later stage, the consequences are very high, Taguchi says try to control at the design stage.

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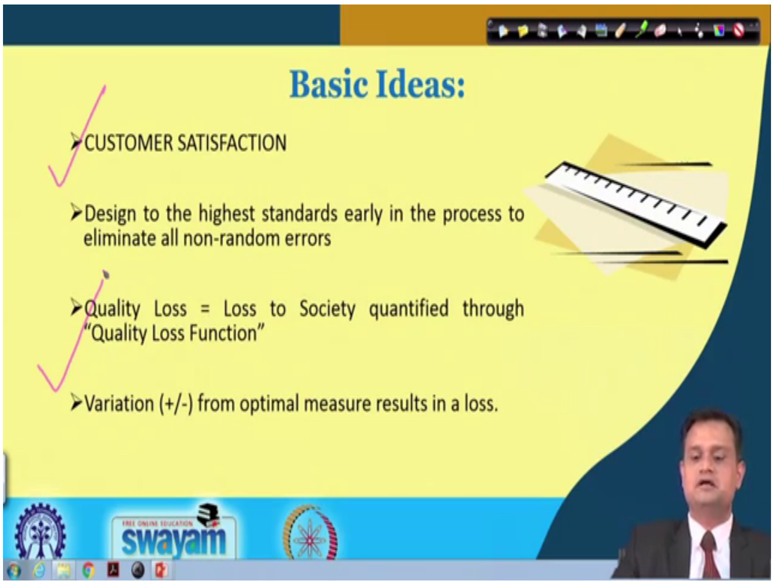

So, this is what we basically try to do in the Taguchi philosophy, my objective is to ensure the customer satisfactions arrived at the design stage. And lost to society that is the quality loss function must be minimized.

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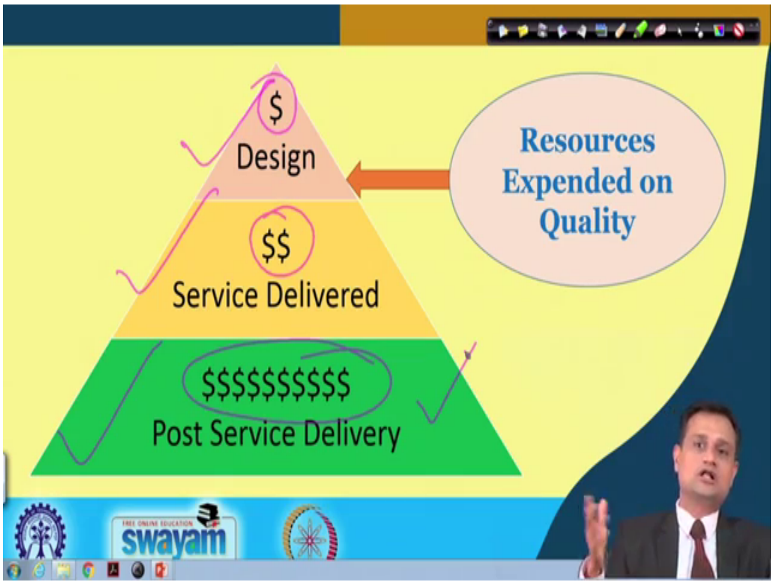

So, with this let us see this, and what do you appreciate. Can you consolidate the learning, which I just imparted? So, here you can very well see that dollar spend at the design stage, dollar spend at the service delivery stage, dollar spend at the post service delivery huge difference. You will spend one dollar at the design stage to correct and improve your system, which is extremely immune.

Service delivery if you make the mistake, you will spend more dollar and post service delivery huge. For example, we are many examples known; just say that you manufactured a car. And now this car is let us say, after delivery is catching the fire. And there are many incidences we know, I will not name the company, but let us say this car is catching the fire, and your customer safety is at stake.

Now, there could be only two incidences out of one lakh car sold, but you cannot ignore. And just see, what you need to do, you have to take entire lot back. And when you do so, your post service delivery, cost is huge. Your brand is lost, future businesses affected, and you have to take the entire production back, and you are totally lost.

You if you think about the service even, it s a total loss of the business, because you cannot do anything, customer came to you, you are not satisfied through your delivery service second stage, then your customer will never show his face, and there is a total loss of business. So, please try to appreciate this diagram, which is extremely important. And resources must be spanned, to ensure the quality right at the design stage.

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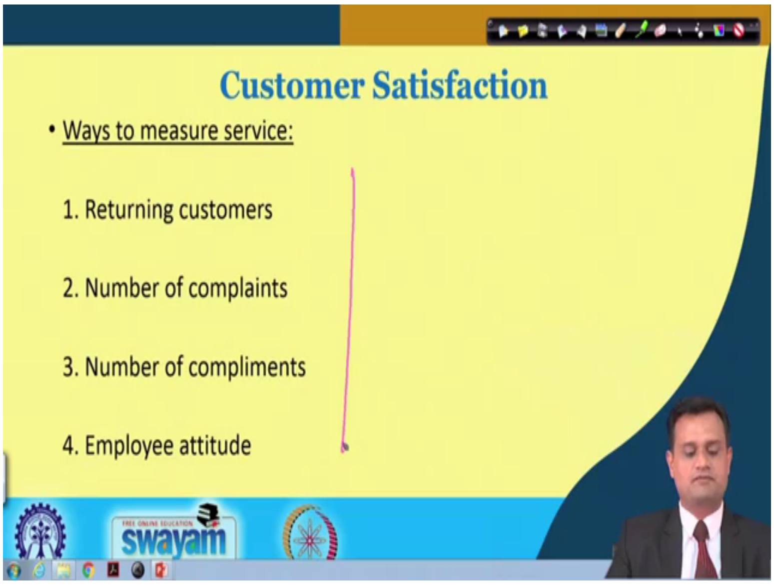

So, these are the symptoms that returning customer, number of complaint, number of complete compliments, employee attitude, all this leads to the customer satisfaction.

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So, typically quality loss function, you can see this figure. This is my target, where I want to achieve my performance lower than target and greater than target, both are the losses. I cannot afford to have this.

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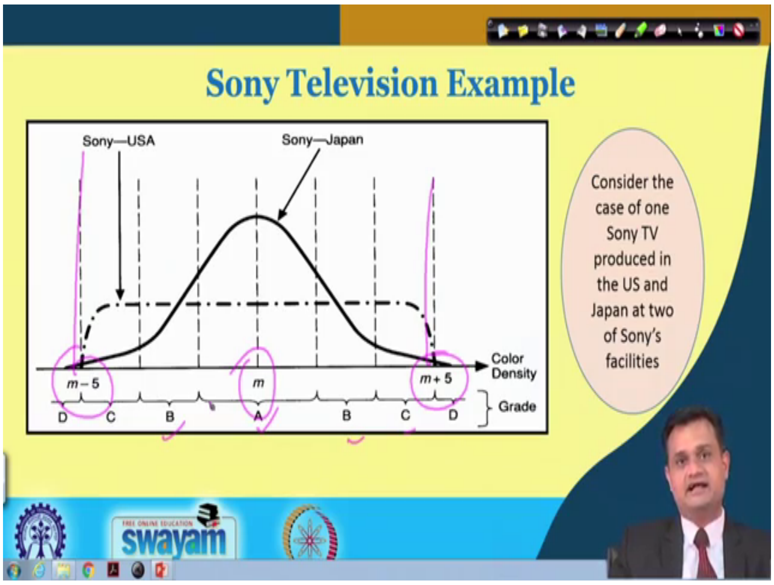

So, now just see this for 5 second, and tell me what do you appreciate. So, here you can see two concepts; one is the US concept, other is the Japanese concept. What do you see here, this is let us say my targeted value. And consider the case of Sony TV produce in the US and Japan.

And similar kind of manufacturing facility they are using, now the Sony TV produce in Japan has less variability, Sony TV produce in US is little bit of flatter curve has higher variability. Here the values are more centric towards the target value or mean value, here your values are spreaded. And what you will say, if I talk in terms of the quality, let us say this is my E grade product, this is my B grade product, this is my C grade product, you will see that in case of Sony TV produced in US, you are producing more B and C grade product.

Now, the issue is that m plus 5, m minus 5, so this is what it is here A, B, C grade product. Both the products are within specifications, so they are not actually rejected. So, you have m plus 5 and m minus 5, let us says the specification limits. Both the products, they are well within this specifications, but the grade of product is different. As you deviate from the target, you are producing poor grade product, poor quality product, and then your performance in long run or short term gets affected, which in turns leads to customer dissatisfaction. So, I hope you appreciated this important concept.

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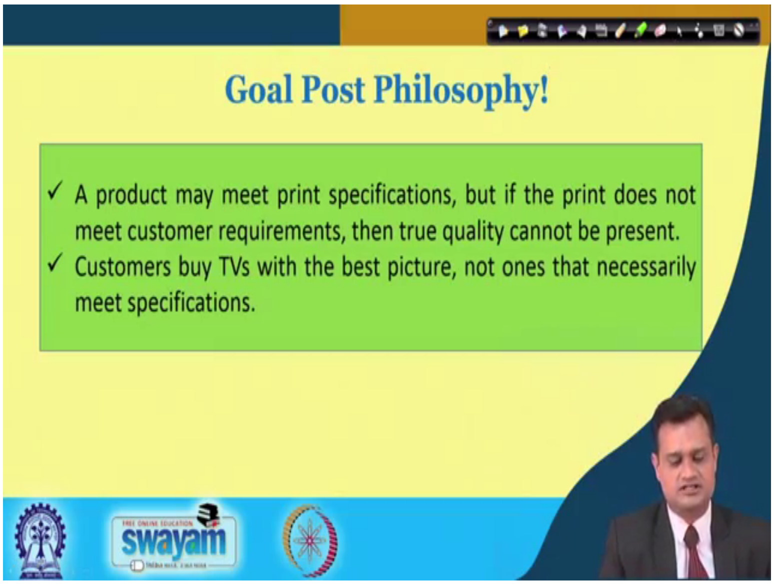

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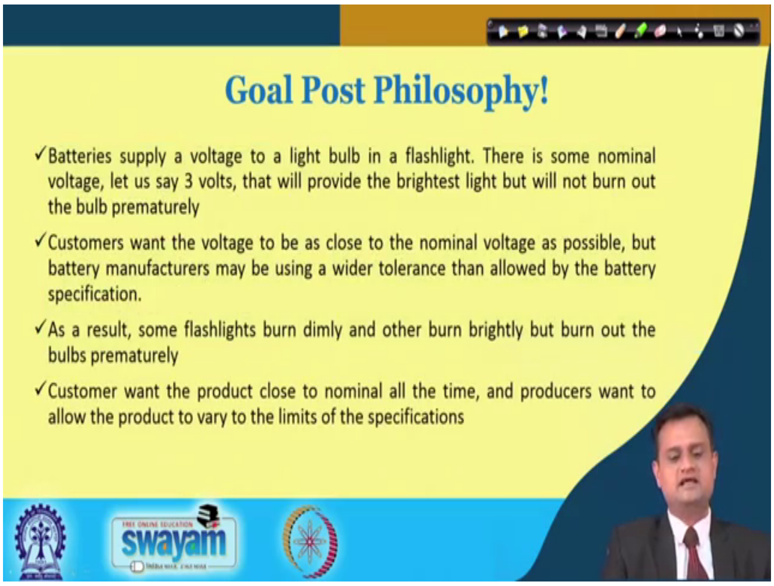

So, there is a goal-post strategy.

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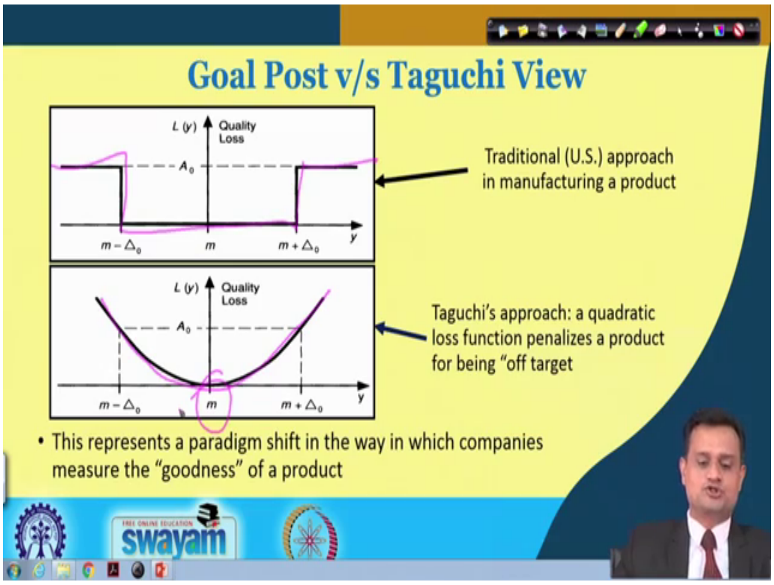

And this goal-post strategy says that this is not acceptable, it means if you just say that I am well within the specification limit, I am ok, it is a US approach, not acceptable Japanese approach says that you need to be as close as possible to the target. And goal-post strategy, this is the goal-post strategy which is not acceptable.

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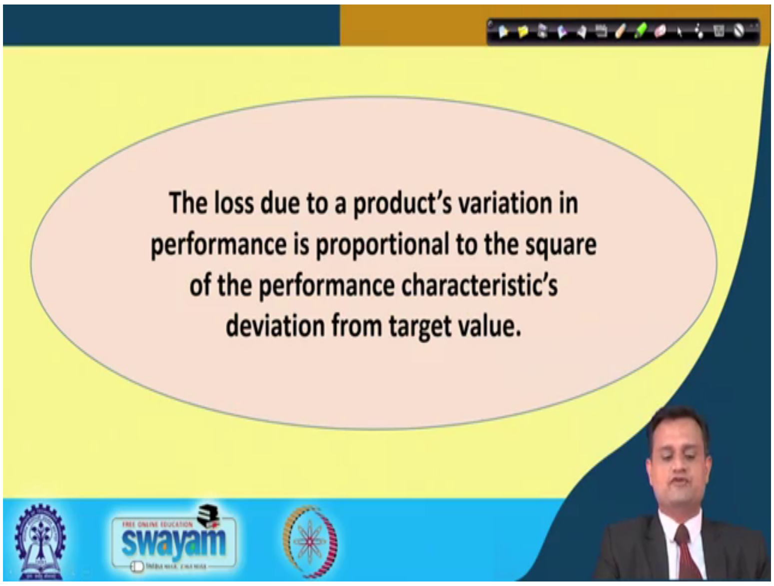

So, loss due to product's variation performance is proportional to the square of the performance characteristic deviation from the target value, and it is the last to society.

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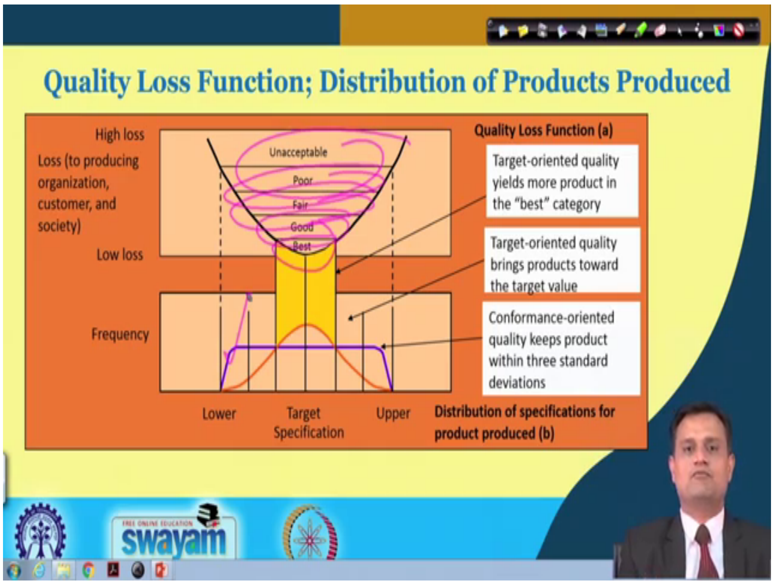

Once again, you can see through this picture that this is the best quality product time producing, this is the good, this is the fair, this is the poor unacceptable. If you are referring this, we just see you are producing more and more inferior kind of products.

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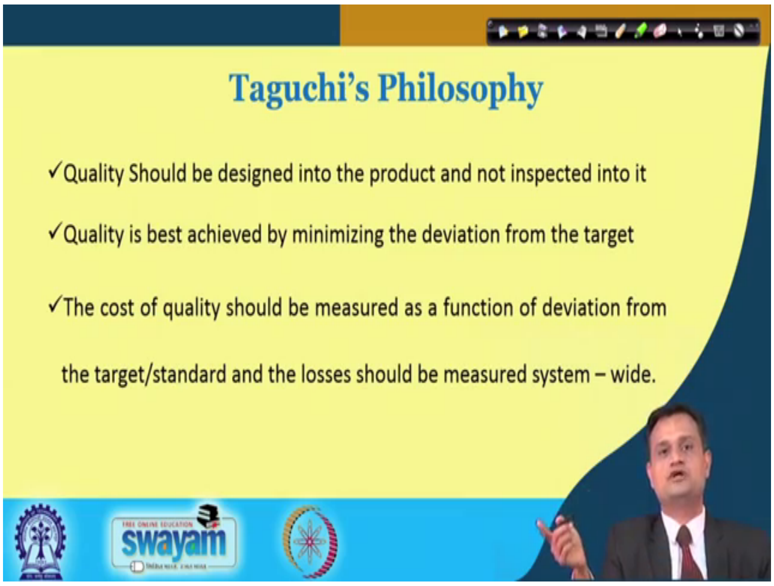

So, I just repeated a couple of things, so that you can appreciate the concept. So, Taguchi philosophy, basically says that quality should be designed into the product and not inspected into it later on.

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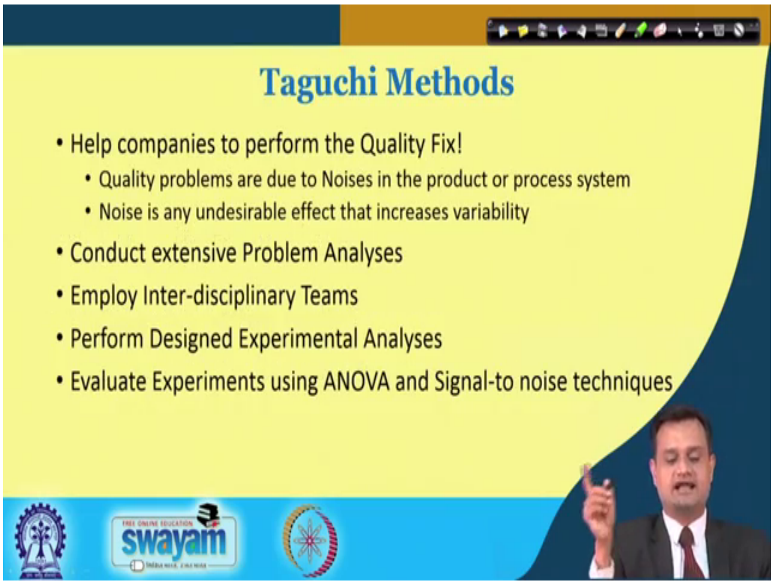

So, minimize the deviation from the target, and this helps the company to perform quality fixes, reduces the say increases the immunity, reduces the variability, under the effect of noise factors.

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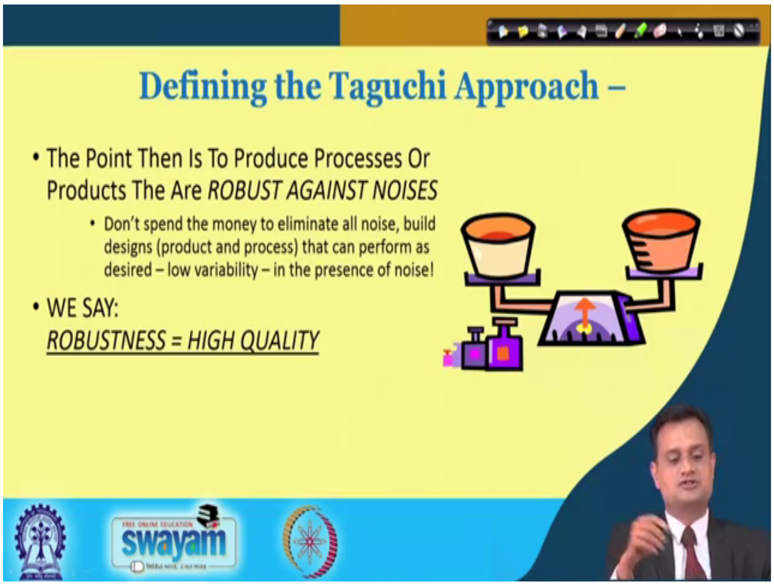

So, this is what we have referred that the point then is to produce the robust design against the noises and have an immune system.

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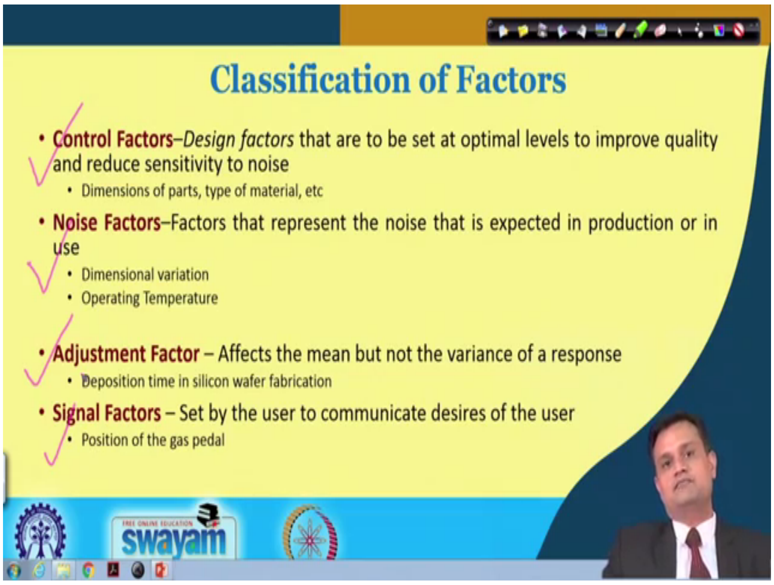

Now, there are a couple of key terminologies that I would like to define. One is the control factor, so this is typically the design factors that are to be set at optimal levels to improve the quality and reduce the sensitivity to noise. So, it may be the dimension of part type of material. There are noise factors, this particular factors, they represent the noise that is expected in production or in use some dimensional variation, operating temperature and so on.

There are adjustable factors, you can adjust this factors affect the mean, but not how the variants of response affect, and deposition time in silicon wafer fabrication may be the example. Signal factor set by user to communicate desires of the user, and producer of the gas pedal may be the appropriate example of the signal factor.

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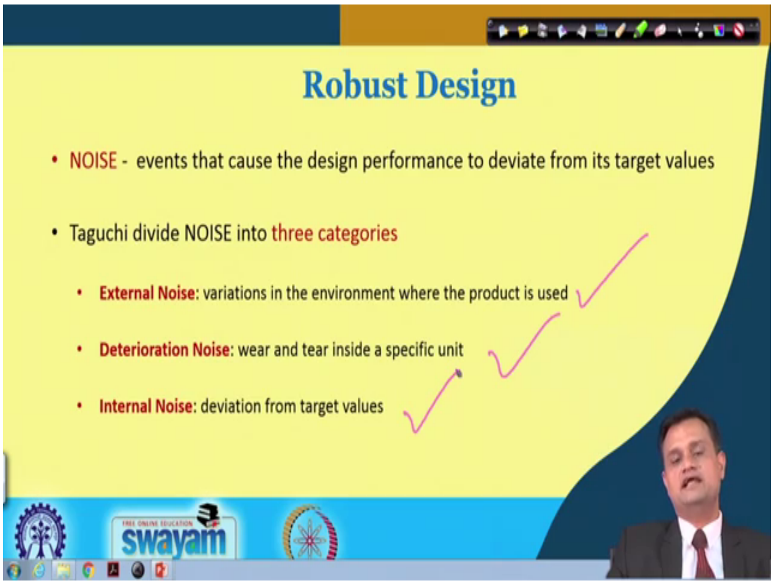

So, have are now the noise. This is the key particular term that Taguchi tries to address, noise means just remember analogous to the viruses you are exposed to, and you want to improve your immunity. So, there could be say three kinds of categories external noise, variations in the environment, where the product is used. Deterioration noise, so wear and tear is taking place over a period of time and internal noise, when you are deviating from the target value.

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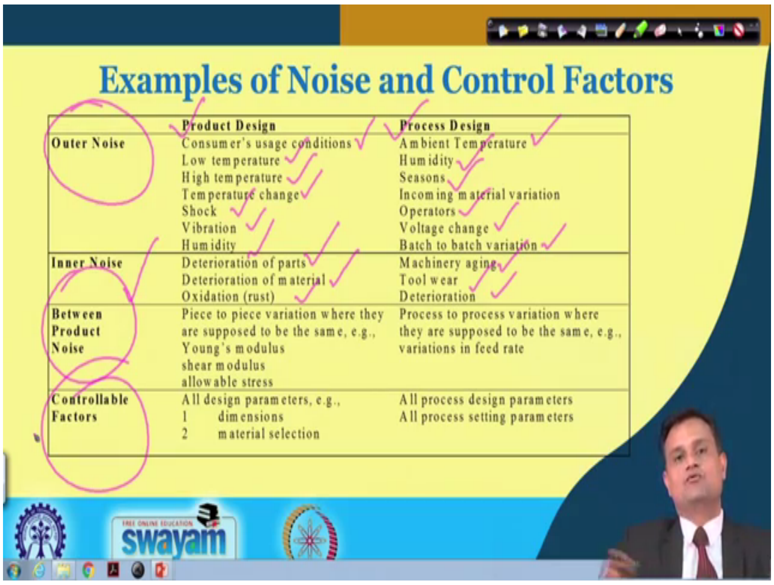

So, these are the different examples of the noises, and you may encounter one or another. So, now here I would like to give you the example of noise, and the control factors. Let us try to see, suppose I consider the case of outer noise. And if I select the product design in one column, and process design in other column, then what could be the outer noise? Customers users condition is the outer noise in terms of product design, low temperature, high temperature, temperature change, shock, vibration, and humidity. These are specific to product design.

When I talked about the process design, ambient temperature, humidity, seasons, operators, voltage change, batch to batch variation these are the outer noise, when you talk about the process. So, you can make your process robust, you can make your product robust through a concept of Taguchi.

There could be inner noise, deterioration of the parts, here entire may take place and that may deteriorate. Say that deterioration of the material, oxidation. Here you can say machine machinery aging, wear and tear, tool wear, deterioration process. Between product noise, controllable factors you can just refer, so that you get the idea of when you are talking about the optimization, robustness of the process, what could be the noise and controllable factors. When you talk about the product, what could be the noise and controllable factors?

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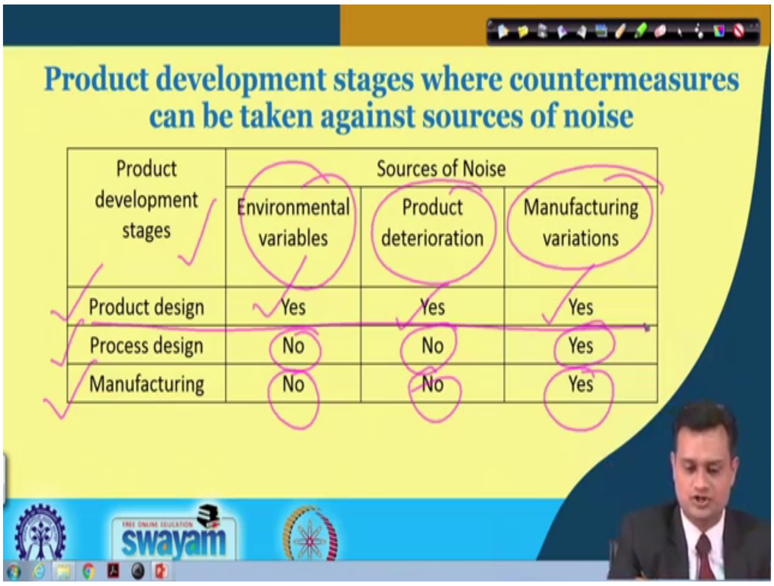

So, this example would have helped you to appreciate the concept. Now, just see that there are various product development strategies, where countermeasures can be taken against the source of noise. Let us try to see, product development stages. Suppose it is the product design, can you control the source of noise from environmental variables yes, product deterioration yes, manufacturing variation yes. At the product design stage, you can control all three.

Suppose, you are talking about process design, you cannot control now environmental variables, because process is set. You cannot control the product deterioration that is the source of noise, manufacturing variation yes, you can control. Manufacturing you cannot control the environmental, product deterioration yes, you can have some control over the manufacturing variations. So, this is where you need to appreciate the product design is the best way to apply the Taguchi concept of robust design.

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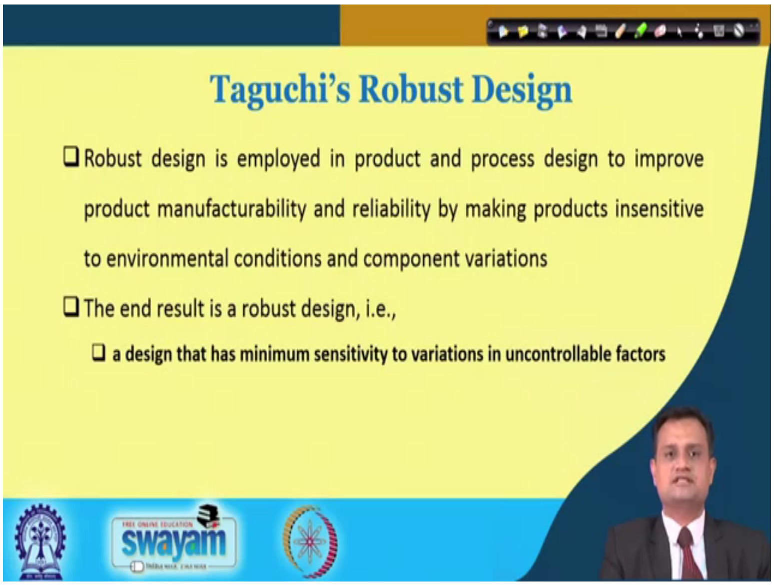

So, this is what we have seen minimum sensitivity to the variation in uncontrollable factors.

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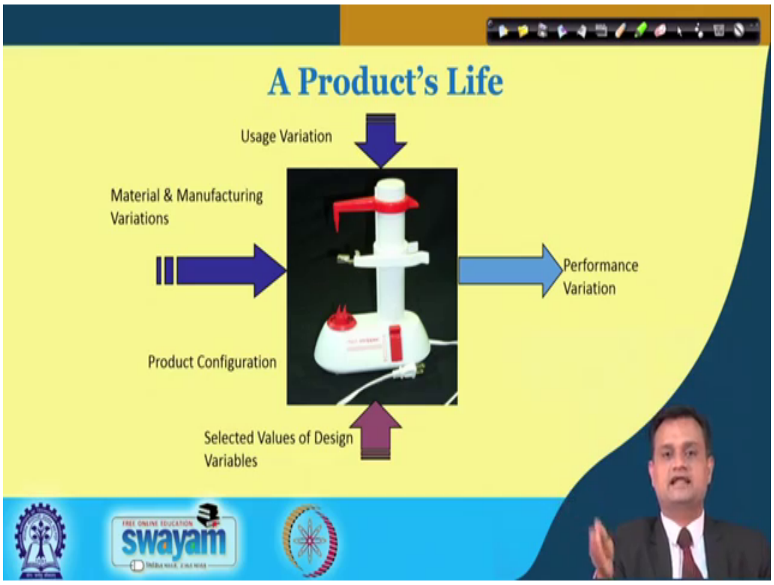

This could be the product maybe you are using some testing equipment, and you have the usage variation, you have material and manufacturing variation, and you have product configuration, you have selected values of design variables, these are the controllable factors. And finally, this will be reflected in your performance variation. If you are deviating too much, then you need to address the control level, and noise factors right at the design stage.

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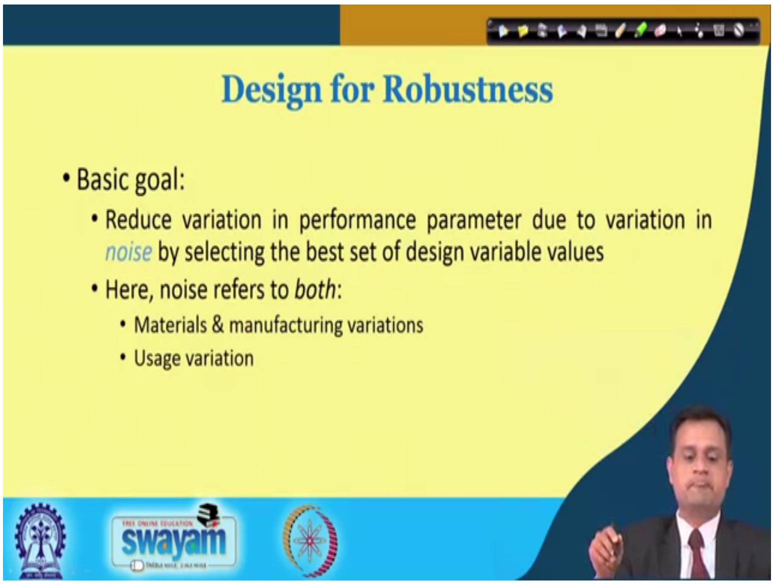

So, designed for robustness is to minimize the variation because of noise.

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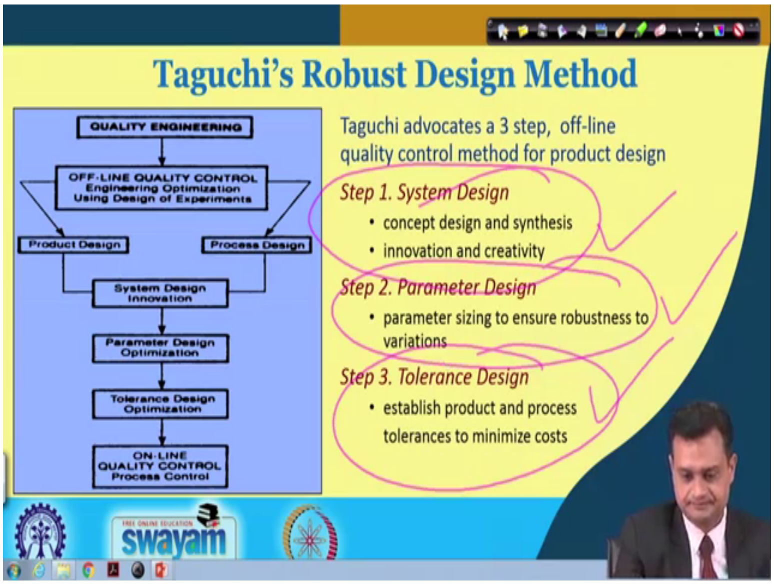

And these are the steps of my Taguchi's robust designed method. First is step-1 that is the system design concept design and synthesis, innovation and creativity. Step-2 parameter design, parameters sizing to ensure robustness to variation. And 3rd is the tolerance design, established product and process tolerances to minimize the cost. Remember this is the best stage to apply the concept of Taguchi. As you advance from here to here to here, your complexity increases.

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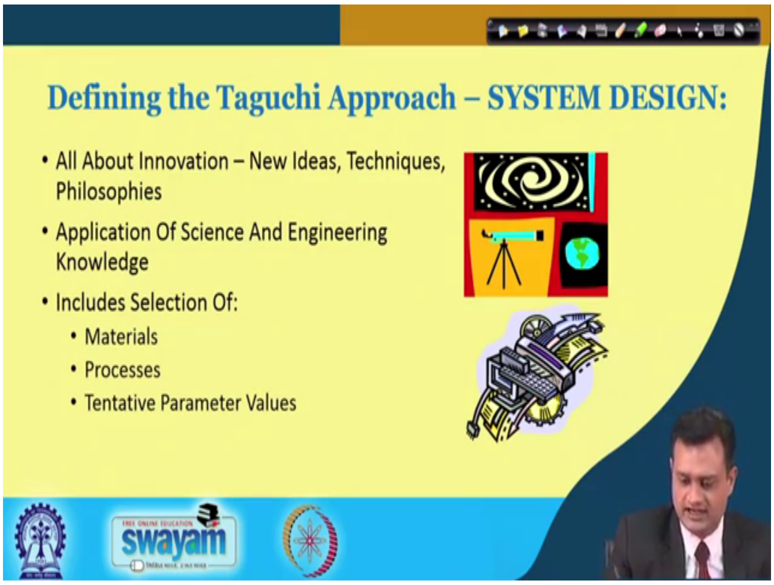

Now, system design as I mentioned, all about innovation, new ideas, techniques, philosophy. And you can choose the material, process, parameter value that is less sensitive to your noise factor, and can give you say better robustness of the product. So, many say, you can see that automobile company or say two wheeler or four wheeler, they are trying to make the reduce the weight of the product that is your automobile, so that your mileage can be improved or they are using the aerodynamic shape. So, all this is the innovation, and you can address at the system design stage.

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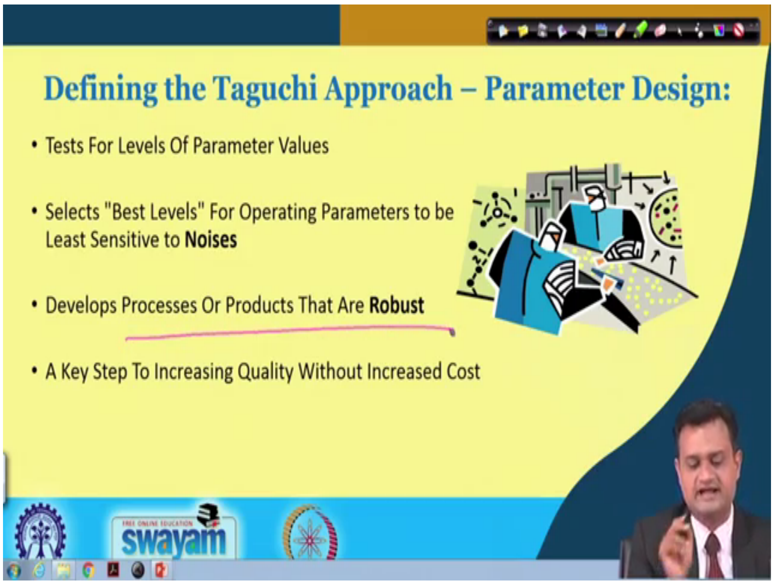

Subsequently, the stage comes that is the parameter design. This is the stage typically, where you think about the Taguchi application of robust design. So, this is where I am trying to create the robust design, and using the Taguchi concepts.

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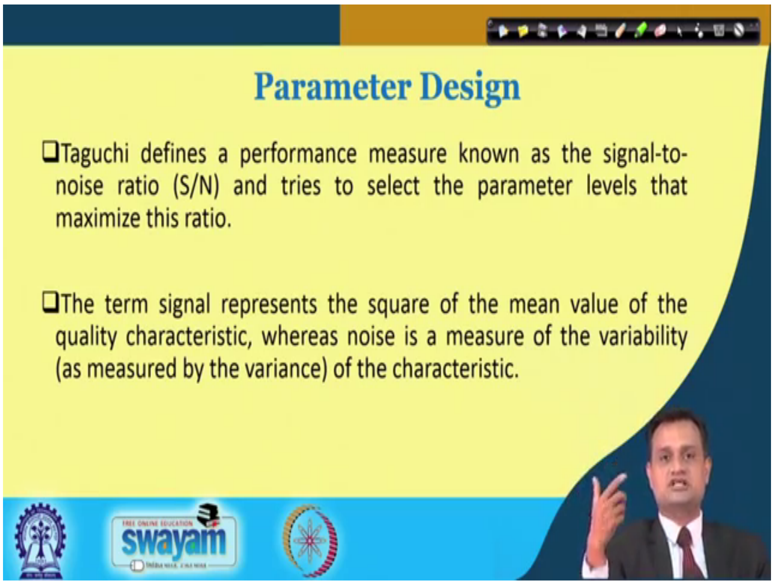

So, Taguchi concept is basically parameter design concept. And he tries to do this with the S by N ratio, signal to noise ratio. Objective is to use the orthogonal array, objective is to consider the noise factor, controllable factor, and design, and execute the experiment in such a way that S by N can be maximized.

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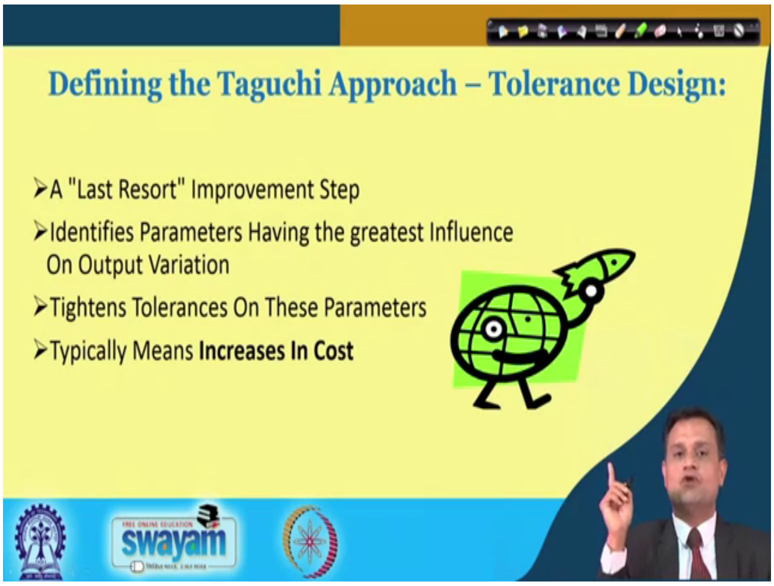

So, this is the tolerance design is the last resort. So, typically when you are going to step three, this will increase the cost, and we are trying to tighten the tolerances. Obviously, to produce those tolerances, you need to have very high end machinery equipments and precision as well as the measuring instrument, this will increase your cost, and this is not desirable. Try to focus on the system states through innovation, and then parameter straight through Taguchi design.

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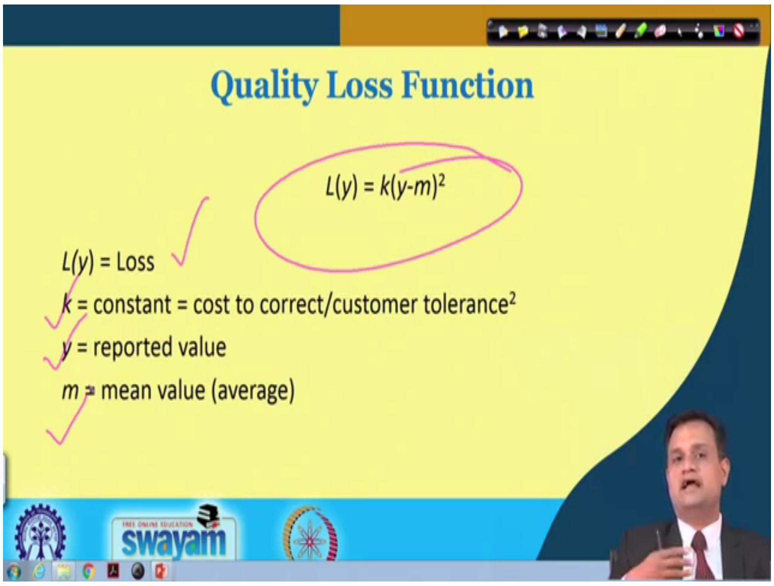

So, this is the quality loss function, Taguchi has proposed L y is equal to k y minus m whole square. So, L y is the loss function, k is the constant, y is the reported value, m is the mean average or targeted value. As you deviate from the target, my loss function is quadratic in nature, and it increases lost to society is increased. So, this is my quality loss function.

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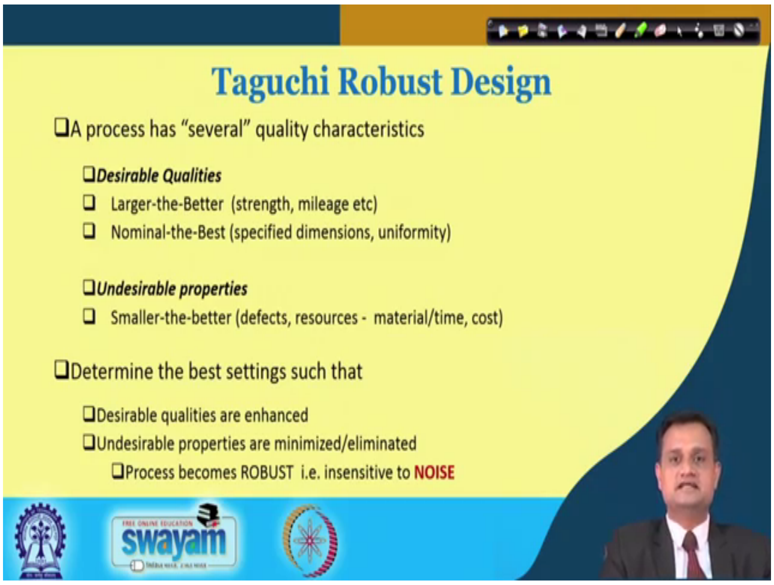

And you can have Taguchi robust designed with certain desirable qualities, undesirable qualities. Just see the example, larger-the-better. Would you like this strength larger or smaller, would you like to have mileage larger or smaller? So, larger is the better, nominal the best. You want to achieve, this sharp diameter exactly 20 mm, specified diamonds, and uniformity is the best, so nominal is the best.

Undesirable properties smaller-the-better. So, this is also true negative side. Would you like to have more defect, no, defects should be smaller, resource consumption should be smaller, cost should be smaller. So, Taguchi gives three concept larger-the-better, nominal-the-best, smaller-the-better. And this is where we are trying to use couple of the equations, proposed by Taguchi in the design of my say Taguchi best parameter design of robust concept.

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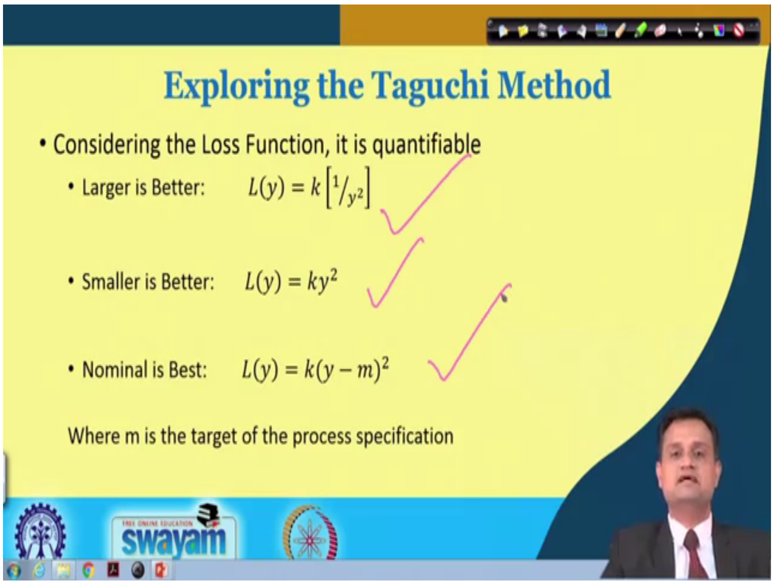

So, the expressions are like this, larger is better L y is typically your say loss function, which is now express like this. We are not going into the direction part, but I can just give you the idea. You take the differential equated with the 0, like you are maximizing and minimizing the function. And then that will help you to get the larger is better, smaller is better, and nominal is the best expressions.

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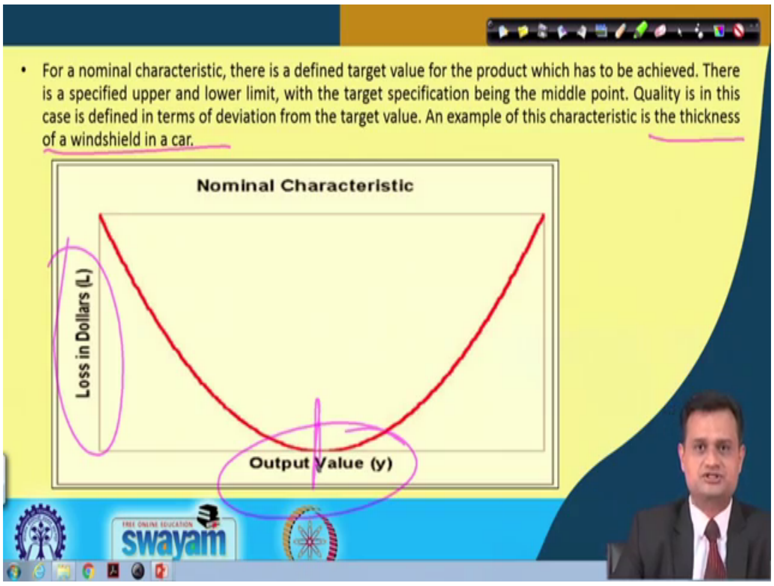

So, once you have these expressions, you can just try to analyze that what does it mean. So, when I say nominal characteristic, and typically what do you see here, this is the loss, and this is the output variable Y. So, an example of this characteristic is the thickness of a windshield in a car. And in this case, you would like to have the target value. So, here target is the best, nominal is the best, this is the example of nominal is the best.

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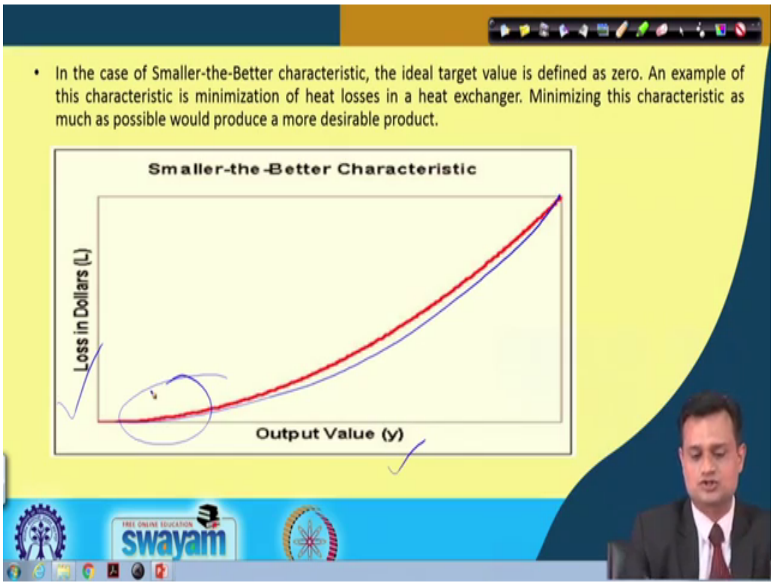

Now, if you see another example, then smaller the better characteristic. So, your responses basically changing, and output is your response loss in dollar. So, as you are say having the lesser one, your loss is reducing, so smaller the better.

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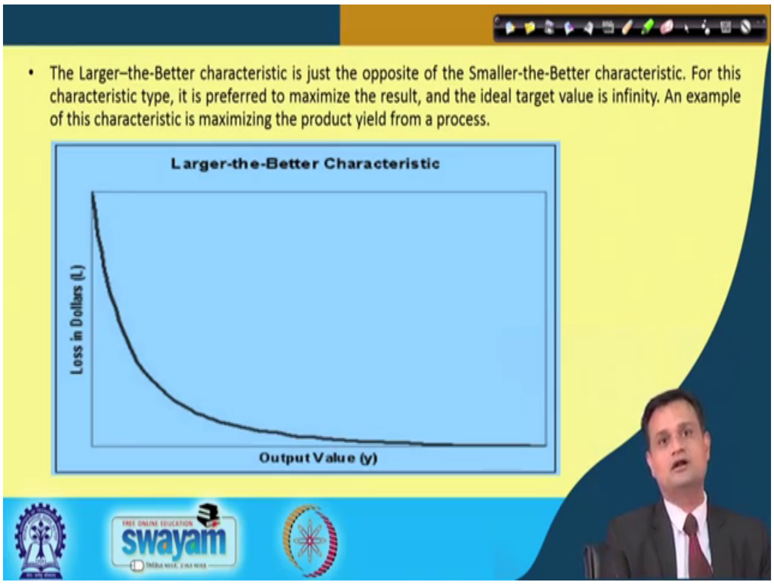

Similar way, you can see the example of larger-the-better. So, you have the larger the response better it is, the loss associated is less. Again I will repeat the example mileage of the car, larger the better, less better efficiency of the fuel, reduces my spending on the fuel.

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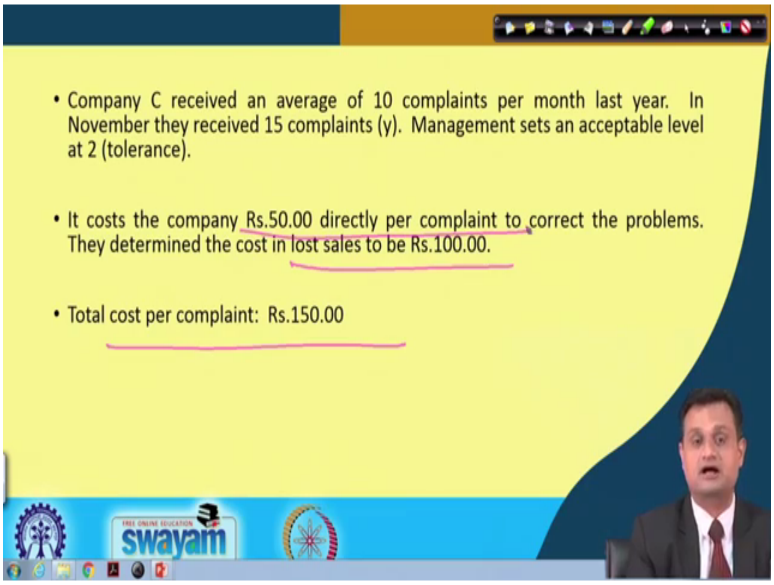

Let us see the illustrative example, there is a company received an average of 10 complaints per month last year. In November they received 15 complaints. Management sets an acceptable level at 2. It cost the company rupees 50 directly for complained to correct the problems. They determine the cost in law cells to be 100. And total cost per complaint is 150. So, just try to appreciate this data loss sales to be 100, then cost for complain is 150. And it calls the company rupees 50 directly for complaint.

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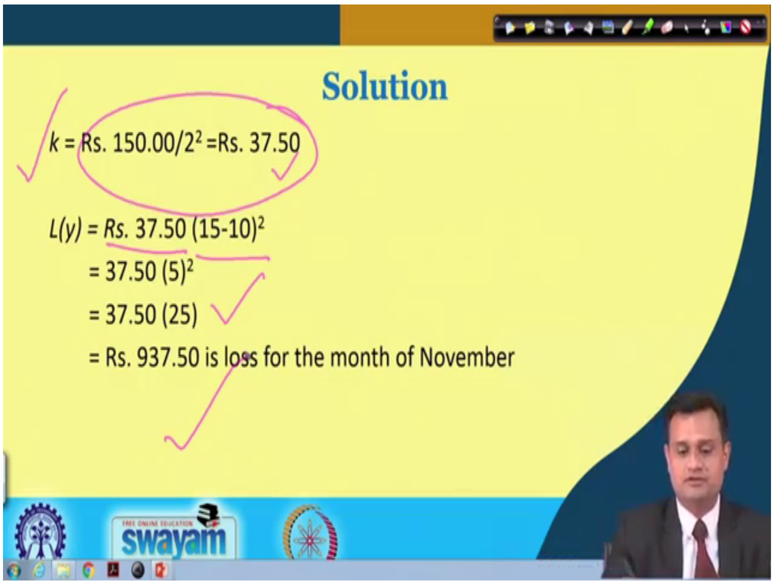

So, with this data set, I will just do little competition. So, my k basically sorry my k basically 150 divided by 2 square, so 2 is the tolerance. And I am taking this to find the value of k, which is the coefficient in my loss function. So, this comes out to be 37.5, I just plug in the values in my L y. So, 37.5, 15 minus 10 whole square my y minus m whole square, so this gives me 937.50 is loss for the month of November. So, you can see that how much loss you are making by deviating from the mean or target value that you can complete using the parabolic function described by Taguchi as a loss function.

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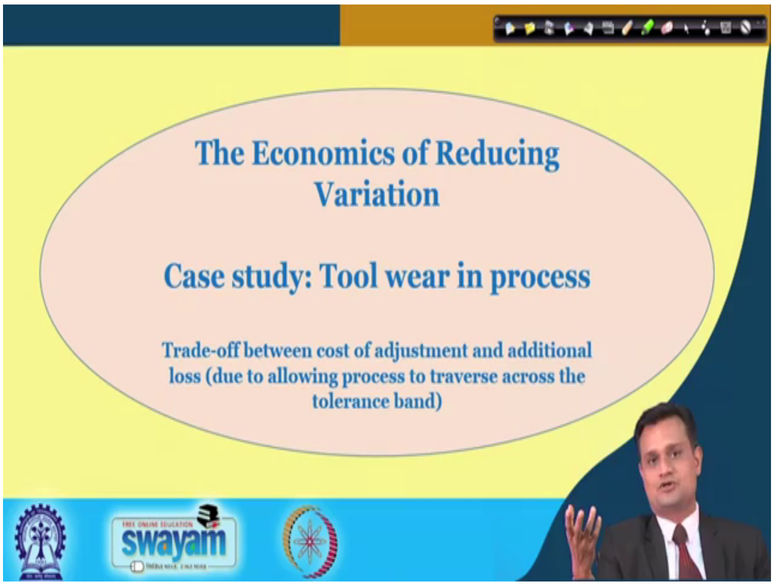

Now, let us see the economic reading variation, and there is a case study of tool wear in the process. Now, here you need to analyze the trade-off between cost of adjustment and additional loss, due to a allowing process to travels across the tolerance band. So, the situation is like this, I have a machinery. I would expect that machinery to be set at a particular value target value produces the nominal targeted dimensions.

Now, I may have to do the adjustment, and there is a cost associated. If I do not do the adjustment, and if I allow it to operate away from my target, then my customer may get dissatisfied because of the poor performance of the product, and then there is a loss associated with the customer.

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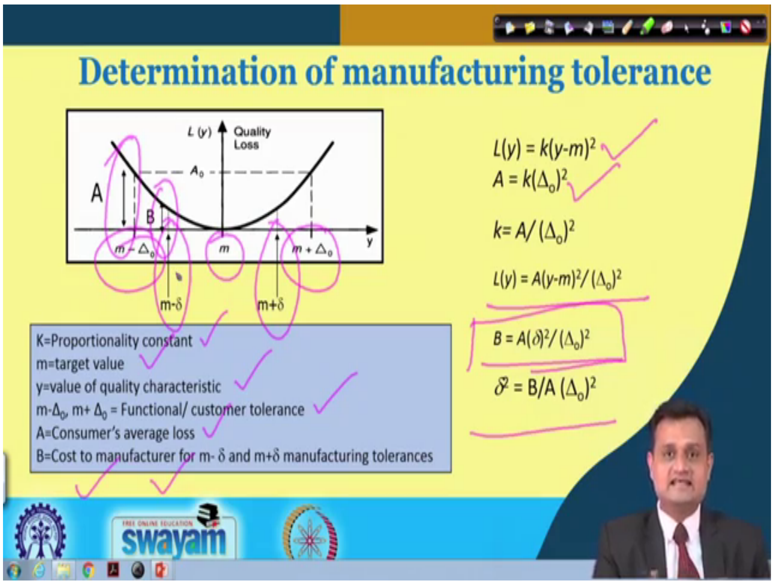

So, just try to see this, it would be better clear that this is let us say my targeted value m, m plus delta 0, and m minus delta 0. So, k is the proportionality constraint, L y is equal to k y minus m, A is equal to k delta 0 square, m is the target value, y is the value of the quality characteristic or your response m minus delta, m plus delta 0 is the functional or customer tolerance, A is the consumers loss, you just see this is the consumers loss. B is the cost to manufacturer for m minus delta this is my m minus delta and m plus delta manufacturing tolerances.

Now, what is happening here? My L y can be transformed into this, and I can write the B, which is the cost to manufacturer as a delta square divided by delta 0 square, and delta square can be expressed like this. Now, here you can see that if my manufacturer or I as a manufacturer would resist adjusting, then I will have to encounter over a period of time loss A that is the consumers average loss, and this loss will ultimately result in the loss of business. So, I have to see the trade-off, whether I would accept B or I would expect my consumer to expect A, which in turn will have a very negative impact on my business.

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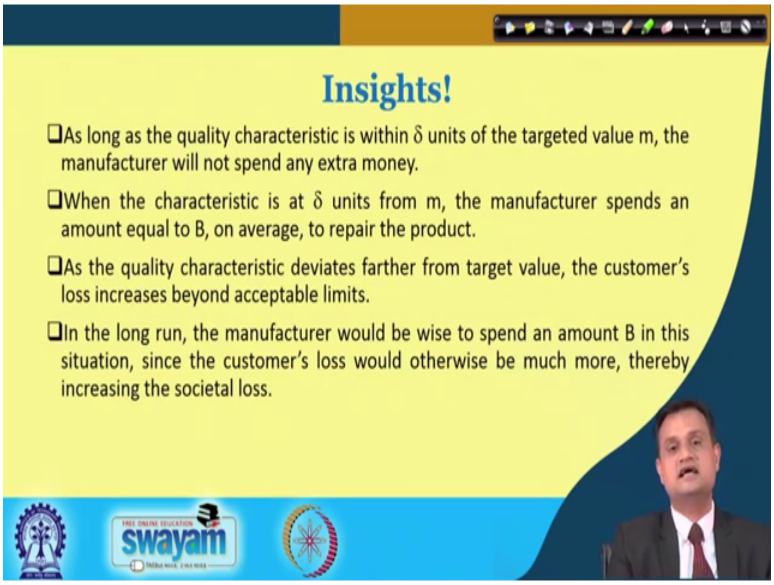

So, these are the insights as long as the quality characteristic is within delta, the targeted value of m, the manufacturer will not spend any extra money, when the characteristic is at delta unit from m, the manufacturers spans about equal to B, so that my customer does not feel unhappy to repair the product. As the quality character is deviates further from target value, customer loss increases and I must see the trade-off.

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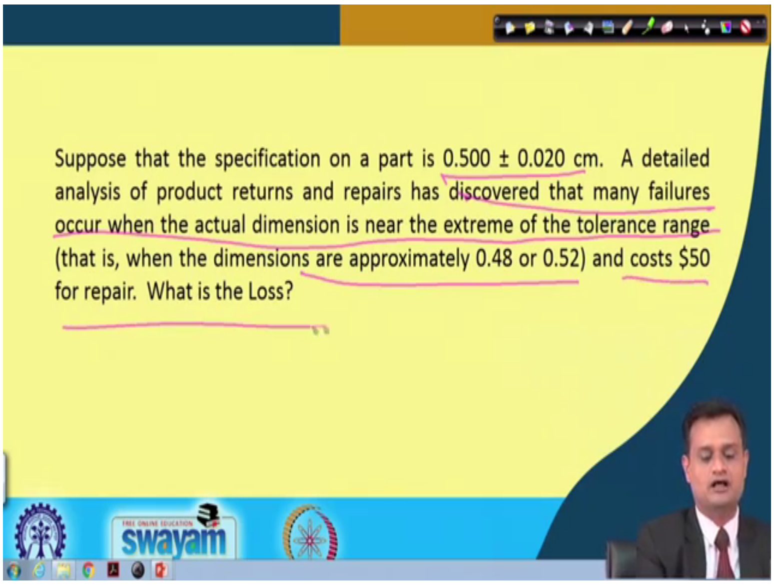

So, I have the illustrative example. Let us say you have a part 0.5 plus or minus 0.02 is the specification. And you have discovered that many failures occur, when the actual dimension is near the extreme of the tolerance range. And approximately dimensions are 0.48 to 0.50 cost is 50 dollar for repair, what is the loss.

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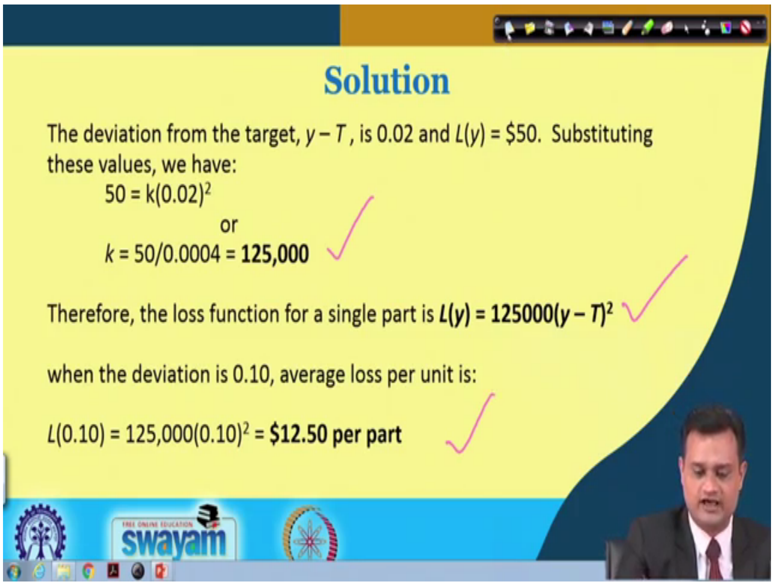

So, you can just use the expressions, I have given plug in the values find the k, L y, and L 0.1. So, this comes out to be 12.5 dollar per part. So, this is what is the loss, you will incur.

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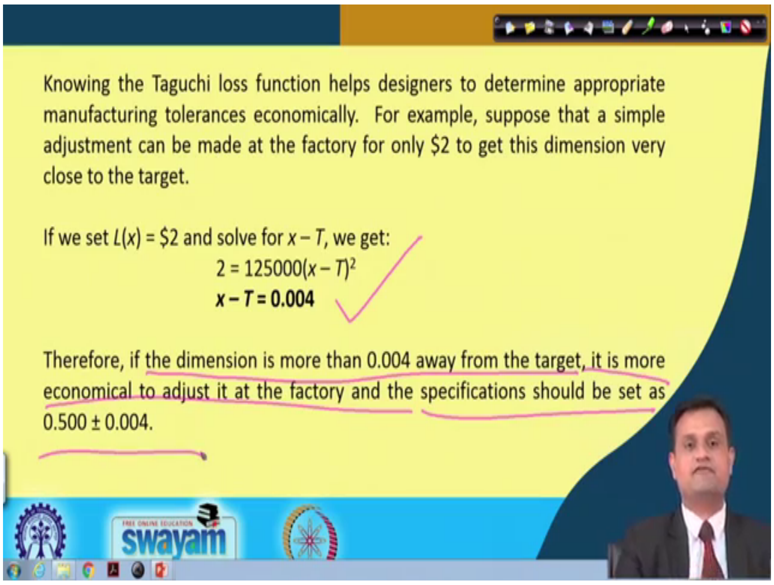

And then if you say that I have dollar two to get this dimension, then very close to the target, some correction you have to apply, then you just see interestingly that what is it. So, it is just 0.004, it means that if the dimension is more than 0.004 away from the target, it is more economical to adjust at the factory and the cost would be extremely less the specification should be said at 0.5 plus or minus 0.004.

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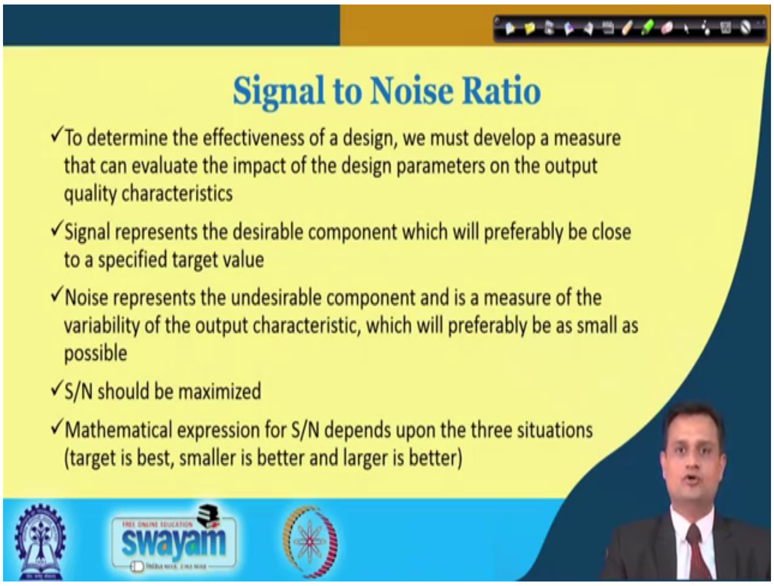

So, this example will really help you to appreciate that what is the concept signal to noise ratio, signal is something desirable, noise is not desirable we all know, and signal to noise ratio must be optimized.

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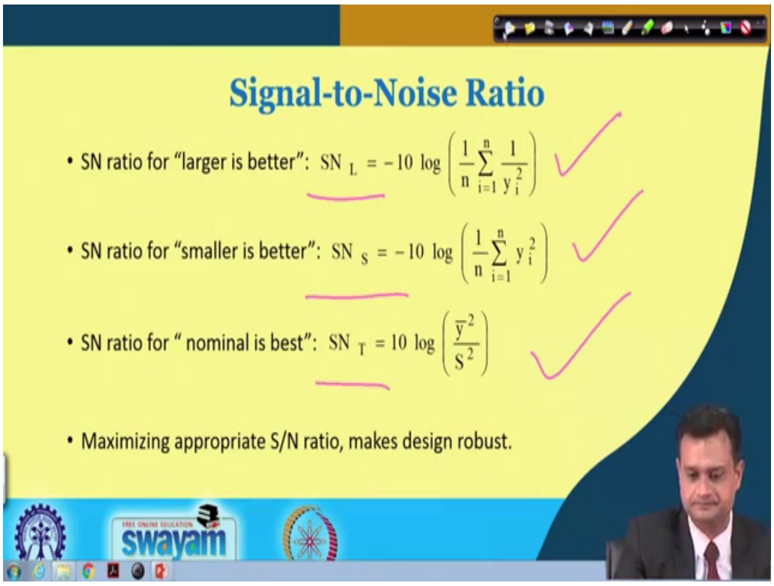

So, these are the expressions which Taguchi has proposed for signal to noise ratio. We have already seen, this is just the modified version of this S N L, larger is better, greater the mileage. Smaller is better defect, nominal is the best, diameter I am producing.

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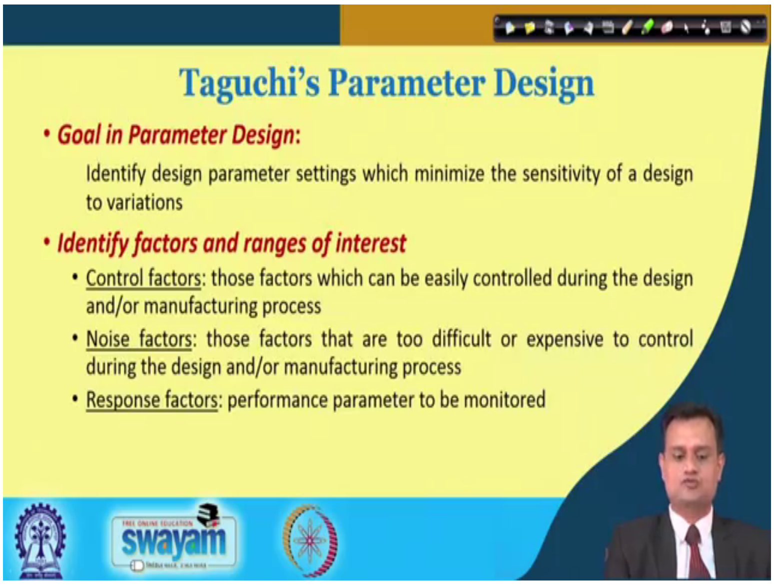

So, finally intelligence design, goal in the parameter design is to identify the factors and ranges of interest for control factors, then noise factors, and the response factor.

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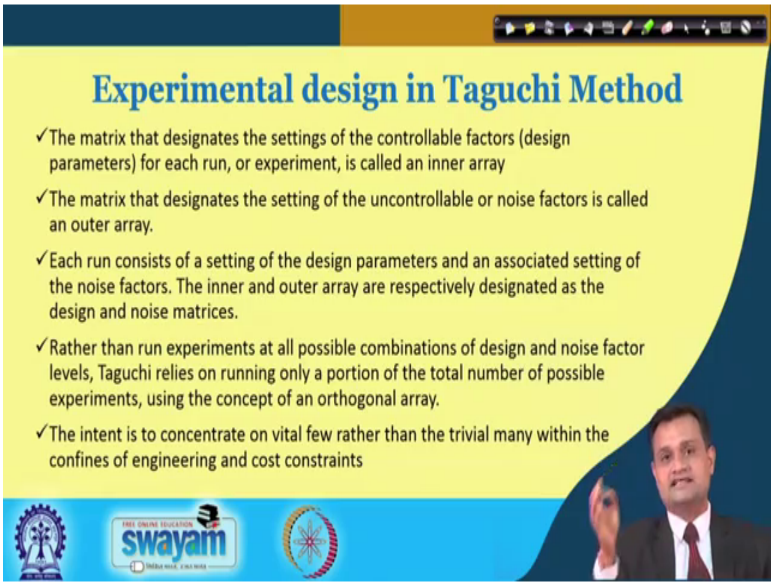

And typically, it operates like this. We will see the illustrative example in the next class next lecture. So, there is something called an inner array, and typically I consider the control factors, they are setting in the inner array. There is something called outer array, I will try to put uncontrollable factors or the noise factors in the outer array, each run will consist of a setting of the design parameters, associated setting of the noise factor not only controllable factors, also the noise factor for that particular setting experimentation will be done.

And it is effect on the response will be seen, and I would like to see that my S by N ratio can be minimized. So, the range or the parameter of setting which can give me the maximum S by N ratio is chosen and is desirable.

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So, this is what we need to do that managers job is to identify the problem, brainstorm, contribute to experiment design. Facilitators job is to design experiment, run experiment, analyze, and confirm.

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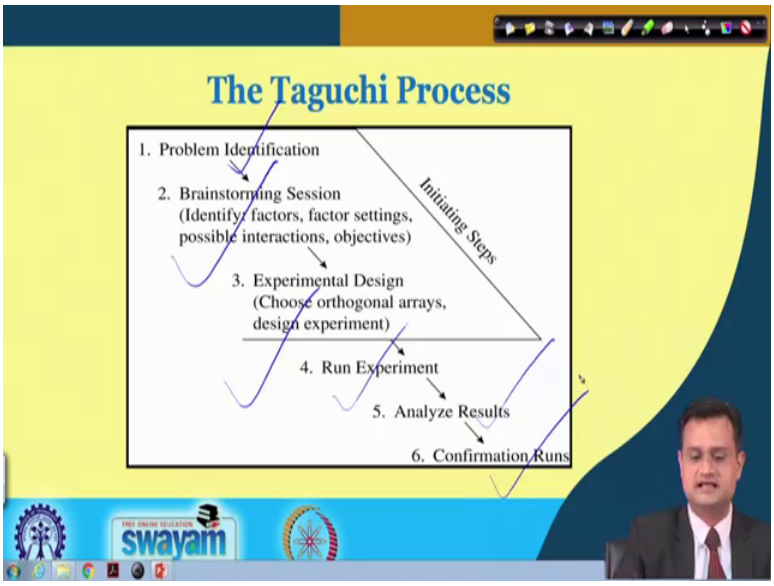

So, this is typically the steps; problem identification, brainstorming identification of factors, noise as well as control, setting objectives, experimental design based on orthogonal array, run experiment, analyze results, and confirmation of the runs.

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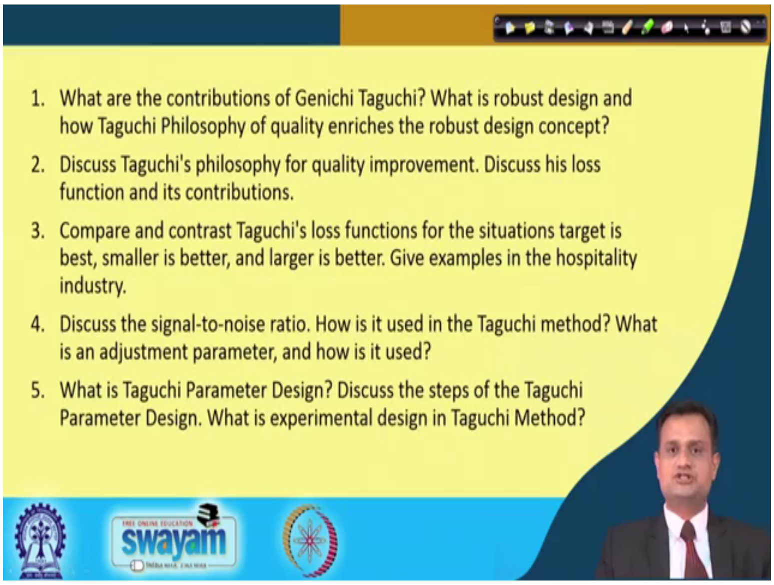

So, with this I am floating couple of think it for your introspection and revision, what are the contributions of Genichi Taguchi, what is the concept of robust designed, discuss the philosophy, and S by N ratio, and other concepts involved. What do you mean by larger is better, nominal is the best, smaller is better, what is your understanding on S by N ratio, and what is parameter design, and what are the steps we tried to execute as a part of parameter design.

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So, you can refer a couple of references.

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And this is the robust design approach based on S by N ratio, considering the impact of controllable and noise factor simultaneously for achieving the robust design. So, thank you very much for your interest in loving the concept of Taguchi design, I explained you the various fundamentals and concepts for Taguchi design. We will also see in detail the example illustrative example of Taguchi design. So, till that time revise the concepts, and appreciate and digest the Taguchi philosophy, and keep internalizing the concept start to application be with me enjoy.