Six Sigma
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Lecture No. # 33
Taguchi Methods

Good afternoon, it is the resumption of our lecture series on Six Sigma and the specific topic that I have chosen today to discuss with you are two hours long. It is like one hour for the first one, which is the basic idea of robust design and the second is Taguchi methods, how did Taguchi accomplish his robust design, those are the two topics I will be covering today (Refer Slide Time: 00:48).

If you start with the first slide here, you notice this is a temple, that is about almost 1000 years old, it is in Nepal and it is made fully of wood. Wood is the construction material for this particular temple and it has you know live through snow storms and hill storms and rain and everything else and you know tropical sunshine and everything else.

And look at the look at the structure today, it is still standing there and it is pretty firm and most of the original carving can still be seen there and it is just amazing that such a thing could last there alongside the on slot of all these natural calamities and everything else and particular the harsh weather that is there is Nepal, that is an example of what we call a robust design, a design that is unaffected, whose performance is unaffected by the environmental factors; it is basically not at all sensitive to the vagaries of the environmental factor.

How did we achieve this and what are some of the insides that we have along the way and what can the quality engineer do, this is like one of the key missions in a mission such as six sigma, what does he do, how does he achieve robust design on an experimental situation, in an experimental situation, how does he do that?

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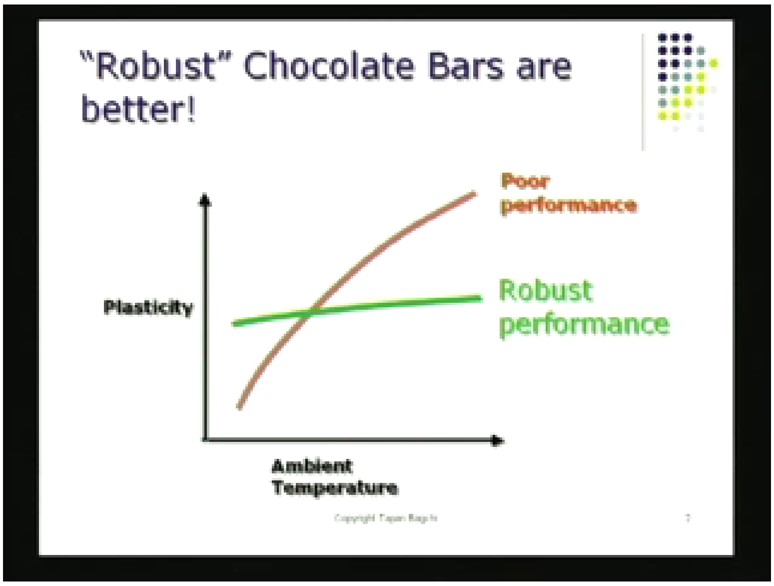

Let me start with this little example that is, of a design for that is being sort for chocolate bars. Now, as you know with global trade, our business has really expanded and the barriers have come down and you can buy chocolates made made in Switzerland, in Asia, you can buy Japanese food products on the shelves in Malaysia and so on and so forth. It is all pretty easy and you know it is not very difficult to find apples from Europe being sold in India, for example, that is called all quite common.

Now, with this happening naturally, there was this anxiety on the part of merchandisers, these sales people, they wanted to market some Swiss products in a particular Swiss cheese and also Swiss chocolate in Asia.

Now, if you live in Singapore or if you live in Kuala Lumpur, if you live in Bombay, or if you live in Madras, for example, Chennai, it is very easy for the design that is quite all right, a product design that is quite alright in Europe, not to be so successful under the conditions in which the tropics are, because particularly couple of things are quite different between Asia and Europe; one of which is humanity, the other is heat, it is not unusual to find temperatures in, for example, parts of India when it will be 45 degree Celsius or a 115 degrees Fahrenheit, that is not very uncommon, in the middle of summer you might find temperatures like that.

Now, going back to this story of chocolates, some company wanted actually, some Asian company wanted to basically market Swiss quality chocolate bars in Bombay and one of the things they tried was, they imported some chocolate bars from Switzerland and they tried to sell them they tried to sell them, obviously, those chocolate bars, they were big hit with kids, because kids always love chocolates, but the problem was that these bars they had high plasticity as far temperature was concerned.

So, if you look at the x axis, the x axis is ambient temperature, that is like the condition, that is in the environment and if I have a chocolate bar, that is got this kind of plasticity that actually means, it is highly multi point, it is highly sensitive or its stiffness is highly sensitive to temperature. What would happen is, in winter time it would turn out to be pretty stiff, it would be pretty difficult to bite into; but in summer, it will all melt and become a like a blob, it will be become a blob of chocolate. Now, obviously the kids did not mind except their mother started complaining they said, well look when my child comes home, the the the hands are dirty and of course, when he sticks one in his pocket, the shirt also gets dirty and so on and so forth.

So, I we really do not feel that these are good good chocolate bars; they should not be probably sold here. So, there was this big huge problem, when someone just blindly try to sell chocolate bars that were really fabricated, they are really, they are manufactured and they are quite successful in Europe, they take, they try to sell the same chocolate bars in in in Asian countries. It turned out that, this was really not a robust design compare, contrast that to this chocolate bar.

Notice, this one is got robust performance which actually says, that its plasticity which is around here somewhere, it does not really change much with temperature as the ambient temperature is changing from low to high, which could be probably from 0 Celsius to something like pretty close to 45 or 50 Celsius here, there is not that much change in the plasticity of this chocolate bar, this one is got a different recipe, the difference between this chocolate bar and this chocolate bar is the difference in recipe and this is exactly what causes the change in the properties of chocolate bar and the green one turns out to be a robust chocolate bar (Refer Slide Time: 06:03).

Now, couple of things to remember here; one is of course, we have to find the right setting for the plasticity for this. So, we got to find this design target and I am going to tell you about that as we go along into this talk, we got to find the right plasticity for this green bar, that is like something that I can adjust. If I adjust a recipe, I can take it up or down, I have to find the right level for it, that is like one thing that we have to do; the second thing that I have got to do is, I have got to take a chocolate bar or the old recipe that is this red recipe and convert it into this green recipe, this is what I have got to do, only then it will become a robust thing.

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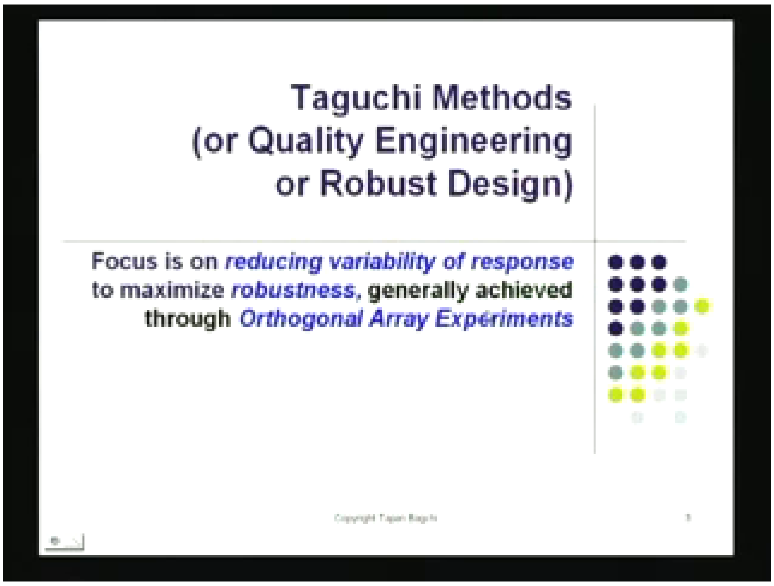

Now, let us see how this was approached by an engineer whose name is Genichi Taguchi, Taguchi's methods have become pretty popular and they are they are basically all called Taguchi methods. And there are different approaches to try to produce robust processes and also robust products, products that hold on to their good property, even if the environment becomes hostile, even if the environment becomes kind of you know not something that is like the rain and the snow and so on in Nepal for example, that is an example of when the environment becomes hostile, how did we do this, that couple of goals in Taguchi methods; one is of course, reduce the variability of response, that is one of the goals.

Notice here, if you go back to the chocolate bar situation, this red bar has high variability, it is got pretty high variability in in performance, that is like one of the goals of robust design, you got to make sure you reduce variability and you got to achieve robustness; that means, that thing should stay the same, that performance should stay the same, how is it to be done?

Now, as we have learned through this course at various points, I have brought along this idea of design of experiments, design of experiments is a method by which you can play with multiple factors, these could be the elements of the recipe or the processing conditions that you can play with, and the result is always to try to achieve the final design, that is the optimal design for your purpose, this whole thing is done in a very systematic way, and the way this planning and the planning for this trials is trials is done is done under the frame work of DOE, Design Of Experiments.

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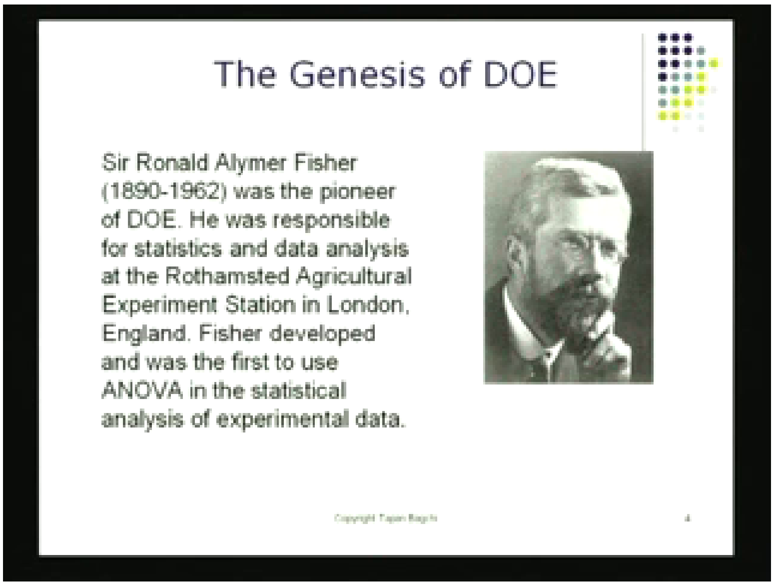

And we will be looking at that again as we go into this, the genesis of DOE, how did DOE come about, well around world war and even before that, Europe tried to, many countries in Europe they tried to raise their farm production, that was like one of the missions they had and naturally population was growing and they wanted to make sure that the farms produce more corn, more wheat and stuff like that, and in particular when world war two came along, a lot of men were killed.

So, there there were not as many hands on the farm and for the limited support, with the limited supply of manpower, they still were looking for this opportunity to try to produce more, out of the farms. Ronald fisher Sir Ronald fisher, he was a statistician, he looked at this problem and he came up with a with an approach that is called the factorial design approach, here he allowed you, he allowed the experimenter to manipulate multiple factors together multiple factors together and also he provided a data analysis with that.

So, when he conducted the experiment, you would produce some data, he also gave us a data analysis for that, and that analysis method is called ANOVA, this is like one of the contributions, one of very important contributions that Ronald fisher made.

This led first of all raised output of a agriculture, that is like one of the things that Europeans were able to enjoy, because if this in particular in U.K, the second thing that also fisher did was, he made sure that people did not conduct what we call one factor at a time experiment. So, now I have talked about this before, so you recall, if I do one factor at a time experiments, when another factor is changed, there may be an interaction between the first factor and the second factor and this is always something, this is something that we are just curious about and many times this can be destructive, the interaction can be destructive. So, you may not get good performance if you conduct your experiments, only by varying one factor at a time and then you try to add things up, things do not go always go that way.

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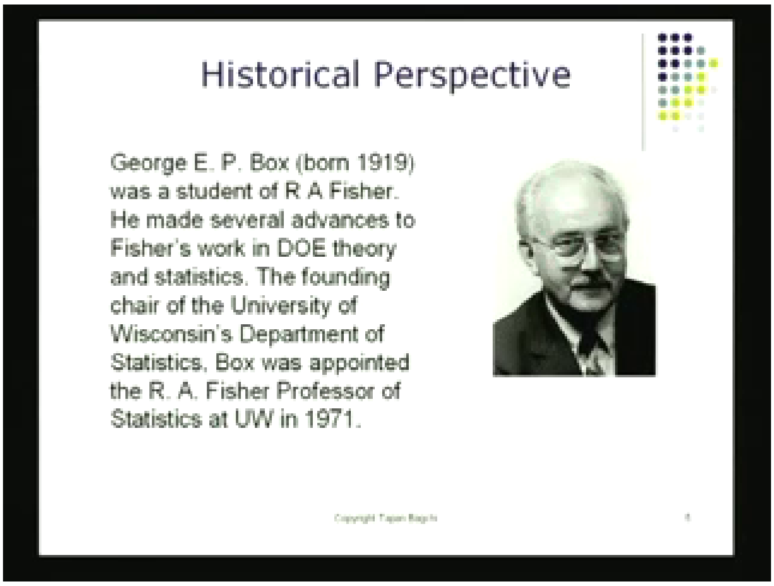

That was one of the things that Ronald fisher tried to get away from, one of one of these stalwarts who was also worked in this area of design of experiments was George Box, he worked in at the university of Wisconsin and he not only himself, but also many of his students, they actually led to a lot of contribution, lot of very important contributions in this general area of design of experiments, they applied it to various techniques, many were theoretical, many were practical, many were highly significant, these contributions came from George, Fisher and his students.

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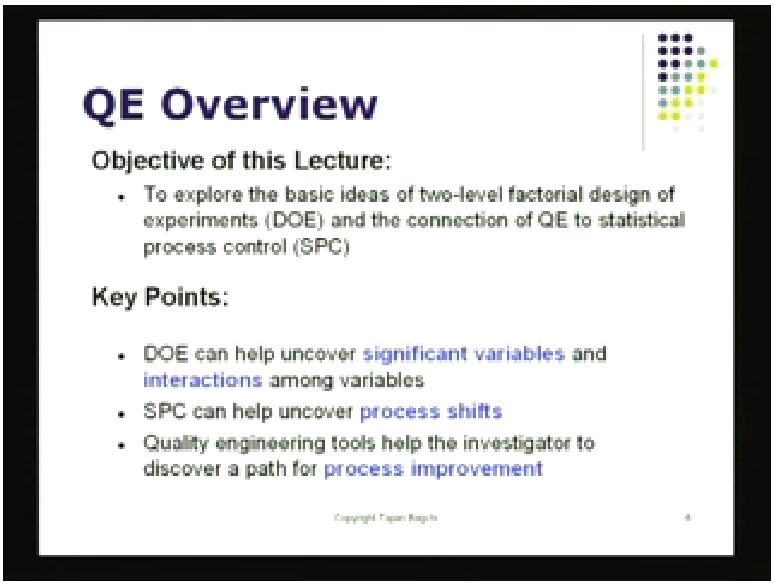

Now, what is quality engineering, let us just try to catch catch look at this, the objective of this lecture is going to be, we will try to see what two factor, two level factorial designs can do for us. In fact, what we are really trying to do is, what do we gain by going to a multifactor experiment as suppose to a single factor experiment, that is something that we will try to understand, couple of things that we will try to understand one of which is of course, we got to uncover this significant variables, we got to make sure we understand, by doing the experiments we understand, which of the different factors are really active, they have the largest impact on the output, that is something we would like to know. The second thing we would also like to know is, are there interactions between the effects of the different factors, this is something we would like to be able to do.

If you compare that to SPC, Statistical Process Control, statistical process control does not really get into evaluating the effects of various factor, statistical process control basically is a method by which we can detect shifts in the process. What we are really looking for is, we are looking for process improvement and that can be done in a big way adopting the methods of quality engineering and the core of quality engineering, basically comprises this technique of design of experiments or DOE.

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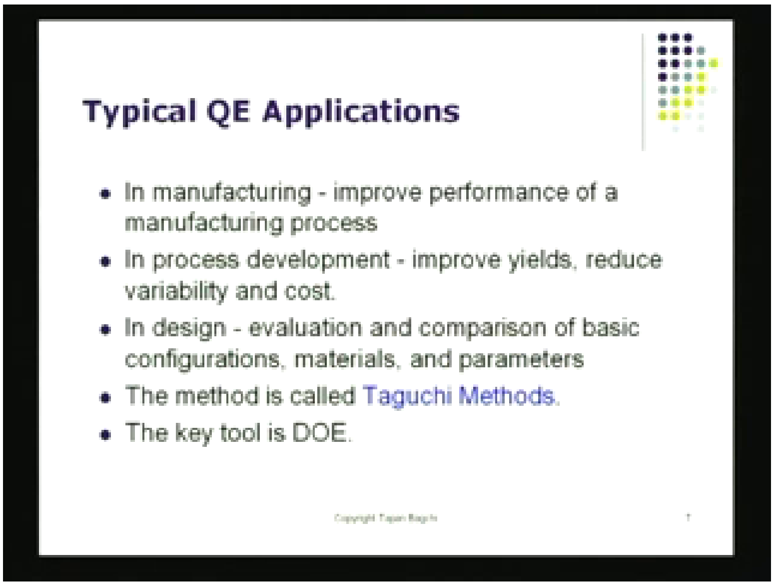

That is what we are going to be looking at what are some of the typical applications of quality engineering? In manufacturing we can apply this to try to improve performance of a manufacturing process that is something we can do quite easily.

When we have a process, we can improve yields, we can reduce variability, we can reduce defects and also we can reduce cost, in design we can evaluate many different alternatives, and that is also something that we can do quite easily, if we are using this approach of quality engineering. And of course, the most shall I say talked about method in quality engineering are the Taguchi methods, and the key tool for doing these various things, various steps in quality engineering is DOE, Design Of Experiments.

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That is, what we will be looking at, as we go into this topic here. Let us take a look at what Taguchi methods really are and of course, this gentleman is making some chocolate cakes.

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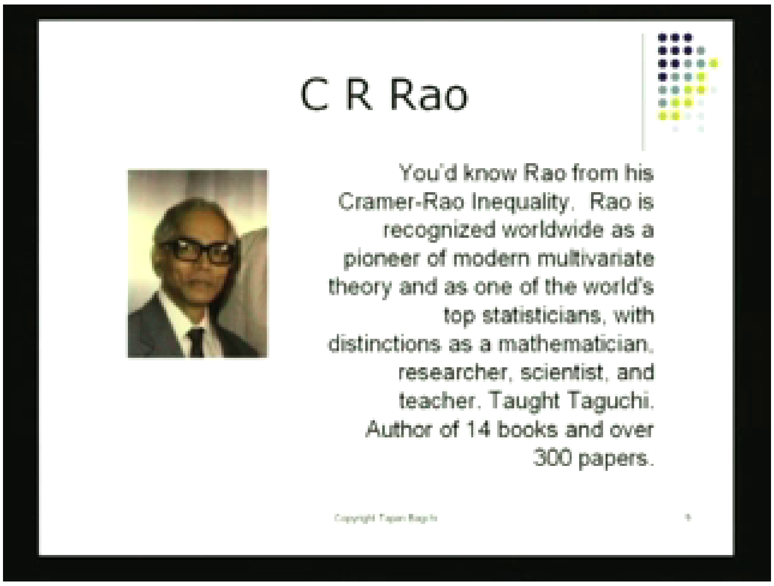

And let us see how would, how does one go about producing good good you know recipe for chocolate cakes. One very important person and this is doctor C R Rao, he is in Pennsylvania right now, he is in Pittsburgh and he is also one of the powerful people a very highly knowledgeable person in the area of design of experiments in statistics in general.

In fact, it turned out that this gentleman Genichi Taguchi, he studied under C R Rao at the Indian statistical institute in Calcutta and he picked up the methods of design of experiments from doctor C R Rao. Doctor Rao is obviously, highly accomplished, he is written about you know 15, 16 books and he is got over 300 papers, general papers and that is like you know a very high level of achievement that he is made, his contributions are recognizing world over.

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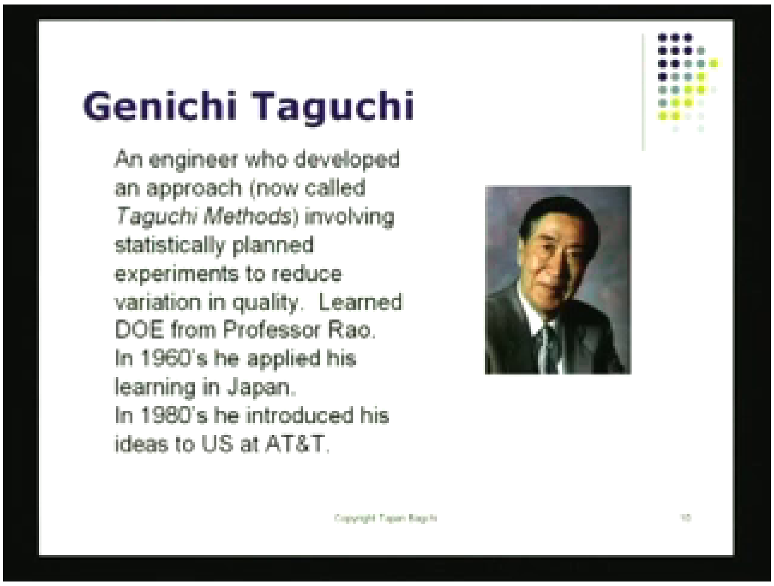

Taguchi was one of his students; Taguchi came to study design of experiments and analysis of variance and so on under professor Rao. Taguchi was an engineer and his interest was actually to try to impact, try to influence industry practices. In particular, when the process appeared to be complex, Taguchi tried to approach this in his own way, applying the principles of DOE, but he wanted to keep his life simple and he also wanted to keep the experimental slide simple.

And we will see that as we go along, Taguchi also made some other contributions, Taguchi basically opened a new chapter, all together a new chapter in the perception of quality, in the expression of quality, in the measurement of quality, this is where he took us a lot closer to the customer that had been done before. So, that is like something that Taguchi also achieved.

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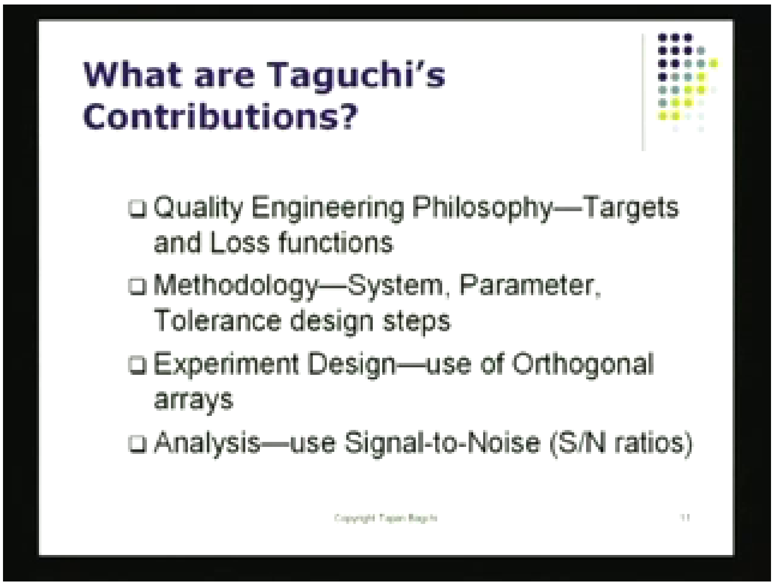

Let us see how he moved into this, what are some of his contributions? First of all, he gave us a new philosophy, he gave us something that is called the loss functions, he also emphasize the idea of targets and I am going to be illustrating these things as we go into this, the discussion on Taguchi method. So, these are couple of things that Taguchi gave, also Taguchi gave us a methodology, he gave us something that comprises three steps in trying to design a new product, for example, there is the system designs step, then there is the parameter design step, which is the robust design step, then you got tolerance design, this are three steps that are required if you want to achieve good performance in the final problem.

Also, Taguchi made a contribution in popularizing a simple way to conduct multifactor experiments, and these are called orthogonal experiments, and they are based on something called orthogonal arrays. And last of all, for data analysis also, being an electronics engineer, being an electrical engineer, Taguchi was very fond of signal to noise ratios and his own way he tried to bring that also into his data analysis. So, that is also another contribution that Taguchi made.

So, he gave us targets, he gave us loss functions, he gave us the method of system design, parameter design and tolerance design, then he gave us the use, he highlighted the use of orthogonal arrays, that is something like something like the factorial experiment, but this is a lot simpler, then of course, Taguchi also highlighted the use of the utility of signal to noise ratio.

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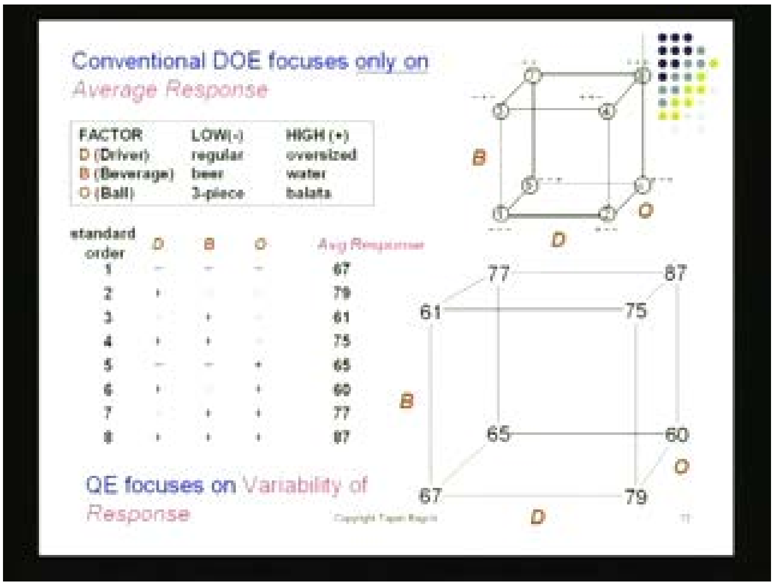

Let us go back a little bit into the framework of design of experiments, you have recognize the matrix which is to the right, this matrix is actually, it came from that golf game example that we gave, we those are those are those are you know some teams that were playing golf and they wanted to find the effect of balls, they wanted to find the effect of drivers, then they wanted to find the effect for example, of beverage and they wanted to sort of see what would be the correct correct choice for the driver for example, or for balls, or for example, the beverage that people were drinking, they wanted to sort of see, can we come up with the optimum choice for the driver with which you hit the ball, the drink that you take while you are playing a golf, the game of golf and also the ball that you choose to play the games.

Now, notice here, I am using a matrix and the same matrix has been represented here in the DOE terminology, in the DOE system, there are eight experiments to be run, there are three factors involved, each factor has two settings; low and high, notice here, low and high. And I have just marked it here with minus and plus minus and plus, notice here there is a certain pattern that the settings of D follows as I go from trial 1 to trial 8. The settings for factor B also changes likewise from minus, minus to plus plus and then again minus minus to plus plus and the selection of ball that goes from minus minus minus minus to plus plus plus plus.

What is exactly happening here, while the first experiment will be run or the first game of golf would be played with the driver, that is the regular driver with a beverage, that is your beer and with a ball that is the three three three piece ball, that will be my first game. In the second in the second round, that I play driver will be changed to oversize.

So, I have got oversized driver, the rest stay the same and I play the game again; on this side, I have got responses which is like the average response; average response if I repeat the game, five times, perhaps ten times, it all depends how much money I have to pay to the golf coach, I play those rounds and I workout my average and I calculate my average and those averages are shown here, those averages are also shown here for the different settings in this matrix, this matrix also is showing the same thing and this settings, the factor settings are shown, in this matrix here notice the factor here B, the factor D, and the factor O, those are shown here.

Now, conventionally conventionally, we will be using this design of experiment which is like this study here; conventional, we have been using them to study average response, this is something that Taguchi found was not enough to produce good design, yes you could probably find you know can I if I wanted to maximize yield or if you wanted wanted to minimize defect, I could probably use a design like the conventional DOE design, not much of a problem there.

But if I wanted to achieve, what we call a robust design, I have to do something more, I have to look at really the variability at each of these settings, I have to I have to look at the variability of response at each of these settings and that is really the focus of what we call quality engineering.

So, the conventional design of experiments, these runs would try to basically focus on the average response and determine factor effects based on that; what quality engineering does, it looks at the variability of that response as the response. So, the response here is, not just the average scored that I have when I play golf, but also the variability's that I have at each of these settings. So, 61 might be the average, but the individual scores might have been 57 and then 65, then maybe 58, 62 and so on and so forth. So, I have basically, multiple multiple responses, it is the variability of that, that is also of my concern when I am looking at this problem as a quality engineering problem.

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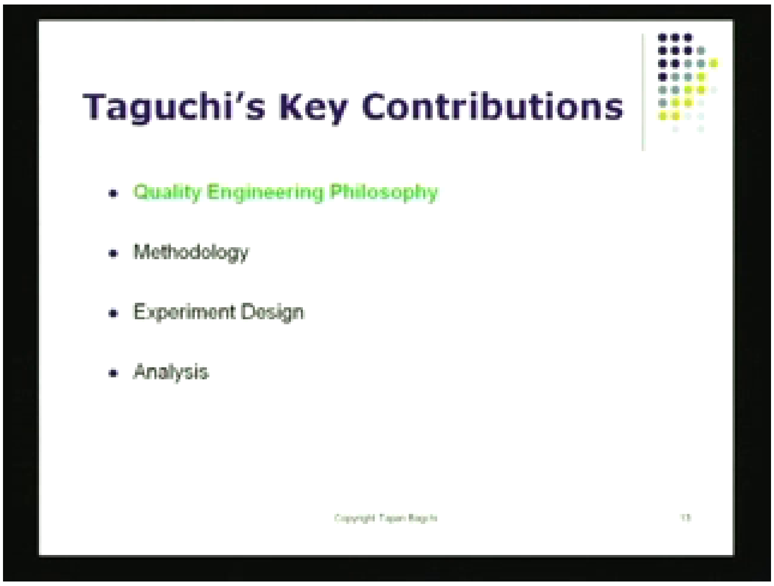

What are Taguchi's key contributions? These are very important, if you look at the first contribution that Taguchi made, he gave us a new philosophy. He did give us other things also, but let us just take a take a look at the philosophy that Taguchi gave.

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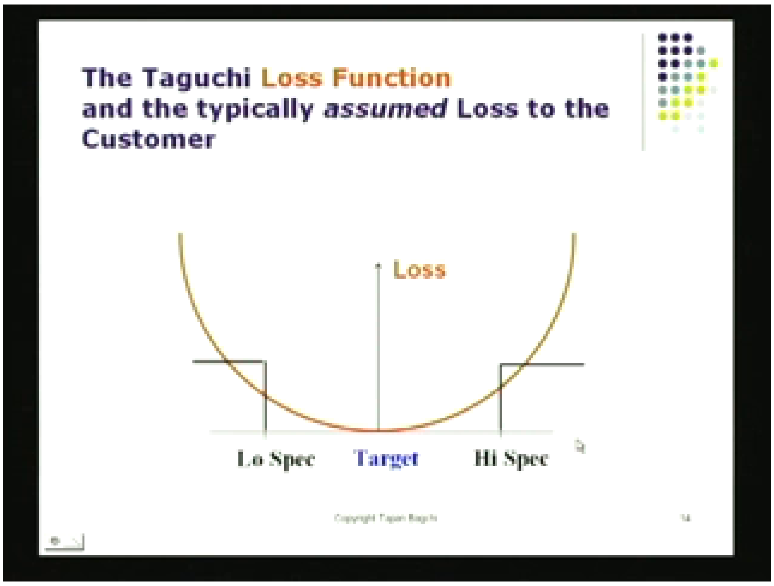

Here is a plot, and notice here on the x axis, I have got some quality characteristic, it could be for example, the size of my shirt, it could be my my shirt size that could be the quality characteristic as far as this shirt is concerned, that is what I have plotted on the x axis. Now, as far as I am concerned, I have a unique neck size and therefore, to be satisfied to the maximum extent, I must get a shirt that fits exactly my neck. So, I really when I put the button on, I get exactly the fit that I want.

So, now that is 42, if that is 42 centimeters, my target setting then is 42 centimeter and that is the shirt that is going to give me maximum satisfaction as far as neck fitting is concerned. If it goes away from their, suppose I buy a shirt that is size 44 or 46, my losses are going to increase, what kind of losses are these?

For one thing, I may have to basically take it to take it back to the store, that is additional transportation cost or I may have to take it to a tailor and ask him to adjust the thing, that is something I will also have to do and perhaps, I may not be able to do that if the shirt is too tight. So, I will have probably a loss there also, as I go away from the target. Now, what is been the convention of way of quality, quality perception?

The conventional view has been, it does not really matter what product you are looking at, we have always gotten away by giving a specification, that is become our language. When I try to convey something, I try to convey my requirements, all I have done is, and I have given it perhaps the nominal value. I do not even call it the target value, I just call it the nominal value plus minus some tolerance, that is all I that is all I have been doing when I have been trying to communicate my requirements.

But what Taguchi said is this, let us see if you have set your limits at high and low, it is not true that a shirt that is of this size suddenly becomes from good to bad, that does not quite happen, it actually happens gradually, and it rises by this concept of loss and this loss actually Taguchi articulated that by calling it the loss function and I am going to show a little formula for calculating this loss function.

What it really means is, any quality you are looking at, there is always a best value that the customers wants you to have; if you are not quite there, you as the user or society at large will incur a loss, because that quality was not delivered at the target, it was delivered somewhere else . So, the old idea of trying to control quality by looking at whether the product is within or not is not good enough, we will have to look at it really from the point of view of saying, how far is it from the target that is there, that is going to be the real real measure of quality.

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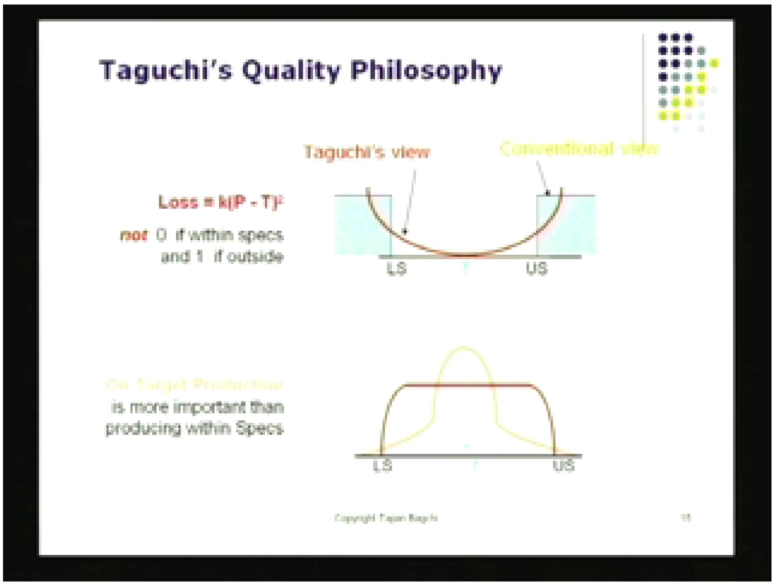

Let us take a look at let us take a look at couple of these things, the first thing of course, is the conventional view of quality which just says, anything that is off spec, suddenly it becomes bad. Once I land up in the area that is like off spec, outside spec limits, things suddenly become bad, Taguchi said that is not true. The moment you deviate from the target you are incurring, society is incurring a loss and you are imposing a, you are basically inflicting a loss on society, and that actually is, will will take place even if you move just a little bit from this and the amount of that loss can be given by this loss function.

So, it is not true that loss is 0, if you are within specs and loss suddenly becomes 1 or some large number, when you just exceed spec, just exceed the upper spec limit for example, or fall below the lower spec limit, that is not the way we should be perceiving quality, we should really see is it on target or is it not on target. Let us take an example where this were really proven out in the field, as you probably know the Japanese, they make very good TVs and one of the companies that produces fabulous TVs are the, is the Sony company.

And in the 80's when the Sony company was you know in the business of producing what they call the Trinitron TVs, they started exporting these TVs to US and of course, to Europe and so on and so forth. In the US, these TVs became very popular, in fact I have most of my friend, they ended up buying Sony Trinitron TVs and they in fact even recommended that, if you are trying to buy a TV, please go ahead and get a Sony Trinitron TV, that is going to be good for you, that was fine. What happens was these TVs, they suddenly became very popular and because they were good TVs, and they displaced a lot of American TVs from the market place.

Now, this would be, there will be fewer GE TVs fewer vesting house TVs and so on and so forth, those really those really they they started to lose their market share, like the American autos for example, they started losing their market share as the Japanese products started to come in. And this is naturally protested by the American workers, they said this is not fair, because you are taking away our job, you are taking away our market and so on and so forth yes, we like you product, but it is going to be at a very high cost, very high social cost. So, the Japanese thought about it and one thing they thought of doing was, bring in the parts and do the assembling which will provide a lot of jobs, fair fair number of jobs and let us do the assembly in the US.

So, Sony company, they set up a plant in San Diego, San Diego is a little town, not very far from, it is a it is a decent town, not very far from Mexico for example, the Mexican border; there, Sony people, they set up their factory, the TV assembly plant, they got the parts from Japan, but they did the assembly all there and these were of course, American workers that were doing this, and these people these American workers, they would doing all the fine adjustment for color, you know contrast, brightness and so forth, they were making those adjustments as the TV was being getting assembled.

Say, so then then of course, the TVs coming out of the san Diego plant, they also started to sell and it went fine, there was no real problem there, these TV were selling just fine, suddenly there were complaints from the field people, users did not quite like the Sony TVs that they were buying now. The Japanese kept track of which TV that the customer was using, came from which place, was it from, was it supplied by Japan, or did it come out from San Diego.

What they found was, that complaints came, mostly from the San Diego plant TV, the ones that were produced in San Diego, those are the ones that really led to a lot of complaints, then they started looking at manufacturing practices, they looked at the operations very closely, how the TVs were getting assemble, because the parts were the same, so there was not much kind of issues as far as the parts were concerned TV parts.

But they found, what they found was that, when the TV was being assembled in san Diego, the worker tried to make sure that it just met specifications.

So, if he for example, color had to be adjusted, he made sure that he twisted the knobs and the and the screws and so on and so forth and brought the performance, brought the color density for example, exactly within specs, just within specs and that is it, and he left it there, and he did the same thing with contrast, he did the same thing with tuning and so in and so forth. All the adjustments were made just to bring that TV that had just been assemble, just within spec that is it, and then of course, it was you know pushed off and it was packed and sealed and so on and so forth and sold.

So, most of these in fact, all of these TVs, they were assembled to make sure that they met specs specs and these were like upper and lower spec limit, the contrast was this, TVs made in Japan were not made according to this philosophy; there what the what the workers tried to do was, they identified they were told what the target was and the target was pretty clear, the target was here and they wanted to make sure that the TVs assembled came as close to this target value as possible, as they were getting assembled.

So, color was adjusted to be right on its own target, contrast were adjusted to be right on its own target, various change and adjustments those were to be made that were to be made they were also put exactly at target. So, result was this, when these TVs came out most of the quality characteristic, they were right on target and these led to very few complaints from customers, very few complaints.

So, hardly any people who receive TVs like this, hardly any people who receive TVs like this the difference was these these two types of what we call in statistics, we call them population, the population of TVs produced from San Diego, they made specification, but they did not lead to as much satisfaction in the hands of the customer at the, in the in the house of the customer as close to the Japanese TV that was assembled such that, they were smack on target when their shape, those led to a led to a high level of satisfaction and fewer complaints.

Now, this again highlighted the fact, what you really have to do is, when you are doing design or when you are doing assembly, please make sure that the quality characteristics are as close to this target value as possible which of course, is determined by a process called QFD, Quality Function Deployment, and the same thing what we have done, when you were trying fix the plasticity for the chocolate bars, remember the green chocolate bar line, the green line that goes along. I have to find that hardness or that stiffness, that is ok for children, and children perhaps who are between 6 and 12, they are the ones who should really judge how stiff that chocolate bar should be, then of course, I will get a decent chocolate bar.

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Taguchi focused on offline quality control, he said all these stuff all this stuff, this quality engineering thing, it is got to be done, not when you are doing production not like SPC, it is got to be done before that, it is got to be done in r and d, it is got to be done in the design shop, that is you that is where you control, what you call offline quality control; that means, it was not quite at the production stage yet, you did this before, you got the got the design ready for production, that is why it would it would have to be done.

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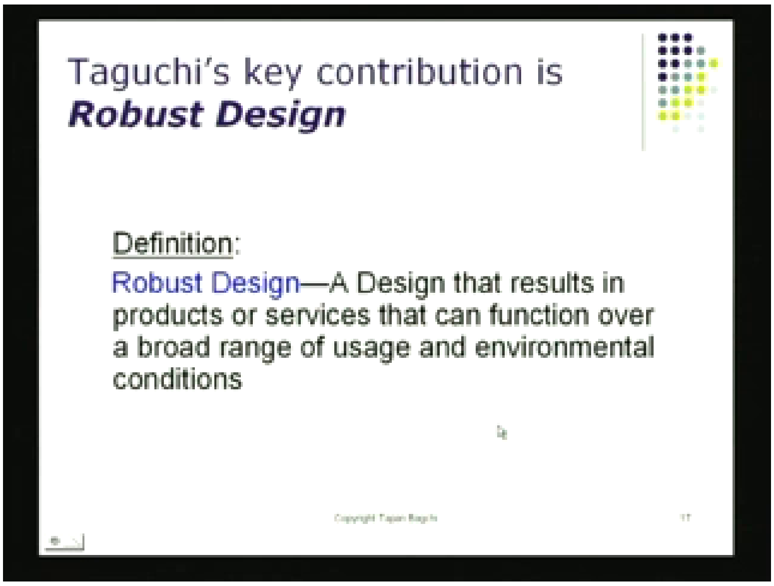

This will lead to a lower cost to society overall, and this led to what we call the idea of robust design, a design that results in products or services that can function over a broad range of usage and environmental condition, such as variation in temperatures, such as variation in humilities, such as variation in the quality of the components that you are using to do this simply and so on and so forth, these are factors that the designer can specify optimally when he is doing the design.

If he does not do that, then of course, these things cannot be controlled once the technology transfer has taken place and the the the plant is doing the job of manufacturing, they cannot really do r and d there, this r and d has to be done quite engineering relays is a part of r and d, and this is got to be completed before you before you hand over the design to the to the a manufacturer or the manufacturing unit.

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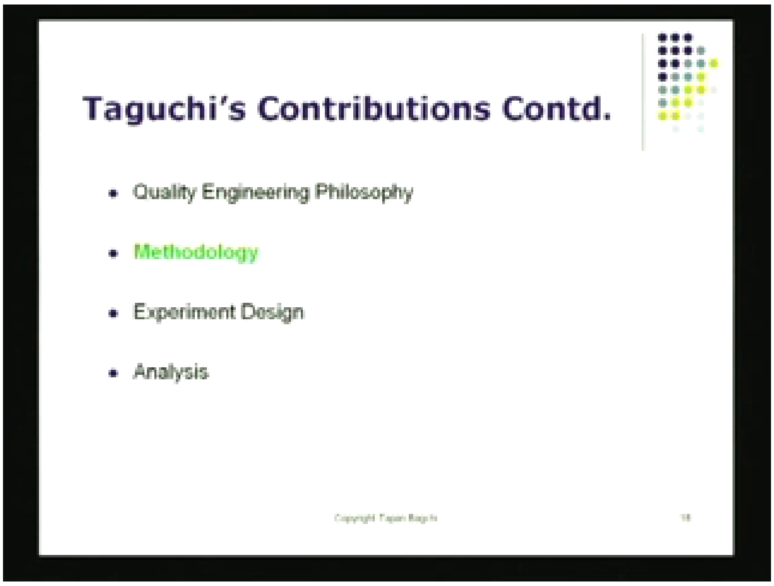

Now, what is the approach, how do you really approach quality engineering? The method is as follows.

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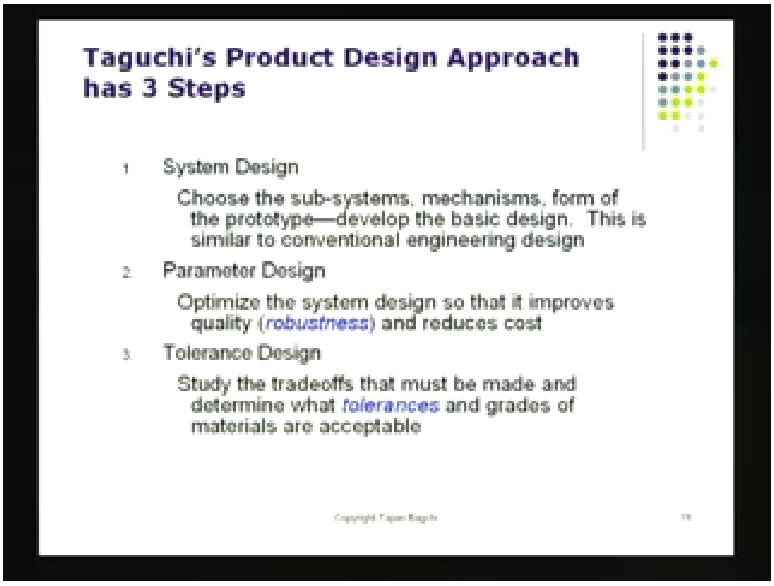

The total design step, the total design processes fit into three steps according to Taguchi. The first thing, of course is functional design or system design, this is the step when you choose subsystems or mechanisms and so on, and you apply basic principles of physics, chemistry and anything else, and engineering and so on and so forth, and then you come up with your first system design, your concept is there, this is the conceptual design and you produce the few prototypes perhaps.

So, you got now a functional design that is performing all right, this is your system design phase, the second phase is when you when you manipulate the design parameters, and you come up with what we call the parameter design, this step is called parameter design, this is also called the robust design step, or the quality engineering step.

What we are doing here is, we have selected certain parameters for for each design, for each product design, that we want that we want to come up with, we ended up with certain design parameters, those are the requirements that we put down there, those requirements have been put down there, and now I have the requirements. In quality engineering, I will be manipulating those factors I will be manipulating those different factors and I would try to see can I improve the performance, can I make that performance robust, this is what I will be doing in the parameter design step. And of course, once I have got my parameter set at the right, in the optimum setting, I have got to provide a tolerance for it and that is done at the third step called tolerance design.

So, quality engineering or robust design, it really proceeds in these three steps, first you have got system design, then you have got parameter design, or the quality engineering or the robust design phase, and the third step is tolerance design, these are the three steps and you must move systematically between these.

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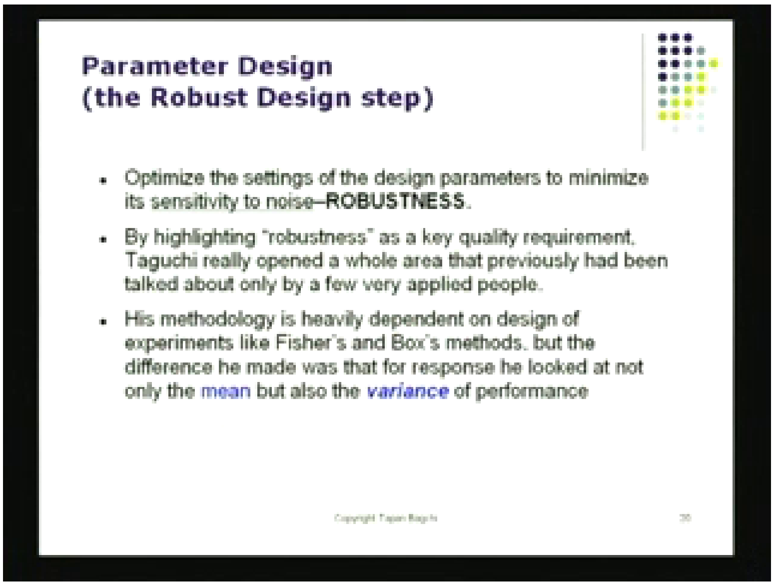

How do we really do this parameter design? Let us let us try to see how we achieve our robust design, how we end up doing this, what we are really trying to do here is something that we got to go after is robustness; robustness is something that we got to go after it, and what really disturbs this robustness? It is actually the environmental factors, they design parameters that have been picked for any product that you have, those have been fixed pretty well, and they are in your control and you can set them the way you want.

But unfortunately, when the product is actually used, it is being subjected to the impact of the various environmental factors, what I have to make sure is, for example, if it is just this pen if the choice of the fluid, if the choice of the ink or the solvent is not good, then in a dry room, this pen is going to dry up very quickly. As supposed to another, choice of a solvent which is going to last longer, so that means, the parts, the components of this thing that are highly, that that are easy to vaporize, that are high vapor pressure, those should not be there in a pen, if they are there, it is going to dry up very quickly. So, it is not going to be a robust design, if you got to use in sun for example, it really will not be something that is going to be of much use, if it is not a robust design.

The same thing goes if I am trying to write upside down, if it if it can suck the suck the ink as I am using the pen, if we can suck the ink up there to the tip without too much trouble, then there is no problem there. But it is very possible that that the fluid is not able to come up to that point, because the position is now upside down, that is also going to be an example of a poor design, a robust design will make sure that the flow is there through out.

So, there are various examples that you can come up with, that is there. What we are looking for is, not only we are looking at main performance or the average performance, we are also trying to look at what we call the variance, and this variance is caused by the impact of the, this this is a variance in your response or the actual performance, and this can be impacted by environment factor. The goal of robust design is to try to make sure that the design is insensitive, basically to the impact of this noise.

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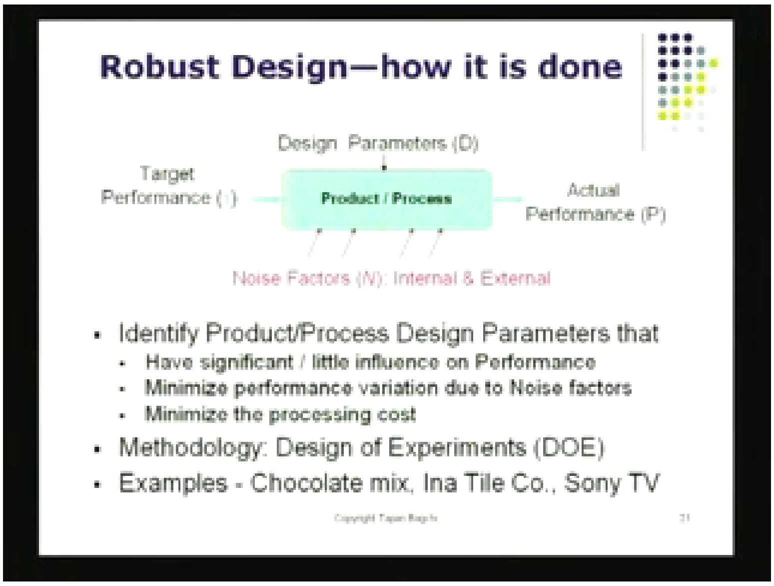

If you look at a if you look at a system, you have what we call design parameters, we got certain target settings that we have to set, then we got these noise factors, then we got the actual performance. What we have to really do is, in robust design we got to identify the product process design that have little influence on performance, or significant influence of performance.

So, the first thing I have to do is, on the various design factors, I have to find those factors that have an impact on performance, this is something I have got to separate out, and DOE is a great way to do this. DOE is a great way to try to manipulate these different 5 5 or 6 different factors, and find the 1's, 2 or 3 that are really the significant one. This isolation is very important, this separation is very important, this identification is very important, this is done as step number 1 in robust design.

Then of course, we got to make sure we minimize the variation in the output, we do something by which the design becomes less and less sensitive in the environmental factors, to the impact of environmental factors. The third thing of course, we should try to do is, we should try to minimize processing cast, that is also something we should be able to do. The method used for this is DOE design of experiments, and there are many examples. I have given some examples, chocolate mix, then the tile company trying to produce floor tiles, and Sony TVs, and there are many many other examples of robust design.

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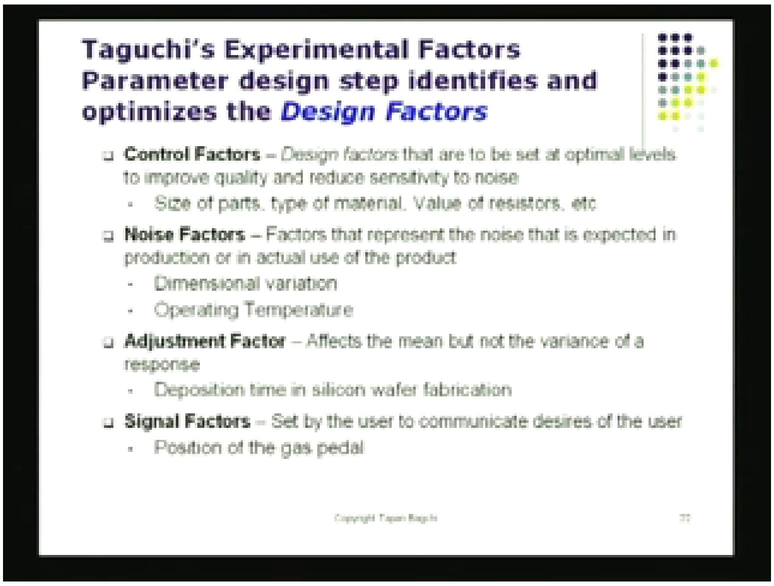

Let us try to get a little deeper into this, there are certain things that are called design factors, these are the ones that I am going to change. So, for example, for a pen if I if it is a writing medium, this is going to be writing tool basically, it is going to be the choice of the tip, the quality of the ink that I am using, the delivery system, the holding system, the protection of it and all, these are all design parameter, I can change them.

As far as robustness is concerned, like I said earlier, if this pen misbehaves in hot sun for example, or if it dries up too quickly in a dry room, it is not a good good good design it is not a good, it is not a robust design, because I am not going to be using this pen all the time, what we call ideal situations, ideal conditions. I am not going to be doing that, I will be using in perhaps hostile environment, but it should retain as good performance, that is going to be a robust design if it retains as good performance that is going to be a robust design.

To do that what we have to do is, we got to obviously, identify the control factors, we got to identify noise factors, we got to indentify the adjustment factors, and what we call signal factor, these have to be identified, and Taguchi clarifying that almost every system will involve these factors, it is our job, the quality engineer to make sure that we understand these factors.

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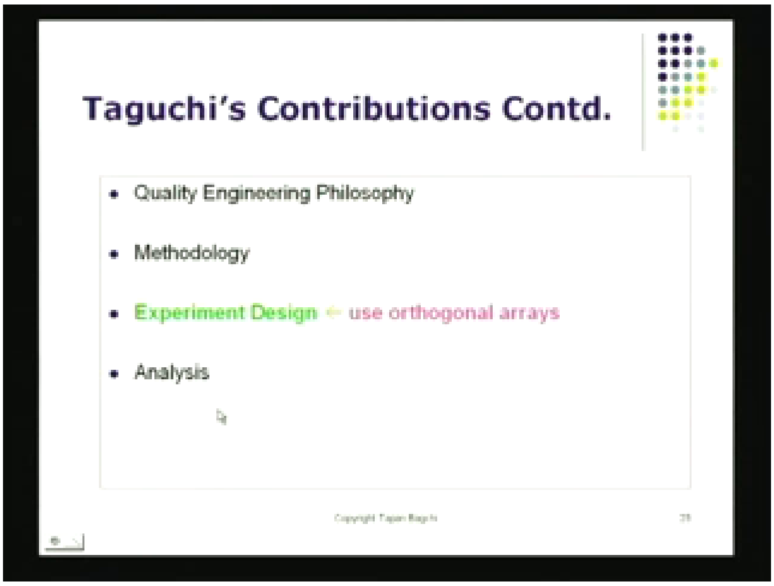

How do we basically find the right settings? And for this Taguchi provided a method, and these these methods, they utilize a special structure, a special matrix structure for the settings of these different parameters, that is something that is done by what we call use of the orthogonal arrays, I am going to be giving you some examples of these.

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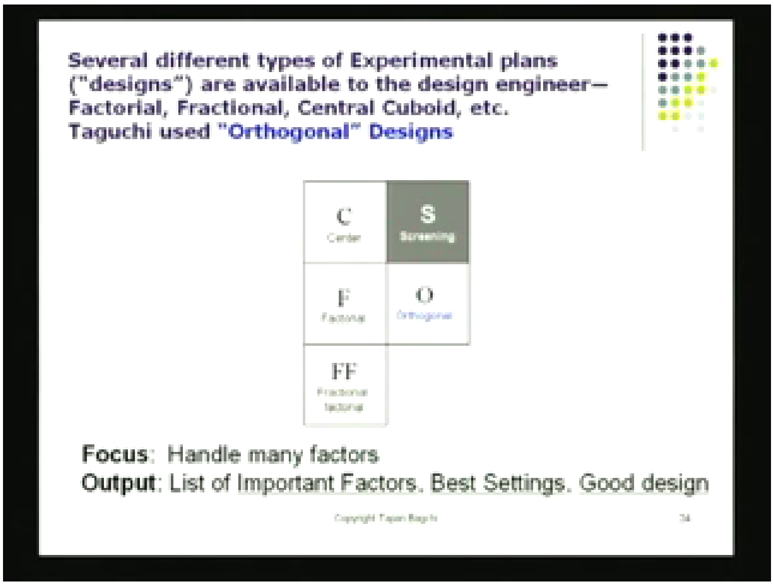

There are various types of experiments you can run. If you got multiple factors to play with, there are various types of experiments you can run; you can run what we call full factorial designs, full factorial experiments or you can run fractional factors experiments, or you can run what is called central cuboids experiments, or we can run just the plain and simple orthogonal experiments.

Now, what is the use, what is the difference between these different experiments? First of all they are matrices, these are these controls the number of trials you will have in a experiment. And number of trials, basically determine what you can do with the experiments, what what kind of message you can get out of the experiment.

So, full factor experiment, basically they tell you a lot, they will tell you about not only about main effects, but also about interaction effects, all those things can be found by full factor experiments. If you are looking at central cuboids design for example, in some cases, we want to really generate the response surface, we have to come up with a mathematical formula for the for the response surface.

For this what we have to do is, we have to use it, use some other points in space aside from what the full factor design is doing. So, I have got the full factor plan, I collect some additional data at some other points which are specified by the central cuboids design, and that design is going to help us guide and find the parameters for the regression model which will be for the response surface, that I can then go ahead and apply some other technique, some other optimization technique, and I can I can optimize the process or yield or something like that.

Then, there are partial factorial designs which means, I do not really run all the trials of the full factorial design, instead I drop some, and I drop them very sensibly, I do not drop (()), because it all depends on the purpose for which I am running the experiment. If I am interested in only knowing main effects, that means single factor effects, I will probably be dropping some of the interaction and capabilities, and for that I can drop some of the trial, and then I can do. And one extreme situation is the orthogonal array, when I can only find main effects and nothing more than main effect, and these are the ones that still can tell us a lot about the behavior of the system, and these are the ones that were basically exploited by Taguchi, Taguchi exploited orthogonal experiments, and we will be taking a look at those we will be taking a look at those.

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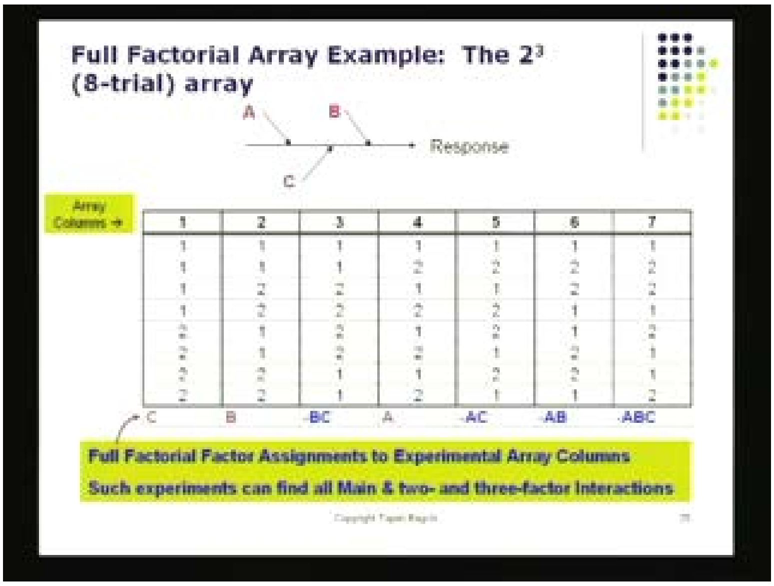

Let us take an example. Suppose, I have an experiment, suppose I have a process and I have got a simple fishbone diagram that you recognize here, and it is got three factors here, A,B and C. And I am basically very curious about the response of the system, or I am I really want to know, is A important as far as response is concerned, is B important as far as response is concerned, is C important as far as response is concerned. That means, does A have an impact on response, does B have an impact, does C have an impact, these are the three questions I have.

I may also have an an an an an an enquiry about any interaction that is possible between A and B, do these factors say A and B, do they have an interaction, do they reflex, say interact with each other, or do they act in a sense what we call independently or additively, is there an interaction between A and C, and is there an interaction between B and C, and is there such a thing as A, B, C, three level interaction, are these things present in the system. Many times when the system is given to you, you do not really have an equation that will tell you the, what these dependencies like.

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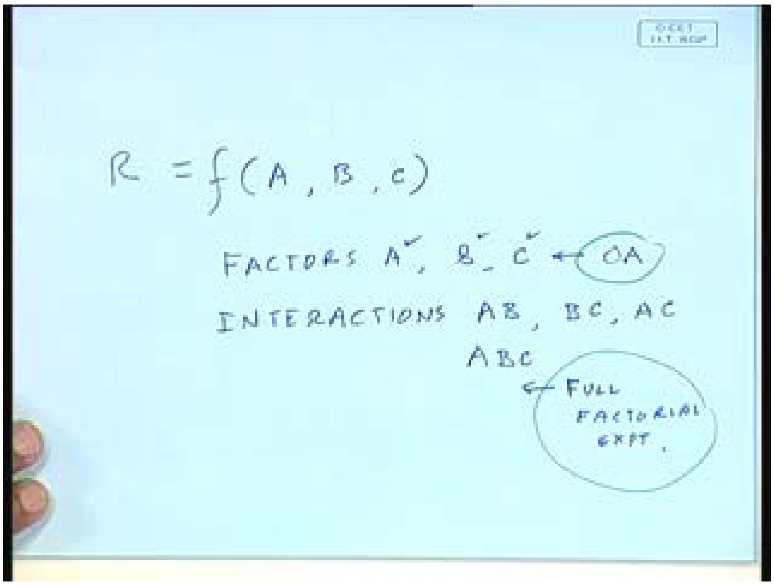

For example, if I look at this curve here, I look at response as the function of what we call A, B, and C. Now, this could be the effect of factors A, B, so I could just have factor effects A, B and C.

I could also interactions AB interaction, or B C interaction, or A C interaction and also perhaps the third order interaction A B C, these things, these are the ones that make life complicated, these are easy to evaluate and if I just have to focus on these, I could use what we call an orthogonal array. But I have also to find in addition to this, if I also have to find these, I have to use what we call a full factorial experiment full factorial experiment.

So, I could run these experiments, I could run basically orthogonal array experiments, or I may have to run full factorial experiments, it all depends on the purpose of the experiment; purpose, the reason I want to study this thing if it is the, if this is to be done empirically, I will have to run a matrix experiment and I am showing you a matrix. If you come to this table here, I am showing you a matrix, these are trial, trial number 1, 2, 3, 4, 5, 6, 7, 8 and look at the factors factor A, B, and C, and these are the settings now, these are the settings now of the different levels.

I am going to be a, first I am going to be a very simple experiment; I will put A at two levels, B at two levels and C at two levels. So, for A, I have got 1, 2, 1, 2 and so on. So, I notice these are changing as I go from trial 1 to trial 2 to trial 3 and so on and so forth, these settings are changing 1 and then 2, then 1 and 2 and so on, so forth. For B also, I have got two settings there, 1, 1, 2, 2, 1, 1, 2, 2 and for C also I have got 1, 1, 1, 1 and 2, 2, 2, 2.

When I combine these settings of A, B and C, the way it is been done here, the remaining columns, they easily allow me to calculate these interaction effects. For example, the A B interaction effect can be found by taking tips from this column; A C interaction can be found by taking tips from this column; B C can be found from this, and A B C interaction can be found from this (Refer Slide Time: 45:52).

What is the advantage here, I ran 8 trials, from that I am able to find not only the main effects of A, B and C. I am also able to find these two factor interactions and also one three factor interaction which is possible, all this could be done if I would run the full factorial experiment, and such an experiment of course, is the most powerful one. I am running two cubes, that means a total of eight experiments is what I am running here, and that involves now three factors, this is like one way.

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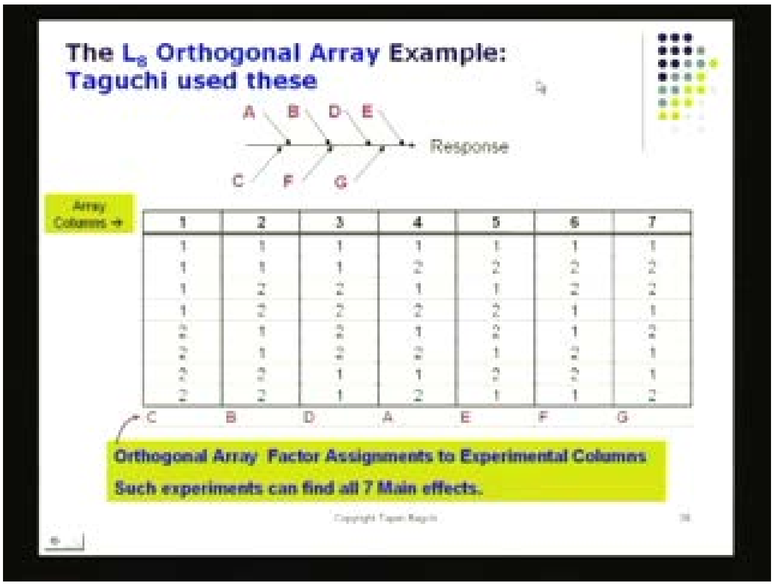

Now, suppose for some reason, I suspect may be there is not much interaction between these different factors, then of course, these columns appear so earlier, these columns B C, A C, A B and A B C, these columns I would be idling, because I have got nothing there, there is nothing wrong in assigning other factors, that also hopefully will not have an interaction with A, B and C and those can be D, E, F and G, I have now put in I have now put in this matrix.

I have assigned now seven different factors, when I am studying only eight trials, when I am conducting only eight trials, I am conducting eight different experiments, and I am now going to be studying the effect of what we call seven different independent factors and such a plan is called, what we call an orthogonal array plan.

What is the advantages of these plans, as positively full factorial plan, for one thing it lets you study many more factors like here with the same eight trials, I am able to run eight experiments I am running eight experiments and I am able to study seven factors. When it came to, when we when when we went back to the full factorial experiment this one, there with eight trials I am able to study the effect of basically A, B and C, three factors only. But what we gain with the full factorial design is the effect of interactions also; this is not something that I can do with my O A, O A is this one, with this I cannot study. In fact, it tells us that the these interactions they are now confounded with main effects.

But what Taguchi found was at least in 50 percent of the cases 50 percent the cases, we could get away by doing O A experiments and not much would be lost.

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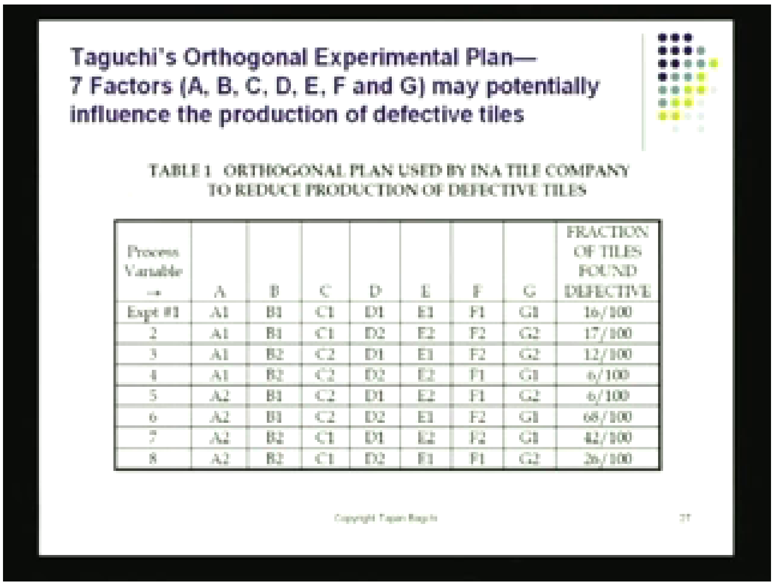

Process Variable →	A	B	C	D	E	F	G	FRACTION OF TILES FOUND DEFECTIVE
Expt #1	A1	B1	C1	D1	E1	F1	G1	16/100
2	A1	B1	C1	D2	E2	F2	G2	17/100
3	A1	B2	C2	D1	E1	F2	G2	12/100
4	A1	B2	C2	D2	E2	F1	G1	6/100
5	A2	B1	C2	D1	E2	F1	G2	6/100
6	A2	B1	C2	D2	E1	F2	G1	68/100
7	A2	B2	C1	D1	E2	F2	G1	42/100
8	A2	B2	C1	D2	E1	F1	G2	26/100

We will be taking a look at some of these things, I have got an example here, let me show this example to you there was a tile company and the name of the tile company, was the INA tile company, they they had a peculiar problem, they had a a a (()), they had like a like a in Hindi we call (()), an oven in which these tiles were big and then tiles combined a large number of factors, there would be the recipe for it, there will be China clay there, there will be moisture, there will be various things, various component went into making the mix, then of course, their process conditions, heat and the amount of ventilation that was there and so on and so forth, those things would be there.

The placement placement of those tiles before baking took place, all those things, these were like control factors. The problem was, this company was suffering from very poor yield, there were 20, 25 percent of their production was actually good quality tiles, the rest they had to crush back again and they dump it again and and make the raw tiles again and then bake them again. So, it was like a lot of rework, lot of waste lot of rework, huge (()) in this particular example huge (()). So, what they tried to do was, they said well is there some way by which we could optimize the setting for these factors, and they identified by brain storming, they were able to identify seven different factors.

At that time, Taguchi heard about this problem and he became involved and he started to advice them and what Taguchi did was, he setup a simple orthogonal array, and I am showing that on the screen here. The process factors are these A, B, C, D, E, F and G and he setup this matrix that comprised eight trials. And for each of these process factors, he chose two levels, these were the extremes in the working range in which these these different variables could be changed, could be altered. So, the first one could be changed between A 1 and A 2, second one could be changed between B 1 and B 2 and so on.

These were distinct numbers, these were distinct settings, but they were clearly two settings for each factor; having done that, Taguchi run that ran the trial. So, the first set of tiles were made under this setting, on the right hand side I report the fraction of tiles found defective and notice here, just 16 here, 17 here, 12 here and so on and so forth. So, I have here the numbers, in couple of places of course, they are pretty bad as you can really see and in the other cases they are pretty good.

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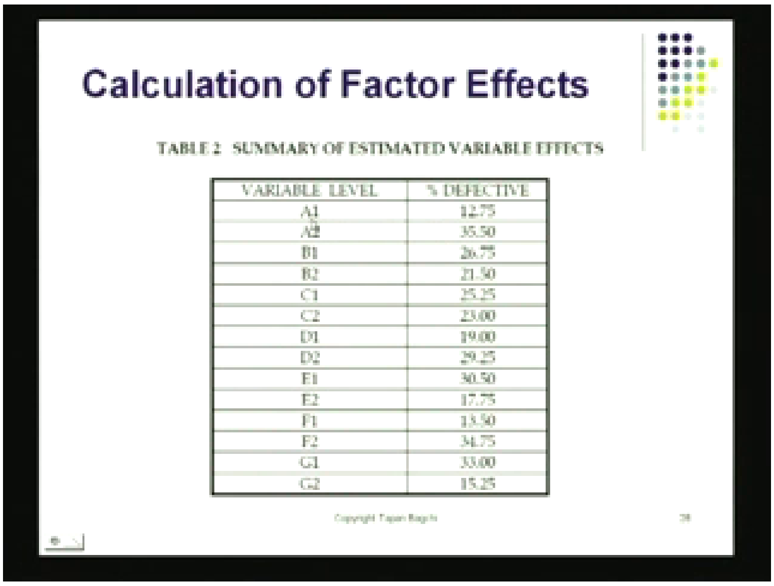

VARIABLE LEVEL	% DEFECTIVE
A1	12.75
A2	35.50
B1	26.75
B2	21.50
C1	25.25
C2	23.00
D1	19.00
D2	29.25
E1	30.50
E2	17.75
F1	13.50
F2	34.75
G1	33.00
G2	15.25

Now, this is the data that was then analyzed and how was this done, we calculated the averages and I am going to show you one or two examples of this calculations. I am going to be just taking a little sheet of paper here. And I will use my calculator I am going to be working out for example, for A 1 we are going to be finding this percent defective, let us do that.

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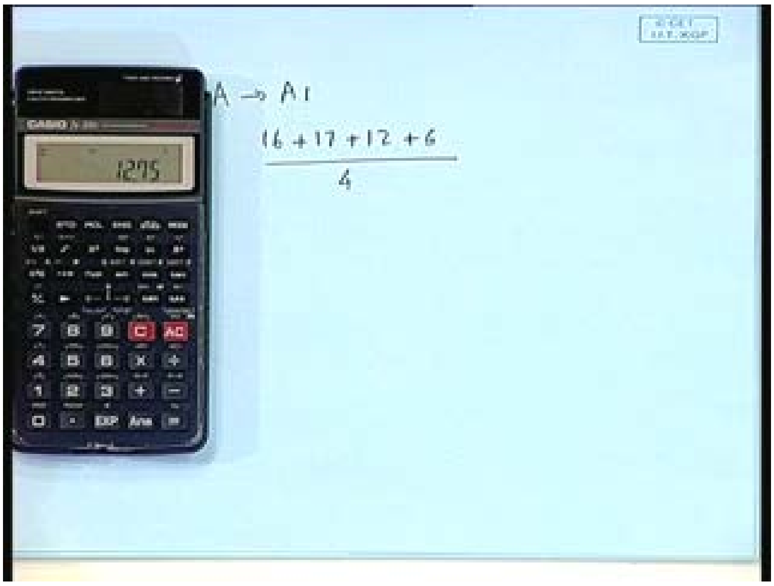

All all I will have to do for that is, I have to basically add up these settings under which runs had been made with A set at A 1 A set at A 1, what are the readings? Readings are 16 plus 17 plus 12 plus 6 divided by 4 and let us do that, let us do the number there.

We have 16 plus 17 plus 2 plus 6, we will do the total and we divide that by 4, 12.75, just take a look, the first reading is 12.7 5. Similarly, I could do A 2, I could do B 1, I could do B 2 and so on, so forth. So, in fact, these are the averages, this is the average percent defective found when A, factor A was set at A 1, and factor B was factor A was set at A 2 and I got this reading.

Similarly, for B, when B was set at B 1, I would get this reading; when B was set at B 2, I would get this reading and so on and so forth. If you see this way, the way this matrix is organized the way this matrix is organized, there is a property of it and that is called the orthogonal property, because of which I am able separate out the effect of a, factor A, factor B, factor C, factor D and so on. I am able to do that, when I do that, I can show the results graphically, this is of course, a numerical display of the thing.

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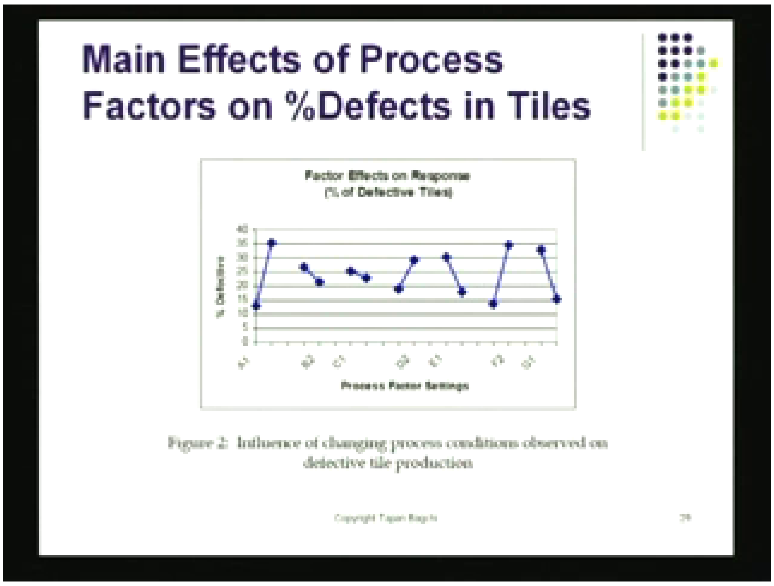

When I show it graphically, I can now show you the effect of A, when A changes from A 1 to A 2, percent of defects go up. When B change from B 1 to B 2, percent of defects come down, similarly percent of defects come down here, they go up here, they come down here, they go up here and so on and so forth. Now, if the goal is to reduce the effects, I should not be using these settings, I should be instead be using these settings here.

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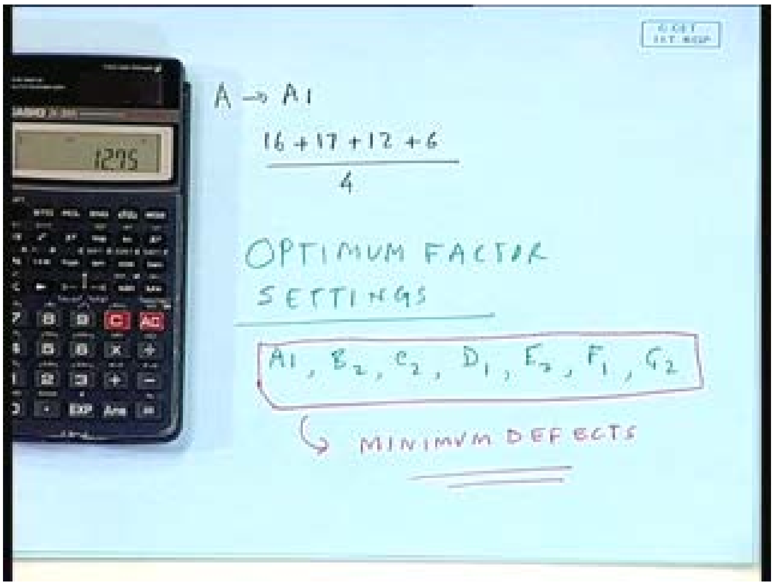

So, my optimum settings here is going to be, if I write down the optimum settings you can go by going back to my sheet there, optimum setting, optimum factor settings, these are going to be for A, it is going to be A 1, then for B, it is going to be B 2, because that is going to give me a lower rate of defects, C is going to be C 2, D is going to be D 1, E is going to be E 2, F is going to be F 1, and G is going to be G 2, these are these are these are my optimum settings. If I now run a process with these ratings, I should expect to see minimum defects and that would be done in what we call a verification experiment and this was done basically by Taguchi, this was done.

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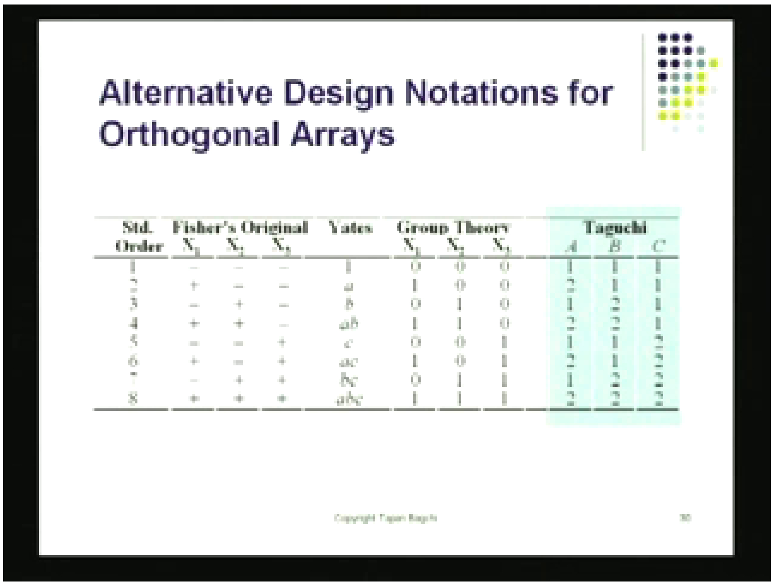

Once the once the data was complete, it was done this way, this is like a great example where a simple plan was used, a simple experimental plan was used, and he has accomplished a lot. He in fact, he was able to reduce the defects from a pretty high level to a pretty low level, just for manipulating the factors in a way that would be guided by this O A, the orthogonal array and he was able to do that.

This is one of Taguchi's major major contribution, he gave us an empirical method that turned out to be pretty simple, straight forward method, and that is like what exactly what we showed in the thing. Now, this is not a new design, this is not a new plan, similar plans have been there before and in fact, what Taguchi did was, he just made a clever use of an existing plan that was already there, this was clearly not a full factorial design, it is a partial factorial design, it actually was partial of the a part of the full factorial design that would be there. If you if you remember, this factor involved seven factors.

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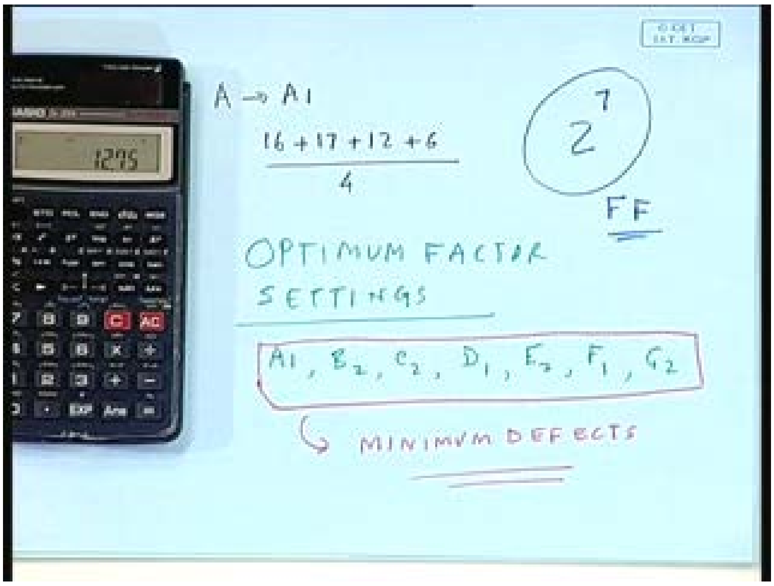

So, in actual fact even if I had 2 factors only, I would have had to run so many full factorial trials and Taguchi did not have to do that. Taguchi just used the 8 line orthogonal array, we will follow this in a couple of minutes, we will be following this. So, just wait for the next hour, thank you.