**Six Sigma**
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**Lecture - 46**
**Taguchi Method: Illustrative Application**

Hello friends, once again you are welcome to our ongoing Six Sigma journey. And let us move ahead in our ongoing phase of DMAIC cycle and at present we are discussing the improve phase of our DMAIC a cycle. So, as a part of this we have talked about various design of experiment, concepts, we emphasize that try to improve the quality right at the design stage.

And now we are talking about, Taguchi method. We have already seen the fundamentals and key concepts of Taguchi method in the last lecture. Now, in lecture 46, we will try to see the Illustrative Application of Taguchi Method and basically how we try to conduct the parametric design, which is the soul purpose of Taguchi method towards having the robust design robust processes.

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So, let us appreciate the quote from none other than Genichi Taguchi and he says that quality is measured as the total loss to society caused by a product. So, you are producing grade a, grade b, grade c product as you are deviating from the target, you are imparting a loss to the society. So, the moment product is shipped, the loss has started and this may be in terms of warranty cause, this may be in terms of safety issue, environmental damage or failure in terms of its performance at the customer end.

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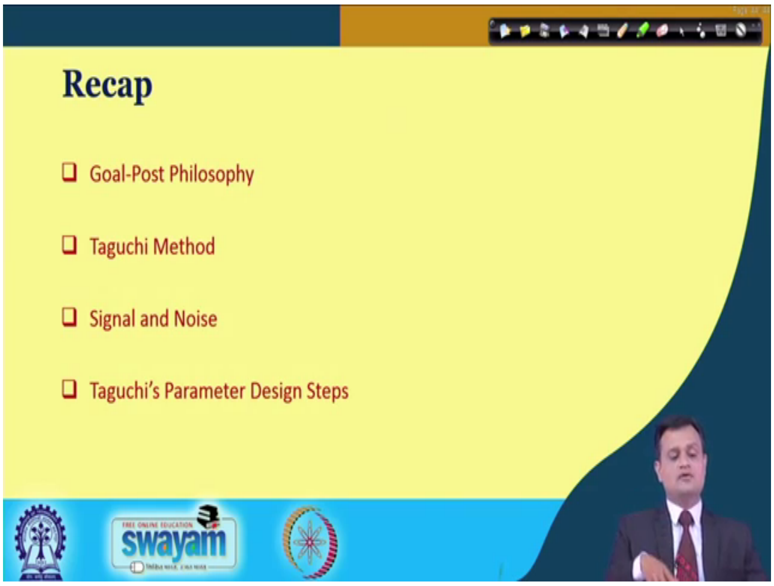


So, we had discussed in detail all these concepts related to goal-post strategy, Taguchi methods, signal and noise, Taguchi parametric design steps.

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And we will now move ahead with an illustrative application. So, typically steps involved in Taguchi processes, we will just try to revise orthogonal arrays, this is the central part orthogonal array is the central part of Taguchi's concept of conducting experimentation. Orthogonal array selection rules illustrative example, some critique on Taguchi method and some outstanding features of Taguchi method.

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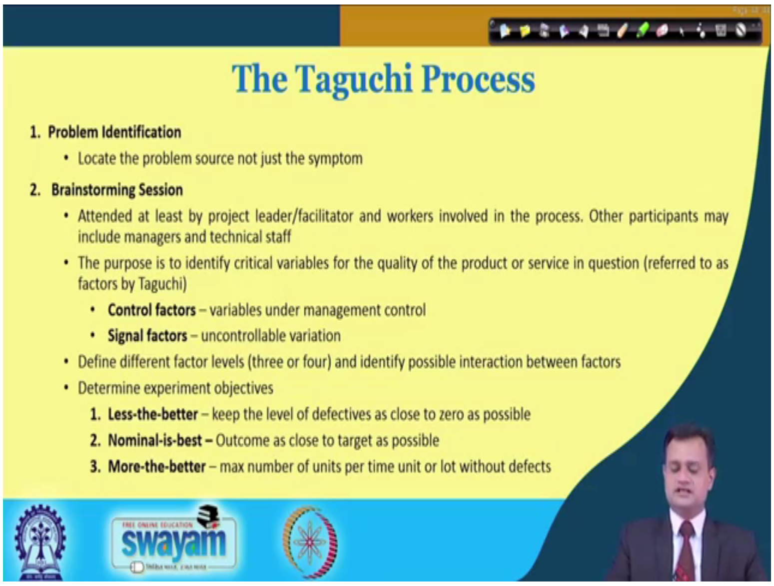


So, typically the Taguchi process goes like this, there is a problem identification and then you go for the brainstorming. So, you basically try to identify the control factors and the signal factors and you also try to determine the objectives or your experimentation. So, whether the quality characteristic, which you are considering would be of the nature; for example, less is the better, nominal is the best, more-the-better, we discuss these issues in detail.

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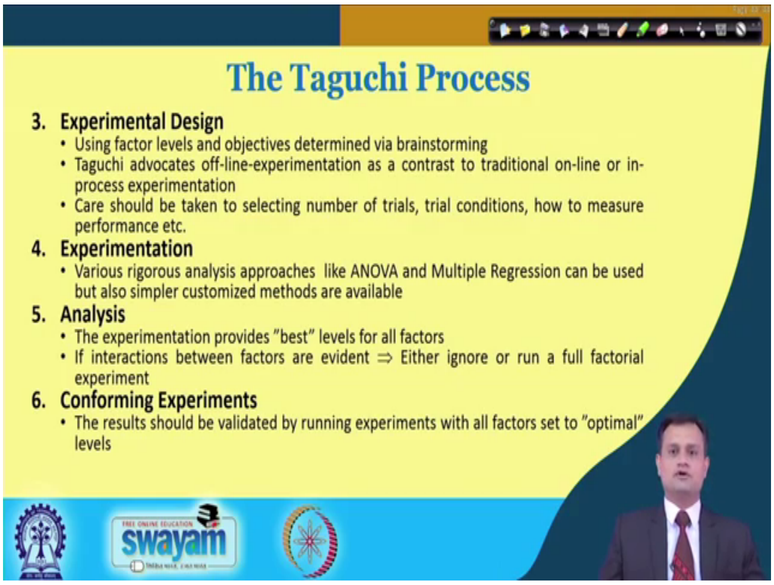


So, this decisions you take in the brainstorming session. Then you go for the experimental design. And here you say basically, conduct the you develop the design and this is based on the orthogonal array. So, you select an appropriate orthogonal array to say, meet your objectives for creating the experimental design and then actually you do the experimentation.

You can analyze using the ANOVA approach or multiple regression can be used for analyzing the results of experimentation, then you do the analysis. And basically this is the point, where you are trying to figure out the best levels in terms of robustness for a particular product or process. And then you may like to confirm the experiment by rerunning the experiment for the set levels.

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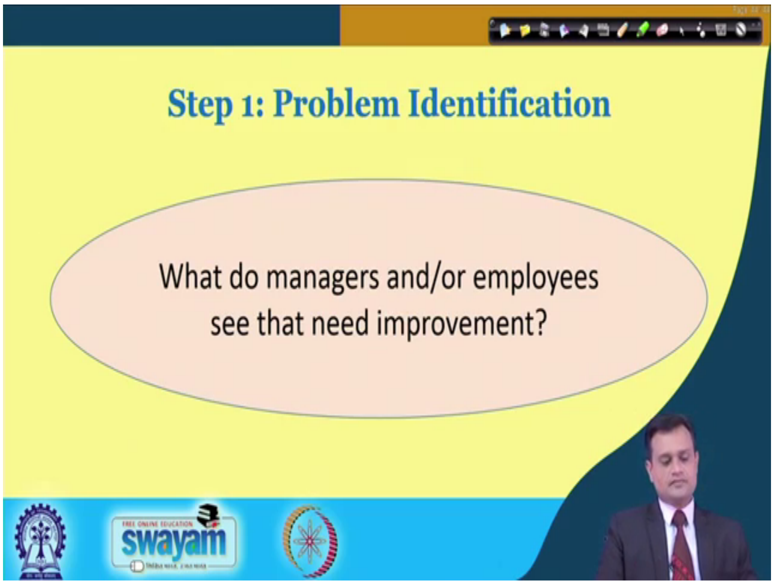


So, step 1 is problem identification. So, what do managers or employees see that need improvement. So, you are trying to find out the problem and there could be many symptoms, customer complaints, rejection, rework or say internal or external failures, there could be many symptoms based on which you would like to say identify the problem.

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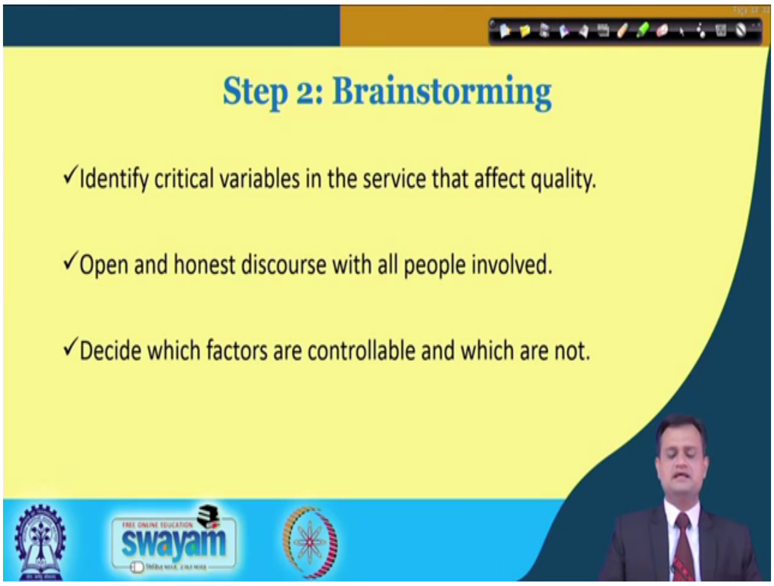

Brainstorming as I mentioned is about identifying the critical variables. Then the service or manufacturing that affect quality and open and honest disclosure with the people brainstorming is basically required.

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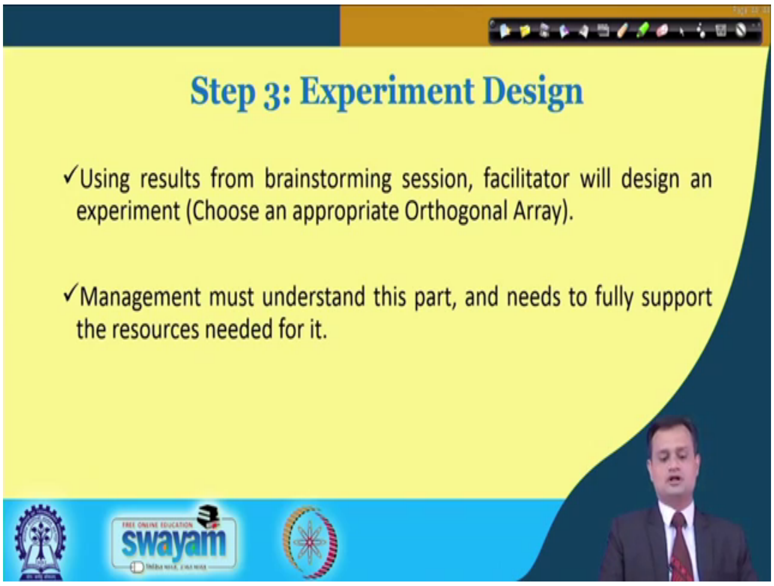


Here experimental design is based on orthogonal array.

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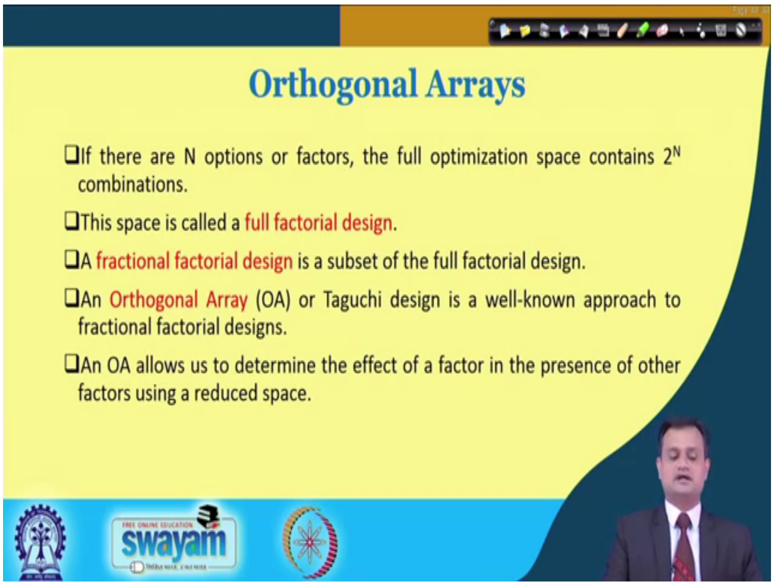


And let us try to get a feel before we use actually the orthogonal array that what is the purpose of orthogonal array and how do we utilize it. So, typically it is a mathematical concept. And let us say if there are N options or factors, the full optimization space is basically to raise 2 N and this space is called full factorial design. So, we have discussed that it is not economical, and convenient to go for full factorial design. So, we go for the fractional factorial design and the use of orthogonal array in Taguchi design is again a well-known approach to fractional factorial design.

So, this falls well within the domain of fractional factorial. In case of fractional factorial, we were trying to investigate the alias structures confounding effects and then by defining the relationship generator, we were trying to reduce the number of runs, number of factors. And here we will try to do the same thing means conducting the experimentation in less run, but Taguchi has proposed the use of orthogonal array. So, typically Orthogonal Array or OA allows us to determine the effect of factor in the presence of other factor using reduce space.

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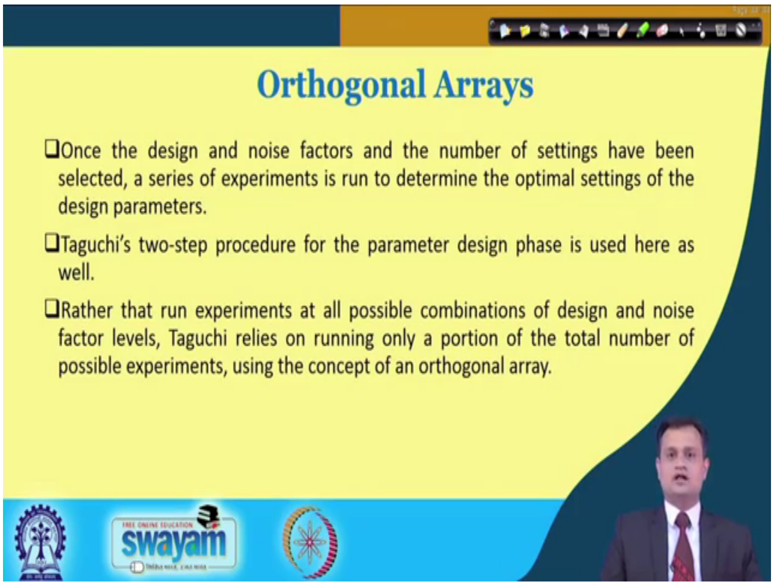


So, my orthogonal array once the design and noise factor, how will I use it, once you have the design and noise factor of finalize, the number of settings have been selected. And a series of experimentation to determine the optimal setting of the data design parameter is conducted. So, now, in what sequence, what way you should conduct the experimentation, this is basically guided by your selection of a particular orthogonal array.

So, Taguchi's two-step procedure for the parameter design is used and you conduct the experimentation. So, rather that run experiments at all possible combinations of design and noise factor level, Taguchi relies on running only a portion like fractional factorial of the total using the concept of orthogonal array. So, in fractional factorial, you had the concept of aliases confounding effect here, you are trying to achieve this by using the readily available orthogonal array design based on the rigorous mathematics.

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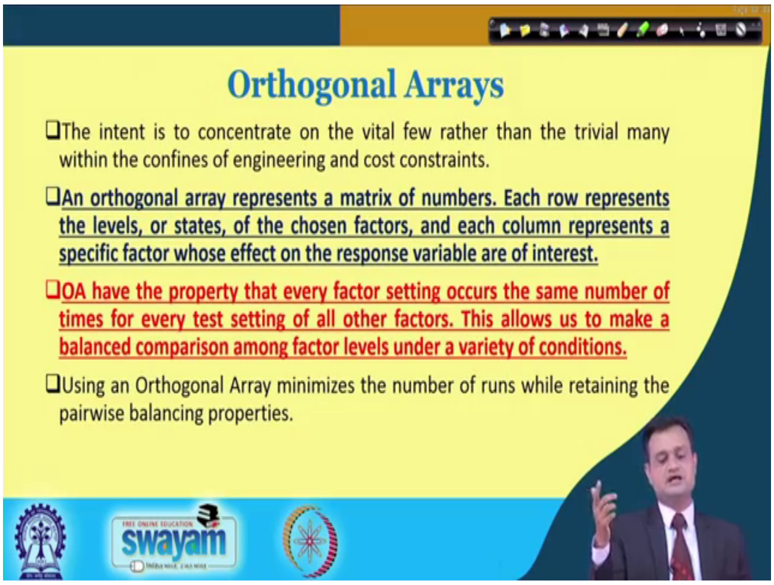


So, orthogonal array typically represents a matrix of numbers what you will find is basically the matrix of numbers. And it basically helps you to focus on vital few rather than focusing on the entire experimental space exactly what we did in the fractional factorial. So, each row represents the levels, or states, of the chosen factor and each column represents a specific factor whose effect on the response variable are of interest. So, this is what we try to do with the help of orthogonal array.

And typically this OA they have the property that every factor setting occurs the same number of time, please remember this is a very important property every factor setting occurred the same number of time for every test setting. And this typically allows us to make a balanced comparison among factor levels under a variety of condition. So, there is no bias and orthogonal array allows us to conduct the experimentation for different setting of the factors same number of time and hence it is a balanced design.

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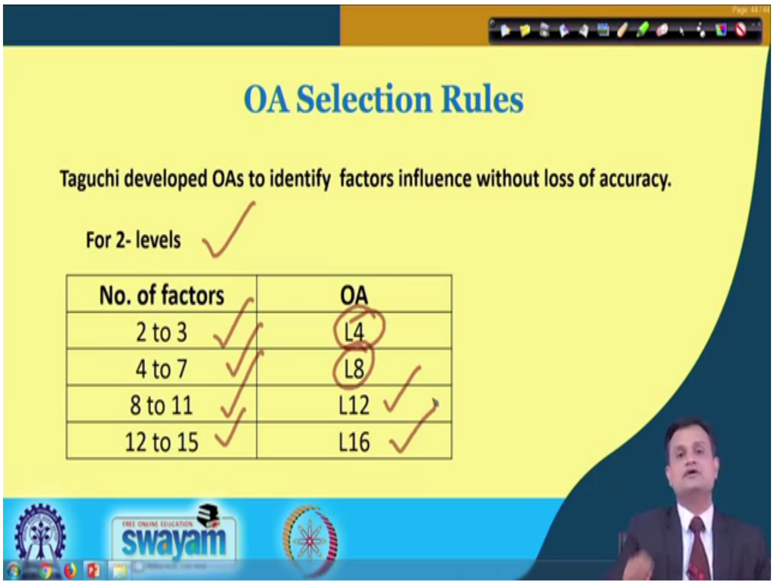


Just see there are some norms for using the orthogonal array. If you will refer the books suggested reference book suggested by this course typically let us say Mitra then you will find all the orthogonal array is available in the appendix of the book. So, now, we accept take the orthogonal array, which is readily available for deciding the experimentation strategy in what way I will conduct the different runs of my experimentation. So, for that, because there are many orthogonal arrays available for 2 levels, for some factors ranging in the 2 to 3, 4 to 7, for 3, 4 level 4 level and so on, so we will follow certain guidelines for selecting the orthogonal array.

So, just see here that if you have 2 levels; if you have 2 levels and number of factors are 2 to 3, you will select L 4 orthogonal array from the appendix of the suggested book. If you have 4 to 7 number of factors, you will select L 8. If you have 8 to 11, factors ranging from 8 to 11, L 12 and if you have 12 to 15, you will select L 16 orthogonal array.

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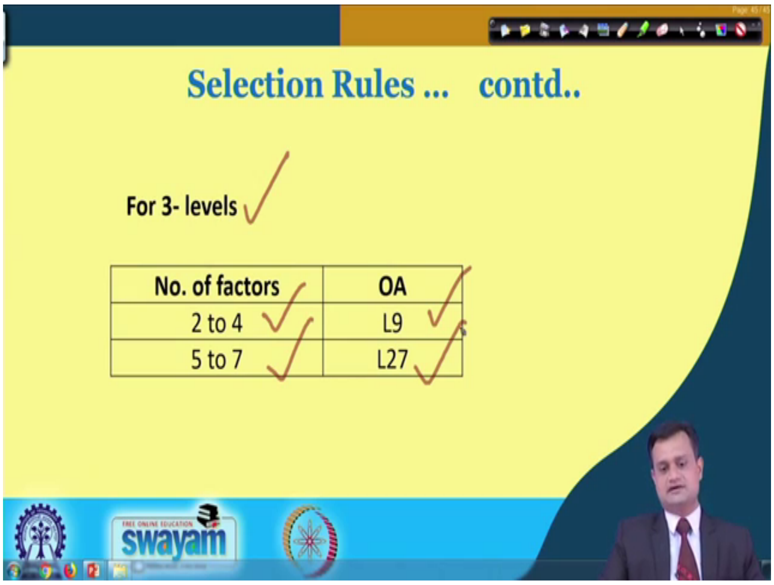


So, what orthogonal array contains I have already mentioned. Now, similar way just see that for 3 levels, if you have the factors in the range of 2 to 4, you will select L 9 orthogonal array for deciding your experimentation strategy. If you have 5 to 7, you will select L 27.

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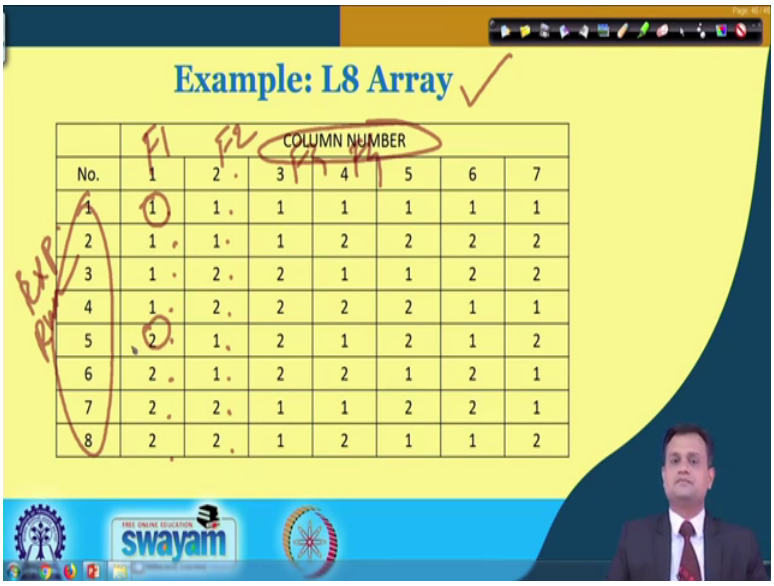


| No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| 3 | 1 | 2 | 2 | 1 | 1 | 2 | 2 |
| 4 | 1 | 2 | 2 | 2 | 2 | 1 | 1 |
| 5 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 6 | 2 | 1 | 2 | 2 | 1 | 2 | 1 |
| 7 | 2 | 2 | 1 | 1 | 2 | 2 | 1 |
| 8 | 2 | 2 | 1 | 2 | 1 | 1 | 2 |

So, this is what exactly we try to do and just see the example that here is the L 8 orthogonal error. Similar kind of tables of orthogonal array for different levels and different number of factors, you will find in your textbook or in your referred book appendix. Just see here that there is a number 1 to 8, there is a column number. So, here as I mentioned, I will define the factors, factor 1, factor 2, factor 3, factor 4 and so on. And this will be my experimental run, so this will be my experimental run.

So, now, what exactly it means let us see you will find here 1 1 1 1 2 2 2 2 then 2 1 1 2 2 11 2 2, so it is basically a metric of numbers as I mentioned. Now, what to do with this? So, 1 indicates the low level, because it is for 2 level 2 indicates the higher level.

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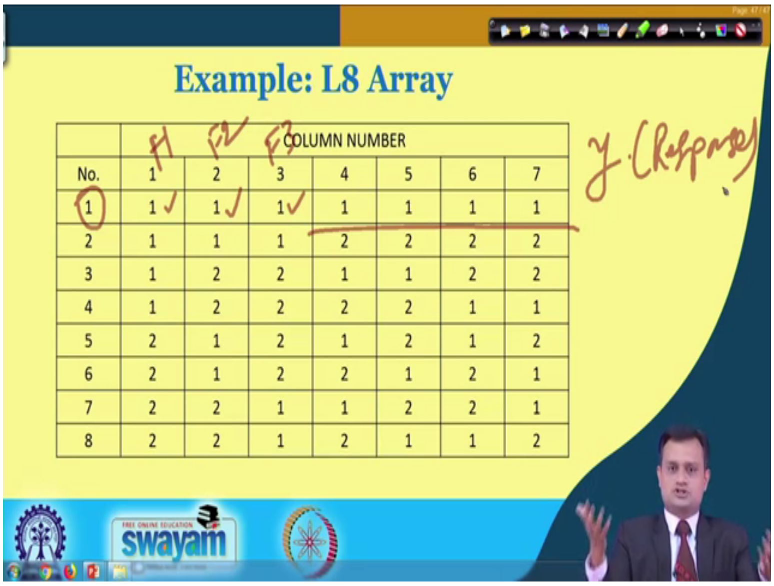


| No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| 3 | 1 | 2 | 2 | 1 | 1 | 2 | 2 |
| 4 | 1 | 2 | 2 | 2 | 2 | 1 | 1 |
| 5 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 6 | 2 | 1 | 2 | 2 | 1 | 2 | 1 |
| 7 | 2 | 2 | 1 | 1 | 2 | 2 | 1 |
| 8 | 2 | 2 | 1 | 2 | 1 | 1 | 2 |

So, this means that when I will conduct the first experimentation, I will set my factor 1 at low level that is the 1, factor 2 again at the low level, factor 3 again at the low level and all are at the low level. So, what I will get here is the y that is my response. It means suppose I am conducting let us say the machining experiment and my response is surface finish. And let us say I have the different factors for example, speed, feed, depth of cut, coolant property, my fixture and many other things, so these are the factors and all the factors they are set at the low level.

And what is the low level for that you need to have, the domain knowledge, process knowledge. And then only you can say that, yes, if I am referring a factor like temperature than 10 degrees the low level, 15 degree is the medium level or 50 degree is the higher level. So, for that you need to have the domain knowledge, but let us assume that we know the process, we have the domain knowledge, then I will set all the factors at the lower level in my first experimental run, and I will get the response y 1.

Similar way, you just see that what you are doing here to you are setting this first 3 factors at low level and remaining factors at the high level. Similar way you see experimental run 3 this is at low level, high level, high level, low, low, high, high. Now, this is something that we have already discussed either you say minus or plus or 1 or 2, it is the same thing.

If you want to indicate the low level you can say 1 or minus; if you want to indicate the high level, you can say to our plus. So, book to book that could be variation, but here, because I am referring the orthogonal array; orthogonal array are always represented in terms of metrics of the numbers 1, 2, or 1, 2, 3, whatever may be the number of level.

So, now, here if you recall I mentioned about difficulty in changing the factor. Now, if you can recall just tell me, if I just have to assign a particular factor, which is more difficult to change then would I like to assign it to this or this or you can select any column. So, my question is if I have to assign a factor, which is difficult to change from low to high and high to low means number of changing number of changeover should be kept minimum. In that case the factor, which is difficult to change would be assigned to which particular column.

So, these columns are just the representation of some number, which we say the level helps us to execute the experimentation, but as an experimental we should not forget that the difficulty in conducting the experimentation can be minimized if you assign a particular factor to the appropriate column.

So, now if you just see then in this particular column, if I look at then first 4 that is known is second. So, only one time I need to change the factor. But if you see this I will have to just. Let me draw it again here, only one time, I need to change the factor here from low level to high level, but if I refer the column 2 then this is 1 then this is where I will change it, once again I will change is to high to low once I will change it to low to high. So, you can see that 1, 2 and 3, so 3 times I need to change the setting.

And if a factor is difficult to change in terms of the setting from low to high or high to low, then I must assign it to the 1st column and likewise I will assign the factors to different columns, so that the factors, which are difficult to change can be assigned to the columns where number of times change your is less. So, please keep this important advice in mind and this is very important when you assign the factors to different columns.

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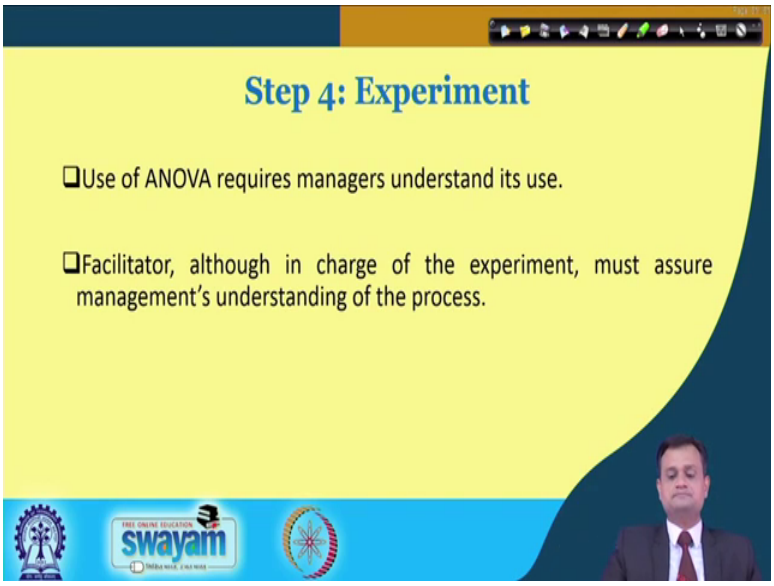


Now, you can use the ANOVA to analyze the results or you can also analyze the averages of the responses that is also possible and you can conduct the experimentation and you can analyze the results.

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So, then sometimes you may like to confirm the experimentation. So, you may set up a new system using the data from the experiment you can test and validate the results. So, many times if the experimentation has a grade consequence implications then you may like to validate it by having the another run another setup and collecting the data analyzing. Now, let us see the illustrative example connector assembly.

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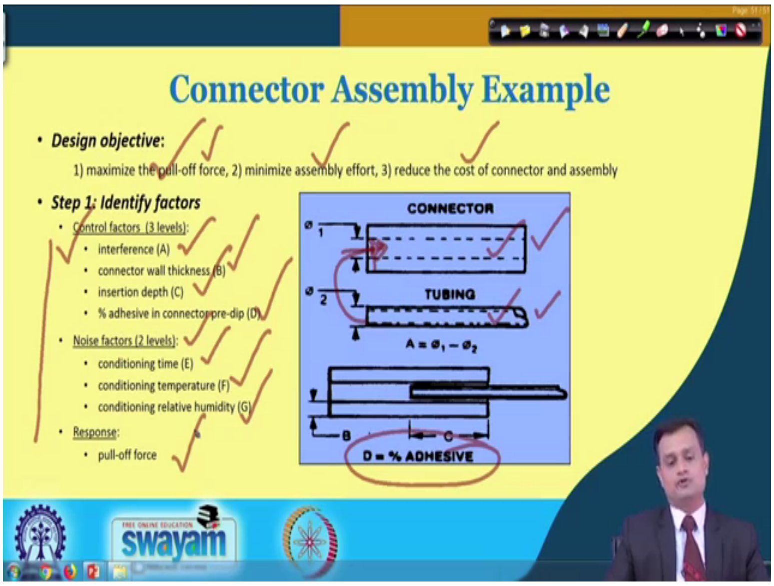


So, the example is like this I have a particular connector and this is typically my tubing. So, you can see here that there is this is the hollow portion and this will go into this. So, this portion will go into this. So, there is a character assembly. So, there are only two components and my objectives are like this maximize the pull-off force minimize the assembly effort, there should not be much difficulty in assembling two parts.

And third is reduce the cost of connector and the tubing or assembly. So, I will also put some adhesive in order to have the proper fixing of my tubing and the connector. So, just see that based on my process knowledge, I have identified control factors noise factors and the response, which needs to be maximized response needs to be maximized in this case.

So, here maximize the pull-off fall so that you can have a very tight fitting. So, control factors are expected to be said at three levels. So, suppose if I say interface then low level, medium level and high level. Similar, way connector wall thickness then insertion depth and percentage adhesive all these are controllable factors. So, I am keeping it as control factors, there are a couple of noise factors like conditioning time, conditioning temperature, conditioning relative humidity, this factors are not very much in your control, but they are known factors. So, noise factors they are set at 2 levels and I have the response that is the pull-off force. Now, let us try to see that what way we can go ahead in our experimentation.

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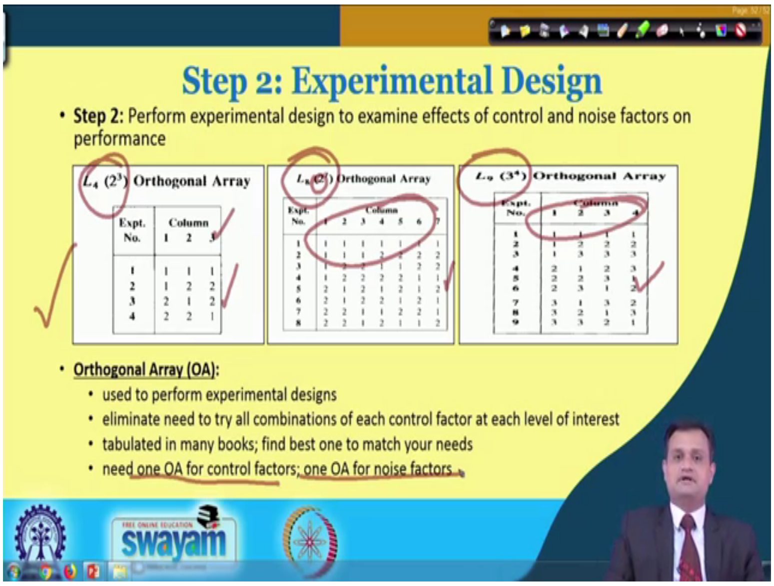


So, just see here you will have couple of relevant orthogonal arrays which can be utilized for this particular problem. So, you have L 4 2 raise to 3 orthogonal array your L 8 2 raised to 7 orthogonal array and your L 9 3 raised to 4 orthogonal array. So, you can see that here you have only 2 levels and the 3 factors, 3 factors here, you have to level this is the 2 level and the 7 factor, here you have 3 label and the 4 factor. So, these are some of the orthogonal arrays that you can refer from the appendix. So, this is typically used to perform, the experimental design. And it eliminates the need to try all the combinations of each control factor at each level of interest.

And this is as I mentioned tabulated in many books, you can refer Mitra or you can search on the internet, you will get the complete say appendix of orthogonal arrays. So, you need one orthogonal array for control factor, one orthogonal array for noise factor. Please remember compared to my traditional fraction factorial design, here I am emphasizing on the inclusion of the noise factor, I am not blocking my design, which we did in the RCBD. So, I am trying to incorporate the influence of the noise factor in my design. And then I am trying to find out the optimal setting of the parameter at which my product can process or product can perform in a robust way. So, I will need one way orthogonal array for control factor, one for noise factor.

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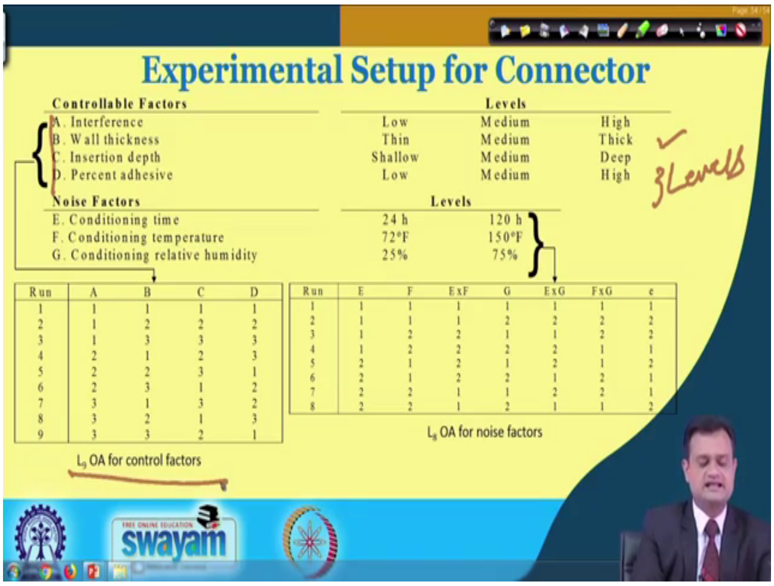


So, with this let us see now this is something that you just tried to appreciate control factors. I have put A, B, C, D; interface, wall thickness, insertion depth, percent adhesive. So, here I have the levels low, medium, high; thin, medium, thick; shallow, medium, deep; low, medium, high basically 3 levels. Now, I have the noise factors E F and G. So, here you have 2 levels conditioning time 24 hour to 120 hour, conditioning temperature 72 degrees Fahrenheit to 150 degree Fahrenheit, 25 percent to 75 percent.

So, fine I have defined the using my process knowledge or using my domain knowledge, I have defined the levels of the factors and also have selected the factors. Now the question comes what is the appropriate orthogonal array for controllable factors as well as the noise factors. So, for controllable factors you just see that there are basically 4 factors and there are 3 levels. So, here I am selecting L 9 way for control factors from where it is if you by chance you have forgotten.

Let us go back and see our guideline. So, the guideline is like this that if you have 3 level so I have 3 level and the factors are in the range of 2 to 4. So, my case is this so I am selecting L 9.

Now, let us see for the noise factors. So, this is what I am selecting for L 9 for my controllable factors. Now, here there is some catch and you will say that there are 3 factors each is set a 2 level. So, basically I have 3 factors 2 level. So, now, just try to see that 3 factor to label what could be the appropriate orthogonal array. So, here is the 2 level and if I the 3 factors obviously L 4, but here my process engineer has a suspicion that there could be a possibility of some interaction effect among, the noise factors. And instead of 3, he is considering couple of interaction effect as well as the error part as a part of the system and he is selecting L 8.

So, if you ignore these then you can go with L 4 also. So, just to avoid the confusion, I have clarified that here if you see now, the selection of my orthogonal array then I am selecting deliberately. This particular orthogonal array which is L 8 if you go by the guideline this is 3 factor 2 level you will obviously, end up with L 4 nothing wrong with L 4 also, but here I feel that there could be some interaction effect possible. And hence I am selecting this particular array this particular orthogonal array, which will have 8 run and here you will see that you have 1, 2, 3, 4, 5, 6, 7, 7 factor some of the factors are indicated as the outcome of interaction.

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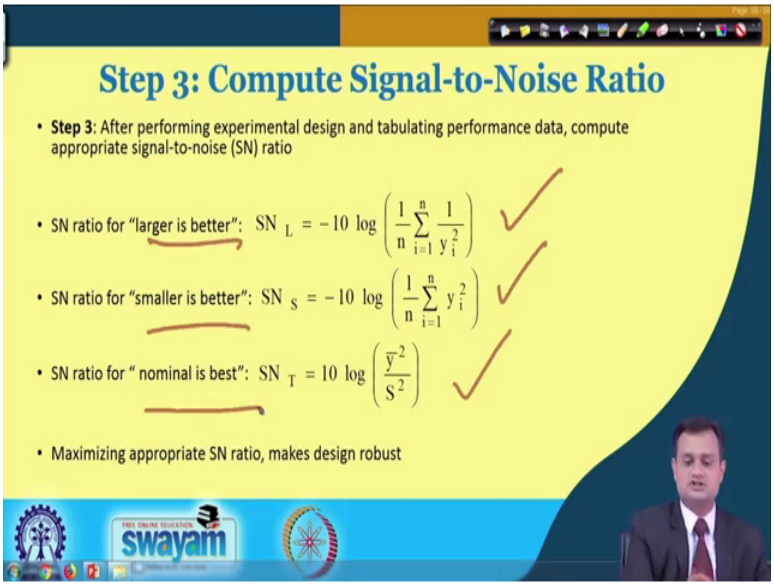


So, now let us try to see we have already defined these ratios that larger is better. So, I have to compute the signal to noise ratio in order to find, the optimal range of my parameter and what is optimal here signal is desirable noise is not. So, the one which maximizes my S by N ratio or SN ratio, I will consider that particular setting as the optimal setting for my parameter. So, these are the expressions, we have already seen for larger is better smaller is better nominal is better and we can easily use it.

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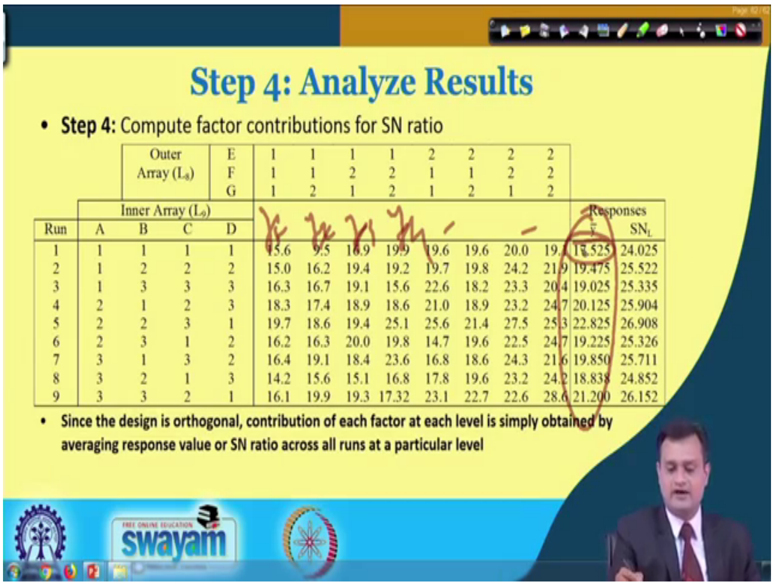


So, now, just see how my arrangement looks like. So, my arrangement looks like this way that here I have runs, I have selected L 9 orthogonal array. And here I have selected L 8 orthogonal array you will see that here for the sake of convenience I will just considered the main effect interaction effect I have some suspicion, but I am just trying to keep it aside and I am selecting the L 8.

Now, this will also help me to how say more number of say experimentation combination see if I would have selected and for that instead of. So, much I would have terminated it at 4, but here because, it is L 8 then 1, 2, 3, 4, 5, 6, 7 and 8. So, I have the more number of combinations of noise factor and the control factors available to be more accurate ensure about my response.

So, here your response is basically the pull-off force I should not have the assembly, which can be easily get opened up and I have the full of force as my response variable which needs to be maximized. Now, just see how this particular experiment works. So, now, I have A, B, C, D and E, F, G suppose I am getting here it is post 15.6 what does it mean 15.6 is basically a pull-off force, for a particular setting I need to have, I need to exert in order to open the assembly.

Now, what is this experiment. So, in this experiment I have kept A factor A at low level, B at low levels, C at low level, D at low level and simultaneously I have kept in the outer array this is typically called outer array, where the noise factors are indicated control factors are indicated in the inner array that is the beauty of Taguchi's design. So, here I have kept in a new array controllable factors A, B, C, D at all at low level and my E, F and G, which are the noise factors in the outer array also had low level. So, when everything is said at low level the response I am getting is 15.6.

Now, just think about the another. So, let us say 9.5 again I am conducting the experimentation see this selection of orthogonal array is just all about selecting the strategy to conduct the experimentation, these values you do not get just like that you have to conduct the experimentation and then only you will have the value of response variable. So, now, just see that one second I am going by run 1 here all the factors, which are controllable set at low level 1, but here noise factor E is at low level, F is at low level, G is at high level, when I look at this particular combination.

And run the experimentation then my pull-off force is 9.5 just take another example randomly 24.3, what do you see here this pertains to this my A is set at the 3 level high level, low level, 3 is high level, medium level and my noise factors high level, high level, low level and the response I get is 24.3. So, I hope the idea is absolutely clear that orthogonal array is just an error or metrics of numbers, which helps us to conduct or execute our experiment in a particular way it gives us the strategy to conduct the experimentation. And guide us for executing the experiment and taking the value of getting the value of response variable.

So, now what I am doing here I am just computing the average of all this. So, 15.6 plus 9.5 plus 16.9 all the values divided by say total number that is 8 here. So, you will get 17.525. So, I calculated the averages of all these y 1, y 2, y 3 this is the y 1, y 2, y 3, y 4 and so on to get this.

Now, once you have this you can refer the equation of signal to noise ratio and you just see here you have the signal to noise ratio and you can compute the SN ratio for each particular set trial. So, here I want to maximize my pull-off force so obviously, I would be using the express or larger is better and you just see the computation is very simple this is nothing, we are to do minus 10 log 1 by n you know that y i square. So, you have total 8 settings y i. So, y i values you will take and then you square, it reciprocal summation and then you will have the value of SN. So, this is the value SN.

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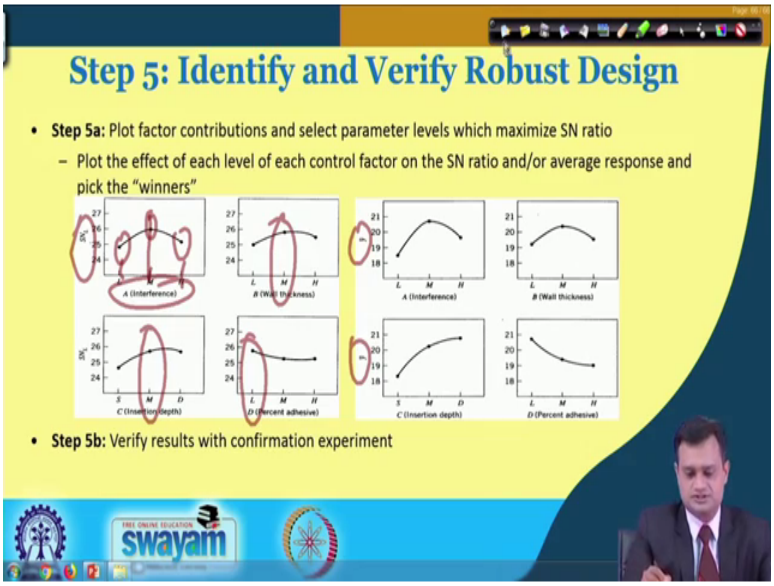


Now, once you have completed this the task is very simple, you plot the factor contributions and select parameter level which maximizes S by N ration. I want to maximize my pull-off force so obviously, I how to maximize my I have to find out the factors setting which can maximize, my response that is pull up force. So, what you can see here that this is my SN and this is the factor A interface and when I put this at low level, medium level, high level what I get that at medium level of setting of factor a controllable factor my S N ratio is maximized.

Similarly, you see here thickness medium level, insertion depth medium level maximum has by and maximum response, here it is at the low level. And you can also see, this is basically with respect to y bar, so average response, so, more or less it is same.

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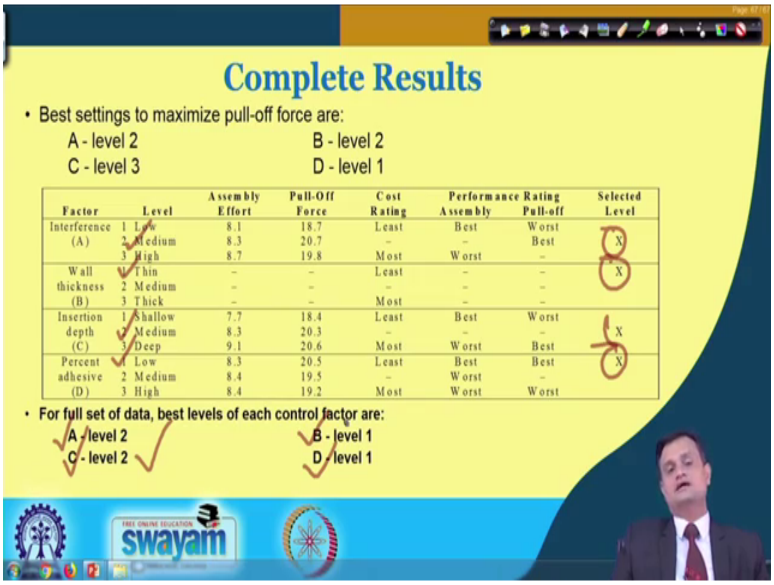


So, now I am just putting it here and I am just crossing that what is the best here. So, medium level is the best here, for my first controllable factory interface that we have seen. In the figure also for this it is the lower level, for this it is the medium level, for this it is the lower level. And I will say that I will have the robust design, which will maximize my response under the influence of the noise factors; I am not neglecting the noise factors, when my factor A is set at level 2, my factor B is set at level 1, my factor C is set at level 2 and my factor D set at level 1.

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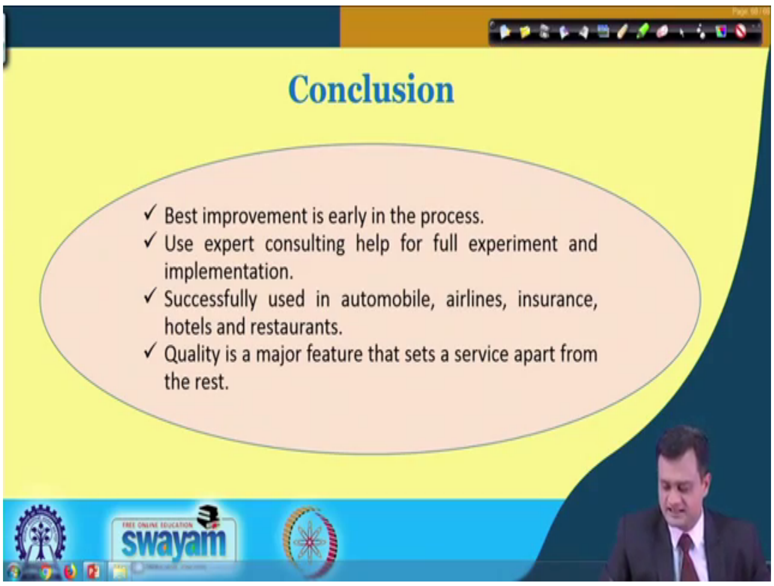

So, this is the outcome of my Taguchi's design and this can really help me to draw important conclusion that best improvement is possible in the early stage of the process or product design. And use export consulting help for full experiment and implementation and successfully, this is used in automobile, airline, insurance, even service sector, hotels, restaurant.

So, just think about couple of examples where you feel that such a good technique, which simultaneously considers the impact of controllable and the noise factors in maximizing the response is towards the robust design can be considered. So, just think about couple of examples in manufacturing and service sector where this particular approach can be effectively utilized.

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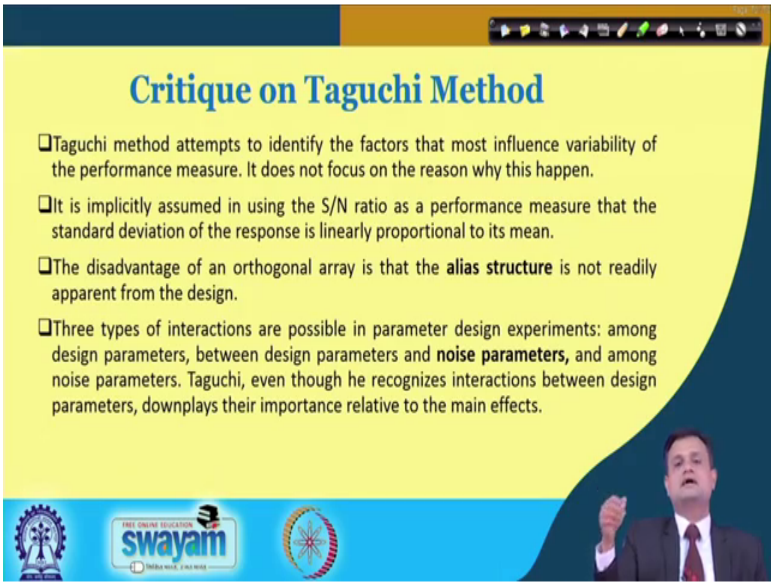


Now, there are some critique on the Taguchi method. So, experts they say that Taguchi method attempts to identify the factors that most influence variability of the performers measure. And it does not focus on the reason why this is happening. So, fine and this particular component is little bit lagging that we are not going into the detail that why this variability is there.

It is implicitly assume that SN ratio or S by N ratio as a performance measure that the standard deviation of the response is linear to proportional to its mean, but many times this proportionality, linear proportionality may not be valid. So, this assumption sometimes may have some little negative effect on my analysis.

Advantage of an orthogonal array is that the alias structure is not readily apparent from the design, I cannot figure out. So, in fraction factorial we have identified the alias structure confounding effects, here it is not possible. So, apparently I cannot do and I might be conducting the experimentation, where some redundancy may prevent. Three types of interactions are possible among the design parameters between design and noise and among the noise. So, Taguchi even though he recognizes the interaction between design parameter, downplays their importance relative to the main effect.

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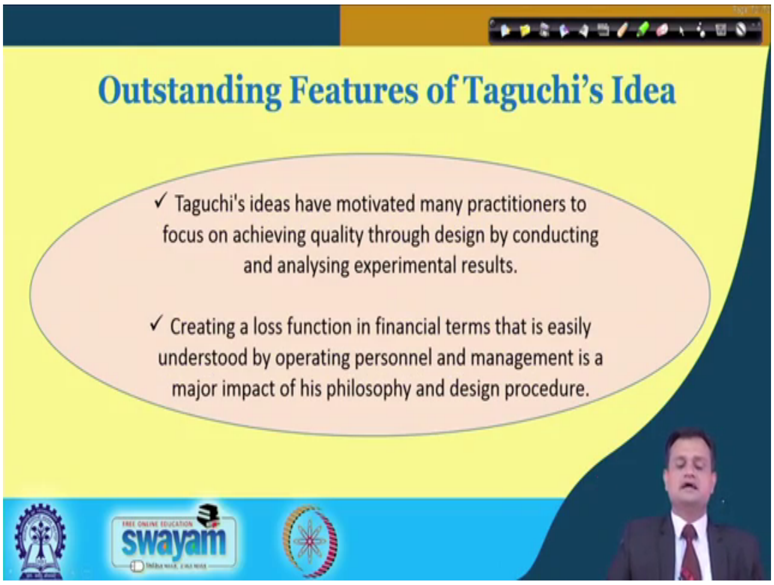


So, this is something that we accept as a critic drawback of Taguchi method, but despite of this Taguchi method has given the excellent results. And the outstanding feature says that this idea robust designed to good idea S by N ratio have motivated many many practitioners, it is a simple to use approach. And they can focus on achieving quality through design by conducting and analyzing the experimental results.

Creating the loss function in financial term easily understood by operating personnel, management. And then it has a major impact, this is the major impact of his philosophy and design procedure that you can do the financial evaluation of these also.

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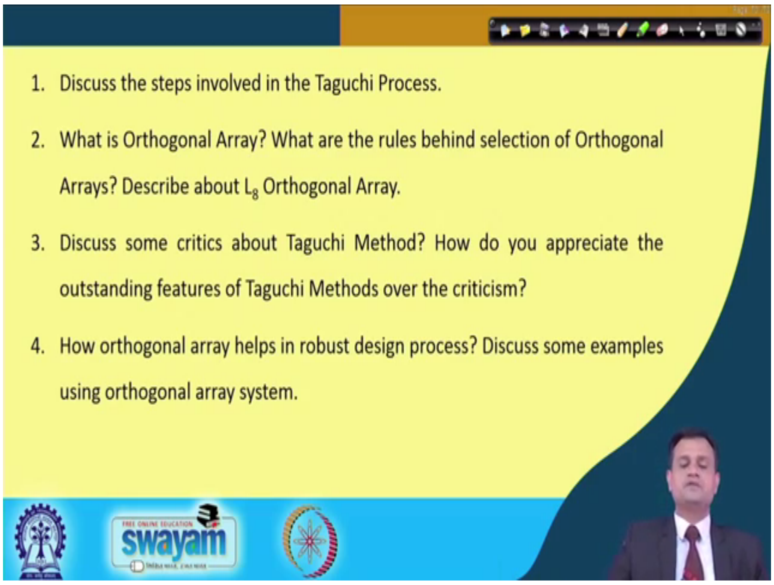


So, just think it before we end. Discuss the steps involved in the Taguchi process, what is orthogonal array? And what are the rules behind the selection of orthogonal array? Describe something about L 8 orthogonal array? Discuss some critiques of the Taguchi method? How do we appreciate the outstanding features over the criticism? And how orthogonal a helps in having the robust design process? Discuss some examples using the orthogonal array system?

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So, you can use this references for better understanding.

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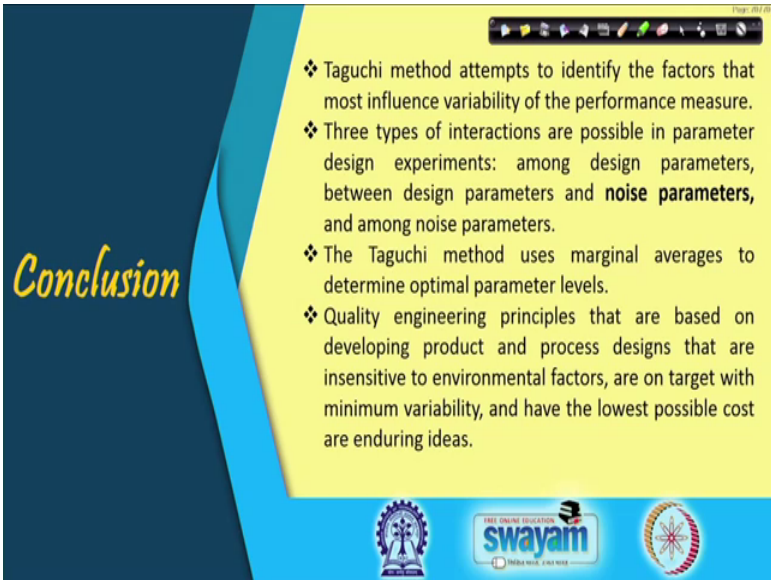


And Taguchi method as I said is basically the method, which tries to minimize the deviation from the target, loss to the society and creating the better and robust design through parametric design for the service and manufacturing industry. So, thank you very much for your interest in learning this particular say topic illustrative example on Taguchi method. Please keep revising, you will internalize the concept if you listen the video 2 times, 3 times or refer the suggested textbook and your idea will be better clear.

So, thank you very much once again and be with me in our six sigma journey, enjoy.