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

Lecture - 38
Introduction to Design of Experiment

Hello friends, I welcome you to our ongoing Six Sigma journey. And we are step by step advancing in our DMAIC cycle Define Measure Analyse Improve and then Control. So, this lecture is 38 number lecture and I would like to introduce the topic of design of experiment. And help you to appreciate the various issues involved in conducting an effective an efficient experimentation.

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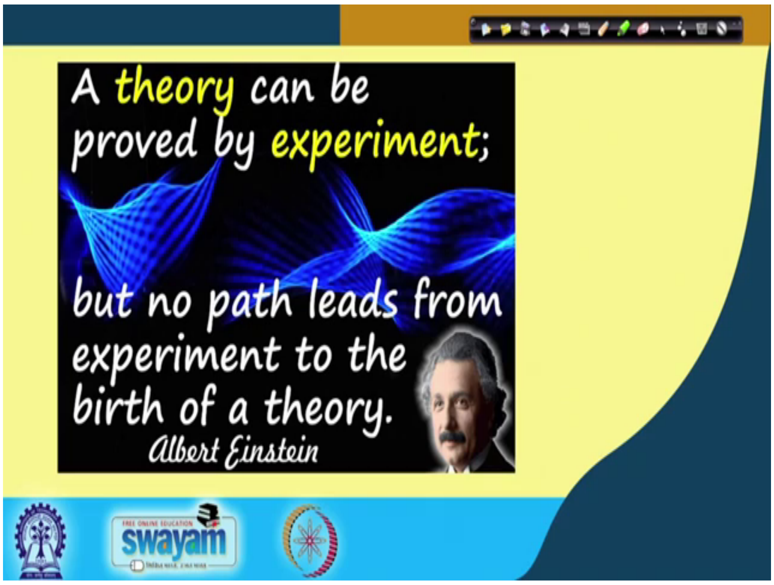

So, let us appreciate a beautiful quote given by Albert Einstein, a theory can be proved by experiment, but no path leads from experiment to the birth of a theory. So, this is where the importance of experimentation lies, you can propose a theory, but you need to prove it by experimentation and then this theory can be well accepted. So, we have to appreciate the importance of experimentation in our day to day professional life whether in the manufacturing sector or service sector.

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Now, before I proceed we are at a particular juncture. And now it is a time to revisit that where we are in our six sigma journey.

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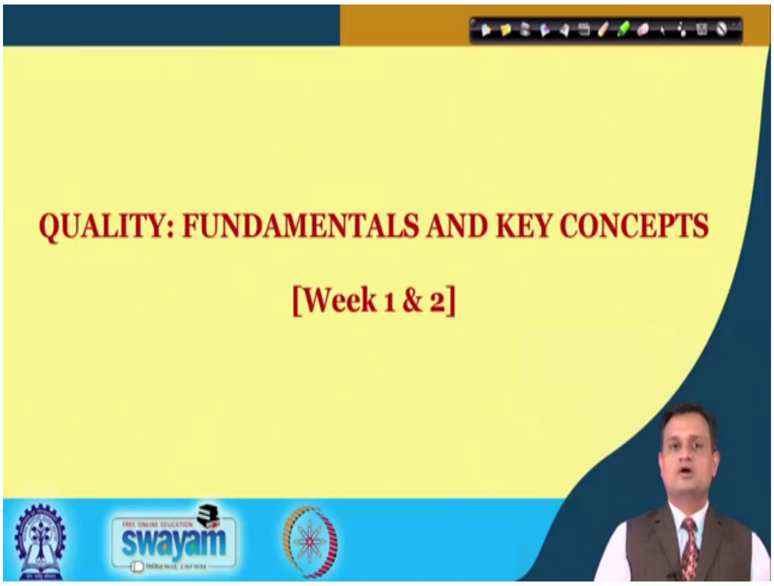

So, let us have a quick recap quality fundamentals and key concepts we have discussed in week 1 1 week 2.

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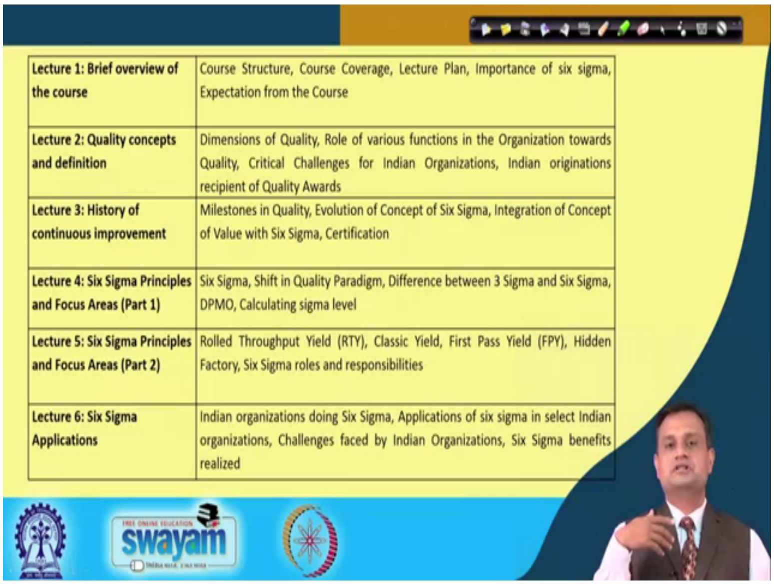

And typically in week 1 we have talked about the various quality aspects definitions, history of continuous improvements, six sigma principles and focus areas DPMO DMO, then first pass yield and then some of the Indian organisations implementing six sigma.

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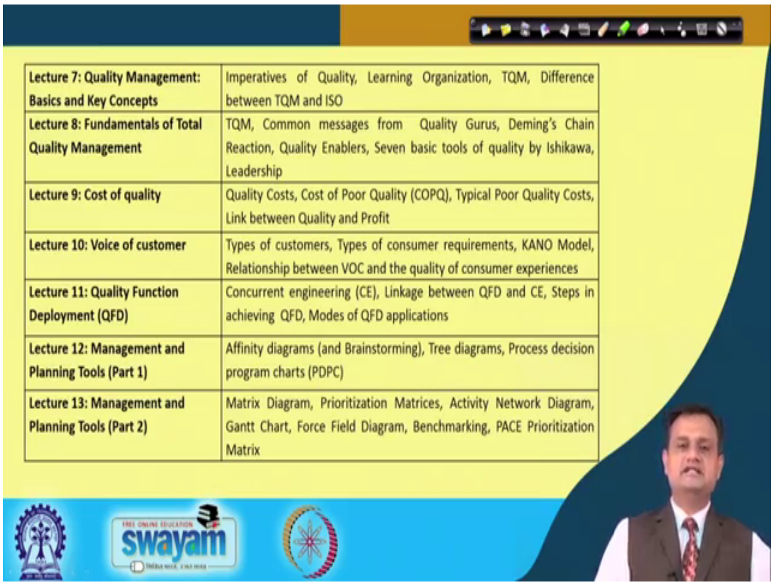

Then in week 2 we had a detailed discussion on quality management basics, then fundamentals of TQM, cost of quality QFD management and planning tools part 1 part 2. And then we moved to the first phase of our DMAIC cycle and that we talked about in week 3.

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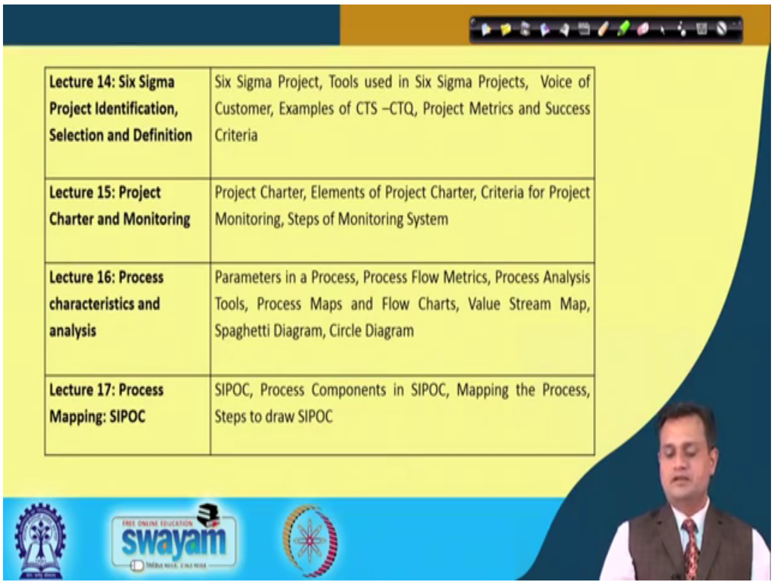

So, as a part of define phase we talked about six sigma project identification selection and definition project charter and monitoring, process characteristics and analysis and a very important tool SIPOC. So, this was basically the part of define phase, then we moved to the second phase that is the measure phase. And we covered the measure phase in week 4 and week 5. So, you had week 4 various learning points.

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So, data collection in summarization part 1 part 2. Measurement system analysis fundamentals, measurement system analysis a very important topic gauge R and R study fundamentals of statistics, probability theory. Then subsequently in week 5 you had seen process capability analysis. Process capability analysis measures and indices process capability analysis Minitab application.

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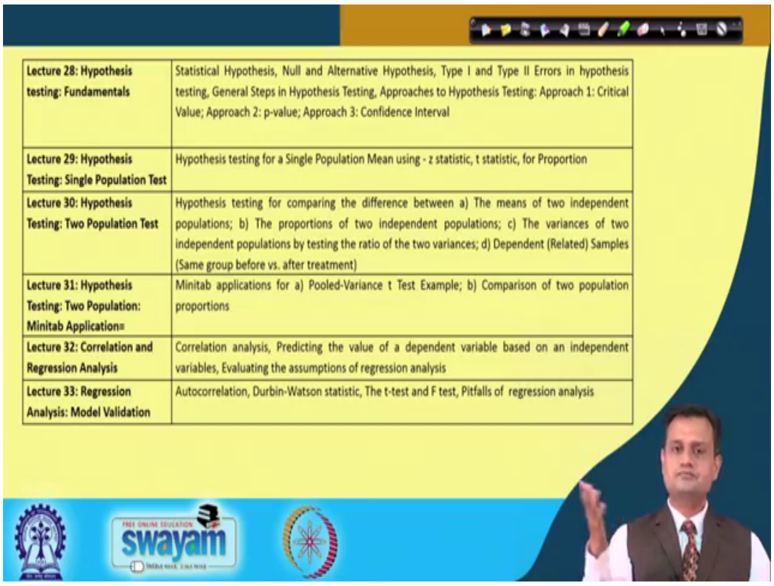

And then we had seen the non normal process capability analysis. Then we moved to the analyse phase and week 6 and 7 we devoted on the analyse phase; so in week 6 we talked about hypothesis testing for single population, for 2 population. Then we had seen the hypothesis testing Minitab application, correlation regression analysis and regression analysis model validation.

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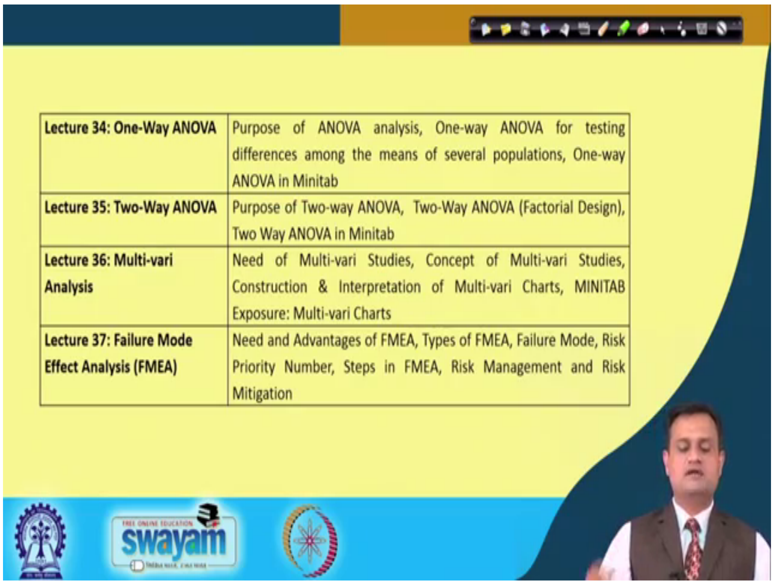

Lecture 34: One-Way ANOVA	Purpose of ANOVA analysis, One-way ANOVA for testing differences among the means of several populations, One-way ANOVA in Minitab
Lecture 35: Two-Way ANOVA	Purpose of Two-way ANOVA, Two-Way ANOVA (Factorial Design), Two Way ANOVA in Minitab
Lecture 36: Multi-vari Analysis	Need of Multi-vari Studies, Concept of Multi-vari Studies, Construction & Interpretation of Multi-vari Charts, MINITAB Exposure: Multi-vari Charts
Lecture 37: Failure Mode Effect Analysis (FMEA)	Need and Advantages of FMEA, Types of FMEA, Failure Mode, Risk Priority Number, Steps in FMEA, Risk Management and Risk Mitigation

Week 7 we talked about 1 way ANOVA 2 way ANOVA multi vari analysis. Failure mode effect analysis that was the last topic we had discussed. And we had seen the importance of such a simple but logical tool. In identifying the potential failure modes right at the design concept stage of the process or products manufacturing or service and how it can help the practitioners, managers to take some of the corrective measures at a very early stage in the design stage of the product or process.

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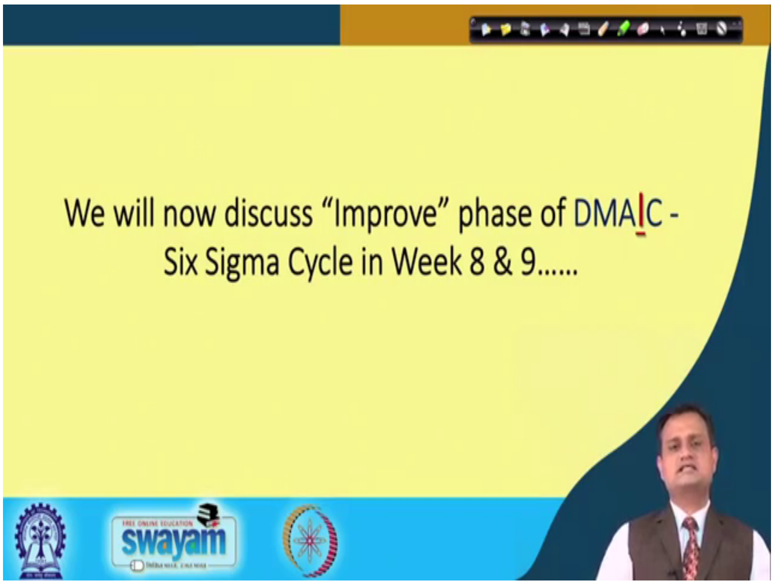

Now, with this, this is the departure now or continuation in our DMAIC. And now we will discuss the improve phase of our DMAIC six sigma cycle week 8 and week 9.

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So, typically week 8 we will begin with this lecture, that is introduction to design of experiment, randomised block design, randomised block design Minitab application, factorial design factorial design Minitab application. Then week 9 we will devote our time and discussion on fractional factorial design fractional factorial Minitab application Taguchi method key concept and some illustrative application of Taguchi method.

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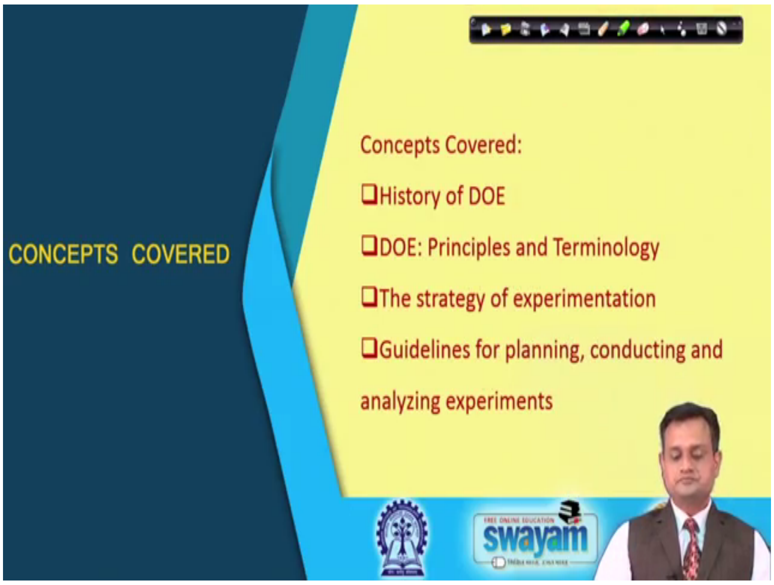

So, with this let us try to see that what we would like to appreciate as a part of this lecture. That is introduction of design of experiment we will see some history of DOE how the concept has evolved over a period of time. DOE principles and terminology the strategy of experimentation, what are the key points, that has an experiment experimenter you should consider; and guidelines for planning conducting and analysing the experiments.

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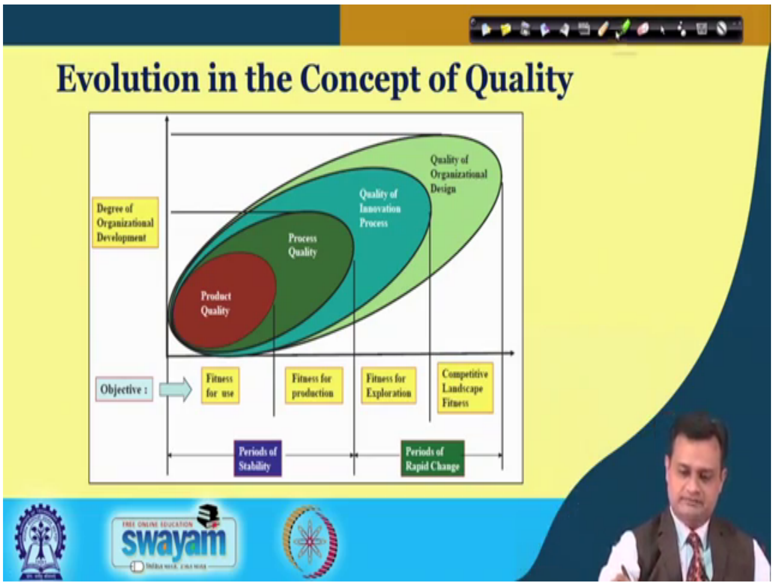

So, just see this and what do you appreciate can you tell me? So, this is the evaluation in the concept of quality. And the fine we say that product quality is the first fitness for use, process quality is the fitness for production, quality of innovation that is the process quality of organisational design. So, this was the period of stability and this was the period of rapid change.

So, degree of organisational development and with respect to that my objectives are changing. Now, whatever phase you take, when a particular phase whether it is product quality, process quality, quality of innovation or may be organisational design you need to address couple of issues right at the design stage; and when you do so you actually take the help of design of experiment.

So, design of experiment is a statistical technique which helps us to address couple of issues right at the design stage. And that is why this discussion the design of experiment and related topics we have considered as a part of or usually considered, as a part of say improve phase of the six sigma cycle. So, improve right at the design stage do it right first time. So, this is what we have appreciated.

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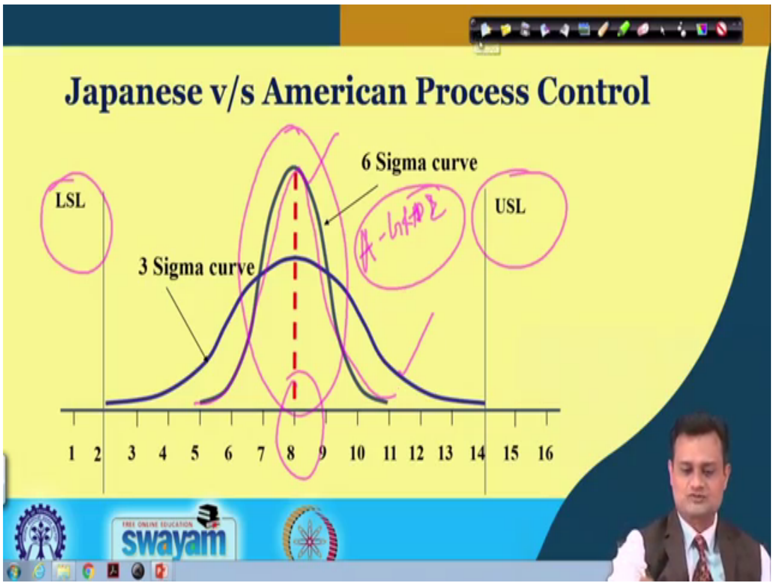

Once again I would like to remind you, you should not go away from this particular diagram because this is the crux of this course. Six sigma means, less variability. Free sigma means, higher variability six sigma means producing more a grade products. And I am very close to my target and my variability is very very less. Even if you compare it with respect to LSL and USL, your this six sigma process is well within say your LSL and USL.

Even if there is a shift in my mean may be because of wear and tear setting in the machine or operator skill or whatever. Then also I am in a comparable zone. And my level of rejection would be very very less. So, this is what we try to achieve through DMAIC cycle. And design of experiment really helps us to realise our ultimate objective of reducing variability right at the design stage.

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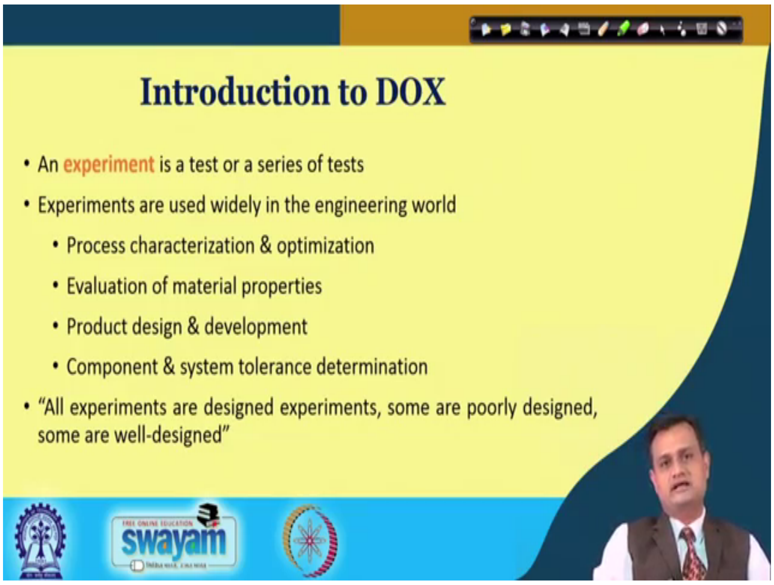

Now, let us see what is the DOX or design of experiment. So, typically it is an experiment is a test or series of test you try to conduct. You go to doctor and doctor would ask you to go for couple of test, when you explain your problem and then you will have the diagnostic report you will go back to your doctor. And then doctor will give you some recommendation some prescription to improve the status of your health.

So, basically experimentation is part of your improvement strategy. And when you know exactly what is happening, you can recommend better strategies better solutions for improving the state of situation. So, experiments are used widely in engineering world. Process characterisation and optimisation whether my processes are operating at the optimal level or not I can figure it out by using the design of experiment strategy.

Evaluation of materials and it is properties very important when you look at the material and strength, another tensile strength, compressive strength and another properties. Then basically it is an outcome of say composition of a particular say material and it is important to evaluate the material properties. Product design and development right at the concept stage. Component and system tolerance determination this is also part of my design of experiment.

So, there is a very good saying that, all experiments are designed experiments some are poorly designed and some are well designed. So, you may have your intuitive way to conduct the experiment you may have your own approach for conducting the experiment we all in our day to day life conduct the experimentation. But whether it is right strategy or wrong we many a times do not know unless we face the consequences.

So, here design of experiment is a well developed statistically driven field which helps us to conduct the experimentation in a systematic step by step procedure so, that we can rely on our output as well as we can take the couple of recommendations and the actions with better confidence.

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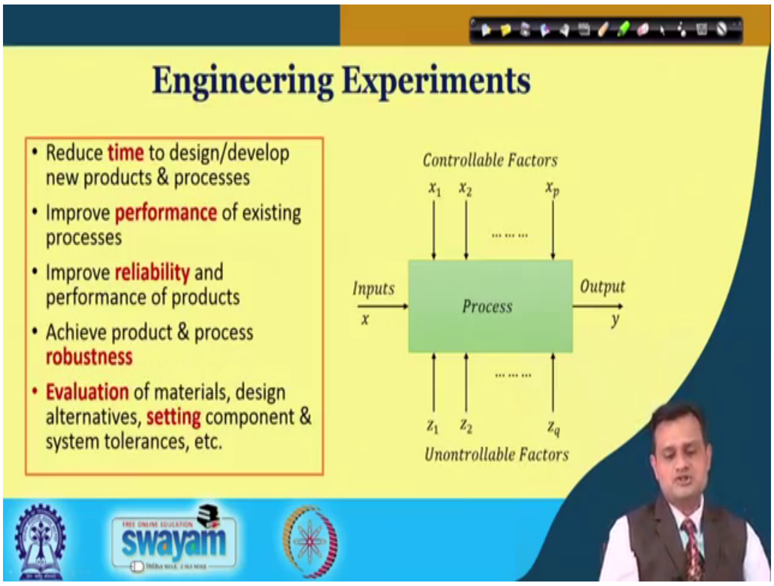

So, typically you have an engineering experiments to design and it helps to reduce my time to design develop new products or processes because, I have addressed many of the concerns and issues through experimentation. So, I can now go ahead with the full flat production or the process and this is where it helps.

Improve the performance of the existing processes. Fine you have a process, but there are couple of problems you can conduct the experimentation in order to see that whether your process is operating at the optimal parameter setting or not. Improve reliability and performance of the products achieve product and process robustness I must have the product, which is extremely less say sensitive to the various nuisance factors maybe the external factors like humidity may be the usage condition and many other things. So, I need to have the robust product; evaluation of material design alternative. So, typically I have something like this you have a process you have the input, you have the output you will say controllable factors and you will have uncontrollable factors.

Let us try to take a live example, spontaneous example of my delivering this particular lecture. Now what are the inputs I am using the text, I am using the various sources. For example, this particular topic design of experiment and another topic I will be extensively using the book design of experiment by Douglas Montgomery. And couple of examples are picked up from this particular book. So, these are my inputs.

Now I have structured the input, decided my strategy to deliver it is a process part and I am delivering. What is the output? Output would be a video lecture a learning material that will help my student's practitioners to digest the concept. Now, what are controllable factors? So, in this particular process controllable factors would be my selection of the textbook; that is in my hand. Then preparation of the slides; then examples to be given at for a particular slide all these are controllable factors.

Even the selection of my dress it is controllable. But when I say uncontrollable factors, so let us say there is an electricity problem or there is a problem with the recording system which is unforeseen and there could be or may be let us say my health is not good. So, uncontrollable factors and your process is to be made immune to this kind of uncontrollable factors and controllable factors you try to decide the best optimal level.

So, that you get the best output optimal output in terms of quantity and quality as an outcome of your process. So, this is the exactly what we try to address as the part of design of experiment.

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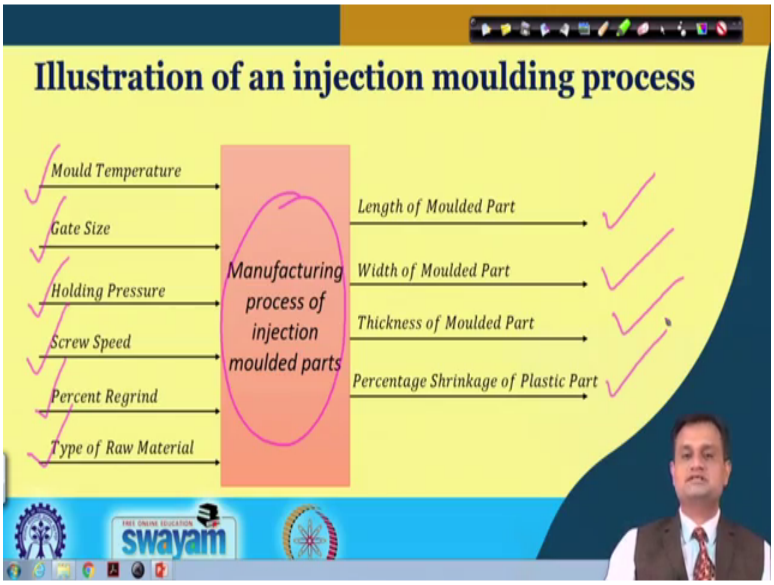

Now, I am just giving you another example that those who are in the manufacturing domain. So, manufacturing process of injection moulded parts, you have mould temperature gate size holding pressure screw speed percent regrind type of raw material as the inputs. And as an output you will have length of the mould part, width of the moulded part thickness of the moulded part and percentage shrinkage of the plastic part.

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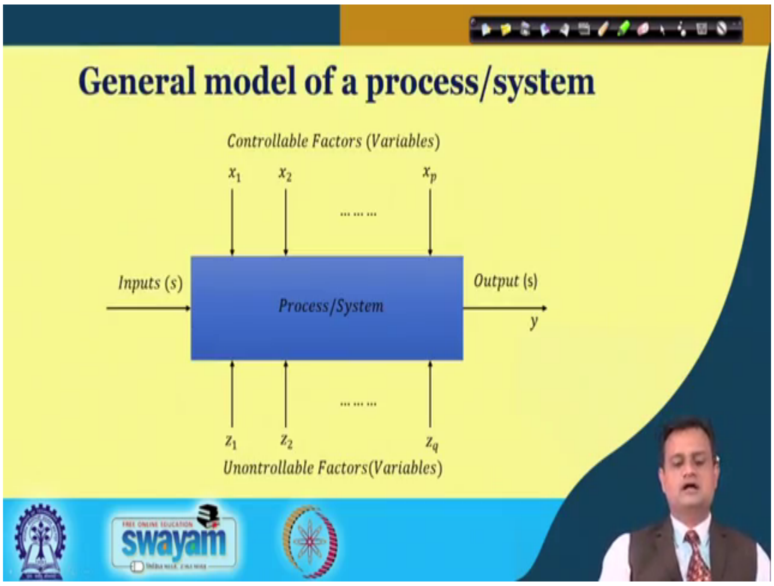

So, you need to have little bit knowledge of this manufacturing process. If you have then you can at least appreciate the input and output of this particular process which is injection moulding. So, we have the input and output and we have controllable and uncontrollable factors. And I would like to minimise the impact of uncontrollable factors. And I would like to set my controllable factors at the optimal level; so, that my inputs can be best converted into the desired outputs.

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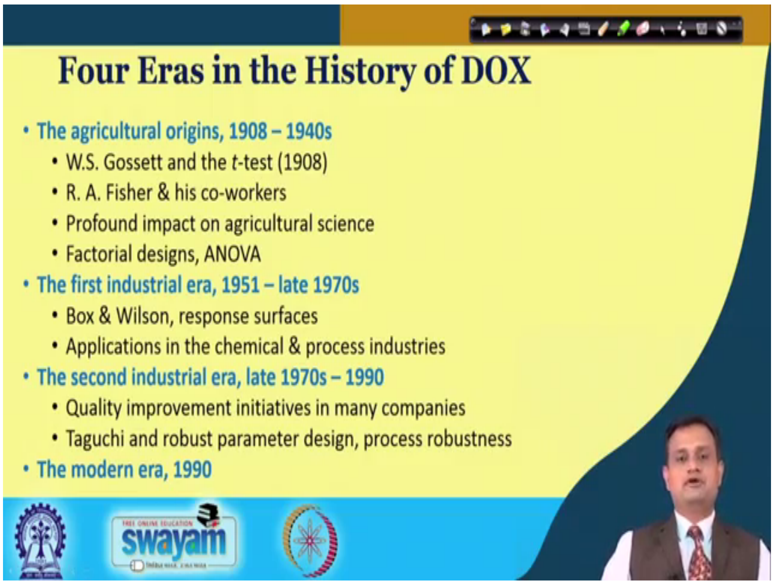

So, just see the history of DOX it is interesting; so it is not that something we are discussing just in last 5 years you can just see that 1908 may be 100 years back, people have started working on this. And 1908 to 1940s even you see the Gossett and t test 1908. So, that was the initial step in conducting the hypothesis testing and analysing your experimentation statistically.

Then fisher and co worker they have contributed a lot; then profound impact on agricultural science. So, this was the area where they were very much interested to see the impact of humidity temperature fertiliser and the soil, these are the various input factors. And what is it is impact, on the agricultural produce quality production and this is where this experimentation strategy has gain lot of importance. Then there was factorial design ANOVA we have seen.

Then industrial era started 1951 to late 1970s Box and Wilson response surface. So, I want to see the response surface of my dependent variable my response variable. And I want to figure out that what could be the optimal level for operating my process. So, this is where some research was done then applications in chemical and process industries that was basically executed.

Then the second industrial era say late 1970s to 1990. Quality improvement initiatives in many company; they adopted the use of DOE and Taguchi and robust design parameter design concept that has evolved as an extension or as an integral part of DOE. And finally, there is an modern era 1990 where we are trying to integrate and club various techniques for improving my products and process is right at the design stage at a very early stage.

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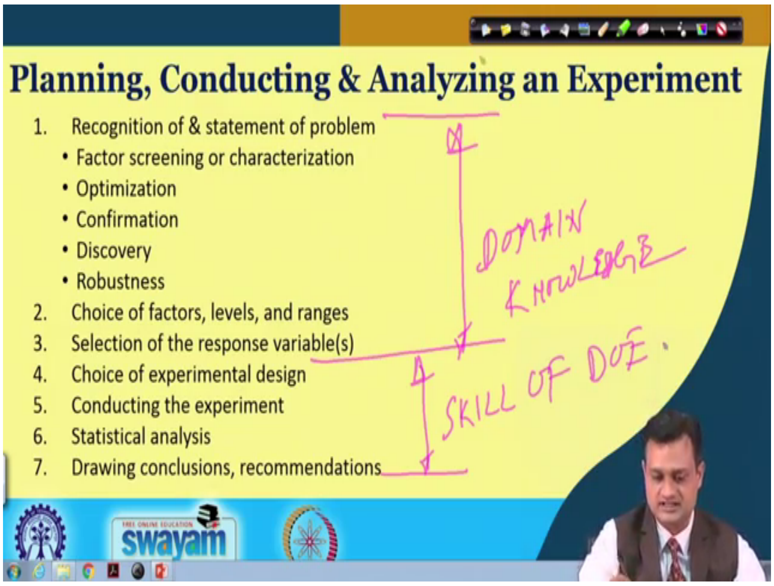

So, let us see how will you conduct the experimentation. What is the planning conducting and analysing an experiment what is the strategy? So, let us go step by step point number 1; recognition and statement of problem very very important. So, what are the factors screening are characterisation needs to be done for a particular process you cannot consider all the factors optimisation confirmation discovery and robustness.

These are the preliminary issues that we try to address at the recognition of and statement of the problem. Means exactly what I want to achieve what I my objective what are the factors that are impacting my system, and what are the new things that I want to discover. Then point number 2 choice of factors; levels and ranges.

Suppose you say temperature is a contributing factor or humidity is a contributing factor or pressure is a contributing factor. Then what could be the ranges of this temperature pressure and humidity and this range is needs to be decided based on your process knowledge domain knowledge. And then you would like to conduct the experimentation for this.

Then selection of response variable; whether I am interested to analyse the yield of the agricultural produce, productivity, surface finish or length of my moulded part. What could be the characteristic, that I would like to analyse as a response variable. Choice of experimental design then 5th is conducting the experiment. So, choice of experimental design; depending upon the situation you have various variety.

Like, randomised complete design randomised incomplete design, randomised complete block design RCBD. You have factorial design you have fractional factorial design you have say Taguchi design so mixture design there are various varieties. So, depending upon the situation you choose the particular strategy for conducting the experimentation. So, that is the choice of experimental design then you actually conduct the experiment.

And then you do the statistical analysis to figure out that what are the factors that are really statistically important or not. So, again ANOVA we will use extensively. And you have studied the 2 way ANOVA analyses. So, there would not be much difficulty in conducting this step number 6. Step number 7 drawing conclusions and recommendations and proposing an action plan to the top management.

Now, please see here that when I am trying to follow this 7 steps, up to step 3 you need domain knowledge. So, this demands basically the domain knowledge or knowledge of the process or particular problem you are trying to address. And this is where your skill of DOE design of experiment will come in picture. So, I must say that knowing only DOE will not show the purpose you must know the context you must have a knowledge about the factors affecting, what is the response variable what could be the possible levels.

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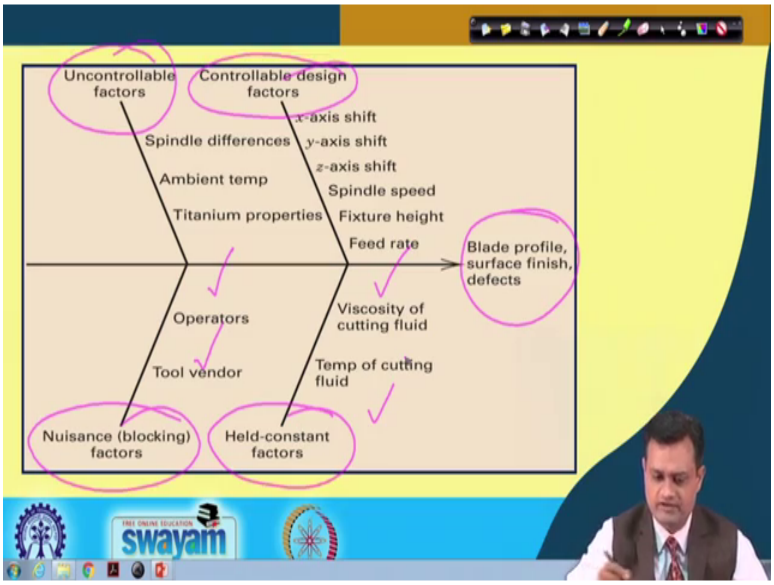

And once you have this knowledge then only you can apply their skill of conducting experimentation using DOE. And then you can really conduct a meaningful experiment which can yield some important results. So, just see this example of cause and effect; that I want to have a good say blade I want to have a good blade finish.

And let us say I want to see the effect blade profile surface finish defects I am setting here the controllable design factors x axis shift y axis z axis shift spindle speed fixture height feed rate. You have uncontrollable factors spindle differences ambient temperature titanium properties you have some nuisance factor which is to be blocked. So, we will see what is blocking. So operator tool vendor, and then you have some held constant factor may be viscosity of cutting fluid temperature of the cutting fluid.

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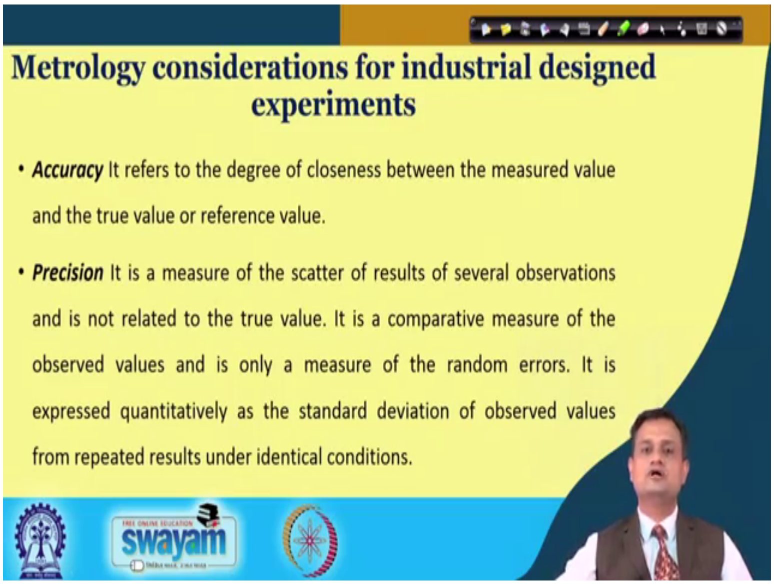

So, when you think about an experimentation you cannot just accept all the factors equal you must segregate them into different categories controllable uncontrollable maybe noise factors or the factors to be held constant. So, we will use this concept as per our requirement; and not necessary that you segregate the factors all the time in 4 categories. If required you can only say controllable and uncontrollable factors.

Now, we have already talked about the measurement system, but just I would like to remind you that there is a very good principle to be appreciated; and this is GIGO. GIGO stands for garbage in garbage out. So, if you say how poor data which is an outcome of a very very poor or ordinary measurement system; obviously, whatever great effort you will put your experimentation will lead to the wrong conclusions.

So, we discuss this part in detail in our lecture say measurement system analysis gauge R and R here once again I would like to remind you that accuracy is basically your closeness to the measured value closeness to the target value. Precision means my instrument should be precise enough to reproduce the readings when the same reading is taken again and again and the closeness among the readings is precision.

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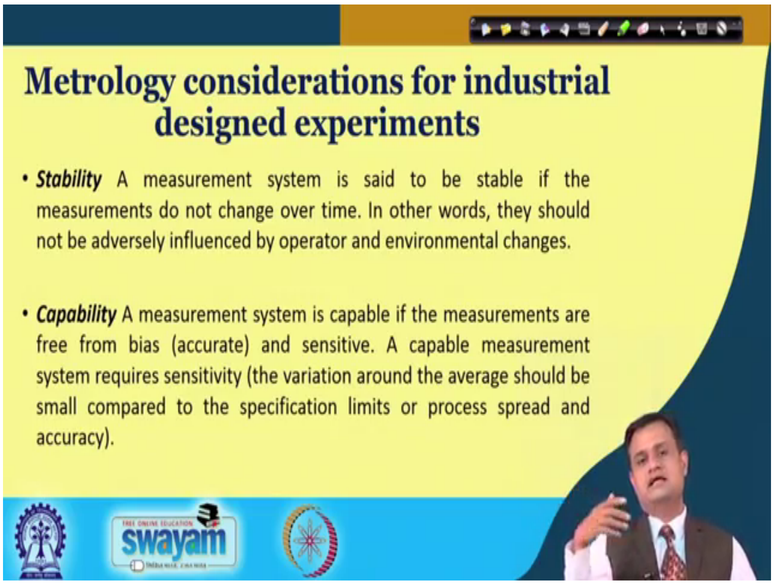

Stability over a period of time if I take the reading my instrument must remain stable measurement must remain stable. Suppose I have checked 1 reading in the morning with Vernier caliper and same reading if I check in the evening that should not be significant difference. In capability so your system is capable if the measurements are free from bias.

So, we had seen the bias that suppose you are taking the temperature reading, the example we discussed previously with the thermometer. Then for lower maybe it is taking some higher reading or higher it is taking lower reading then there could be some bias. And this bias should also be properly addressed before I start collecting the data for my experimentation.

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So, selection of quality characteristic for industrial experiment is an important issue. And you must see that CTQ critical to quality the quality characteristic which is easy to measure an important must be considered. So, it should be a continuous variable as far as possible and it can be measured precisely, accurately with stability; so many a times if you choose some very very complex phenomena to be measured. Then either you need highly precise instrument or such kind of measurement are not very much accurate stable and this can also cause the problem.

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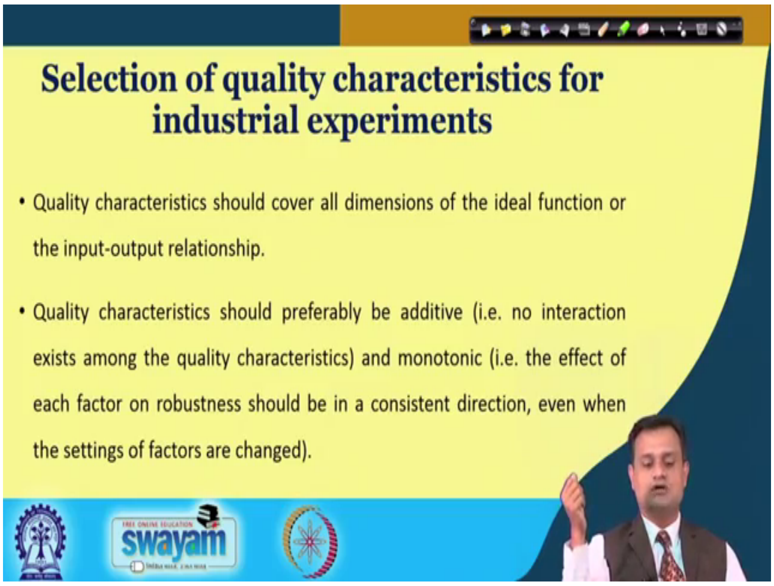

So, it should occurs say quality characteristic should cover all dimensions of the ideal function input output relationship. And preferably be additive no interaction exist among the quality characteristic. So, effect of each factor on robustness should be in a consistent direction even when the setting of factors are changed; so this where the couple of concepts on my design of experiment.

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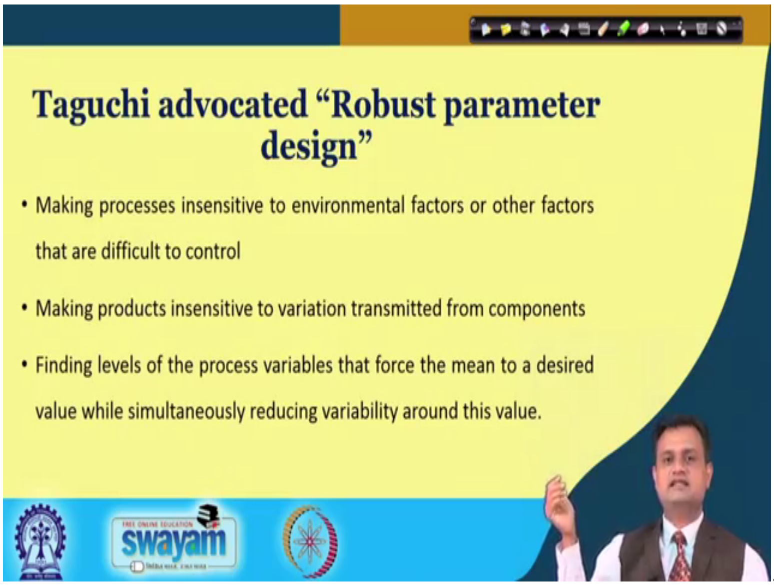

Now, Taguchi we will see it in detail, but just to introduce he proposed a concept of robust design. And he believes that as you deviate from the target there is a loss to society. It means it is not enough to achieve within specification, but as you go away from the target your target value you are basically producing lower quality products and it is a loss to society. We have seen that six sigma spread is very less compared to 3 sigma my process is in six sigma are more centric towards the targeted value. And that is exactly what I try to achieve through experimentation using the Taguchi concept.

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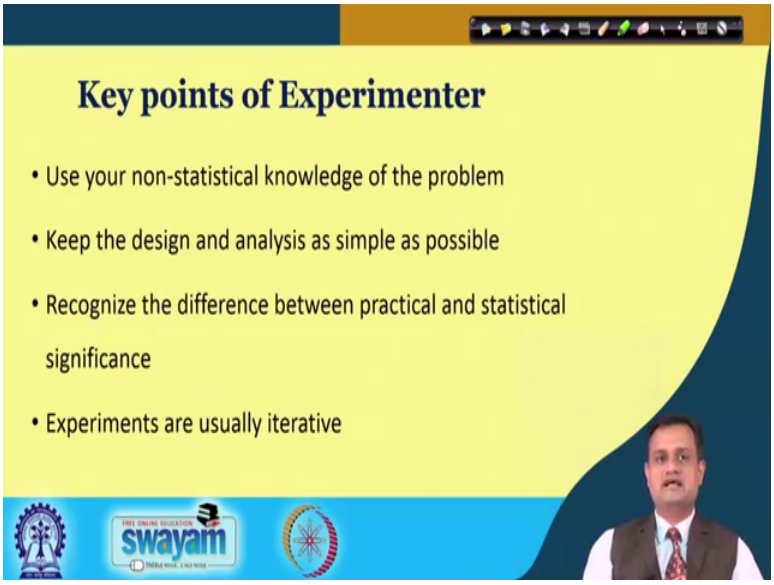

So, there are key points of the experimenter use your non statistical knowledge of the problem. So, you must have the domain knowledge keep the design and analysis as simple as possible recognise the difference between practical and statistical significance. Sometimes you find some p value. And let us say your alpha, now you are familiar your level of significance set level of significance alpha is 0.5. You have calculated the p value for a factor let us say temperature.

This is the observed significance level. And let us say this comes out to be 0.001. So, this is very very less and you will reject. Now, let us see another example, where your alpha is same set significance level which is 0.05. Now let us say your observed level of significance is point 0.49. So, there is only 1 percent difference. Now would you like to reject your null hypothesis for such a small difference?

For such a small difference in the alpha and the p value means set significance level and the observed significance level, you have to apply your practical knowledge. Experiments are usually iterative. So, I told there are enormous benefits of conducting DOE. It improved yield and stability return on investment process, capability consistency it reduces the manufacturing cost.

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Avoids the duplication rework reset can be minimised and design and development time can significantly be reduced. I would just like to share 1 statistics that as a rule of thumb; if you are in a typical high tech industry like maybe laptop mobile manufacturing; and if you are late by 4 to 6 months in launching your product. Then almost you loose 50 percent of the total productivity profitability that you may realise during the entire life cycle of your product.

So, just see that you have a product that will go through the inception, then say rapid advancement and then maturity and then decline. So, there is a total profitability and you loose almost 50 percent. If you are late by say 4 to 6 month in launching your new product. So, you cannot afford and you also cannot afford to launch a poor quality product. And that is where the DOE comes in picture.

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You need basically 4 set of skills; in conducting DOE planning skill, l statistical skill, teamwork skill, engineering skill it is a cross functional approach you need to have the people from production, procurement, design manufacturing and then only you can set a right premise for conducting DOE. And then you can really conduct the meaningful experimentation.

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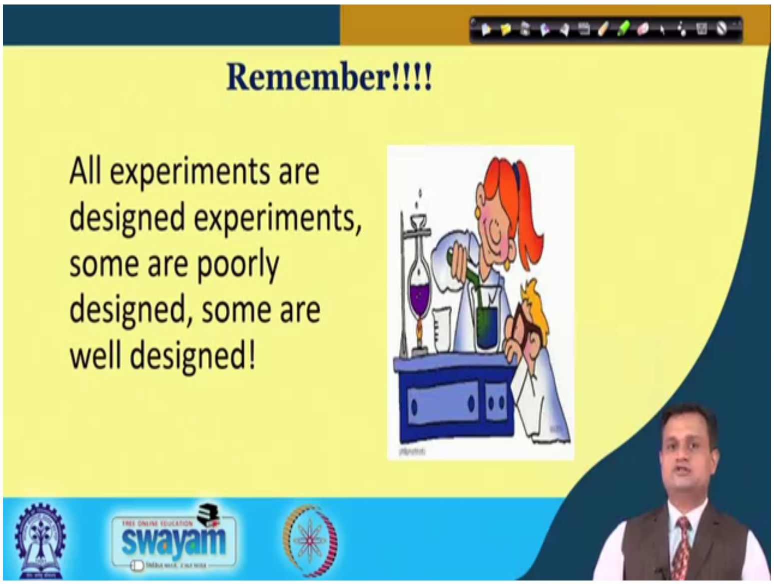

So, once again I would like to remind you all experiments are designed experiments whatever way you want to do some experimentation intuitively, there is some design involved. But some are poorly designed some are well designed if you want well designed take the help of DOE.

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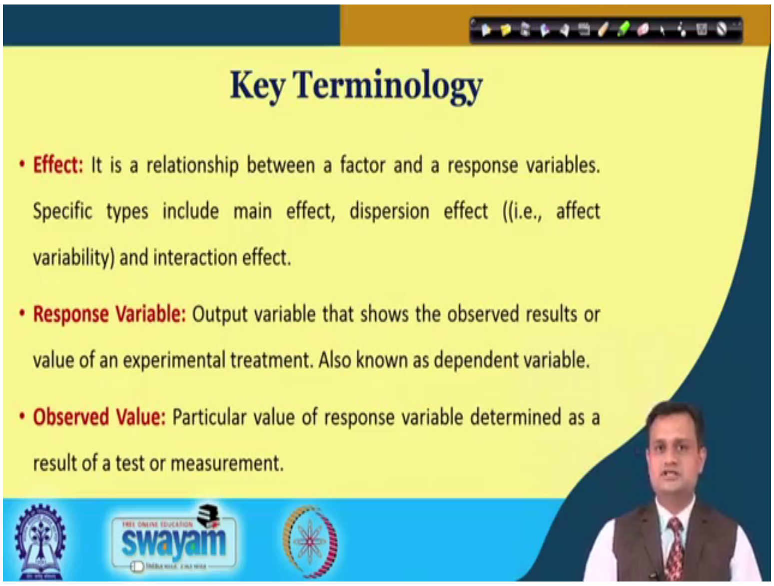

There are key terminologies effect; so relationship between factor and the response variable. Response variable that is the output variable that shows the observed results and I am interested. Like, productivity yield of the agriculture observed value particular value of the response variable determined as a result of test.

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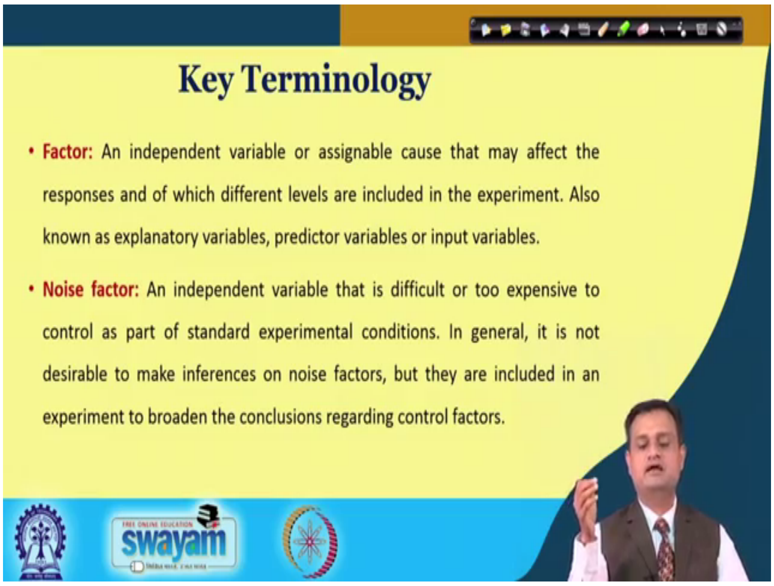

Factor it is an independent variable assigned cause that may effect the response. And noise factor independent variable that is difficult to control or too expensive to control as a part of standard experimentation condition.

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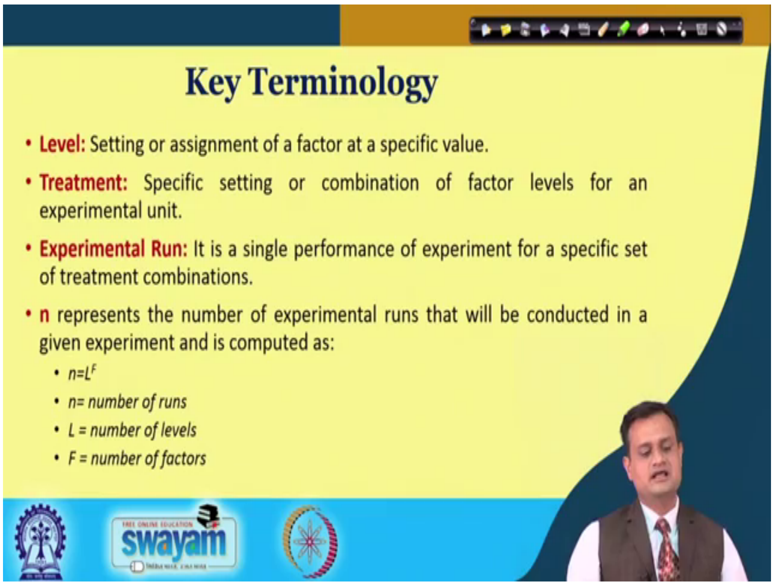

There are some important terms before we finish level setting or assignment of factor at a specific value. For example, temperature we had seen the example of detergent say versus temperature in it is impact on the ability to remove the dirt. So, here your temperature is set at 3 level 10 degree 25 degree 50 degree so these are the levels.

Treatment specific setting or combination of factor levels for an experimental unit. So, you are using a particular brand of the detergent and temperature. And then you are trying to conduct the experimentation for a particular combination that is called treatment; n is experimental run. So, in a single performance of experiment for a specific set of treatment combination n represent the number of experimentation run. And you can determine this very easily n is equal to L raise to F n is number of run L is number of level and F is number of factors. So, you can figure out that, what could be the number of experimentation.

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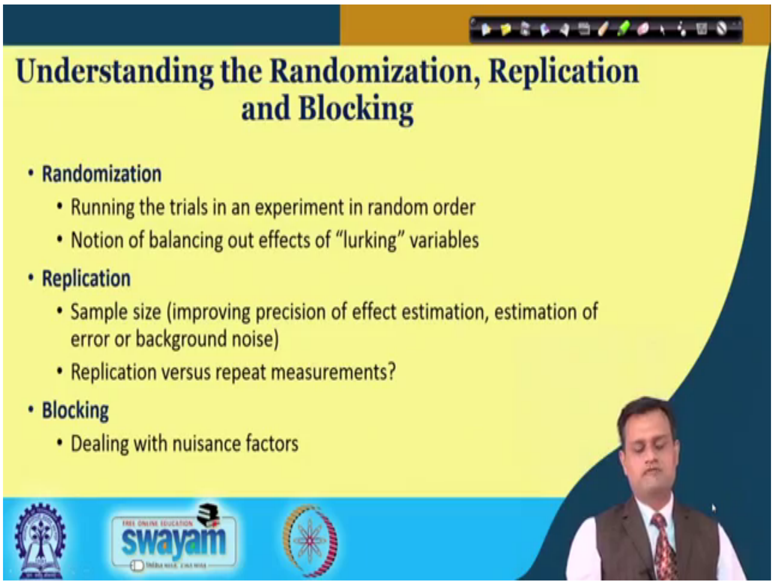

So, there are couple of terms that is randomisation replication and blocking; randomisation run the experimental trials in random order; so that bias can be avoided, replication sample size or you try to replicate repeat measurement and blocking you would like to block couple of nuisance factors.

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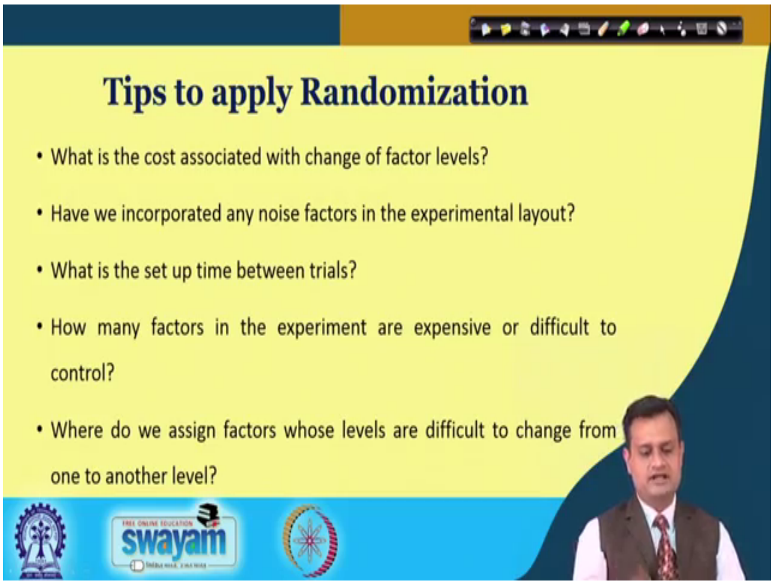

So, there are couple of tips to apply randomisation, you think about the cause set of time. And then you try to figure out that how the randomisation can really help you.

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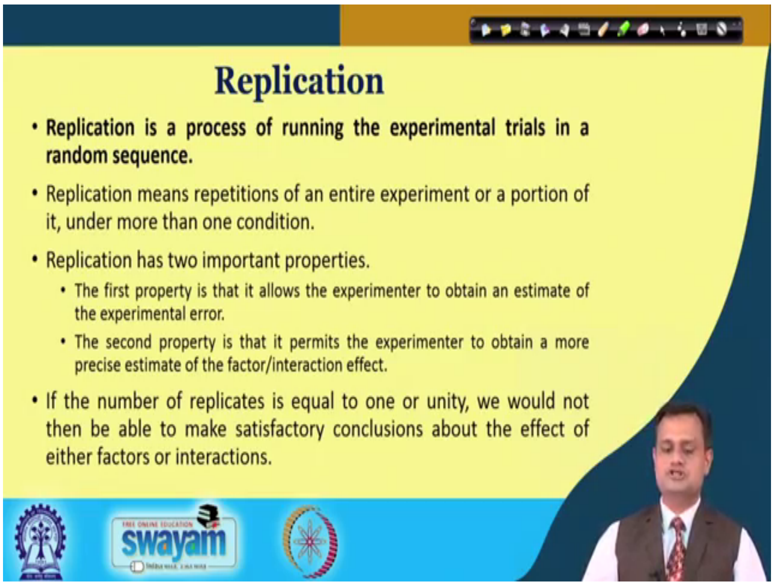

Replication is process of running the experimental trail in a random sequence. Here you are replicating in order to be more accurate in terms of your error with respect to your measurement system; and when you take the reading at different level replication if there is any bias possible that can be captured.

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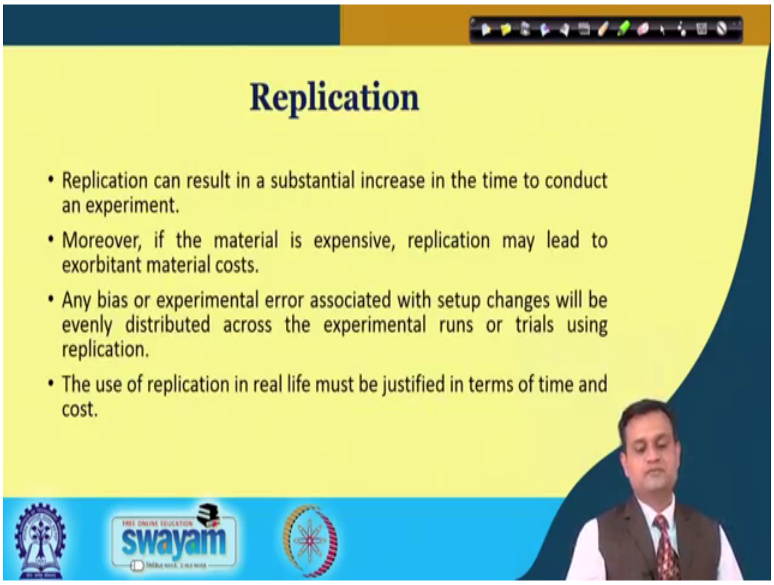

Replication and then repetition here I am not changing the setting I am just repeating. So, you may not be able to detect the bias, but this is less expensive. And for a particular setting you can repeat the experimentation. And see that whether your system instrument system is stable or not.

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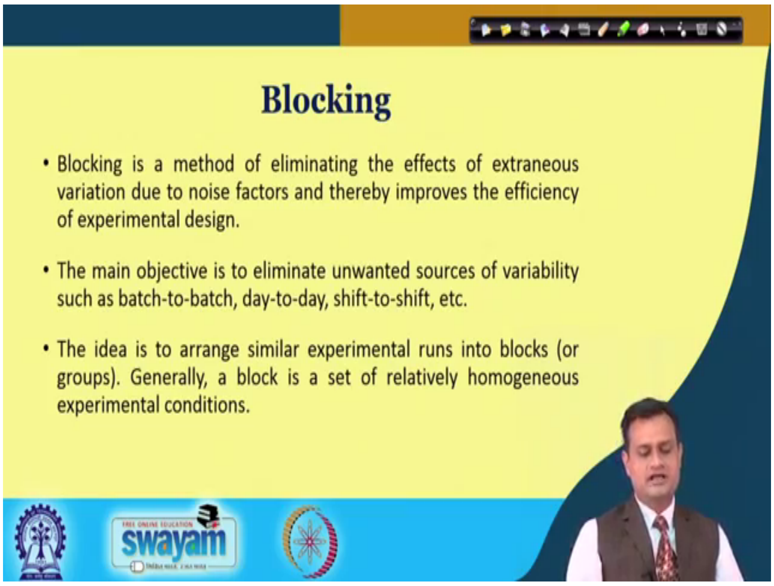

And blocking. So, there are many factors we will see this concept in detail later on that batch to batch production shift to shift production day to day production, I need to block them; otherwise if the homogeneity is not maintain then my experimentation result will drastically be affected. So, many a times suppose I am purchasing the material from different vendor. And 1 vendor is not capable to supply the entire material; then I have to block this effect I am running the production in shift 1 to n free. And suppose I proved the null hypothesis, that produce of shift 1 in terms of quality is not equal to shift 2 and shift 3. Then I need to block this factor.

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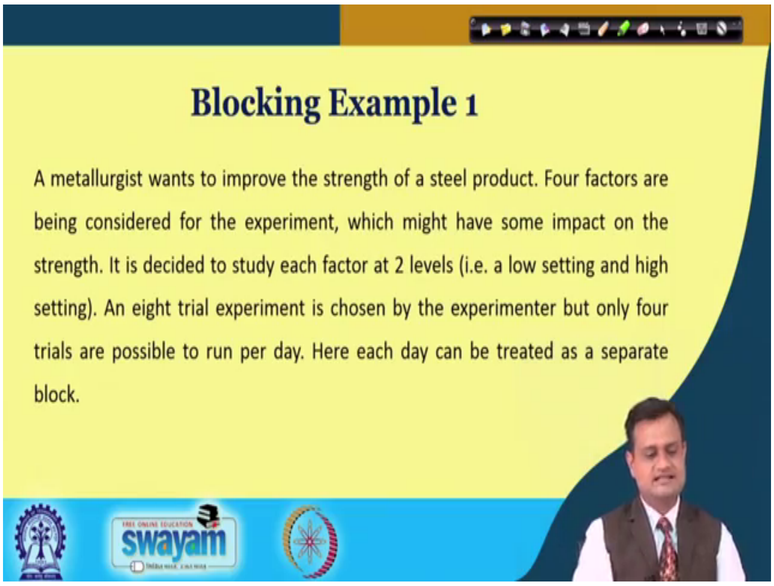

So, you can see 1 example; a metallurgies wants to improve the strength of steel product; 4 factors are being considered for the experiment that might have some impact on the strength. And it is decided to study each factor at 2 level low setting and high setting 8 trial experiment is chosen by the experimenter. But only 4 trails are possible to run per day per shift. So, each day can be treated as a separate block. I have put another example where you are having the batch to batch variability and that needs to be blocked.

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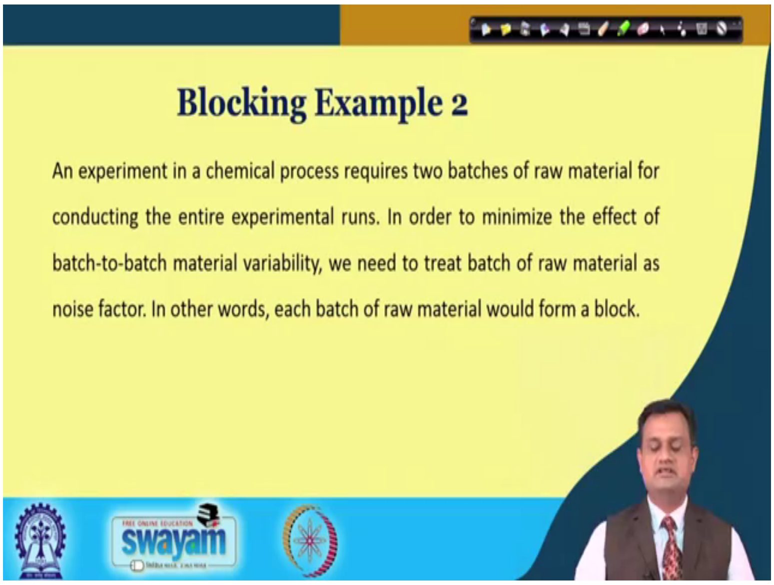

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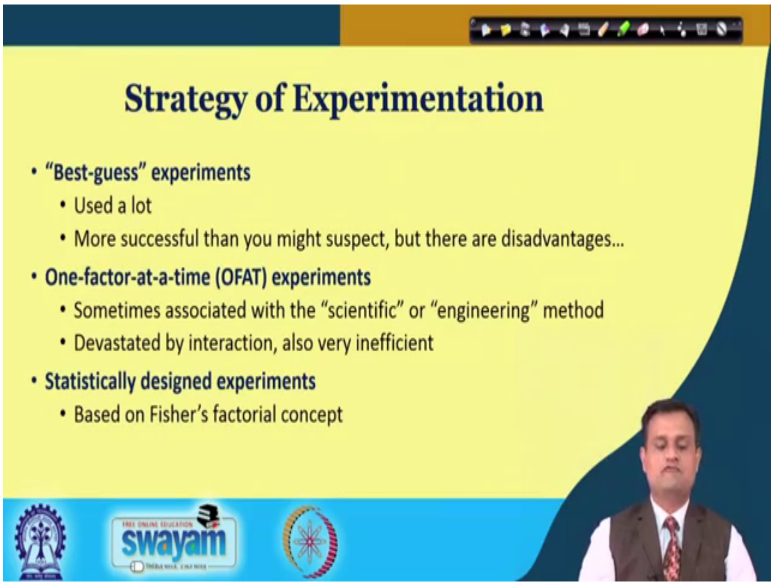

So, finally, strategy of experimentation it is may be the intuitive best guess may not re yield the concrete result. 1 factor at a time I am just changing one factor with respect to the initial setting; we will see it and then I will change the another factor, by keeping the other factor with respect to the initial setting. Suppose you have set both the factors initially at the low level, then you change another factor.

Let us say factor 2 to higher by keeping the first factor at the initial setting that is low level similar way when you are changing the first factor to higher level keep the other factor at the low level that is the initial setting and this is called one factor at a time. And then you have Fisher's approach. So, there is a big say world of design of experiment and this is what we are interested in.

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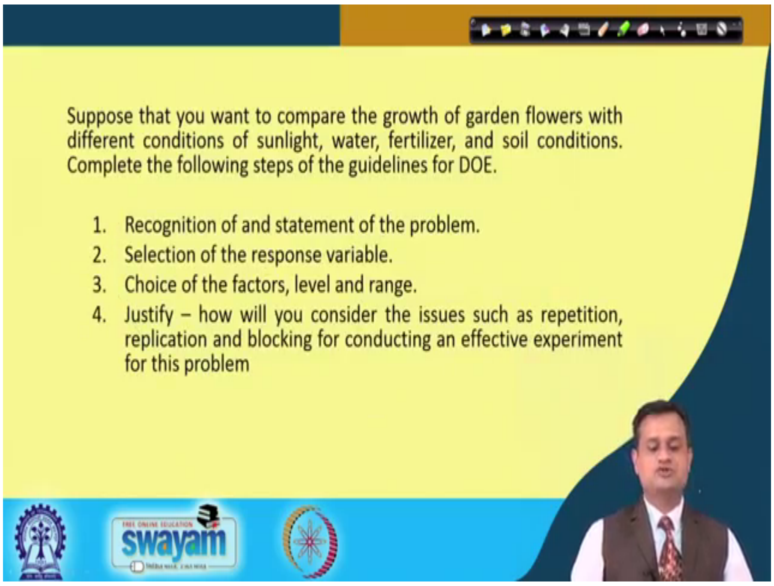

So think it over the situation; suppose you want to compare the growth of garden flowers. I am giving you something interesting example with different conditions of sunlight water fertiliser soil conditions. Complete the following steps as a part of DOE recognise an statement of the problem selection of the response variable choice of the factor justify how will you consider the issue such as repetition, replication blocking for this. If you do this I think you are welcomed in the domain of your improve DMAIC phase improve phase and now you are entering into the world of design of experiment.

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So, these are the references you use; and mainly I am referring the text Douglas Montgomery for this design of experiment discussion.

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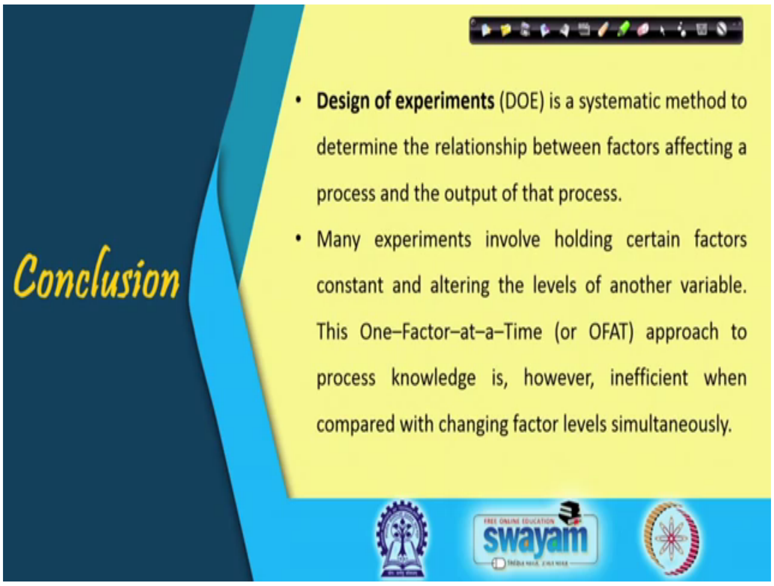

So, it is a systematic method to conduct the experimentation and figure out the impact of factors on the response right at the design stage So, thank you very much for your interest in learning this particular topic, internalise it revise it have a good hold on the topic and be with me enjoy.