Quality Design and Control
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Lecture – 51
Quality by Experimental Design

During this week, we will be discussing an important topic called Quality by Experimental Design. So, mainly we will be discussing the use of experimentations or in specific terms.

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The use of experimental designs for designing a product as well as when you talk about the designing a product; obviously, we have in your mind, the quality features. Now, this is an important topic and whenever we talk about quality improvement for a product or for a process or for a system, many a time, we are for the experimental design and there are many types of designs; obviously, the this is a very vast topic.

So, what we have tried to cover in this particular lecture session only those important concepts which are very very vital for designing and experimentation for quality improvement purpose.

And I hope that these the 5 lecture sessions, we will we will cover all the basics of experimental design and how the experimental design is related to quality improvement

in specific terms on the lecture one, we will be introducing the concept of experiment experimentation and we will also explain the terms associated with experimentation important features of experimental design. In lecture 2, the basic principles were experimental design will be discussed in detail and including the experimental design methods there are the different kinds of methods you are supposed to use.

So, what are those; we are going to discuss in lecture 3, a specific design called completely randomized experimental design, we will discuss in detail and after we discussed this particular design, we will be referring to the variations in this randomized experimental design.

So, you also must know in how many different forms the randomized experimental design may you out for lecture 4, factorial experiments with numerical exercises, we will cover and the lecture 5, 2 to the power k factorial experiment. It is a special part; it is a special experimental design which is widely used.

We will be talking about including the fractional factorial experiment.

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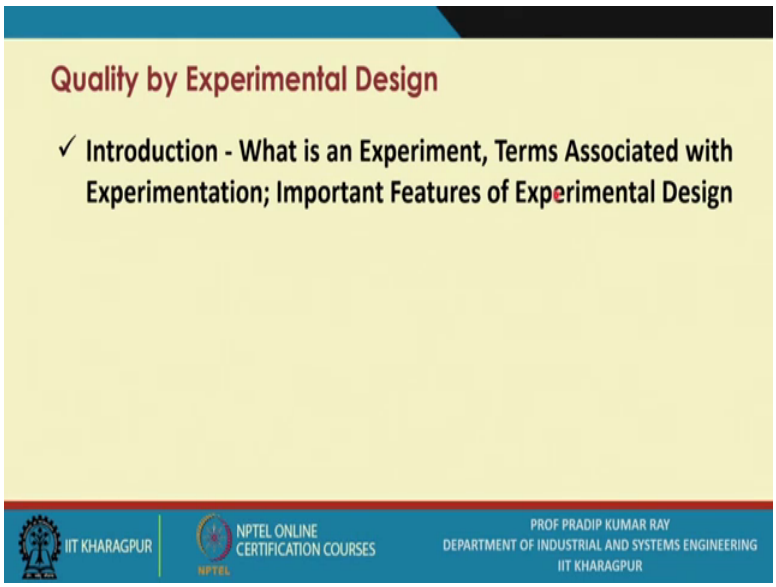

Now, let us talk about so, the experiment and experimentation. So, in these particular lecture sessions, I will be introducing the concept of experiment experimentation and then I will be defining the terms associated with experimentation and what are the important features of experimental design ok.

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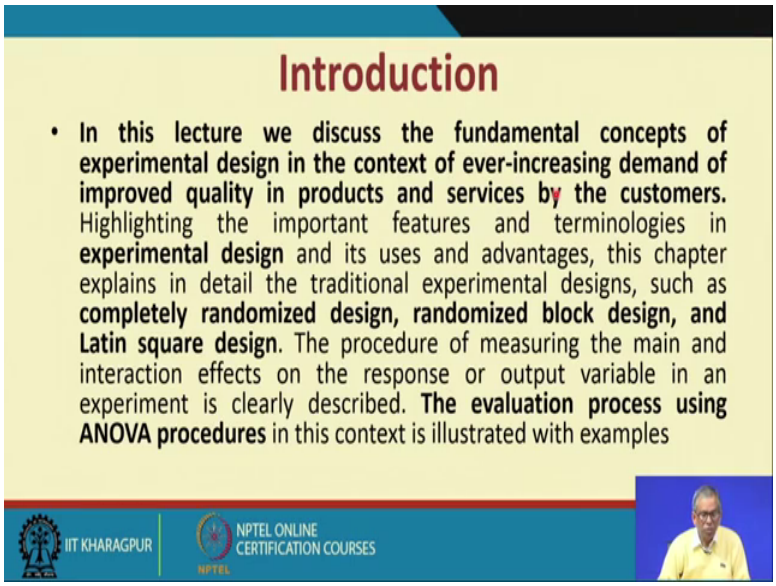

So, what will be the lecture content? Now in this lecture, we discuss the fundamental concepts of experimental design in the context of ever increasing demand of improved quality in products and services by the customers; that means, the basic purpose is if you want to improve the quality of your product or the process or the system.

Many a time, you need to use the experimental design methods highlighting the important features and terminologies in experimental design and its use is an advantages. Now this particular lecture session explains in detail the traditional experimental designs, we will be focusing on that such as completely randomized design, experimental design, randomized block design and the Latin square design.

So, these are the three important designs we will be discussing in this lecture session, the procedure of measuring the main and interaction effects on the response or the output variable in an experiment is clearly described and the evaluation process using annual procedure analysis of variance procedure, we will explain and we will illustrate all the you know the methods with suitable examples.

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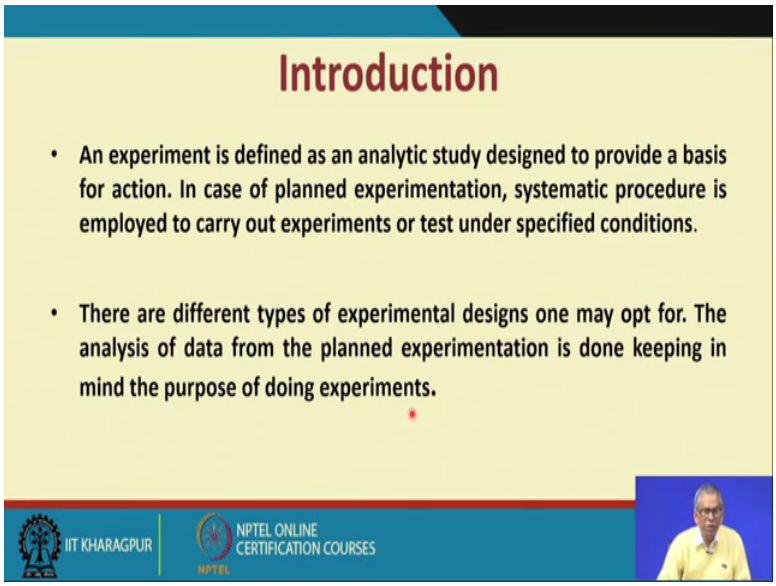

Now, what is an experiment? So, let me first define it an experiment is defined as an analytic study designed to provide a basis for action; that means, certain unknowns and its effects, I need to be understood and the and then and then what sort of action in the form of proposing a new design you have to you have to suggest in case of planned experimentation.

Systematic procedure is employed, now here, what we are going to; what we are going to do like say we will be referring to the planned experimentation, it is not just unplanned experimentation or we will carry out the experiment experimentation ok, arbitrarily. So, that we must not do we cannot do. So, a systematic procedure will be read out, there are different types of experimental designs; one may opt for depending on the particular condition particular constraints.

So, you have to select a particular design and in the literature, you will find that as you come across the varieties of situations; obviously, the experimental designs also of different types and in a given situation in a given you know the condition you have to select the most appropriate design the analysis of data from the planned experimentation; that means, when you carry out an experiment.

Obviously, you will be generating the data and you need to analyze the data and a particularly these analysis of data from the planned experimentation is done keeping in mind the purpose of doing experiments.

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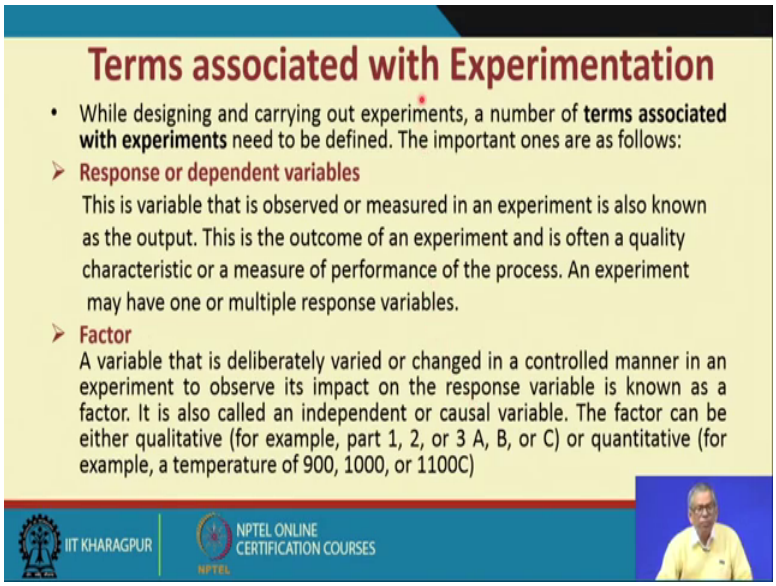

So, now, before we explain the different types of experimental designs, let me defined the different terms and terminologies associate with experimentation, you must have a very clear idea and about these the terms about these concepts while designing and carrying out experiments a number of terms, we need to we need to be use or we need to be familiar with.

The important ones are as follows. So, what are the important ones, first one is the response on dependent variables. So, we have we have already discussed; what is a response variable and in a for a for a given product which you are going to design or for a given process which you are going to design or for a given system which you are going to design. First thing you need to do that what kinds of outputs variables you may have and the output related quality characteristics you must be able to identify.

So, this output related quality characteristics are also referred to as the response or the dependent variables and in majority of the cases, what you will be dealing with you will be dealing with not only one response variable, but multiple response variables.

What is the factor; a variable that is deliberately varied or changed in controllable manner in an experiment to observe its impact on the response variable; that means, what it is basically the input variables, sometimes, they are referred to as the input variables and it is also called an independent or causal variables; that means, what we assuming that because of the existence of these variables, you know, you get or the response and

the response is essentially determined by the kinds of input variables ok, you have in a particular design. So, the factor can be either qualitative.

For example part 1, 2 or 3, A, B or C like this, you can specify or quantitative; for example, a temperature of 900 degree Celsius or 1000 degree Celsius or 1100 degree Celsius ok.

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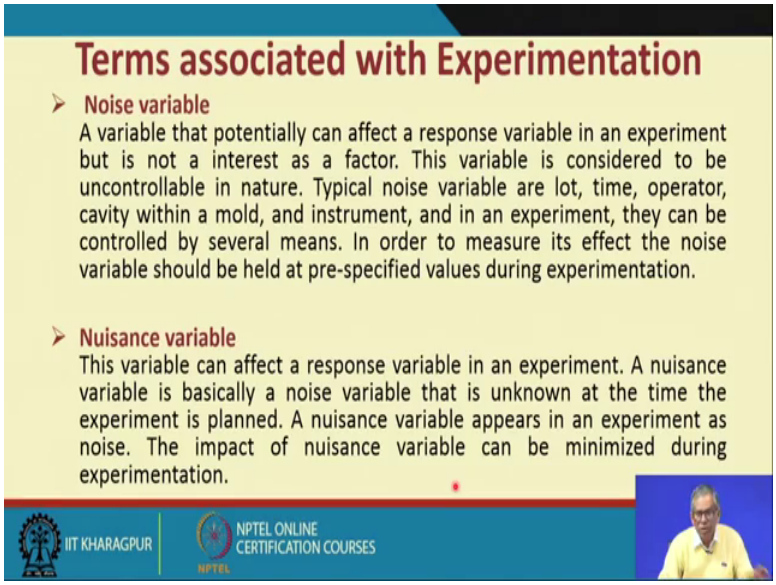

So, this is the input variables or the factors; what is the noise variable, we have already you know we have discussed while we defined the robust design we have referred to uncontrollable noise factors. So, what is the noise variable because in experimentation, you must be aware of the different kinds of noise variables a variable that potentially can affect a response variable in an experiment, but is not a an interest as a factor.

This variable is considered to be uncontrollable in nature, typical noise variables are lot lot size, I mean the time operator cavity within a mold, these are the examples an instrument and in an experiment, they can be controlled by several means.

The point to be noted is that even if there is the existence of uncontrollable noise variables in many experimentation, you need to consider these noise variables and how do you obvious question is that while you carry out an experimentation, how do you control ok, what are the controlling or the means you have to change the values of the noise variables.

So, while we discuss the experimentation, you will come to know that which procedures you are supposed to employ for the purpose in order to measure its effect the noise variable should be held at pre specified values giving experimentation when we cite examples, you will come to know that how do you said the values of the noise variables, what is the nuisance variable?.

This variable can affect a response variable in an experiment; that means, whenever we say that the noise variable a particular noise variable appears for the first time you are not aware of. So, this is referred to a nuisance variable and if the nuisance variable becomes a part of the system; that means, you cannot avoid, then subsequent are subsequently a nuisance variable may be treated as a noise variable.

A nuisance variable is basically a noise variable that is unknown at the time the experiment is the plant, this point I have already highlighted; that means, during the experiment only you come to know that here is a variable which is which you cannot control. So, the first time a nuisance variable appears in an experiment as a noise the impact of nuisance variables can be minimized during experimentation.

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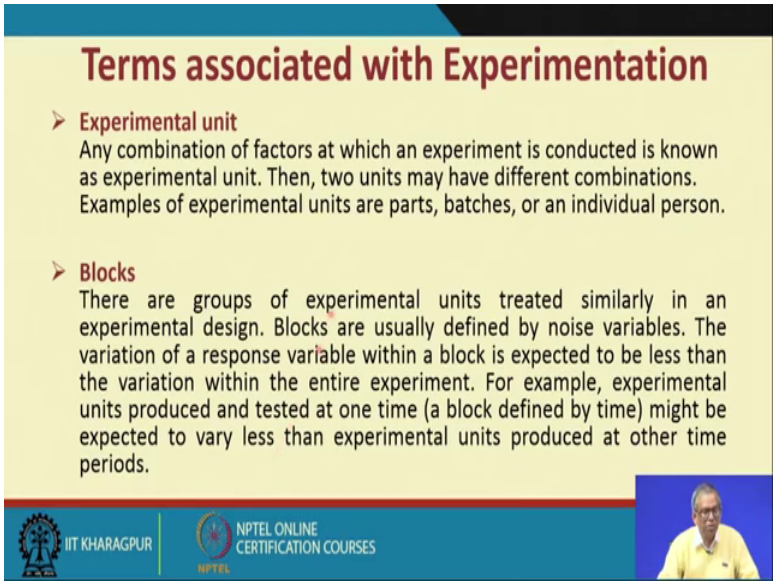

That is one of the objectives definitely. Now, what is an experimental unit and this is an important term. So, you must have a clear understanding of what is an experimental unit.

Any combination of factors at which experiment is conducted is known as experimental unit. Suppose there are three factors A, B and C and the suppose the high level of A, high level of B and high level of C, suppose these are the three conditions you have chosen and then under these conditions, you want to measure the value of a particular output or the response variable. So, this is just a combination. So, there could be many other combinations like say you can have say low level of A, low level of B and low level of C.

So, that is another combinations. So, among the three factors there could be different combinations depending on how many levels you have in each factor, right. So, each combination is referred to as an experimental unit the two units may have different combinations examples of experimental units are parts batches or an individual person.

What is a block? There are groups of experimental units treated, similarly in an experimental design; that means, when you define experimental units, you can classify them under different groups and in each group of the experimental units, there are certain you know, there they are treated similarly; that means, their characteristics are of one type and that is why they may be treated separately, each group should be treated separately or uniformly, then this each group of experimental unit is referred to as a block.

So, blocks are usually defined by the noise variables the variation of a response variable within a block is expected to be less than the variation within the experimentation; that means, what you say this is the suppose the experiment is to be conducted under in 3.

So, in the ambient temperatures say you know the 35 degrees Celsius, 40 45 degree Celsius and 55 degree Celsius. So, the experimental units under 35 degree Celsius may be treated as one block and similarly, when you change the temperature through says a 40 degree ok. So, it may be treated as a separate block and so, there could be many examples or blocks for example, experimental units produced and tested at one time.

A block defined by the time is it like say. So, at 8 o clock, you have collected here doing experiments with say few experimental units. So, this may be treated as a block whereas, in another time. So, in the late afternoon you carry out you carry out the experiment with the same set of or the experimental units, it may be treated as a different block. So, this is the block concept is uniformly or say you know they used in experimentation.

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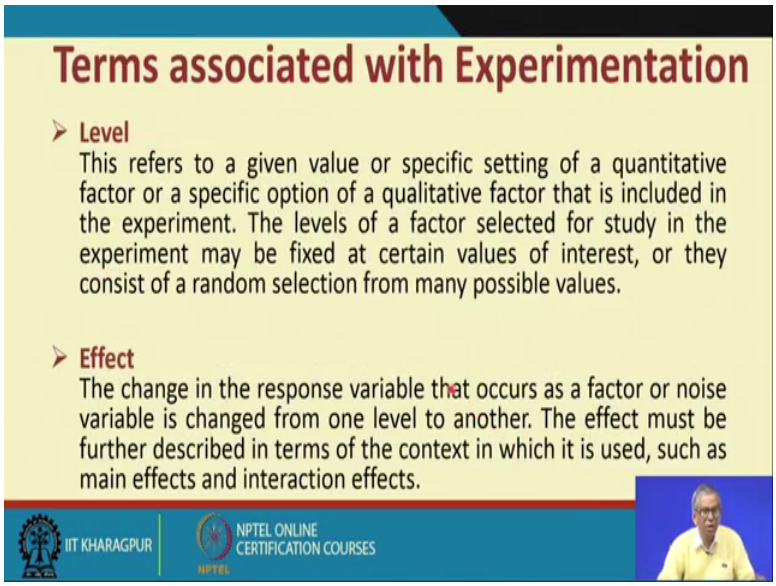

What is the level I have used the trunk or level is refers to a given value or specific setting of a quantity factor or a specific option of a qualitative factor that is included in the experiment.

That means suppose you consider a factor called a, and a factor can have a low value or you can have a high value. So, the low value is one level and the high value is another level, is it ok. So, either it you may define it subjectively or you can define the levels quantitatively or objectively also the; so, levels of the factor selected for study in the experiment may be fixed at certain values of interest or they consist of a random selection from many possible values.

So, this is the point to be noted you say you generate those levels also assuming and then you say that I will generate that the different values of a particular factor and I will select a particular level ok.

That randomly; so, whenever you go through some numerical exercise this point, we will made very very clear, what is an effect the change in the response variable that occurs as a factor or the noise variable is changed from one level to another; obviously, when the input variable and the low level. So, its effect could may not be that significant, but when the same factor you is at the higher level, it its effect on the output response variable may be may be different. So, the effect must be further described in terms of the context in

which it is used that is very very important as such main effects and interaction effects; that means, the main effect means suppose there are two factors.

A and B affecting say the response that is the y; So, y is affected by A both A and B like individually means factor a as well as the factor B is affecting. So, that is the main effect and plus there could be a product term say says suppose. So, the y; value of y may be affected by the product A B. So, that is basically the interaction effect. Similarly, suppose you have got three factors A, B and C affecting the value of y. So, what will be the main effect?

So, the main effect will be the effect of A, effect of B or effect of C, these are the main effects and what is the interaction effects; effect of A, into B, effect of B into C, effect of C into A as well as the effect of A, B, C on y, is it.

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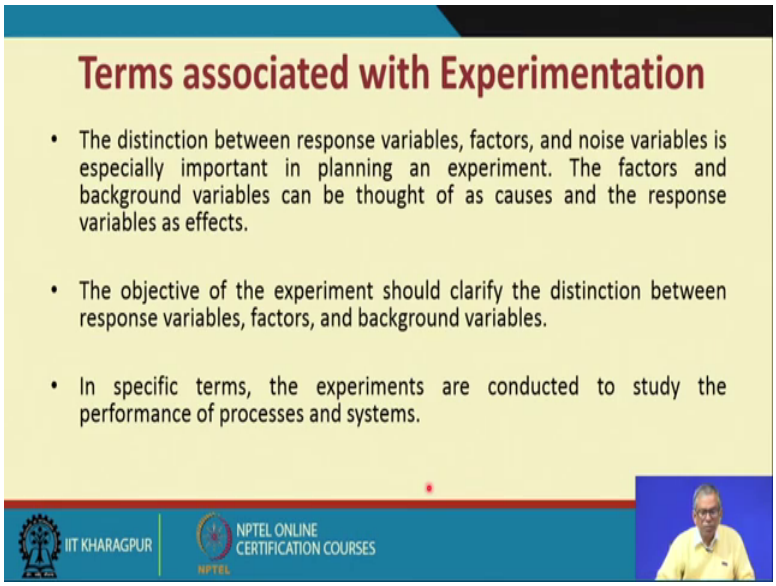

So, this way we define. Now, the distinction between the response variables the factors input variables and noise variables is especially important in planning and experiment. So, this point is to be noted the factors and the background variables can be thought of as causes and the response variables as effect you are aware of a diagram called cause and effect diagram, is it ok.

So, the cause and effect diagram or the issue curve diagram or any draw for a particular system. So, you will come to know that what are the what are the effects in terms of for

the response variables and what are the causes; that means, in terms of the input variables the objective of the experiment should clarify the distinction between response variables.

Factors and background variables; So, when you said the objective trust we made very very clear.

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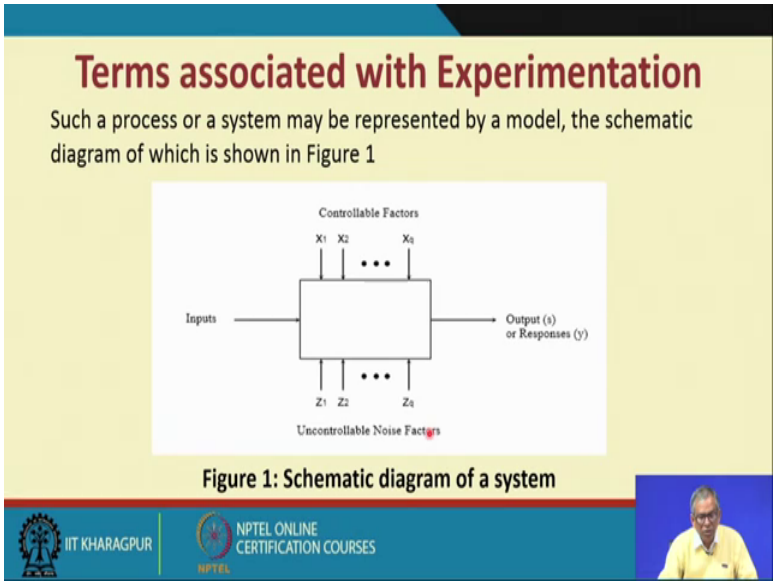

So, that there is no confusion in specific terms the experiments are conducted to study the performance of processes on the systems, is it ok. So, that we only gain system and how do you represent the system in this context.

So, such a process of the systems may be represented by a model, the schematic diagram of which is shown in this particular figure. So, what do you have means this is the systems you moving about then you know there will be input variables there will be you know the controllable factors x 1, x 2 up to x q and similarly you have uncontrollable noise factors z 1, z 2, z q.

And you will have the output or the response variables, is it ok. So, this is basically the notation is y. So, either there could be. So, one response you may consider or you may consider multiple responses, is it ok, in majority of the cases of the number of inputs, you consider is more than one at least 2, whereas, in when you start with you start your experimentation initially, you think of considering just one response variable.

That means, the most important response variable, you must select out of many possible response variables, is it ok, you need to identify the controllable factors and you also need to identify the uncontrollable noise factor. So, this is a schematic representation.

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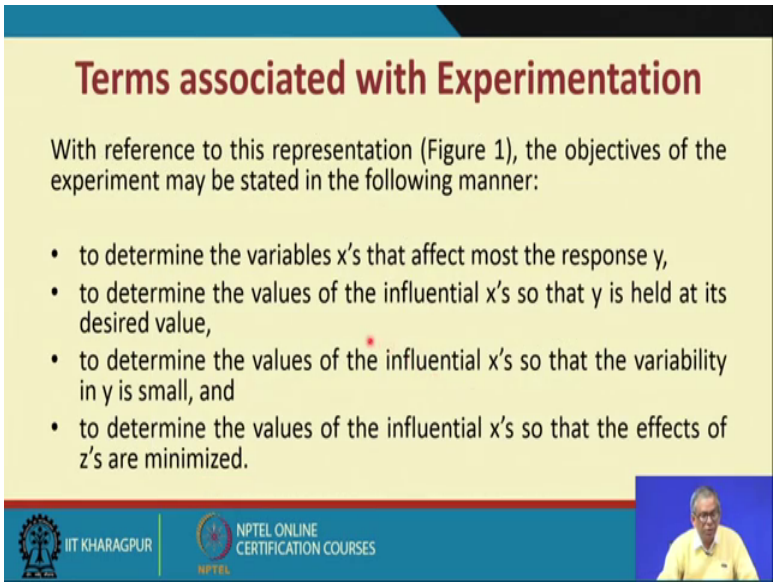

Now, with reference to this representation the objectives of the experiment may be stated in the following manner. So, how do you set the objectives in clear and specific terms you have y's you have x's and you have the z values right.

So, to determine; so, what is the first objective first objective could be to determine the variables; that means, that this x's that effect most the response y; that means, out of many such input variables you considered which one. So, or which set of x actually affecting the affecting the response y ok, most significantly next objective is to determine the values of the influential x's. So, that y is held at his desired value.

So, that is most important like we have stated that that the output value should be held at the target value. So, the target value could be the desired value or the nominal value. So, in order to get the value of y at its target or at its desired what would be the values of the influential x's or the or say significant x the x's which are significant to determine the values of the influential x's.

So, that the variability in y is small as we have been telling you all the time that any exercise on quality is essentially an exercise on variability control. So, definitely you are

setting the target, but the make sure that the variability of y you must be at the minimum level to determine the values of the influential x's. So, that the effects of z's are minimized; that means, that is the condition for robustness what are these z's.

Basically the uncontrollable factors; So, make sure that the performance effect on the performance or the response variable of the z is minimum and then only you create a condition called robustness.

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Now, experiments on processes or products are very common in all types of industrial environments ok, particularly in production system. So, when you start collecting data for experimentation what you are you know whatever the data being generated in a in a particular in a production system ok.

So, under these data are generated under various conditions and even in many cases what you can do; that means, instead of a formerly the doing experiment experimentation. So, when you have this data for the last 6 months data of a process planned.

Now, under different conditions, you can systematically you can study these related datasets and you can put it in the experimental design format experiments range from very informal investigations to well planned studies involving a series of specific experiments like in the laboratory conditions we carry out the experiments.

And then what about the results you get you try to you know get the these results verified in the actual conditions in order to provide an effective basis for action an experimental design must have certain features.

So, who is the pioneer the British scientist R A Fisher proposed the principles of experimentation in late 40s of the 20th century, he is the pioneer, many other authors and researchers have contributed immensely in this area in the next 60 years.

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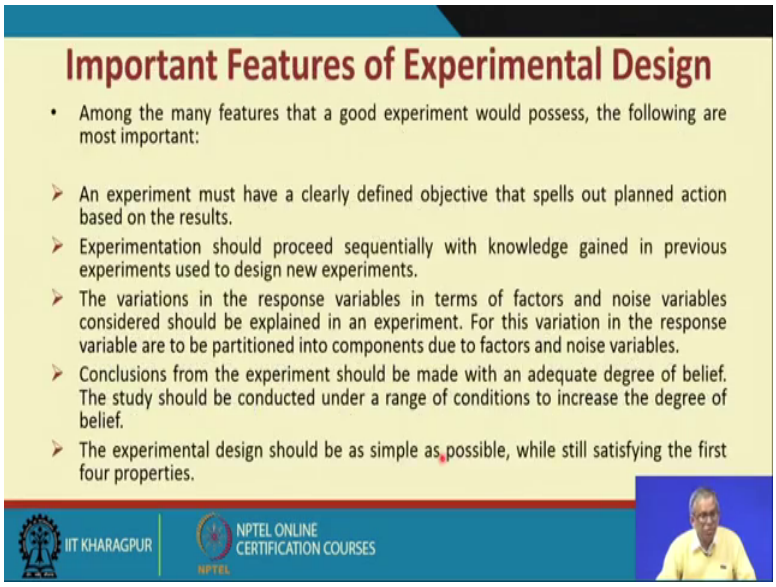

So, among the many features that a good experiment you must be aware of. So, suppose we go for experimentation what are the good features that an experiment must have or what are the specific features a good experiment must have.

So, what are those the features there could be many features an experiment must have a clearly defined objective that is that is point number 1. What is the point number two? Experimentation should proceed sequentially with knowledge gained in previous experiments used to design in experiments.

That means, this is just more than one time activity ok, initially there could be you know one experimentation and the maybe with just two factors started and when you get the results then you think of can you add the third factor or can you add the fourth factor there among. So, it is a continuously the developing scenario. So, the variations in the

response variables in terms of the factors and the noise variables considered should be explained in an experiment.

That means those sort of the condition you must have you must have in mind and while you carry out experimentation for this variation in the response variable are to be partitioned into components due to factors and the noise variables; that means, the variability due to the variables and variability do to. So, the noise factors; So, this is this sort of partitioning concept you must apply conclusions from the experiment should be made with an adequate degree of belief.

So, that is the term could be noted that is what is your degree of belief the study should be conducted under a range of conditions this point we have been saying to increase the degree of belief the experimental design should be as simple as possible while still satisfying the first four properties.

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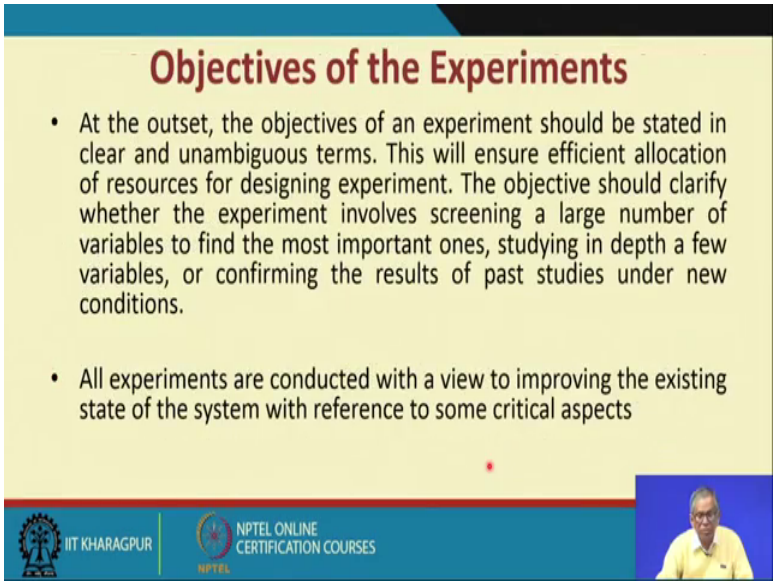

So, objectives already we have mentioned all experiments are conducted with a view to improving the existing state of the system with reference to some critical aspects.

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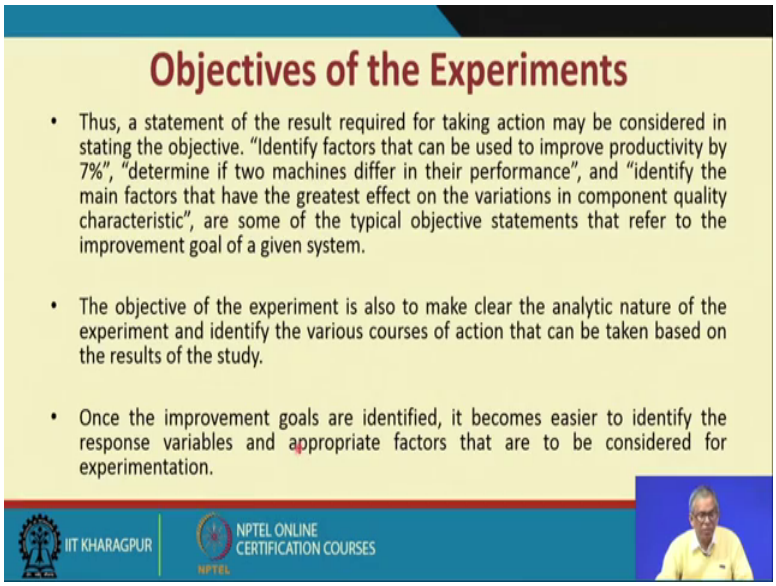

So, these are the examples in fact, like say while you write down the objectives of the experiment a statement of the results required for taking action may be considered in stating the objective in specific terms. So, these are the examples you have.

So, once the improvement goals are identified, it becomes easier to identify the response variables and appropriate factors that have to be considered for experimentations.

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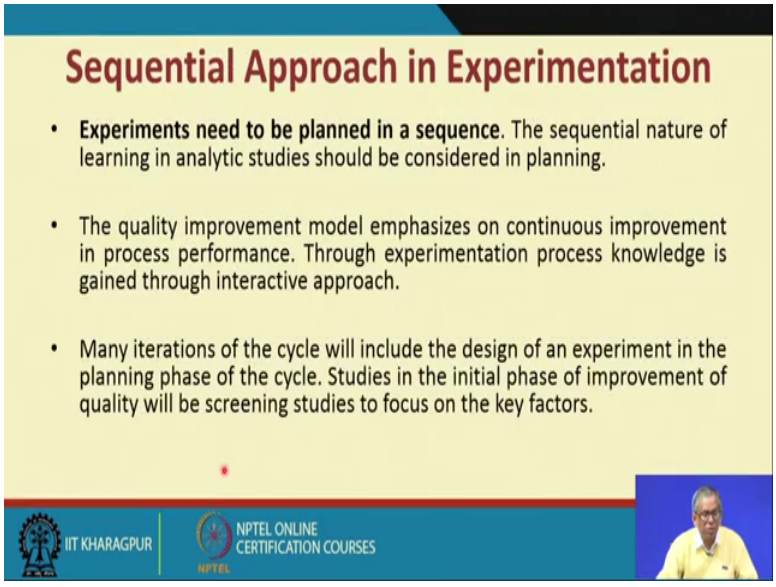

So, we many a time mention that the experiments need to be planned in a sequence; that means a systematic procedure we apply when you when we take up several in vertical

exercise is this will be made very very clear; The quality improvement model emphasizing on continuous improvement in process performance. This we have been emphasizing through experimentation process, knowledge is gained through interactive approach and many iterations of the cycle; we will include the design of a experiment in the planning phase of the cycle ok.

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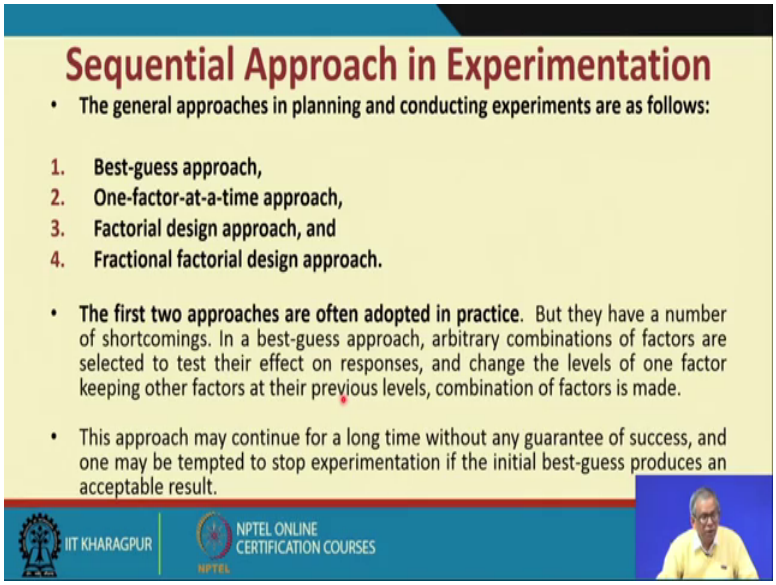

So, these are the points, you please go through all these details. In fact, and in the you know by the subsequently while we discuss the other experimental methods; so, different experimental methods.

So, what are the approaches, we will follow like say the best guess approach you can follow one factor at a time approach. So, this is you know everywhere it is followed, but it violates certain principles, later on, we will discuss factorial design approach many a time, we particularly in manufacturing situations for product development, we apply this technique and one particular fractional factorial design approach, there is a fractional factorial design approach, we apply like say you know by the Taguchi method is based on experimentation.

So, one particular fractional factorial design called the another orthogonal array. So, this particular design he proposes and this is widely used.

So, these are we will used, but there are certain problems with these approaches. So, whenever you know, we whenever you find that this is your experimental approach you need to go for the factorial design approach ok.

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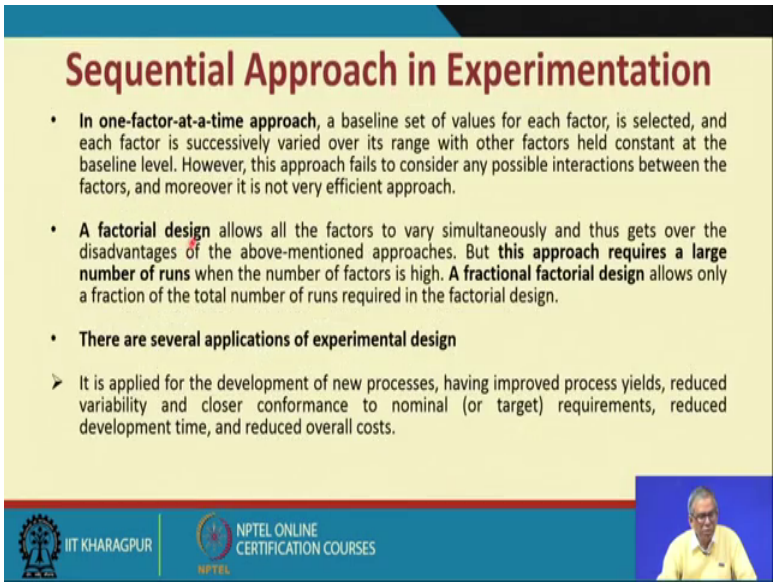

So, all these details are here and each of this one; what are the in what conditions you may apply this particular approach under what condition this is not applicable and in many of the cases, we will find that the factorial design approach is well adopted and there is a scientific reasons for its adoption in almost all the cases and that is why there are several applications of say the factorial.

Design approaches; it is applied for the development of new processes having improve process yields reduced variability and closer conformance to nominal requirements and reduce development time and the reduced overall cost.

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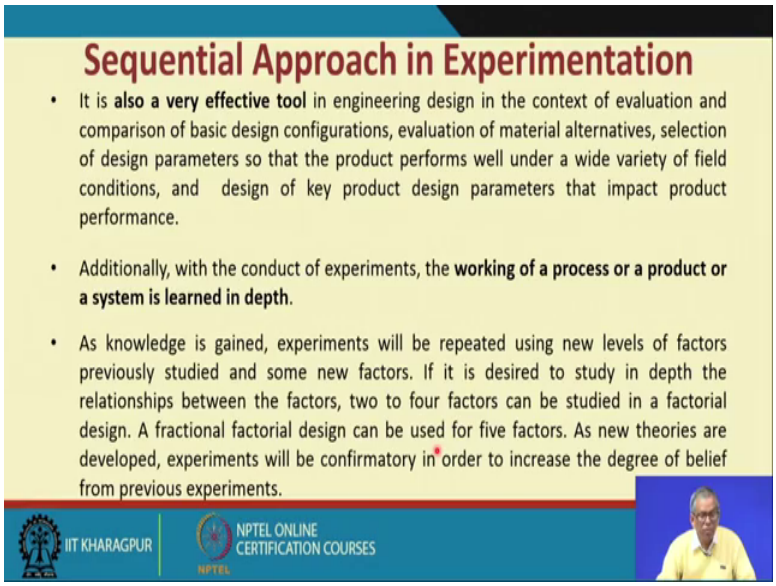

So, what we are saying that all these details we have systematically all these details please go through and. So, you have a clear cut idea that why an experiment should be conducted and through experimentation what sort of gain, you may have how to set the objectives how to identify the response variables and in subsequent lectures we will be discussing about different types of design methods. So, with the conduct of experiments the working of a process or a product or a system is learned in depth.

That is the point to be noted, is it. So, I suggest you all go through all these you know the points.

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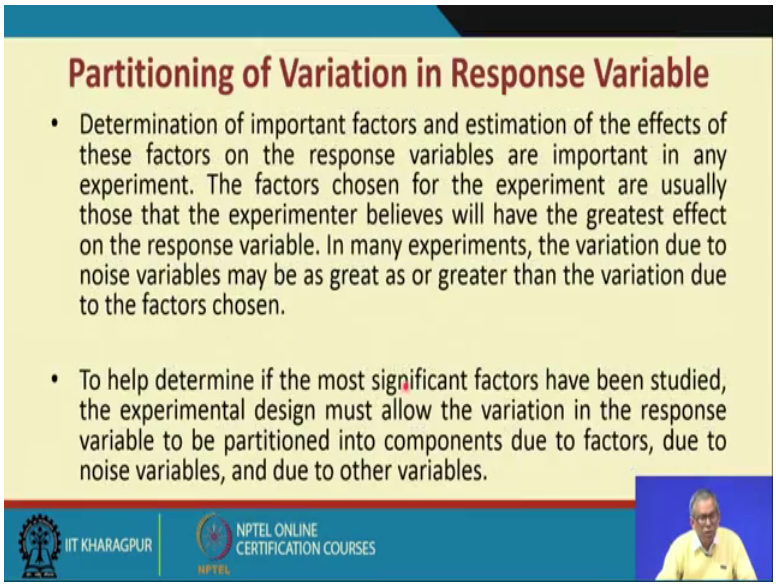

And definitely you know before you go for experimentations, you must have the background knowledge and you must have a clear cut ideas that why an experimentation is conducted to help determine, if the most significant factors have been studied that is most important and the particularly for product development stage like in the offline quality control when you referring two.

So, the experimental design must allow the variation in the response variable to be partitioned into components due to factors ok.

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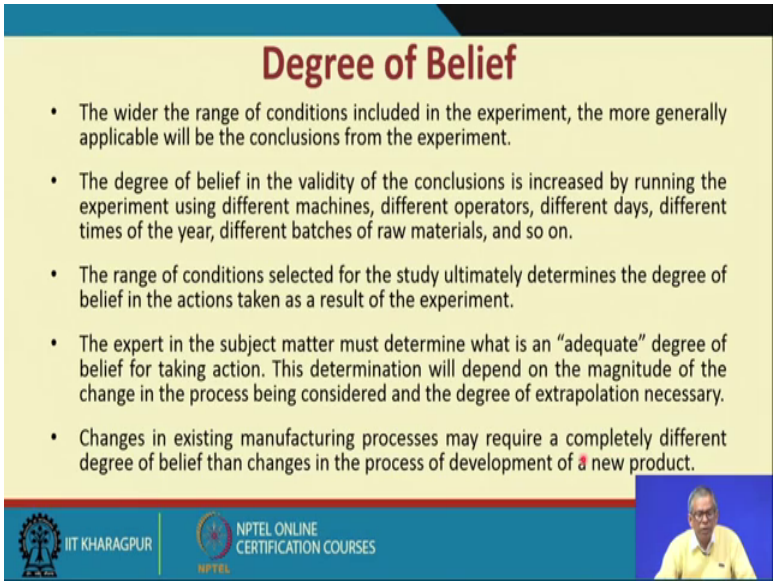

So, this is one factor that is degree of belief.

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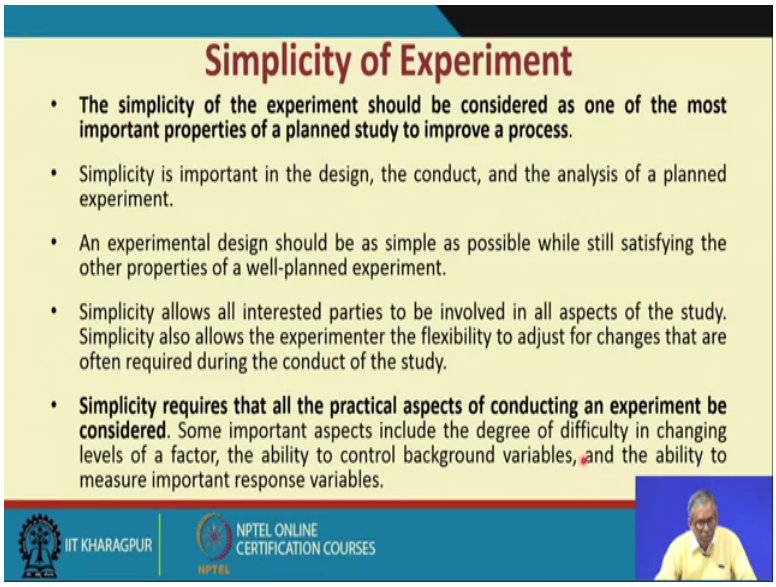

Simplicity of the Experiment.

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And so, that these are the two important factors you must believe in the means here is through experimentation, I propose a design and whenever the experimentation is if the background, you assume that the design, we will ensure the quality performance.

So, in subsequent lecture sessions we will be discussing about various types of experimental design methods.