Advanced Green Manufacturing Systems

Prof. Deepu Philip
Dr. Amandeep Singh Oberoi
Department of Industrial & Management Engineering
Department of Mechanical Engineering
Indian Institute of Technology, Kanpur

Lecture - 25
Simple Comparative Experiments

Good afternoon students. Welcome to yet another lecture of Advanced Green Manufacturing Systems course and this is a course under the NPTEL MOOC's opportunity for you guys. And this course is offered jointly it is offered from IIT, Kanpur and I am Dr. Deepu Philip from IME department, IIT Kanpur. And we have been working on for few days now on aspects of modelling, how to do optimization and how to what are the major aspects that influence the greenness of a process and stuff like that. And we slowly moved into something called as design of experiments, how do we do experimental design or how do we collect data or what is a principle behind experimentation. So, that we can collect data and use that to optimize the performance of the system.

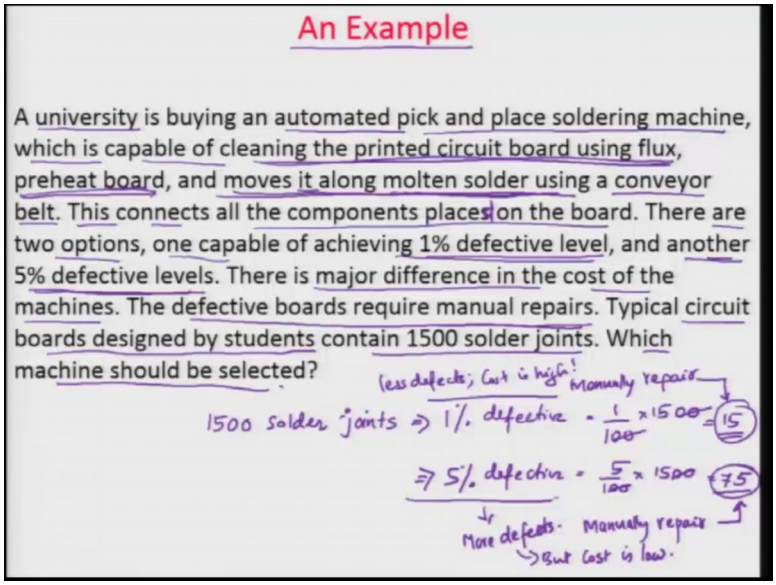
So, we are done some stuff on optimization especially the modelling and using Excel to solve the optimization and we have seen that aspects of it and now we are back to the experimental aspects of it or how the experimentation is being done. And, how will the data collected through experimentation will allow you to as set the particular value for a parameter or a factor. So, that the optimal output from the system is available. For the green manufacturing our interest is to ensure that minimize the use of energy, minimize the wastage, minimize the usage of non-biodegrade degradable cutting fluids, minimize noise, minimize health hazards, minimize ecological impacts those kind of things.

And also you we would like to add a condition saying that without compromising too much on the productivity of the system. So, then for that we will have to collect data. So, only then we can optimize the behaviour of the system and this experimental design aspect that we are learning today is towards its focused more towards its data collection procedure so that you can do optimization.

(Refer Slide Time: 02:18)

So, if you look into today's lecture on this advanced green manufacturing course or manufacturing system, the today's lecture is titled simple comparative experiments ok. And we are going to our learning agenda is start with an example and then come up with the final the reasonably good set of guidelines for designing of these experiments.

(Refer Slide Time: 02:39)



So, let us start with an example today what is going to happen and this is like a simple example which might actually help you to understand the concepts of it. So, a university or a institute is aiming at is going to buy an automated pick and place soldering machine. So, it is a soldering machine what happens is like an electric machine it takes a component, puts it there and then solders by picks and place it and then automatically

solder it. And this machine is capable which is capable this machine is capable of cleaning the printed circuit board using flux. So, it first cleans the printed circuit board using flux Printed Circuit Board is also known as PCB with this issued electronic circuits. So, it cleans the printer circuit board PCB using flux and then it also preheats the board to print is the board means printer circuit board.

So, this is the PCB board and then what happens is it moves this moves at this is the PCB moves the PCB moves it along molten solder. So, solder is like a alloy of tin and lead and stuff like that. So, it is available in a molten condition and this PCB moves this along a molten these molten solders can think of or in a bucket of it and we can moving it along using a conveyor belt. So, the system has a conveyor belt using which it actually drags this printed circuit board into the moltens melt ok. By doing this what happens? The solder will connect all the components placed on the board. So, every components that are placed on the board ok. So, this is basically connected using this solder ok.

So, this should be placed on the board ok. There are two options are available for these machines one machine is capable of achieving one percentage defective level. So; that means, whenever you are soldering, it results in only 1 percent of the solders being defective and another is capable of giving you 5 percent difficulty level. So, it is it will produce more number of defects 5 percent defects is more number of defects in this regard. There is a major difference in the cost of the machines both this machine the machine with the 1 percent defective level and the 5 percent defective level both machines of major difference in the cost ok.

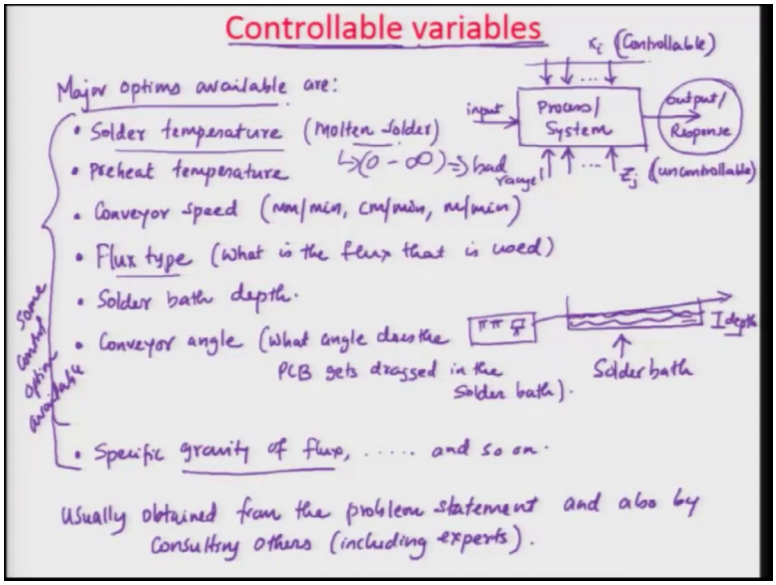
And the issue is that when a defective body is produced when the circuits are not properly soldered, then you require manual repair. So, a human being has to repair these circuit boards manually; that means, you have to pay that person salary and more the number of defects more time will be spent on repairing these boards and hence it will be more expensive. And typical circuit boards designed by students contains 1500 soldering joints. So, in one way to think about is one machine if you have 1500 solder joints, then implies 1 percent defective will be what? Will be 1 divided by 100 multiplied by 1500.

So, is 1 percent. So, you can assume that there is 15 solder joints. So, per board every board on an average, you will miss 15 solder joints. When you talk about 5 percent defective boards so, what are we talking about? It is 5 divided by 100 multiplied by 1500

ok. So, that is 15 times 5 that will be 75 right; 15 times 5 is 75 yes. So, you have 75 of these ones will be defective. So, the what this case you will you will repair or your manually repair 15 of these connections. Here you would require manually repair 75 of these connections ok.

So, this is; obviously, you can probably say that this machine gives you more defects; more defects, but cost is low this machines gives you very low cost compared to this is less defects cost is high yeah. So, the question is which machine should be selected which one should we buy or which one should the university be buying this. So, this is a very simple example which allows us to consider or look into what we call as the experimental design aspects ok.

(Refer Slide Time: 07:29)



So, the first thing that we need to think about is the as I told earlier in the optimization also, we need to think about the variables and here we are going to focus on the controllable variables. If you remember we had drawn the diagram like this, the process or the system we had the input ok; we had the output or response and we had multiple variables X i's. These are the controllable variables controllable variables and we had the Z j's uncontrollable variables alright. So, we saw the experimental design process in this.

So, in this case what we are going to first talk about is what are the controllable variables; major options of controllable variables. Major options available are available for control variables are what are those major options for us. One option is could be

solder temperature ok. Solder temperature is the molten solder how hot it is. So, we would like we are more understand the temperature of it which gives you the molten solder. So, I told you in the example that and moves it along the molten solder so, this statement. So, molten solder what is the temperature of the molten solder is what we are talking about here.

Another example is another possible option is preheat temperature ok. So, when we talk about preheat temperature what we are talking about is the machine is capable of cleaning the printed circuit board using flux then preheat the board. So, what is the preheat temperature that is something that we are interested in, it could it could be one of the options another option is the conveyor speed. So, where did I get the conveyor speed?

Conveyor speed I got it as it basically says and moves it along the molten solder using a conveyor belt. So, it is moved along the molten solder. So, the conveyor belt moves it along. So, the speed at which this printed circuit board moves along the molten solder bath is an important thing. So, what is the speed at which it is going? It can be millimetre per minute centimetre per minute or meter per minute or something like this. It could be some speed.

We do not know what the speed is and depending upon the speed it could it could depending upon how it how it actually works and we talked about another one as the flux type ok. What is a flux the question is what is the flux that is used. So, where did this flux come from ok? So, the flux actually came from it says you know cleaning the printed circuit board using flux. So, which maybe the whichever flux that use might influence a cleaning process and if it influence a cleaning process, then it might also influence the soldering. So, you might want to look into what might be the fluxer the flux type ok.

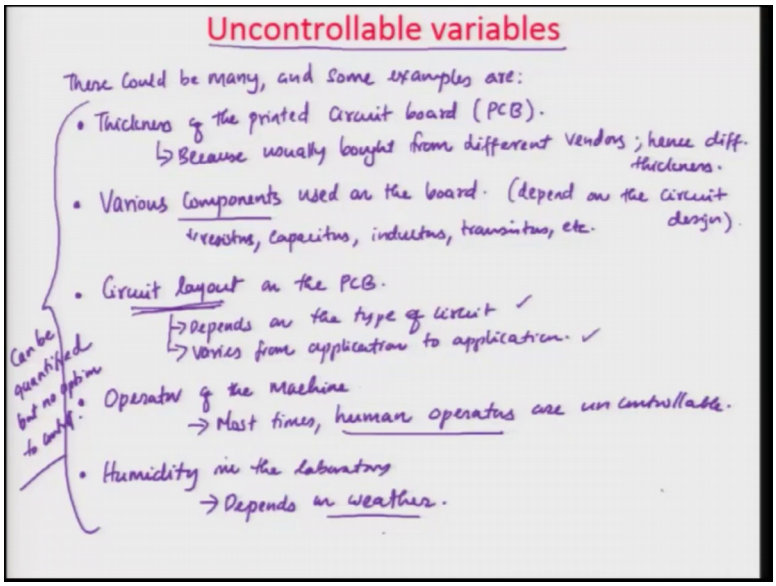
The other one is the a solder bath depth ok. So, or we can think about it does what we are talking about here is, it is basically moves it along the molten solder. So, if you think about the system a it would probably be like you have a printed circuit board coming here in which there are many components that are installed on this. It is a resistor transistor that is a capacitor with legs another things on it. And then it gets into a molten solder this is like let us say your molten solder. So, you might be interested in the depth

of this ok; how much the molten solder would be or it can also called a solder bath depth and this is your solder bath and this gets dragged along this one ok. So, that is another option right.

Then another possibility option is the conveyor angle depending upon what angle what angle does the PCB gets dragged in the solder bath. So, that is one option that we have. then we can also think about something called as the specific gravity of the flux. So, you are anyway using flux for cleaning the boards. So, what is a specific gravity or the flux has one another aspect and so on. There are so many aspects that you can do ok. I just listed some of it and the question is where did I get all these things. Usually obtained from the problem statement and also by consulting others including experts.

So, you might want to go talk to a few experts who work in this area and figure out what is going on and from there you can find out certain variables and these variables we think we can control because some option some control option is available option available ok. This includes this also all right. So, we can somehow control these variables. There is some conveyer speed there could be a dial which you can twist and then that reduces the control speed alright.

(Refer Slide Time: 14:24)



The next option that we have talked about we are still in the variables it is the uncontrollable variables ok. Uncontrollable variables is you do not have any control over these guys and there could be many could be many. And some examples are there are

some examples and the one example is thickness of the thickness of the printed circuit board or what we call us the PCB why you. Obviously, would think that why this is uncontrollable variable. Why is this not a controllable variable? Because these uncontrollable, because usually bought from vendors, bought from different vendors hence different size, hence different thickness.

So, since you mostly by this PCBs from different vendors you will probably get them in different thickness and depending upon the thickness it might impact the soldering of the or the amount of solder that is required right. And various another one could be various components various components used on the board. And so, it is like components will be you can think about as resistors, capacitors, inductors, transistors etcetera ok. You cannot control them because the reason is that these ones depending upon they all depend on the circuit design ok.

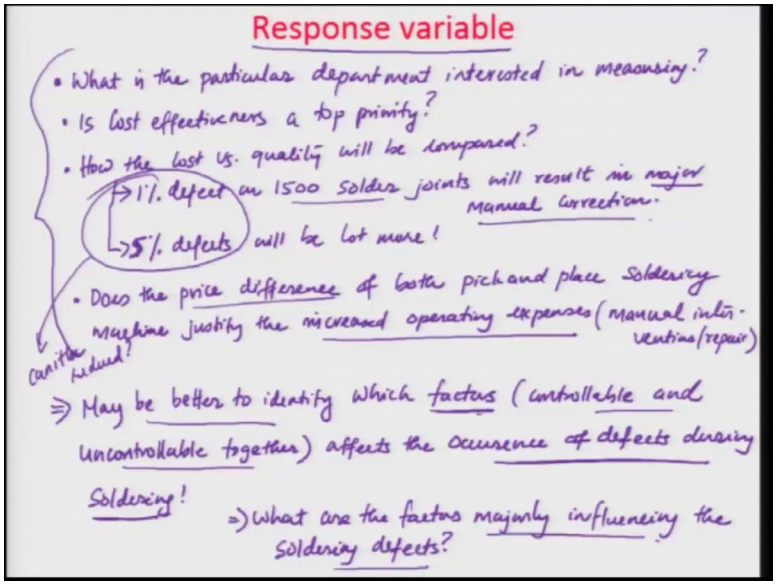
How do you design the circuit? The design of the circuit determines what are the various components, that you are going to use in this right. The other one is circuit layout on the PCB. How is a circuit laid out how no? This depends upon depends on the type of circuit varies from application to application. So, what we are saying here is that in this PCB system the circuit layout can also be a factor, but the point is you cannot control it because it is depending upon what the type of the circuit it is and what application it is being used for.

So, you have no control over it we cannot control it this circuit what comes to you as designed by somebody else. Then there is something called operator of the machine. It is very hard to control operators. Most times human operators are uncontrollable. You cannot control human operators most of the time. Now purely because of the fact, that they have their own mind and human operators do things in their own fashion. So, you cannot really do much about it right.

Then we talk about another example of this will be humidity in the laboratory. If the factory has too much of a humidity, then it is like depends on weather depends on the weather ok. So, whatever the weather is the humidity is influenced by that you cannot control the weather. So, it is like something that is given to you and you have to work within that particular humidity ok. So, all these factors can be measured can be quantified, but no option to control. You cannot control these factors at this point. So,

because they are available there, you can measure it, you can quantify it, but you cannot control it.

(Refer Slide Time: 19:28)



Then we talked about the last variable which is called as the response variable. So, the response variable is the output or for that matter in the previous diagram if you think about it, we are talking about response variable as this. So, what is how do you decide that response variable ok? So, one other thing that is the usual question that we ask is what is the in this case it is what is the particular department interested in measuring or the industry in measuring how many defects are there in the circuit board or are they interested in measuring the cost of the system?

So, that that is one question that they are that is usually tell you what is the a what is the response variable is cost effectiveness or top priority is caused a major priority here or is quality more important. How the cost versus quality will be compared ok? The question here is we are going to compare how are we going to compare the cost versus quality right. One aspects of it is one percent defect on 1500 solder joints will result in major manual touch up manual corrections. So, if you get 1 percent defective one 1500 solder joints, you allow to have major manual intervention to solve it ok.

So, then the next part is 5 percent 5 percent defects will be lot more ok. There will lot more manual touch up that you will require in this case. So, the other thing you can think about is does the price difference of both machines both pick and place soldering

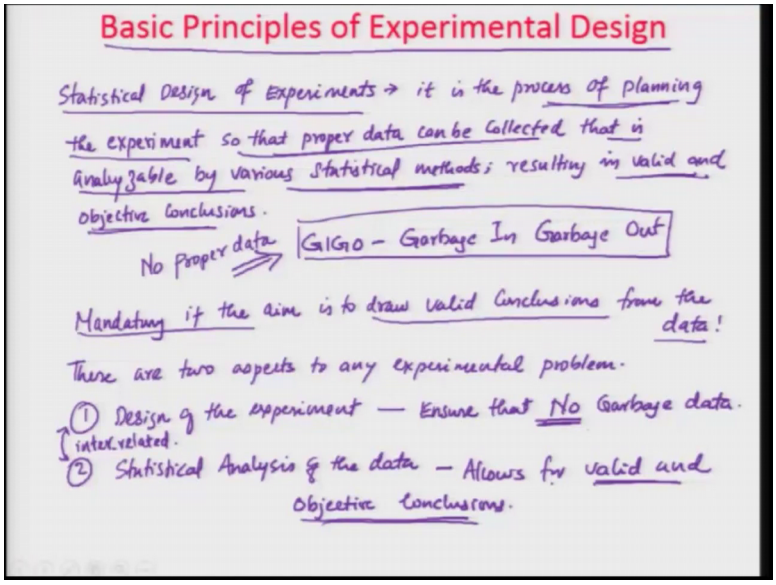
machine justify the increased operating expenses crediting operating expenses. And where is the operating expenses coming from? Manual interventions or manual repair or repair of the solder is the manual the by paying that much money more to an individual is this justified is this increasing operating expenses, justify the price difference between both these machines right.

So the there are many questions that you can come up with and from there you can decide what is going to be what is going to be the response variable. One way to think about it is you can think about us maybe better maybe better to identify which factors controllable and uncontrollable together; controllable and uncontrollable together affects the occurrence of defects occurrence of defects during soldering. So, what we are saying here is maybe instead of looking into all these kind of things all these aspects it may be better for us to identify which are the factors both controllable and uncontrollable together affects the occurrence of defects in soldering or the defects in soldering what are the causes of that what are the factors that are causing that.

So, what are the factors majorly influencing the soldering defects ok. So, one way to think about is if we can somehow control the defects on soldering ok. If this 1 percent 5 percent defects ok; if this can be reduced can it be reduced or what is causing these defects. If we can understand that and try to solve that problem from that side, then the problem of which machine to buy would probably be a that this could be a better problem that we can state in that way.

So, the response variable is always dependent upon what is the criteria or what is the what is a aim of the experiment that or what you are actually trying to do. But remember the response variable is not set in concrete you might start with a response variable as then time progresses you realize thats not the right thing to do and then you typically go back and change thats why experimentation is an iterative process or it is a process that you repeat frequently

(Refer Slide Time: 25:45)



So, let us go back to the basic principles of experimental design and now what we are going to do is we are going to go through what are the major guidelines of designing an experiment and how are we going to achieve that ok. So, the first thing that you need to understand the term is a statistical design of experiments; statistical design of experiments ok. So, this term what is this statistical design of experiments ok; it is the process it is the process of planning the experiment.

It is a process of planning the experiment the experiment so that proper data can be collected. So, that proper data can be collected can be collected. So, it is first the planning of the experiment. So, that proper data can that be collected that is analysable by statistical methods by various statistical methods statistical methods, resulting in resulting in valid and objective conclusions.

So, the statistical design of experiments it is the process of planning the experiment ok. So, you are planning the experiment. So, that why do you need to plan the experiment? So, that proper data can be collected the main aim is to collect data in the proper collect proper data that is analysable. So, the reason of is you collect the data that is analysable by various statistical methods right and once you have proper data that can be analysed by different statistical method, you can draw valid and objective conclusions.

So, remember here this phrase Garbage In Garbage Out. So, if you do not collect data; if you do not collect proper data no proper data if you do not have proper data, then you will get garbage out of the system ok. So, you plan the experiment you how to plan the

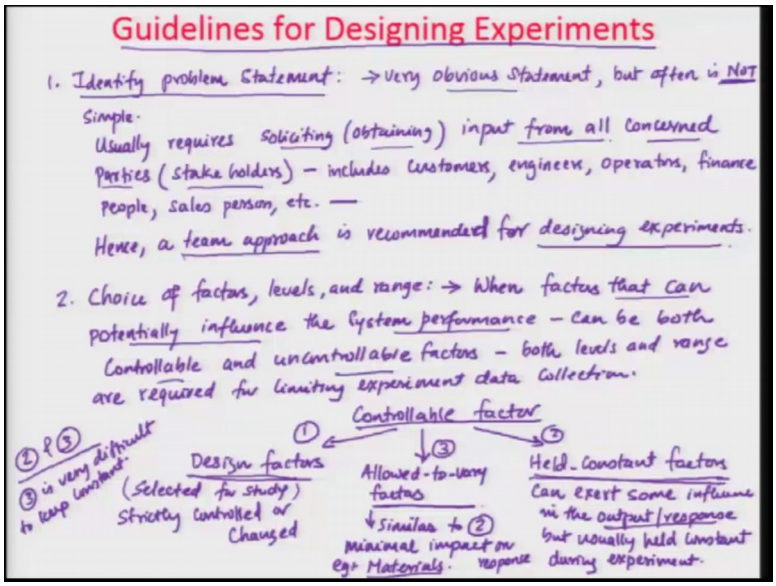
experiment. So, that proper data is collected that is analysable very various statistical method so that you can draw valid and objective conclusions from the data ok. Mandatory if the aim is to draw valid conclusions from the data. If you are just doing an experiment for the sake of experiment, then probably statistical experimental design is not a big deal.

But if you want to draw valid conclusions from the data; if that is the aim for you have, then statistical design of experiments is a mandatory thing. And there are two aspects to any experimental design to any experimental problem ok. There are two aspects to any experimental problem. Number 1 design of the experiment and number 2 is the statistical analysis of the data analysis of the data ok. So, the design of the experiment is what you do is it is ensure that no garbage data.

So, this design of experiment or experimental design or design of experiment ensures that you are not collecting any garbage data and statistical analysis of data it allows for valid and objective conclusions ok. So, you cannot draw valid and objective conclusions if you do not have proper data. So, these two steps are interrelated. So, you can say that the steps 1 and 2 are inter related.

You cannot have one, if you do not have the other ok. So, if you do a garbage data, then you cannot draw valid and objective conclusions. If you do not have a proper statistical analysis; if the data is not collected in the format that you can apply statistics, then you cannot draw a conclusion. So, what data you collect and which format you are going to analyse it is quite important in this case ok.

(Refer Slide Time: 31:23)



So, now we get into what we call as guidelines for designing experiments ok. How are we going to design experiments right? So, the step one the first step in this regard is identify problem statement ok. So, people say this is the first thing you need to do ok; identify the problem statement very obvious statement. It appears to be an obvious statement, but often is not simple ok. So, when somebody says identify the problem say it is looks like is obvious is very simple, but often it is not it is usually not a simple thing to ok. Usually requires usually requires soliciting of information or soliciting or obtaining input usually require soliciting or obtaining input from all concerned parties all concerned parties.

The better term for this is stakeholders. This includes customers, engineers operators finance people salespersons etcetera. So, you how to take input from as much as possible whenever wherever you can get inputs from all concerned parties or all stakeholders you are to collect input it is a. So, before you identify the problem statement you have to solicit or you have to obtain input from all your stakeholders.

So, in the so this may implies what hence a team approach team approach is recommended for designing experiments for designing experiments. Since you have to have all this information solicited from different places is recommended for ok. So, we it is usually recommended that a team approach is followed where you create large multiple multi discipline teams and you solicitate information from those teams. So, that

is a first part e this it appears to be an obvious statement, but it is not an obvious statement. Then comes the second aspect second are part of this one. So, that is we call it as choice of factors levels and range and range.

So, what we are doing here is when potential factors when factors that can potentially influence potentially influence the per system performance the system performance. When you are considering those factors that can potentially influence a system performance can be both controllable and uncontrollable factors. When factors that can be potentially influence a system performance, then when you are looking into this factors when the factors that can potentially influence you think that it can influence a performance of the system can be both controllable and controllable factors both levels and range are required for limiting experiment data collection.

So for example, if you say in the previous case one of the controllable factors was solder temperature right. If I take the temperature range as 0 to infinity, then bad range because you wanted to limit it to something. So, that you can actually control that value and you can collect appropriate data to do the analysis right. And mostly controllable factors; they are divided into two number 1, number 2 ok. 1, the first one is called as design factors and the number 2, the second one is called as held a constant held constant factors. So, the major two divisions are design factors and held constant factors. So, the design factors are they are selected for study ok. You use them for study and the held constant factors are can exert some influence in the output or response.

It can do some influence on the output or the response but usually held constant during experiment. Why are you keeping it constant? Because the impact on the response the impact on the output is usually much low hence you really do not want to vary them during this study. So, you keep them as constant values. There is a third thing that you can think about. It is also there which is called as allowed to vary factors allowed to vary factors ok. So, these are the selected for study and they are strictly controlled.

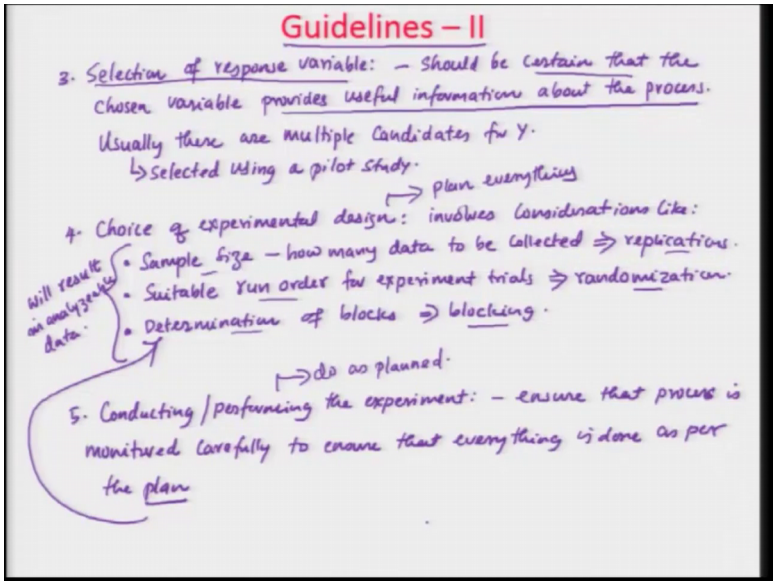
You basically strictly controlled or changed the values are strictly controlled and changed in this regard. In this case they are held constant the held constant factors because they exert very minimal influence on the output of the response and they are kept constant. The thus cases, they are similar to held constant similar to two held constant minimal

impact that is not how much impact on the output or the response the major difference between this is the major example of this is materials ok.

You cannot control the materials that much may you say I am going to make bronze and I am going to use it. But if it is an alloy, then the composition of the alloy can vary from place to place. So, you cannot really control, it you cannot hold it constant. So, the so the difference between 2 and 3 ok; 3 is very difficult to keep constant ok. So, though most of the people consider as 1 and 2 design factors and held constant factors as the most important thing.

There are certain factors a small very small set of factors. They are they have very minimal impact on the output very minimal impact on response, but you cannot really control them or you cannot keep them constant hence you allow them to vary. So, that is the classic example of this is the materials aspect of it right. So, we gone through two of the a two of the major guidelines of the designing of experiments.

(Refer Slide Time: 40:57)



Now let us look at the further set of guidelines in this regard. So, the third one basically we say is selection of response variable; selection of response variable. So, how are we going to select the response variable ok? We have to say we should be certain should be certain that the chosen variable the chosen variable you should be very particular we should be certain that the chosen variable provides useful information provides useful information about the process.

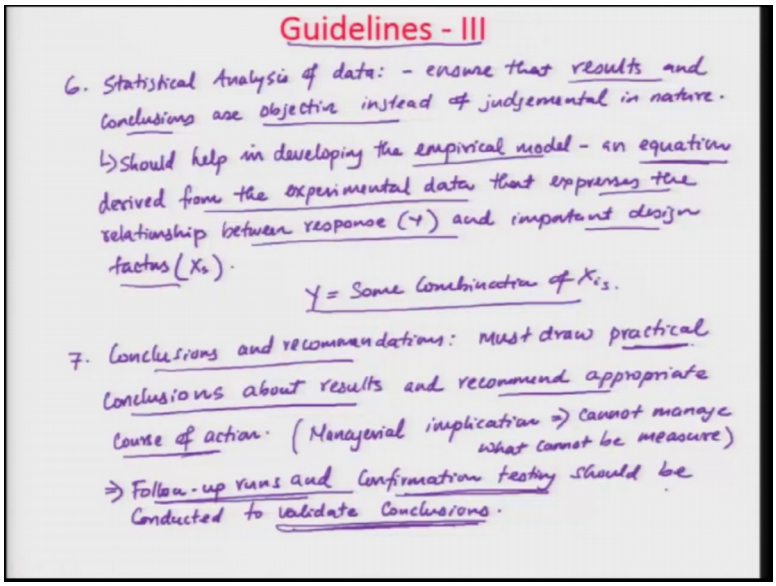
So, the first check in this case is we should be certain that it provides useful information about the process. The information that is about the process should be useful. So, that you can make conclusions out of it right usually there are multiple candidates multiple candidates for y ok. Remember Y is the know you use y to denote the response variables, then how do we select them? Selected using a pilot study.

We do a pilot analysis or a pilot run of the experiment and the pilot study is typically used to decide which is the better one, which is the better candidate that provides the most useful variables in this regard response variable; then the fourth one, choice of experimental design. Now, we are we are ready to collect the data and since we are ready to collect data, we have to involves considerations like there are certain considerations that you have to do in this case. The first consideration is sample size ok which is how many data to be collected or this transfers to what we called as replications ok; how much of data that you need to collect in this regard.

Second one is the suitable run order of the suitable run order for experiment trials ok. We have to decide in which order you are going to collect the data this is called as in a wait translates to what we call as randomization ok. And then last one is determination of blocks of blocks or what we call us blocking. Remember we told in the previous presentation replication randomization and blocking are the three fundamental aspects of experimental design and same thing comes here or decide in the form of sample size the run order and what are the blocks. The reason is that these will result in analysable data ok. We can how the data that can be analysed out of this that is the major reason why we do it this fashion.

Now, the fifth one ok, conducting or performing the experiment or performing the experiment; here conducting or performing the experiment where we do is that ensure that process is monitored carefully to ensure that everything is done everything is done as per the plan ok. And where is the plan? Plan is this ok. So, when you choice the experimental design you plant this. So, here is you this one is plan everything and do as planned that is what happens in this case all right. So, once this is done what we do is we get into the third set of guidelines for the experimental design.

(Refer Slide Time: 46:20)



This is kind of the last set of guidelines and the two more of them sixth one ok. What we do is statistical analysis of data statistical analysis of data. So, where we are doing is ensure that ensure that results and conclusions results and conclusions are objective are objective instead of judgmental instead of judgmental in nature ok. So, what you have to do is the statistical analysis allows that the results and conclusions are objective instead of the subjective or the judgmental in nature; should help in developing the empirical model. Remember we said this empirical model is required for us to optimize things or work on it ok.

So, what is the empirical model? An equation an equation derived from the data derived from the experimental data ok. You are deriving this equation from the experimental data that expresses the relationship expresses the relationship between response that is Y and important design factors important design factors ok. These are your Xs. So, what you do is you develop an equation you develop the empirical model which is an equation that connects the experimental data. This equation is coming from the experimental data and what it does is it expresses the relationship between y and the important design factors.

So, as I said y here you get Y as some combination of X of Xs X is ok. So, that is what we are more interested in doing here in this part of this one and then is the last part the seventh step right is conclusions and recommendations conclusions and recommendations. Now you think that is very easy to do not necessarily the conclusions

and recommendations. The important thing for us is must draw practical conclusions practical conclusions not just any conclusion; the qualifier word is we must be able to draw practical conclusions about results.

So, practical conclusions about the results should be drawn and recommend appropriate course of action. We should recommend not just draw conclusion, we should also recommend a course of action right. So, you should be you should be told this is the in a way you can say it is the managerial implication. The managerial implication is cannot manage what cannot be measured. So, if you cannot measure it, you cannot manage it that is the fundamental idea behind this. So, we are trying to ensure that we measure it; so and so that we know what is a course of action right.

Then finally, also is that you can say that follow up runs follow up runs and confirmation testing confirmation testing should be conducted to validate conclusions ok. So, we should follow up the runs and we should do confirmation testing. Once we did the analysis and we say oh, we are done we got this y equal to some combination of Xs. We built our model, but we should follow it up with a follow up runs and confirmation testing to ensure that our conclusions are valid our conclusions are valid and practical and the recommended course of action is correct in this regard.

So, summarizing this we reached the end of our presentation, but summarizing this what we are saying is that we found out why we do experimentation and why the experimentation the planning to collect the data and the proper format. So, that you can use statistical tools to analyse this data why is it important and so what is it necessity of drawing valid and practical conclusions and recommending a dew course of action is important thing for us.

And in this case the dew course of action is how to convert an existing manage manufacturing facility into a green manufacturing facility or how do you design a green manufacturing facility as a fresh one. With this we conclude today's presentation and expect you guys to read through this follow it up and keep practicing the experimental design aspects of this course.

Thank you very much.