Design For Quality, Manufacturing And Assembly
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Lecture - 17
Paper Helicopter Case Study – Part 1

So, welcome back. Today, as I promised we will be discussing about a Case Study. This is not a real life case study. This is more of a tutorial case study, if you were to learn applying orthogonal array for a design perspective. As we have discussed you are aware that you need to be able to repeat designs, different types of designs; the function should be the same. So, what might be a cost effective way to come up with the different designs? If I am giving you a product design; then, there is some cost that is associated with it even if you have to do 24 experiments.

You put a cost to each of the experiments it is like 1000 rupees; still you will have to spend about 24000 rupees to understand that part of it. Instead this example is about a Paper Helicopter, but it is very interesting. Because there are few parameters in the helicopter that you can adjust and accordingly the responsible change. So, the attributes are the factors will be the parameters. The response in our case is the flight time. I am going to run through this Paper Helicopter experiment using this particular paper.

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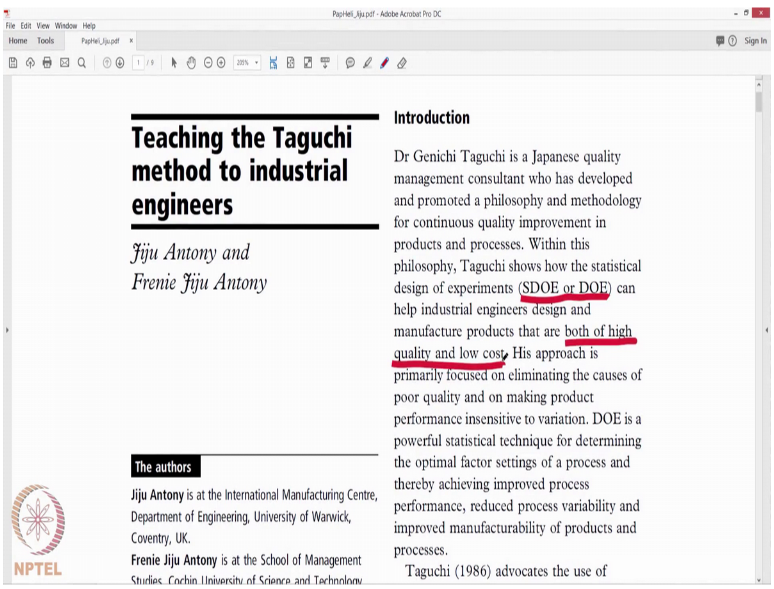

The author of this paper is Jiju Antony and Frenie Jiju Antony. This came out in a journal called Work Study.

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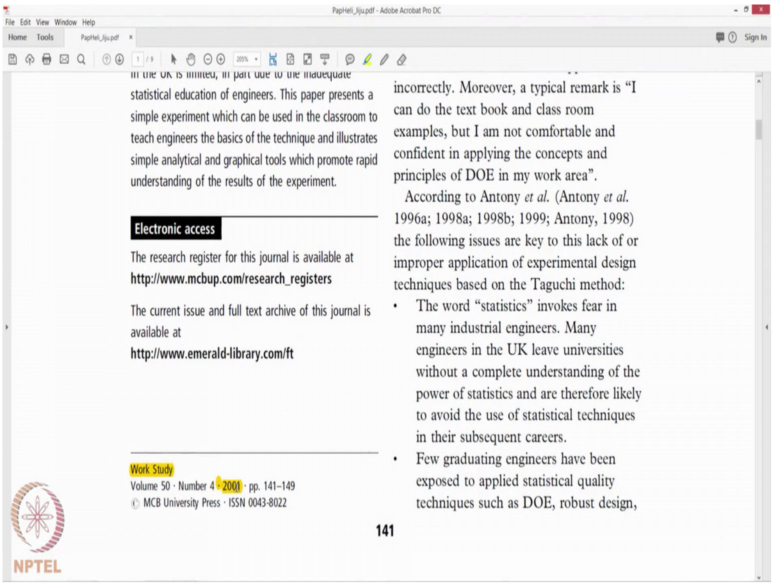
in the UK is limited, in part due to the inadequate statistical education of engineers. This paper presents a simple experiment which can be used in the classroom to teach engineers the basics of the technique and illustrates simple analytical and graphical tools which promote rapid understanding of the results of the experiment.

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incorrectly. Moreover, a typical remark is "I can do the text book and class room examples, but I am not comfortable and confident in applying the concepts and principles of DOE in my work area".

According to Antony *et al.* (Antony *et al.* 1996a; 1998a; 1998b; 1999; Antony, 1998) the following issues are key to this lack of or improper application of experimental design techniques based on the Taguchi method:

- The word "statistics" invokes fear in many industrial engineers. Many engineers in the UK leave universities without a complete understanding of the power of statistics and are therefore likely to avoid the use of statistical techniques in their subsequent careers.
- Few graduating engineers have been exposed to applied statistical quality techniques such as DOE, robust design,

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Yeah, this is came out in a journal called Work Study in the year 2001. This is a fairly old paper, but however, it is a tutorial and it is applicable until orthogonal array lives and until we teach robots design, you can follow this paper because it is a tutorial and it holds good.

So, we will see the organization of the first, what is that title of this paper. It says teaching the Taguchi method to industrial engineers. The paper is based on the premise that industry necessarily needs to use Taguchi techniques to benefit. However, there is a resistance from the industrial engineers for using that. So, this will serve as an enabler for them to use the Taguchi techniques. So, that they know the advantage.

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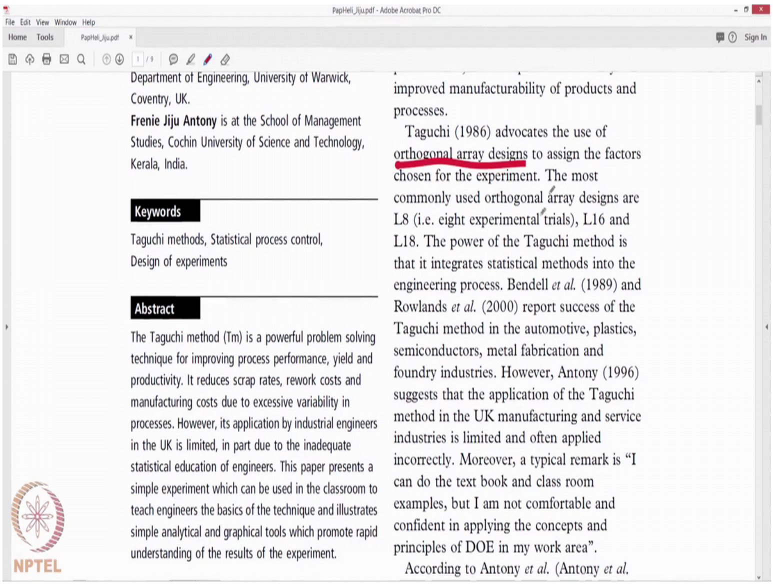
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Keywords

Taguchi methods, Statistical process control, Design of experiments

Abstract

The Taguchi method (Tm) is a powerful problem solving technique for improving process performance, yield and productivity. It reduces scrap rates, rework costs and manufacturing costs due to excessive variability in processes. However, its application by industrial engineers in the UK is limited, in part due to the inadequate statistical education of engineers. This paper presents a simple experiment which can be used in the classroom to teach engineers the basics of the technique and illustrates simple analytical and graphical tools which promote rapid understanding of the results of the experiment.

improved manufacturability of products and processes.

Taguchi (1986) advocates the use of orthogonal array designs to assign the factors chosen for the experiment. The most commonly used orthogonal array designs are L8 (i.e. eight experimental trials), L16 and L18. The power of the Taguchi method is that it integrates statistical methods into the engineering process. Bendell *et al.* (1989) and Rowlands *et al.* (2000) report success of the Taguchi method in the automotive, plastics, semiconductors, metal fabrication and foundry industries. However, Antony (1996) suggests that the application of the Taguchi method in the UK manufacturing and service industries is limited and often applied incorrectly. Moreover, a typical remark is "I can do the text book and class room examples, but I am not comfortable and confident in applying the concepts and principles of DOE in my work area".

According to Antony *et al.* (Antony *et al.*

One of the basic arguments that the author presents is the moment you start talking about statistics and probability, engineers are not very comfortable because that is not necessary part of their engineering curriculum. Even in our case I guess in one of your math course in the early semesters, you discuss a little bit about probability and statistics and that to predominantly your rolled die rolling and all that is it right. Some linear algebra course you are supposed to have a probability component also, not always they teach that ok. So, it is very interesting because this is a common course across different departments; computer science, mechanical, electrical, metallurgy for everyone.

For some departments like computer science, the statistics and probability becomes very important; even electrical, for that case any department mechanical electrical statistics and probability becomes important in at least 3rd year. So, usually the student suffer without the underlying knowledge and as a result of which we spend enough amount of time like anywhere between 2 to 3 weeks trying to explain the basic concepts and then, take you through the concepts on the application concepts.

So, that it is you know we are not alone; that is the only positive thing that we have in the that is good thing that we have; you are not alone that seems to be the case across the world at least in 2000; that is what this paper says. So, you can you know you can make a note of this paper and then, it is free for download. If not you can ask and I will tell you the link from where you can download and this is available. And there are different versions of this whichever version you read this also fine ok.

So, if you look at the introduction to begin with it starts with who Taguchi was and what he did. So, basically he promoted of philosophy and the methodology for continuous quality improvement. So, he talks about the design of experiments. How it will use the industrial designers to manufacture products that are of both high quality and low cost? It is a combination; it is a conflicting objective, if you see it is a trade off always. So, this is a point that you need to you are able to see the font right ok. This approach is primarily focused on eliminating the causes of poor quality on making product performance in sensitive to variation.

The point is we are talking about insensitive variation which is the underlying idea for robustness and then, he talks about DOE being powerful statistical techniques for identifying the optimal factor settings that is what he says here, optimal factor settings. And thereby, achieving improved process performance. Then he kind of briefly introduces something that we have already discussed. Let us see, what they are talking about, Use of orthogonal array to design, to assign the factors chosen for the experiment L8, L16 he talks about.

Then, there is a little bit of literature that people are discussing. Rowland's report success of Taguchi methods in different applications; if you see these are the different applications that the application of Taguchi method in the manufacturing and service industries often applied incorrectly yeah. So, I can do it in the text book and classroom example, but I am not comfortable and confident in applying the concepts at work. This is the basic motivation for this paper. So, we will give you a simple enough example that will have multiple factors and when you change those factors it will affect your response.

How will you use design of experiment to choose a combination of these variables or factors in a sense, I will put a false cost hood; I will say each of your helicopter is going to cost about 1,000,000 rupees. So, you want to build as many less helicopters as you want. Always you can go and validate the original are the exact by building as many helicopters as you want. So, that is the basic idea for this one. Then this Antony himself or herself have written lot of papers you know, there is a series of papers that they have done. What they say is this these are the basic points that they believe why engineers are not able to engineering's in the industry are not able to or not willing to use not willing to use the DOE as statistics.

So, as I pointed out earlier, he says the word "statistics" invokes fear in many industrial engineers. He talks about the UK universities. They leave the UK universities without complete understanding of the power of statistics and therefore, likely to avoid. So, the best place to learn is the best place to learn is your college ok. So, if you donot learn here, it is very unlikely that you are going to learn things I mean of course, you go to a job, you will have to find things to learn there; but something that you are expected to learn out of college, you better learn here. That that is what the first bullet means ok; no one is going to teach probability and statistics, you will have to learn by yourself if you step out of the college without learning that.

Sometimes these graduating engineers are exposed to techniques such as design of experiment, robust design etcetera.

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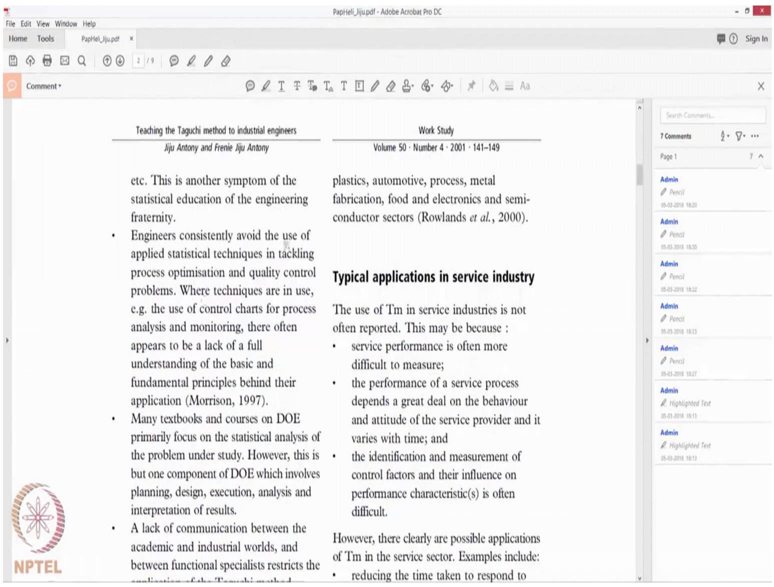
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etc. This is another symptom of the statistical education of the engineering fraternity.

- Engineers consistently avoid the use of applied statistical techniques in tackling process optimisation and quality control problems. Where techniques are in use, e.g. the use of control charts for process analysis and monitoring, there often appears to be a lack of a full understanding of the basic and fundamental principles behind their application (Morrison, 1997).
- Many textbooks and courses on DOE primarily focus on the statistical analysis of the problem under study. However, this is but one component of DOE which involves planning, design, execution, analysis and interpretation of results.
- A lack of communication between the academic and industrial worlds, and between functional specialists restricts the

plastics, automotive, process, metal fabrication, food and electronics and semi-conductor sectors (Rowlands *et al.*, 2000).

Typical applications in service industry

The use of Tm in service industries is not often reported. This may be because :

- service performance is often more difficult to measure;
- the performance of a service process depends a great deal on the behaviour and attitude of the service provider and it varies with time; and
- the identification and measurement of control factors and their influence on performance characteristic(s) is often difficult.

However, there clearly are possible applications of Tm in the service sector. Examples include:

- reducing the time taken to respond to

But that is just a part of it. Engineers consistently avoid using these applied statistical techniques. For instance, if they use there are in the manufacturing industry. They use something called the Control charts. This CP CK ok. In those kinds of situations, what happens is they are only looking at the chat and they might not have a deep understanding of war or how it comes from.

But they know how to use it. They will say the moment the chat crosses, this line it means it cannot cross more than 3 times; if it crosses more than 3 times, then there is some issue with the process. They might not know the underlying physics behind the CP the CK curve and things like that. So, that is the last point ok. They might lack of a full understanding of the basic in the fundamental principles behind their application. So, this is not something that he is claiming, but someone else has written either part of a paper or a book he is just referring to that.

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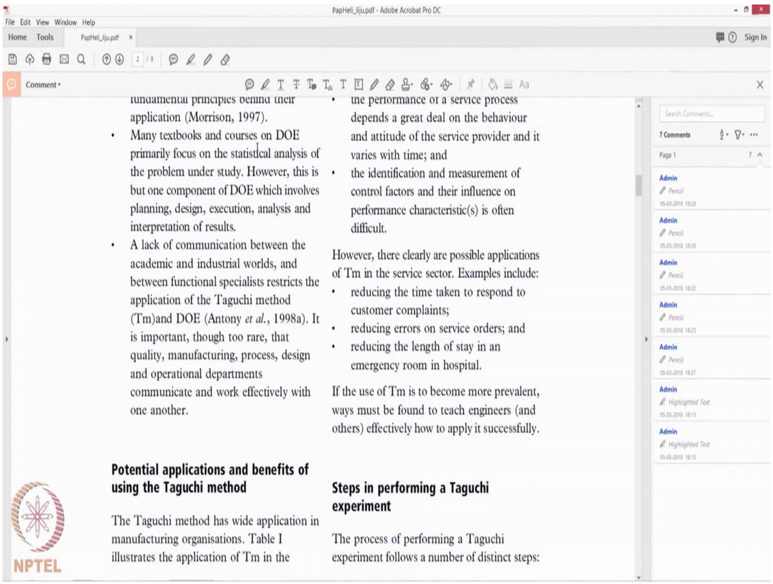

And often times what happens is there are some text books and courses on design of experiment, they focus primarily on the statistical analysis of the problem under study.

But this is only one component of the DOE ok; whereas, you need to be able to do the planning, the design, the execution and inference that become very important. I just tell you this is a DOE, you used to get the responses its only one part of the game; how are you going to analyze; you have a set of responses you do an SN ratio you want to find an optimal combination; how do you ensure that it is an optimal combination? Though there are multiple questions that you need to be able to answer. So, these are the stuff.

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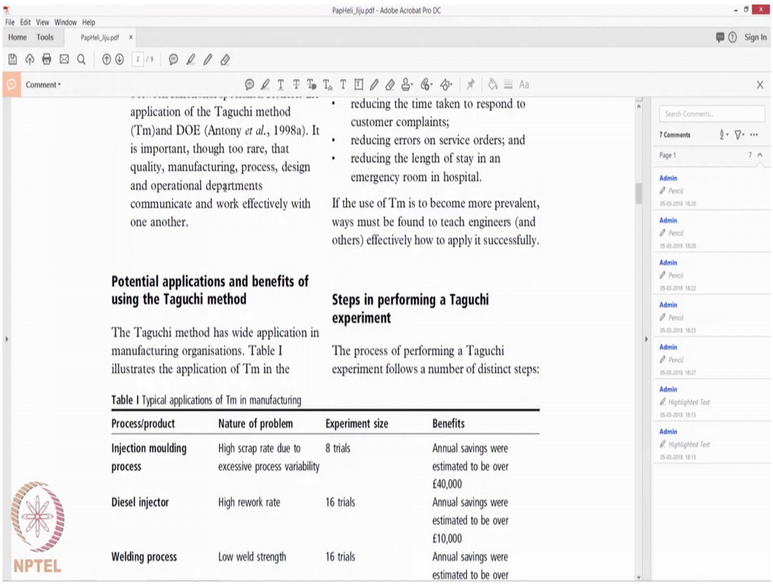

application of the Taguchi method (Tm)and DOE (Antony *et al.*, 1998a). It is important, though too rare, that quality, manufacturing, process, design and operational departments communicate and work effectively with one another.

Potential applications and benefits of using the Taguchi method

The Taguchi method has wide application in manufacturing organisations. Table I illustrates the application of Tm in the

- reducing the time taken to respond to customer complaints;
- reducing errors on service orders; and
- reducing the length of stay in an emergency room in hospital.

If the use of Tm is to become more prevalent, ways must be found to teach engineers (and others) effectively how to apply it successfully.

Steps in performing a Taguchi experiment

The process of performing a Taguchi experiment follows a number of distinct steps:

Table I Typical applications of Tm in manufacturing

Process/product	Nature of problem	Experiment size	Benefits
Injection moulding process	High scrap rate due to excessive process variability	8 trials	Annual savings were estimated to be over £40,000
Diesel injector	High rework rate	16 trials	Annual savings were estimated to be over £10,000
Welding process	Low weld strength	16 trials	Annual savings were estimated to be over

So, you can actually go through the paper for a better understanding. I will not be able to cover each and every sentence. But the interesting part of this paper is also it tells you why an orthogonal array based robust design driven quality for design or rather design for quality is an important stuff. Mainly from a cost perspective for any manufacturing company and they give you ample examples here.

So, we will see for instance he says a the service industries do not reported and there are some reasons why he believed that they donot report it. However, there clearly are possible applications in the service sector reducing the time taken to response to customer compliance ok. Today, Six-sigma based ideas are not only for manufacturing industry. Within an organization, within a large corporation; even choosing a software that a multiple software for doing the same thing.

Let us say that you want to do a structure analysis. Today, right now if you ask me I can name about 10 softwares. How do you choose which software to invest because this is a huge investment? Today, this company there these licenses, they donot come for free this is a huge investment. So, they want to decide which software to buy.

They are not going to go and ask the manager, what software do you want? What they do is they have a systematic procedure; it is a Six-sigma procedure where in people are used to people are asked to use this in different softwares and they will have to give their feedback on what features or what software is important and what features or what softwares are good and why they think why they believe that they need that?.

Then, they will forecast their requirement. For instance, certain softwares are promoted for x application, the software is good; for y application, the software is good. We have the then they might be able to they should be able to forecast; what type of clients or businesses they will get in the future and accordingly, they will choose the software. So, that is one thing and the ease of use and lot of things are there; the ability to incorporate new scripts into an existing code that could be one of.

So, based on all these things there rank the softwares and then, they choose. So, that the process in which this is whole thing happen this is the Six-sigma process. So, today it is not only. So, that is what this paper is about like 17-18 years ago right. Now predominantly in the service industry also people are using Six-sigma yeah.

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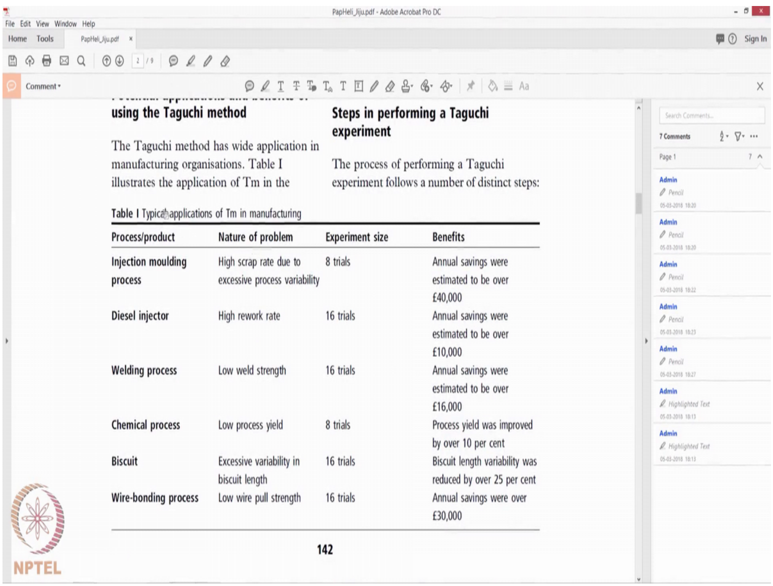

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Welding process	Low weld strength	16 trials	Annual savings were estimated to be over £16,000
Chemical process	Low process yield	8 trials	Process yield was improved by over 10 per cent
Biscuit	Excessive variability in biscuit length	16 trials	Biscuit length variability was reduced by over 25 per cent
Wire-bonding process	Low wire pull strength	16 trials	Annual savings were over £30,000

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So, if you see here what he talks about this typical application in manufacturing; they just give some examples, where people have saved money. If you look at that someone has used an injection molding process. What did they do? High scrap rate due to excessive process variability since there was lot of process variability. This is similar to our tile example.

The components that came out did not mean the specification. Hence, they had to be discarded. So, there was a high scrap rate; how many experiment sizes did they use? 8 trials; only 8 different settings they tried. Of course, there is a cost involved in it because they might have tried different dies. There is a significant investment in that, but they did only 8 trials and look at the benefits that they got? Annual savings were estimated to be over 40000 Euros. This is way back about 18 years ago. Even today, this is a significant amount in a similar fashion, you can see some wire bonding process; the annual savings were about 30000.

So, this is Biscuit; excessive variability in the biscuits length. This you cannot have because they need to be packed right. The biscuit need to even today if you see these biscuits; they are not necessarily of the same size. There is always some tolerance, if you see the biscuit packets are usually lose and if you actually arrange them, they will look to be the same. That is the way that they are arranged ok, but they are not of the same size always that could be because of this some process variability could be there and they have used only 16 trials here.

And then, the biscuit length variability was reduced by over 25 percent ok. Interestingly, what happens is there is no guarantee after all this trial that you will benefit in terms of cost; but for sure, you learn out of the process. You will at least figure out the these are the factors that contribute and you cannot do anything about those factors that will at least that learning will be there.

So, this trials are the DOE that we talk about is a systematic scientific way to deal with those problems are rather address those problems not deal with those problems is to address those problems. You can always figure out that you cannot find a solution for that it will only take a shot at the problem. So, they give this paper more from design perspective if you were to use design of experiments for a new product development. What are the different steps that you will follow, they discuss each step one by one.

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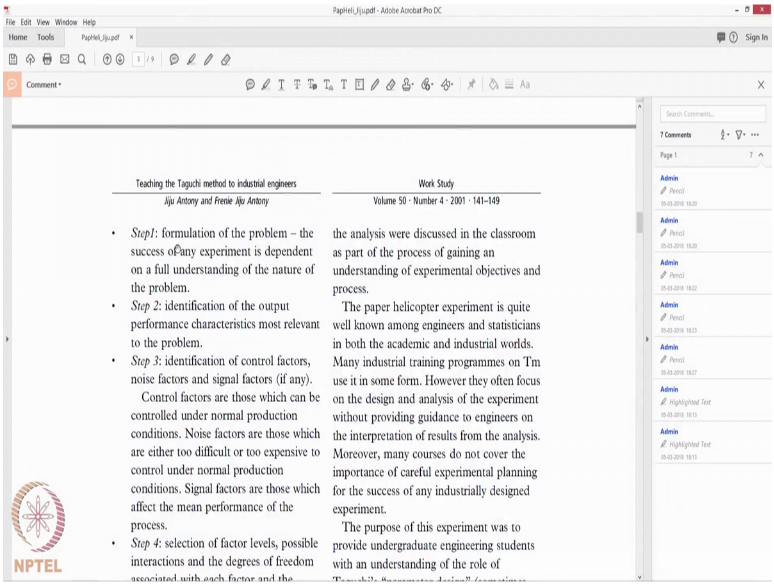

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- *Step1*: formulation of the problem – the success of any experiment is dependent on a full understanding of the nature of the problem.
- *Step 2*: identification of the output performance characteristics most relevant to the problem.
- *Step 3*: identification of control factors, noise factors and signal factors (if any).

  Control factors are those which can be controlled under normal production conditions. Noise factors are those which are either too difficult or too expensive to control under normal production conditions. Signal factors are those which affect the mean performance of the process.
- *Step 4*: selection of factor levels, possible interactions and the degrees of freedom

the analysis were discussed in the classroom as part of the process of gaining an understanding of experimental objectives and process.

The paper helicopter experiment is quite well known among engineers and statisticians in both the academic and industrial worlds. Many industrial training programmes on Tm use it in some form. However they often focus on the design and analysis of the experiment without providing guidance to engineers on the interpretation of results from the analysis. Moreover, many courses do not cover the importance of careful experimental planning for the success of any industrially designed experiment.

The purpose of this experiment was to provide undergraduate engineering students with an understanding of the role of

So, the Step 1 is formulation of the problem, the problem statement. This is this not specific to design of experiment if you think about it. This is what we teach in our functional conceptual design in our product design lab and all that. First is what is your problem statement. So, to question is not what your problem is your problem statement is different from your problem. First you need to know what your problem is, then you need to say what your problem statement is.

You can say increasing the efficiency is my problem. How you are going to increase the problem, I how you are going to increase efficiency will be your problem statement. Under such and such conditions, the efficiency was bad. So, the question is how are you going to increase the efficiency under such and such condition that is what is the problem statement. You cannot have generic problems in which saying I want increase the efficiency of the vehicle. It is not like that. Under such and such conditions, it did not behave as expected. So, we will have to look under this high temperature zones, why it is not performing that well. So, that is a problem statement.

So, formulation of the problem; when we teach your optimization course and all that optimization formulation takes at least 2 to 3 classes that we teach that because that becomes if you are wise enough and you come up with a very good intelligent formulation, your problem is solved in no time. Then you need to identify what is the output characteristic that is most relevant to your problem. If you take the same example of the efficiency, you need not look at only the output efficiency. If your efficiency is connected to multiple components and you understand that the third or the fourth component this is responsible majorly for the output; then you need to worry only about that particular component.

So, you need to be able to say, what is the output performance characteristic that is important to you? You should be able to answer that, it is not necessarily the overall goal. I want to make my system efficient is a very generic statement if you look at it. So, you are not going to worry about making all the components that comprises the system to be efficient. Maybe some of them are already efficient. So, as long as you get that 2 guys who are really inefficient, to be able to perform efficiently; then, your system efficiency will go up.

So, you will only focus on those 2 guys or those 2 component or those 2 modules or those 2 departments to function more efficiently that is a thing that they are talking about. Then you need to choose your factors. If you remember we talked about 2 factors especially when we talked about y f of x and x. So, in that x which is your input variables, there are 2 types of parameters that we talked about; what are they?

Student: Noise parameters.

Noise parameters; k noise parameters and the other one are because what can you do with the noise parameters? Might not be able to control them, noise that is why they are called Noise.

Student: (Refer Time: 19:08)

Sorry.

Student: (Refer Time: 19:11).

No, no. That is more electrical principal. You cannot fill the road noise; you have to live with noise. That is an idea behind robust design. What is variation? Variation is noise. So, your design should be insensitive to that variation. So, the variation needs to be there; that is a basic idea of and often times its good to have the non-linearity. I should have discuss this in a different context, but we will do it here, not a problem.

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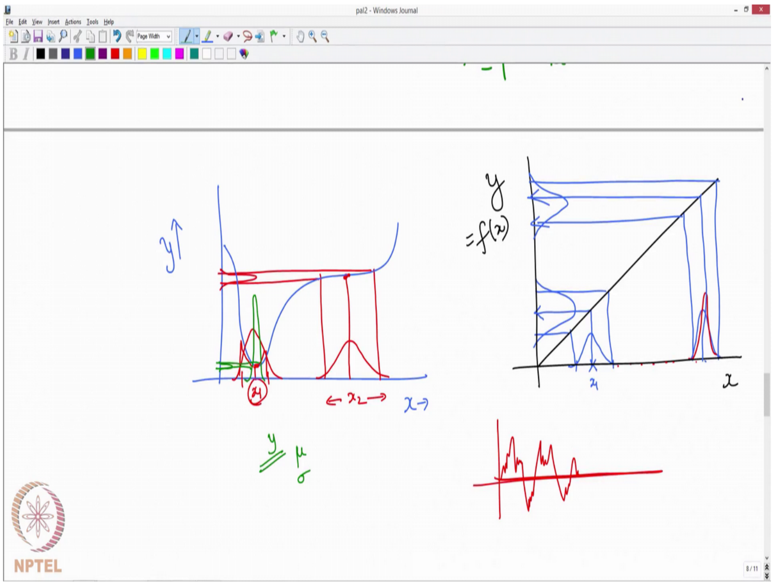

So, we continuously keep talking about insensitive to variation right. Independent variable, dependent variable; this is your process. What do I mean is let us say that this is the input that I am actually interested in; this is the output. However, the moment I say this particular x 1; it is not x 1; it is x 1 plus or minus. It can vary anywhere between this and this; the tolerance for instance. So, how can I represent that variability can use a distribution. So, the moment I say a distribution, my y also has a variability correct. This is what we are talking about. The moment your x has variability your y is also are going to have variability.

The deal is can you identify one of the x's in this particular example where your output variability is going to be lesser compared to your input variability. You understand the question. So, we can go to another point. It should be a straight line; I am just marking let us say the 5th and the 95th percentage. So, it is going to be the variability in my y axis. So, like that can you tell me in which x you might actually get a lesser variation than compared to your input variation? This curve is linear. You will not be able to because it will propagate the same non-linearity from here to here.

However, take this example for a example for instance. Which is the optimal point? If your optima is minimal; this point, but what is the problem with this design point? Sorry.

Student: Linear

It is not linear. Why should it be linear? That you donot have a choice the function itself is non-linear.

Student: (Refer Time: 23:21).

So, for a small change in my x 1 plus or minus, there is a rapid change has he points out ok; immediately changes from here to here. What it says is I design a vehicle a motorbike and then I have optimized it for some operation conditions. The moment the driver deviates a little bit from it immediately the characteristics change. So, though this is an optimal design point, the output changes for a small variation in my input. This is not a robust design point. However, if you consider this point which as per this access is not optimal compared to this point because this is higher than this. This value is higher than this.

However, at this particular point, at this particular point for a variation of x 2 is very small variation in my y; very small. Actually I have drawn it with the variation; practically this variation is even lesser than this. You see that you get an idea. Hence, in this particular graph though this design could be heavier or relatively not as efficient as this design, it is a better design from a robustness perspective because this is what I design it for us for a larger variation also the output variation is less I want that kind of a design.

So, this is the idea of robustness from a in a pictorial sense, but why I discuss this now is it is not true that nonlinearity is a bad trend because you can exploit nonlinearity to find a spot, where you can get a better robustness. In a linear thing you can never do that whichever point you take in this, you will all have the same the output will be the same propagated uncertainty. You can really cannot chose in this; what can you do? You cannot do anything. You have to go and address only the input; unless you reduce this variability, there is nothing that you can do about it. It becomes entirely your process capability whereas, this is a design problem.

There is some zone in my design space that I need to identify and then, I will be able to quantify this. So, it is not true that nonlinearity is bad. Nonlinearity actually gives you option, alternate option. So, this is also a life principle. If life is like a linear thing, you know you are not excited. You donot know what is happening next? If there is a bad thing that is happening ok; you just need to wait and work in the right direction, you need to go in this direction and then you will find a better solution there.

So, it is good that in the other thing that I comes to my mind is your ECG signal. Have you seen your ECG signals; how do they look like; what happens if your ECG signal is like this? There is no life. Unless your ECG signal is like this PQRS, this is life. It should have peaks, it should have valleys. If it is like this, there is no life in that. So, whenever you find bad days in your life ok, donot think that the that is the end; please remember this example; that is what is life is all about. You will get a good day and that is what the design principle is also; you will not get everything that you want. You have 2 choices; you will not get everything that you want here. It is a trade off; you go there life is all about trade off. Statistics can actually explain because everything in your life is about probability. What is the guarantee that you will clear the course this time?

It is only a probability. If you attend the course, if you regularly attend the course, there is a larger probability that you will clear the course. Similarly, if you never attended the course, it does not mean that you are going to fail the course. There is a larger probability that you will fail the course. I need to look at how good your adaptability is to clear the course. So, it is all probability. Everything in life is probability; there is nothing is certain in this life, nothing is certain; none of your lives are certain, none of my life is certain, not my life is certain. If someone tells you like this is certain, this is going to happen; they are not telling you the truth ok.

Let us not get philosophical ok. So, the point that I wanted to bring that is the reason I wanted to bring that is basic the basic idea you need to have some idea about your non-linearity of your design space to some extent ok. You should at least know whether it is linear, it is non-linear because depending on that is what you will have to choose your levels. So, if you remember what we discussed yesterday it is a workflow of the DOE, you need to first tell what your problem statement is; then, you choose your control factors. You actually choose your factors, then you do a factor analysis and then you understand your control factors; that is what they say.

Identification of control factors; then, your noise factors; so the noise factor is something that you have to live with. Control factor is something that you can change. So, if you remember if you appreciate in the discussion that we had right now, the x itself can be considered as a control factor; you can control where you want the x to be. You understand that is a design variable; but the variability of x is not in your hand, you understand that x is a variable. It is going to be random can you control the variability no I cannot control the variability.

If you can control the variability, you can get a beautiful design. I will tell you where. Let us say that for this, this design is what you will get a large variation. Let us say that you had the capability to go and change this red curve into this curve; you will get a very less variability, very less variability you will get. So, in this particular design I have reduced my mu as well as my sigma; the mu in terms of the x and also in terms of the y, it is actually in terms of the y I have minimized both my mu and my sigma; whereas, if you take this guy it might have more or less the same sigma, but the mu is larger.

So, it could be a heavier design. It need not be it could be less efficient than this, but it is robust. But here if you did have a chance to control this variability, then this is a better design for you. So, in this example the choice of x is a design variable; x is a design variable from that aspect. So, you can control what are the operating conditions, you can say I am going to operate the machine in this, but the variability in that operation is not in your hands. So, that part the variability is a noise and where I will run my operation is a controlled variable.

So, the same variable could have 2 connotations; that is what we are talking about here. We are talking about control factors, noise factors and signal factors. Signal factor is nothing but what mean noise factor is a variation of that value and what are the factors that you are able to control. That is what this says. Control factors are those which can be controlled under normal production condition noise are those which are either too difficult, but too expensive to control. Signal factors are those which affect the mean performance of the process. These are stuff that we have already discussed.

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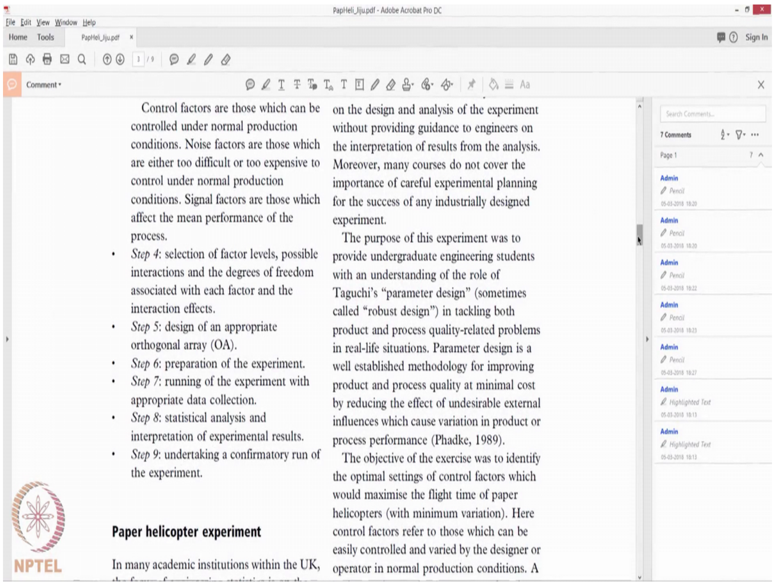

Control factors are those which can be controlled under normal production conditions. Noise factors are those which are either too difficult or too expensive to control under normal production conditions. Signal factors are those which affect the mean performance of the process.

- *Step 4*: selection of factor levels, possible interactions and the degrees of freedom associated with each factor and the interaction effects.
- *Step 5*: design of an appropriate orthogonal array (OA).
- *Step 6*: preparation of the experiment.
- *Step 7*: running of the experiment with appropriate data collection.
- *Step 8*: statistical analysis and interpretation of experimental results.
- *Step 9*: undertaking a confirmatory run of the experiment.

Paper helicopter experiment

In many academic institutions within the UK,

on the design and analysis of the experiment without providing guidance to engineers on the interpretation of results from the analysis. Moreover, many courses do not cover the importance of careful experimental planning for the success of any industrially designed experiment.

The purpose of this experiment was to provide undergraduate engineering students with an understanding of the role of Taguchi's "parameter design" (sometimes called "robust design") in tackling both product and process quality-related problems in real-life situations. Parameter design is a well established methodology for improving product and process quality at minimal cost by reducing the effect of undesirable external influences which cause variation in product or process performance (Phadke, 1989).

The objective of the exercise was to identify the optimal settings of control factors which would maximise the flight time of paper helicopters (with minimum variation). Here control factors refer to those which can be easily controlled and varied by the designer or operator in normal production conditions. A

After that the moment, you select the factors you need to choose the factor levels; this is where you need to know how your response behaves. Because if you believe your response is only linear, then you need only 2 levels per factor. If you believe that it is highly non-linear, how many points do you need; how many levels do you need? Non-linear 3, highly non-linear 4; this is per variable that we are spoken about. So, you will have to kind of adapt it across different dimensions. So, which means that you are going to get lot of points.

But you need to make those decisions. Once you do that this we have already discussed yesterday in detail orthogonal array. Choice of your orthogonal array; how many this is a chicken and egg problem. The orthogonal array is going to be dependent on a number of experiments that I can run. The number of experiments that I am going to be able to run is based on my budget. The other part of it is the number of experiments that I need to run is dependent on the number of factors that I have taken into account. So, based on this, trade off you will have to decide what is the orthogonal array that is suitable for your particular study?

Then, you will have to prepare the experiment of course, then you need to choose or you need to decide upon how you are going to do; what kind of a randomization procedure? That is what this preparation of the experiment is. Then you run the experiment with appropriate data collection. So, you choose the orthogonal array, for each setup you have generated your output sometimes you might want to repeat the each experimental setup that is what we saw because there could be variability within an experiment and there is obviously, variability between the 2 experiments.

Finally, once you get the data, you do statistical analysis. In our case it is as simple as an SN ratio; you do SN ratio and we will see today, how and where you use the SN ratio to get a better design. Finally, you will also have to validate your designs. So, your simulation or your analysis is going to give you some combination that need not be one of the combinations that you have got and how will you make sure that that will give me my optimum response then you will have to go and do verification study.