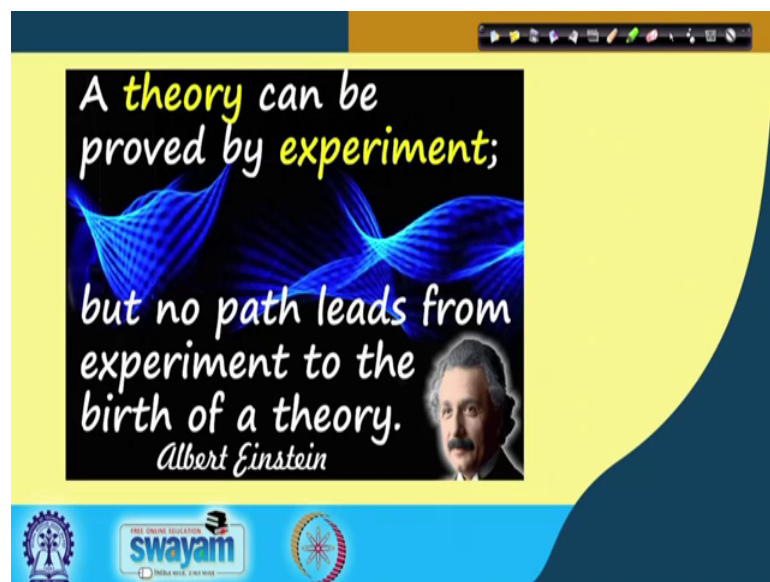


Six Sigma
Prof. Jitesh J Thakkar
Department of Industrial and Systems Engineering
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Lecture - 38
Introduction to Design of Experiment

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

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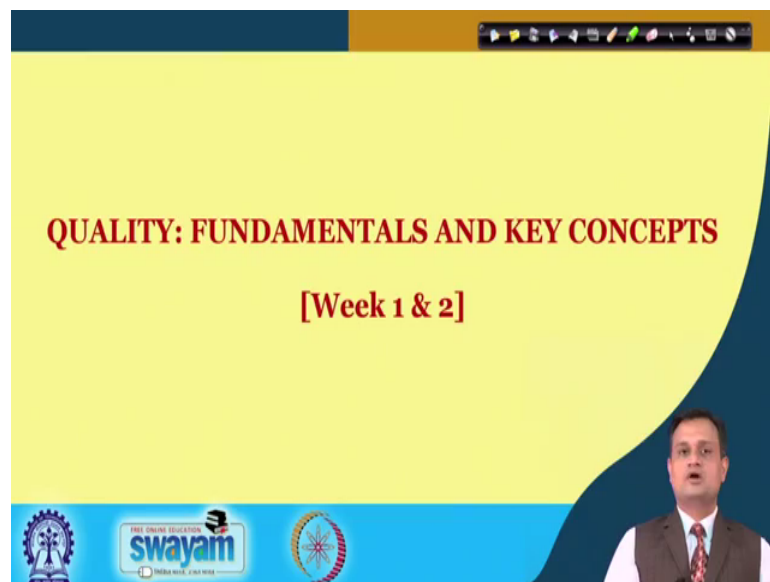
So, let us appreciate a beautiful quote given by Albert Einstein, a theory can be proved by experiment, but no path leads from experiment to the birth of a theory. So, this is where the importance of experimentation lies, you can propose a theory, but you need to prove it by experimentation and then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

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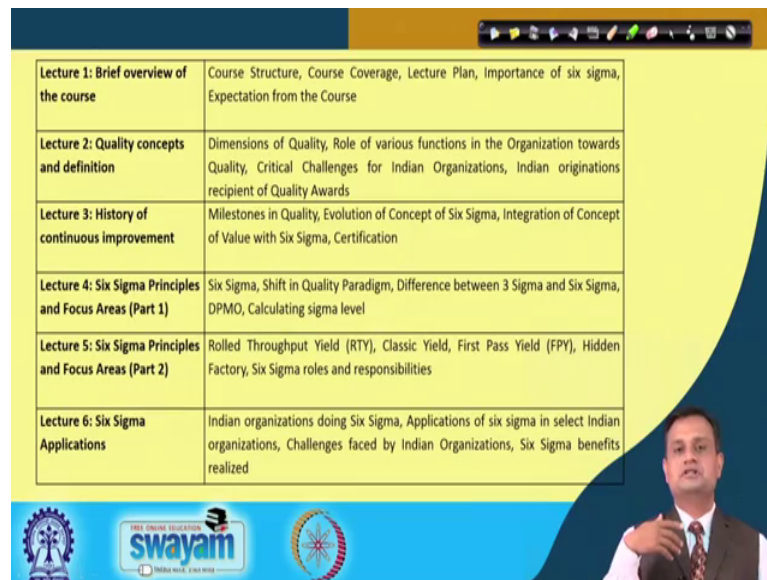
Now, before I proceed we are at a particular juncture. And now it is a time to revisit that where we are in our six sigma journey.

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

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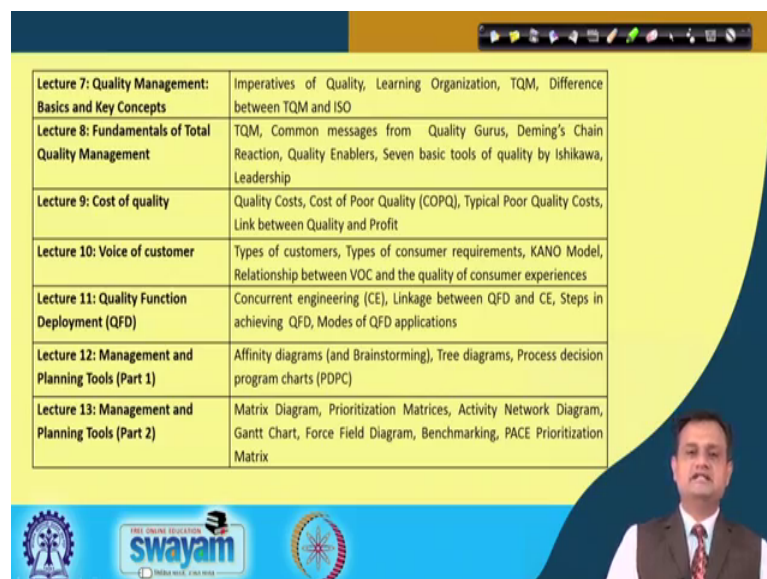


Lecture 1: Brief overview of the course	Course Structure, Course Coverage, Lecture Plan, Importance of six sigma, Expectation from the Course
Lecture 2: Quality concepts and definition	Dimensions of Quality, Role of various functions in the Organization towards Quality, Critical Challenges for Indian Organizations, Indian originations recipient of Quality Awards
Lecture 3: History of continuous improvement	Milestones in Quality, Evolution of Concept of Six Sigma, Integration of Concept of Value with Six Sigma, Certification
Lecture 4: Six Sigma Principles and Focus Areas (Part 1)	Six Sigma, Shift in Quality Paradigm, Difference between 3 Sigma and Six Sigma, DPMO, Calculating sigma level
Lecture 5: Six Sigma Principles and Focus Areas (Part 2)	Rolled Throughput Yield (RTY), Classic Yield, First Pass Yield (FPY), Hidden Factory, Six Sigma roles and responsibilities
Lecture 6: Six Sigma Applications	Indian organizations doing Six Sigma, Applications of six sigma in select Indian organizations, Challenges faced by Indian Organizations, Six Sigma benefits realized

The slide also features logos for IIT Bombay, Swayam, and the Ministry of Education at the bottom, and a video inset of a man in a suit speaking in the bottom right corner.

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

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Lecture 7: Quality Management: Basics and Key Concepts	Imperatives of Quality, Learning Organization, TQM, Difference between TQM and ISO
Lecture 8: Fundamentals of Total Quality Management	TQM, Common messages from Quality Gurus, Deming's Chain Reaction, Quality Enablers, Seven basic tools of quality by Ishikawa, Leadership
Lecture 9: Cost of quality	Quality Costs, Cost of Poor Quality (COPQ), Typical Poor Quality Costs, Link between Quality and Profit
Lecture 10: Voice of customer	Types of customers, Types of consumer requirements, KANO Model, Relationship between VOC and the quality of consumer experiences
Lecture 11: Quality Function Deployment (QFD)	Concurrent engineering (CE), Linkage between QFD and CE, Steps in achieving QFD, Modes of QFD applications
Lecture 12: Management and Planning Tools (Part 1)	Affinity diagrams (and Brainstorming), Tree diagrams, Process decision program charts (PDPC)
Lecture 13: Management and Planning Tools (Part 2)	Matrix Diagram, Prioritization Matrices, Activity Network Diagram, Gantt Chart, Force Field Diagram, Benchmarking, PACE Prioritization Matrix

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

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Lecture 14: Six Sigma Project Identification, Selection and Definition	Six Sigma Project, Tools used in Six Sigma Projects, Voice of Customer, Examples of CTS –CTQ, Project Metrics and Success Criteria
Lecture 15: Project Charter and Monitoring	Project Charter, Elements of Project Charter, Criteria for Project Monitoring, Steps of Monitoring System
Lecture 16: Process characteristics and analysis	Parameters in a Process, Process Flow Metrics, Process Analysis Tools, Process Maps and Flow Charts, Value Stream Map, Spaghetti Diagram, Circle Diagram
Lecture 17: Process Mapping: SIPOC	SIPOC, Process Components in SIPOC, Mapping the Process, Steps to draw SIPOC

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

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Lecture 18: Data Collection and Summarization (Part 1)	Variables and Measurement Scales, Data Collection Methods, Population and Sampling
Lecture 19: Data Collection and Summarization (Part 2)	Need of data representation and summarization, Graphical Methods, Histograms and Bar Chart, Frequency Distribution, Stem and leaf plots, Box and Whisker Plots, Pareto Diagram
Lecture 20: Measurement systems: Fundamentals	Language of Measurement, Importance of Measurement. Gage R&R and its importance
Lecture 21: Measurement system analysis: Gauge R&R study	Properties of measurement systems, Bias and Linearity. Measurement unit analysis. Gage R&R studies
Lecture 22: Fundamentals of statistics	Basics of Statistics, Descriptive v/s Inferential Statistics, Measures of Central Tendency and Dispersion, Shape of the Distribution, Numerical Descriptive Measures for a Population, The Central Limit Theorem, Random Variable
Lecture 23: Probability theory	Basic concepts of Probability, Complementary Rule of Probability, Conditional Probability, Mutually Exclusive Events, Probability Distributions

So, data collection in summarization part 1 part 2. Measurement system analysis fundamentals, measurement system analysis a very important topic gauge R and R study

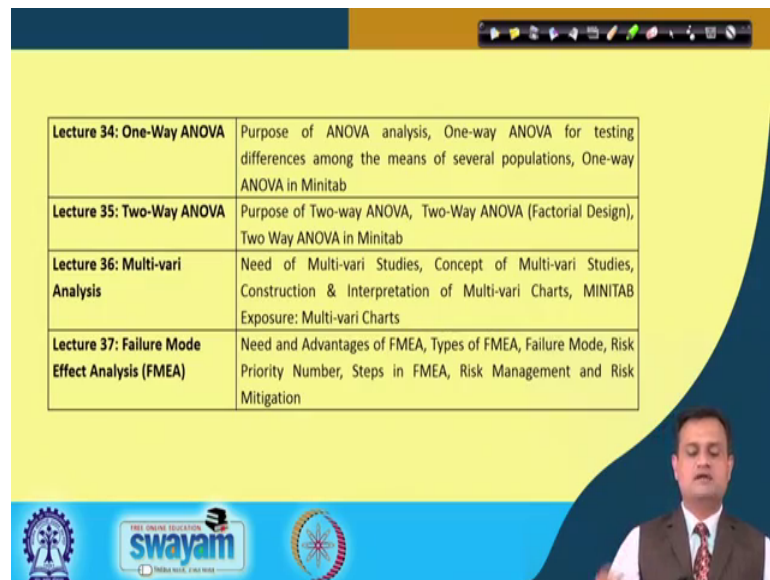
fundamentals of statistics, probability theory. Then subsequently in week 5 you had seen process capability analysis. Process capability analysis measures and indices process capability analysis Minitab application.

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Lecture 28: Hypothesis Testing: Fundamentals	Statistical Hypothesis, Null and Alternative Hypothesis, Type I and Type II Errors in hypothesis testing, General Steps in Hypothesis Testing, Approaches to Hypothesis Testing: Approach 1: Critical Value; Approach 2: p-value; Approach 3: Confidence Interval
Lecture 29: Hypothesis Testing: Single Population Test	Hypothesis testing for a Single Population Mean using - z statistic, t statistic, for Proportion
Lecture 30: Hypothesis Testing: Two Population Test	Hypothesis testing for comparing the difference between a) The means of two independent populations; b) The proportions of two independent populations; c) The variances of two independent populations by testing the ratio of the two variances; d) Dependent (Related) Samples (Same group before vs. after treatment)
Lecture 31: Hypothesis Testing: Two Population: Minitab Application	Minitab applications for a) Pooled-Variance t Test Example; b) Comparison of two population proportions
Lecture 32: Correlation and Regression Analysis	Correlation analysis, Predicting the value of a dependent variable based on an independent variables, Evaluating the assumptions of regression analysis
Lecture 33: Regression Analysis: Model Validation	Autocorrelation, Durbin-Watson statistic, The t-test and F test, Pitfalls of regression analysis

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

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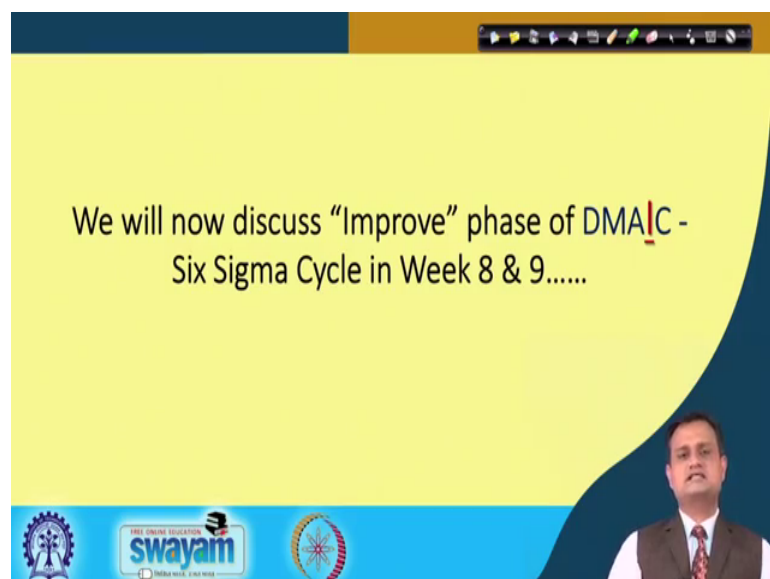


Lecture 34: One-Way ANOVA	Purpose of ANOVA analysis, One-way ANOVA for testing differences among the means of several populations, One-way ANOVA in Minitab
Lecture 35: Two-Way ANOVA	Purpose of Two-way ANOVA, Two-Way ANOVA (Factorial Design), Two Way ANOVA in Minitab
Lecture 36: Multi-vari Analysis	Need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

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

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Now, with this, this is the departure now or continuation in our DMAIC. And now we

will discuss the improve phase of our DMAIC six sigma cycle week 8 and week 9.

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The slide is titled 'Week 8' and 'Week 9' in red text. It lists the following lectures:

- Week 8:**
 - Lecture 38: Introduction to Design of Experiment
 - Lecture 39: Randomized Block Design
 - Lecture 40: Randomized Block Design: Minitab Application
 - Lecture 41: Factorial design
 - Lecture 42: Factorial design: Minitab Application
- Week 9:**
 - Lecture 43: Fractional Factorial Design
 - Lecture 44: Fractional Factorial Design: Minitab Application
 - Lecture 45: Taguchi Method: Key Concepts
 - Lecture 46: Taguchi Method: Illustrative Application

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

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The slide is titled 'CONCEPTS COVERED' in yellow text. It lists the following concepts:

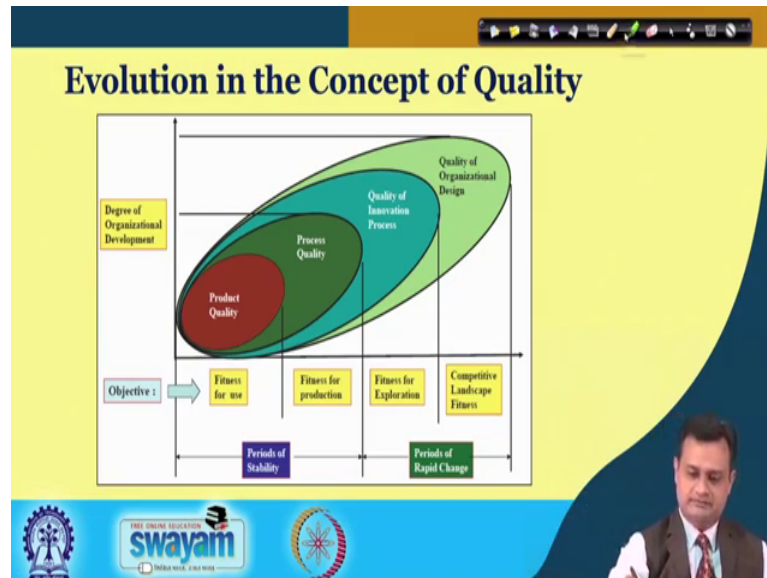
- History of DOE
- DOE: Principles and Terminology
- The strategy of experimentation
- Guidelines for planning, conducting and analyzing experiments

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So, with this let us try to see that what we would like to appreciate as a part of this

lecture. That is introduction of design of experiment we will see some history of DOE how the concept has evolved over a period of time. DOE principles and terminology the strategy of experimentation, what are the key points, that has an experiment experimenter you should consider; and guidelines for planning conducting and analysing the experiments.

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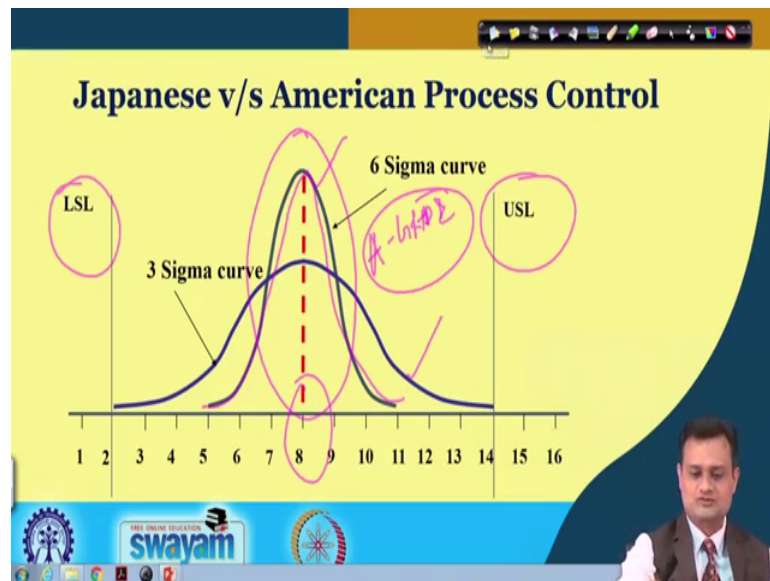
So, just see this and what do you appreciate can you tell me? So, this is the evaluation in the concept of quality. And the fine we say that product quality is the first fitness for use, process quality is the fitness for production, quality of innovation that is the process quality of organisational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

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

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

first time. So, this is what we have appreciated.

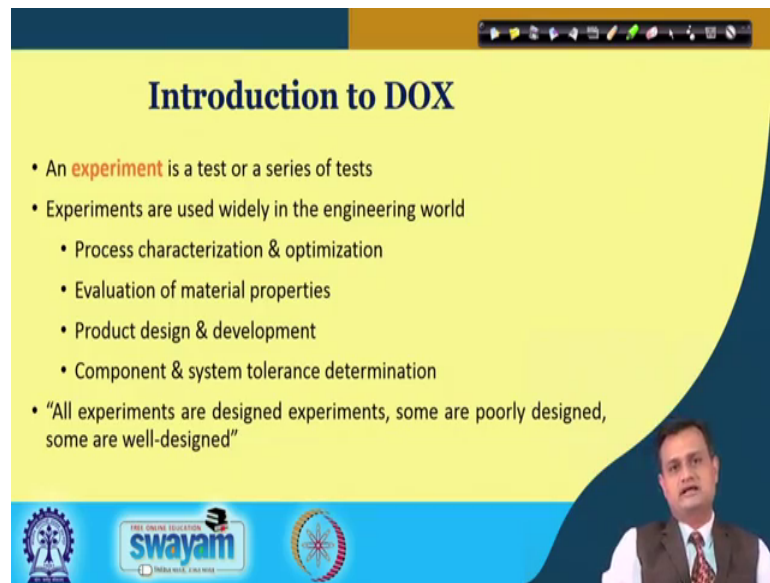
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Once again I would like to remind you, you should not go away from this particular diagram because this is the crux of this course. Six sigma means, less variability. Free sigma means, higher variability six sigma means producing more a grade products.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

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

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The slide is titled "Introduction to DOX" in a bold, dark blue font. It features a yellow background with a dark blue curved border on the right side. A list of bullet points is displayed on the left, and a small video inset of a man in a suit is on the right. At the bottom, there are logos for "swayam" and other educational institutions.

- An **experiment** is a test or a series of tests
- Experiments are used widely in the engineering world
 - Process characterization & optimization
 - Evaluation of material properties
 - Product design & development
 - Component & system tolerance determination
- "All experiments are designed experiments, some are poorly designed, some are well-designed"

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

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

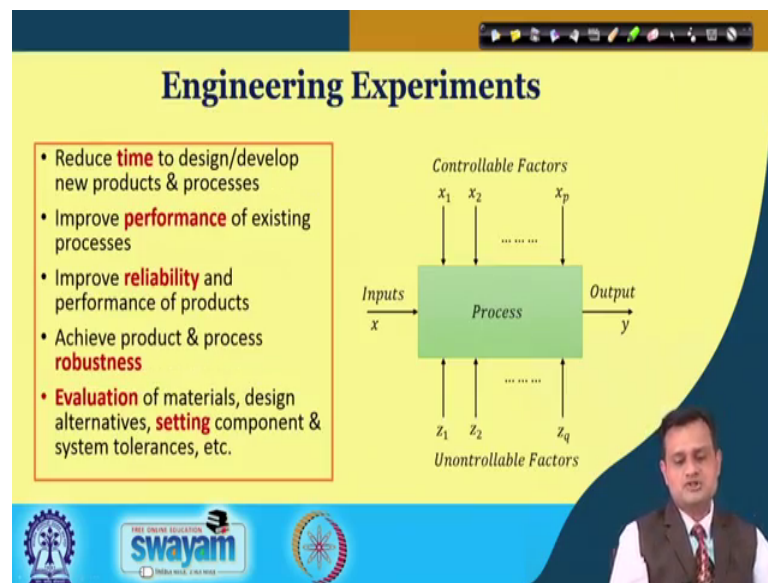
Evaluation of materials and it is properties very important when you look at the material and strength, another tensile strength, compressive strength and another properties. Then basically it is an outcome of say composition of a particular say material and it is important to evaluate the material properties.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

So, there is a very good saying that, all experiments are designed experiments some are poorly designed and some are well designed. So, you may have your intuitive way to conduct the experiment you may have your own approach for conducting the experiment

we all in our day to day life conduct the experimentation. But whether it is right strategy or wrong we many a times do not know unless we face the consequences.

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

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

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

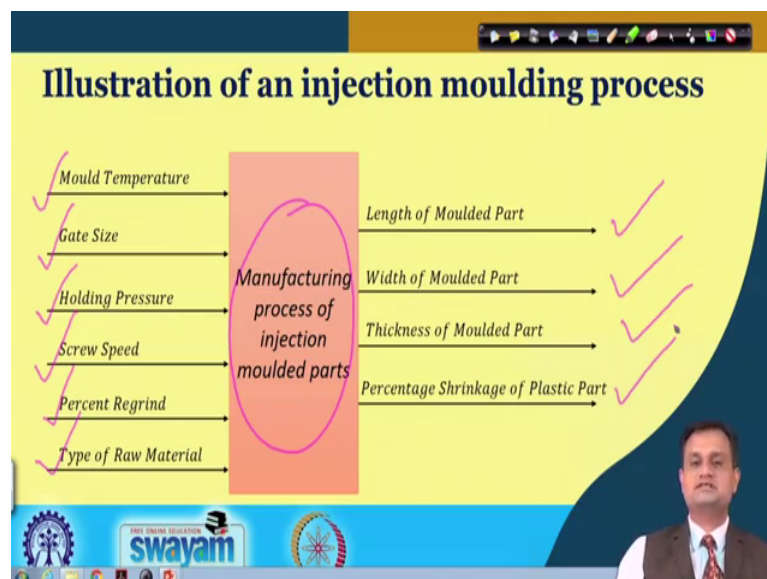
Let us try to take a live example, spontaneous example of my delivering this particular lecture. Now what are the inputs I am using the text, I am using the various sources. For example, this particular topic design of experiment and another topic I will be extensively using the book design of experiment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

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

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

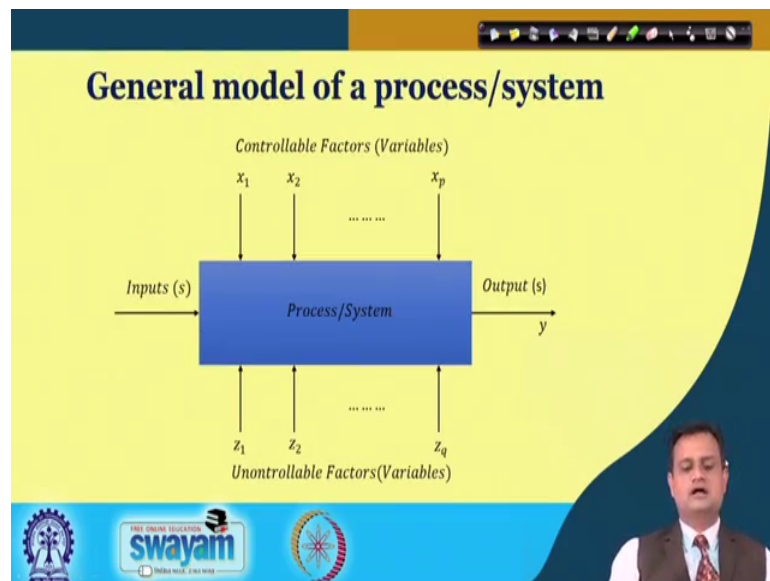
So, that you get the best output optimal output in terms of quantity and quality as an outcome of your process. So, this is the exactly what we try to address as the part of design of experiment.

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

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

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Four Eras in the History of DOX

- The agricultural origins, 1908 – 1940s
 - W.S. Gossett and the t-test (1908)
 - R. A. Fisher & his co-workers
 - Profound impact on agricultural science
 - Factorial designs, ANOVA
- The first industrial era, 1951 – late 1970s
 - Box & Wilson, response surfaces
 - Applications in the chemical & process industries
- The second industrial era, late 1970s – 1990
 - Quality improvement initiatives in many companies
 - Taguchi and robust parameter design, process robustness
- The modern era, 1990

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

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

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

Then the second industrial era say late 1970s to 1990. Quality improvement initiatives in many company; they adopted the use of DOE and Taguchi and robust design parameter design concept that has evolved as an extension or as an integral part of DOE. And

finally, there is an modern era 1990 where we are trying to integrate and club various techniques for improving my products and process is right at the design stage at a very early stage.

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Planning, Conducting & Analyzing an Experiment

1. Recognition of & statement of problem
 - Factor screening or characterization
 - Optimization
 - Confirmation
 - Discovery
 - Robustness
2. Choice of factors, levels, and ranges
3. Selection of the response variable(s)
4. Choice of experimental design
5. Conducting the experiment
6. Statistical analysis
7. Drawing conclusions, recommendations

Handwritten notes: *DOMAIN KNOWLEDGE* (pointing to step 1), *SKILL OF DOE* (pointing to step 4).

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

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

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

Then selection of response variable; whether I am interested to analyse the yield of the

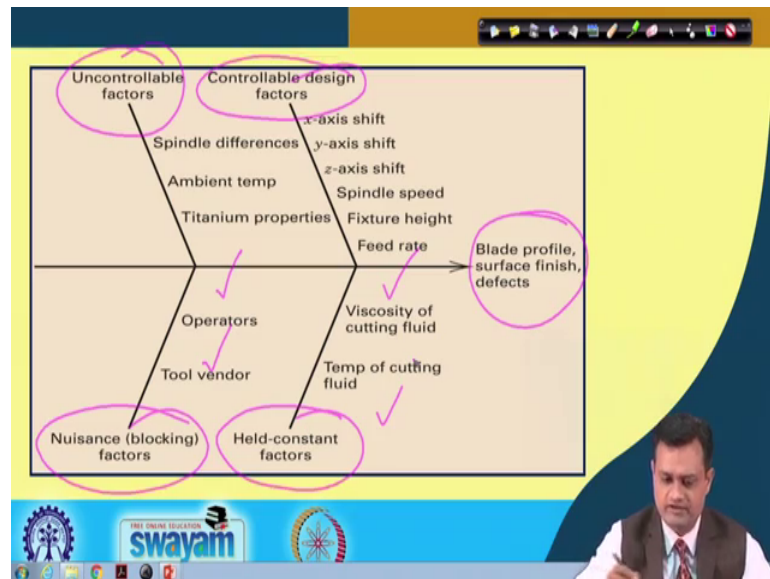
agricultural produce, productivity, surface finish or length of my moulded part. What could be the characteristic, that I would like to analyse as a response variable. Choice of experimental design then 5th is conducting the experiment. So, choice of experimental design; depending upon the situation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

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

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

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

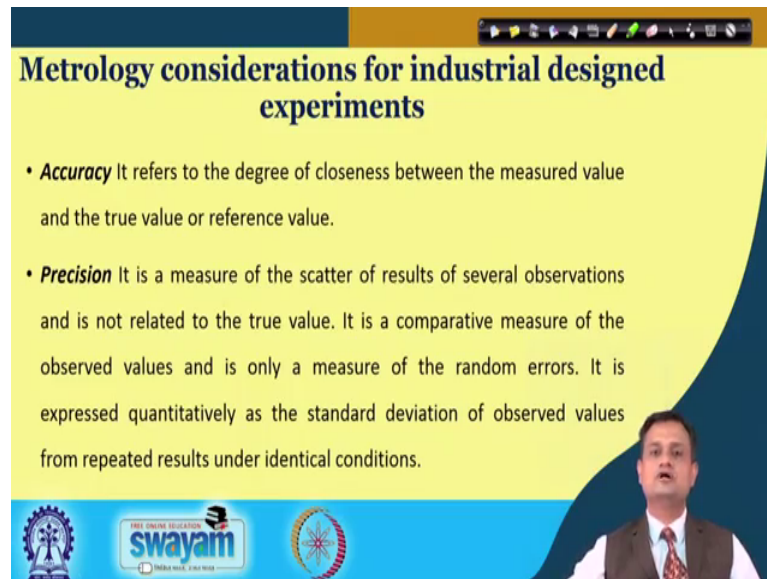
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And once you have this knowledge then only you can apply their skill of conducting experimentation using DOE. And then you can really conduct a meaningful experiment which can yield some important results. So, just see this example of cause and effect;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

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

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Metrology considerations for industrial designed experiments

- **Accuracy** It refers to the degree of closeness between the measured value and the true value or reference value.
- **Precision** It is a measure of the scatter of results of several observations and is not related to the true value. It is a comparative measure of the observed values and is only a measure of the random errors. It is expressed quantitatively as the standard deviation of observed values from repeated results under identical conditions.

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

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

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

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The slide is titled "Metrology considerations for industrial designed experiments". It contains two bullet points:
• **Stability** A measurement system is said to be stable if the measurements do not change over time. In other words, they should not be adversely influenced by operator and environmental changes.
• **Capability** A measurement system is capable if the measurements are free from bias (accurate) and sensitive. A capable measurement system requires sensitivity (the variation around the average should be small compared to the specification limits or process spread and accuracy).
At the bottom left is the Swayam logo with the text "FREE ONLINE EDUCATION swayam". At the bottom right is a small video inset of a man in a suit speaking.

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

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

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Selection of quality characteristics for industrial experiments

- Try to use quality characteristics which are easy to measure.
- Quality characteristics should be continuous variables as far as possible.
- Use quality characteristics which can be measured precisely, accurately and with stability.
- For complex processes, it is best to select quality characteristics at the subsystem level and perform experiments at this level prior to attempting overall process optimization.

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

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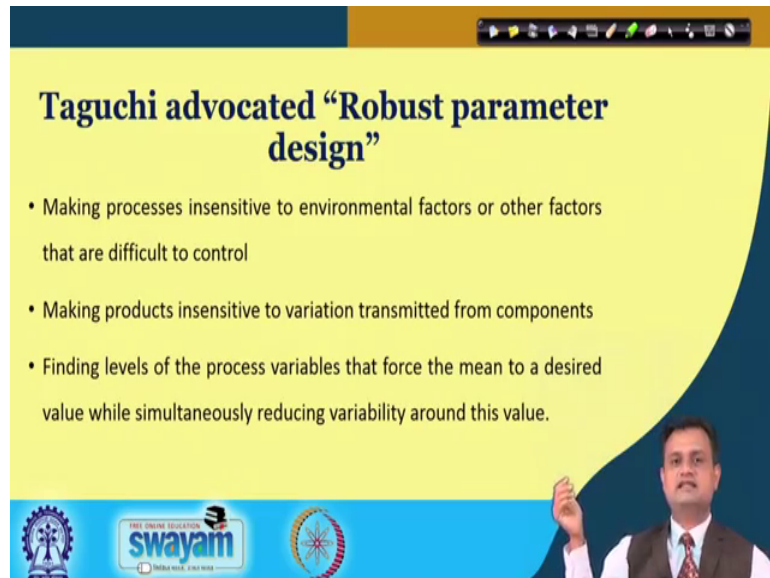
Selection of quality characteristics for industrial experiments

- Quality characteristics should cover all dimensions of the ideal function or the input-output relationship.
- Quality characteristics should preferably be additive (i.e. no interaction exists among the quality characteristics) and monotonic (i.e. the effect of each factor on robustness should be in a consistent direction, even when the settings of factors are changed).

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

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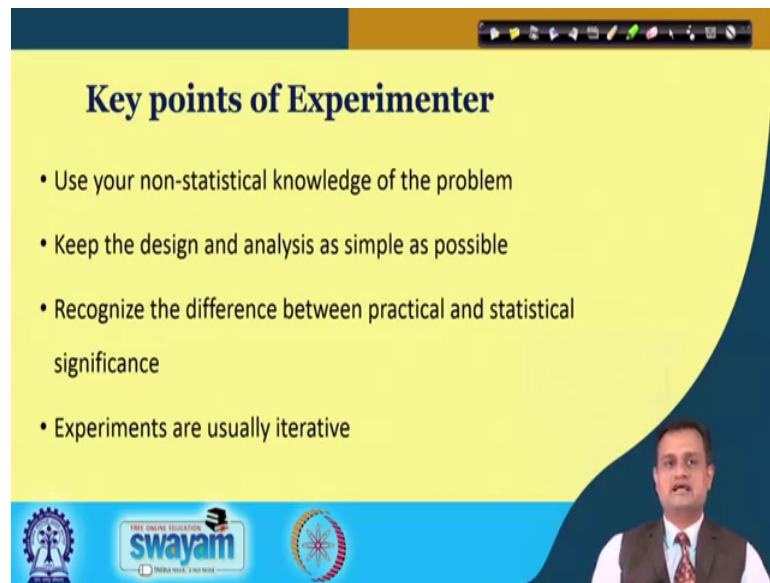
Taguchi advocated “Robust parameter design”

- Making processes insensitive to environmental factors or other factors that are difficult to control
- Making products insensitive to variation transmitted from components
- Finding levels of the process variables that force the mean to a desired value while simultaneously reducing variability around this value.

The slide features a yellow background with a blue border. At the bottom, there are logos for 'swayam' and 'All India Institute of Management'. A presenter is visible in the bottom right corner.

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

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Key points of Experimenter

- Use your non-statistical knowledge of the problem
- Keep the design and analysis as simple as possible
- Recognize the difference between practical and statistical significance
- Experiments are usually iterative

Logos at the bottom: IIT Bombay, Swayam, and a circular logo.

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

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

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

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Benefits of DOE in manufacturing processes

- Improved process yield and stability
- Improved profits and return on investment
- Improved process capability
- Reduced process variability and hence better product performance consistency
- Reduced manufacturing costs

The slide features a yellow background with a dark blue curved border on the right. At the bottom, there is a blue banner with logos for 'swayam' and other educational institutions. A presenter is visible in the bottom right corner.

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Benefits of DOE in manufacturing processes

- Reduced process design and development time
- Heightened morale of engineers with success in chronic-problem solving
- Increased understanding of the relationship between key process inputs and output(s)
- Increased business profitability by reducing scrap rate, defect rate, rework, retest, etc.

This slide is similar to the previous one, with a yellow background and a dark blue curved border. It lists four benefits of DOE. The presenter is visible in the bottom right corner.

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

So, just see that you have a product that will go through the inception, then say rapid

advancement and then maturity and then decline. So, there is a total profitability and you lose almost 50 percent. If you are late by say 4 to 6 months in launching your new product. So, you cannot afford and you also cannot afford to launch a poor quality product. And that is where the DOE comes in picture.

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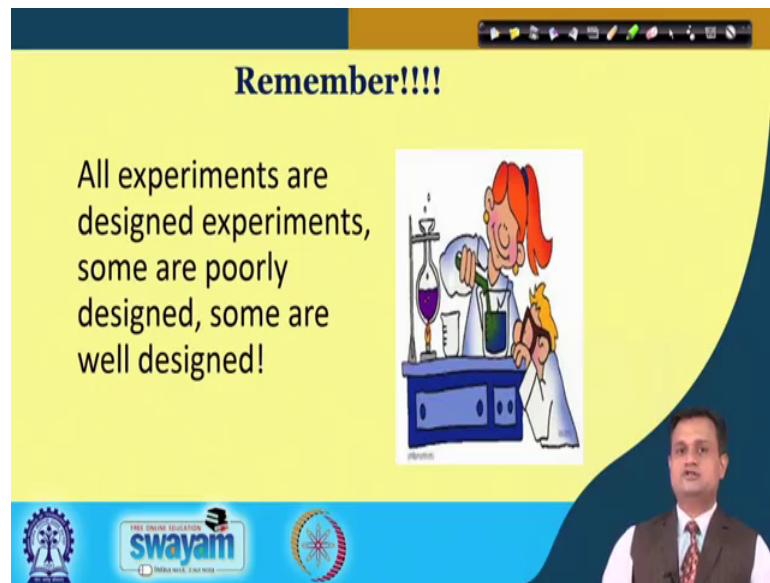
The slide features a yellow background with a dark blue curved border on the right side. At the top, there is a dark blue header bar with a small navigation icon. The title 'Skills required for successful application of an industrial designed experiment' is written in bold black text. Below the title, a bulleted list contains four items: 'Planning skills', 'Statistical skills', 'Teamwork skills', and 'Engineering skills'. In the bottom right corner, there is a small video inset of a man in a suit. The bottom of the slide has a blue footer bar containing three logos: a gear icon, the 'swayam' logo with the text 'FREE ONLINE EDUCATION' and 'INDIA'S MOOC PLATFORM', and a circular logo with a star.

Skills required for successful application of an industrial designed experiment

- Planning skills
- Statistical skills
- Teamwork skills
- Engineering skills

You need basically 4 set of skills; in conducting DOE planning skill, 1 statistical skill, teamwork skill, engineering skill it is a cross functional approach you need to have the people from production, procurement, design manufacturing and then only you can set a right premise for conducting DOE. And then you can really conduct the meaningful experimentation.

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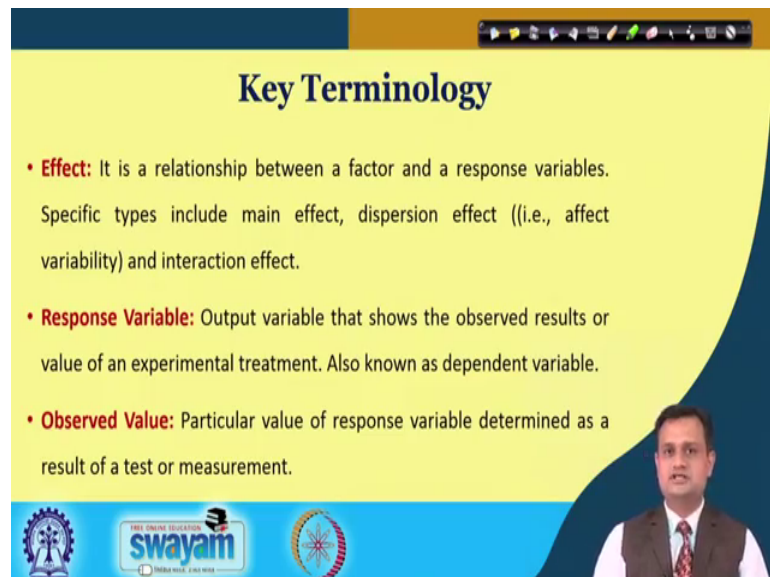
Remember!!!!

All experiments are designed experiments, some are poorly designed, some are well designed!

The slide features a cartoon illustration of a scientist with red hair and a white lab coat, pouring liquid from a beaker into a test tube. A smaller figure is visible in the background. The slide is part of a presentation, as evidenced by the navigation bar at the top and the Swayam logo at the bottom. A small video inset of a man in a suit is visible in the bottom right corner.

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

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Key Terminology

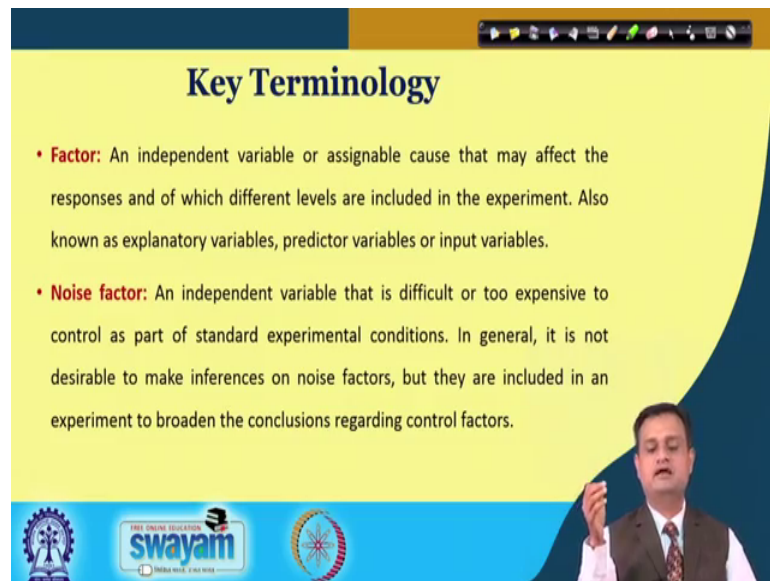
- **Effect:** It is a relationship between a factor and a response variables. Specific types include main effect, dispersion effect ((i.e., affect variability) and interaction effect.
- **Response Variable:** Output variable that shows the observed results or value of an experimental treatment. Also known as dependent variable.
- **Observed Value:** Particular value of response variable determined as a result of a test or measurement.

The slide is part of a presentation, as evidenced by the navigation bar at the top and the Swayam logo at the bottom. A small video inset of a man in a suit is visible in the bottom right corner.

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

value of the response variable determined as a result of test.

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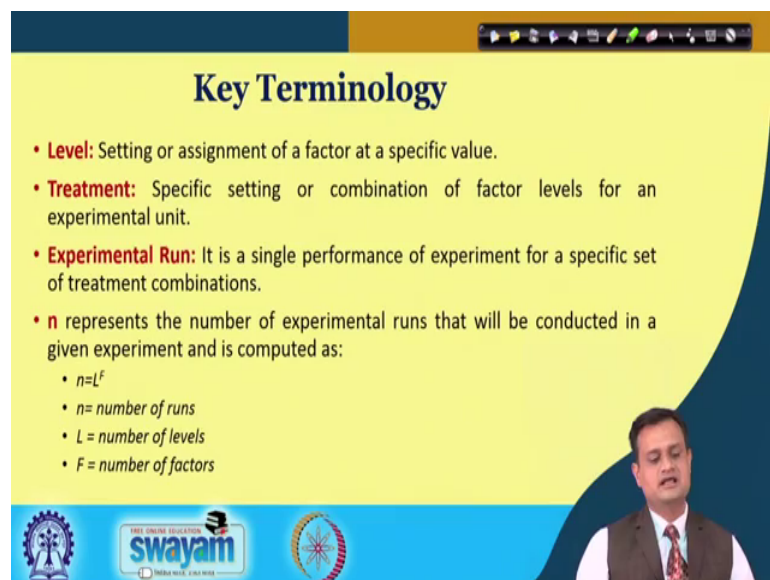
The slide is titled "Key Terminology" and features a yellow background with a blue border. It contains two bullet points defining "Factor" and "Noise factor". A small video inset of a man in a suit is visible in the bottom right corner. The Swamyam logo and other institutional icons are at the bottom.

Key Terminology

- **Factor:** An independent variable or assignable cause that may affect the responses and of which different levels are included in the experiment. Also known as explanatory variables, predictor variables or input variables.
- **Noise factor:** An independent variable that is difficult or too expensive to control as part of standard experimental conditions. In general, it is not desirable to make inferences on noise factors, but they are included in an experiment to broaden the conclusions regarding control factors.

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

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The slide is titled "Key Terminology" and features a yellow background with a blue border. It contains four bullet points defining "Level", "Treatment", "Experimental Run", and "n". A small video inset of a man in a suit is visible in the bottom right corner. The Swamyam logo and other institutional icons are at the bottom.

Key Terminology

- **Level:** Setting or assignment of a factor at a specific value.
- **Treatment:** Specific setting or combination of factor levels for an experimental unit.
- **Experimental Run:** It is a single performance of experiment for a specific set of treatment combinations.
- **n** represents the number of experimental runs that will be conducted in a given experiment and is computed as:
 - $n = L^F$
 - $n = \text{number of runs}$
 - $L = \text{number of levels}$
 - $F = \text{number of factors}$

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

temperature is set at 3 level 10 degree 25 degree 50 degree so these are the levels.

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

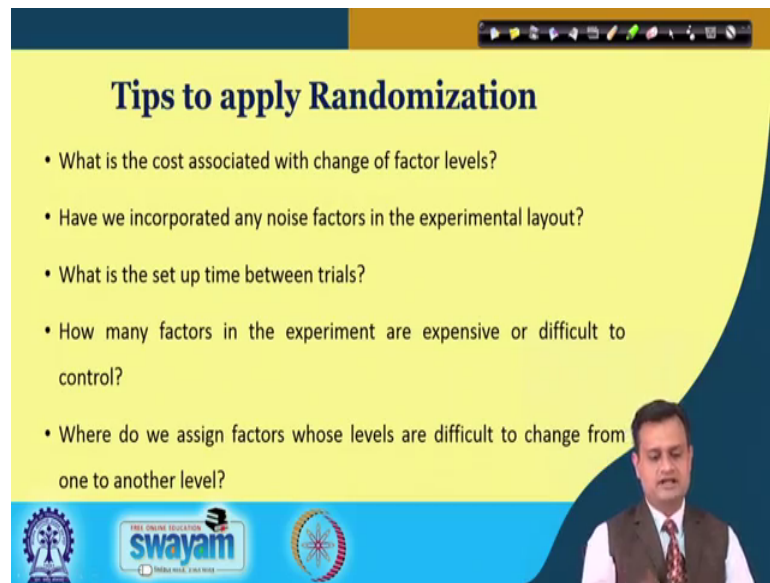
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Understanding the Randomization, Replication and Blocking

- **Randomization**
 - Running the trials in an experiment in random order
 - Notion of balancing out effects of “lurking” variables
- **Replication**
 - Sample size (improving precision of effect estimation, estimation of error or background noise)
 - Replication versus repeat measurements?
- **Blocking**
 - Dealing with nuisance factors

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

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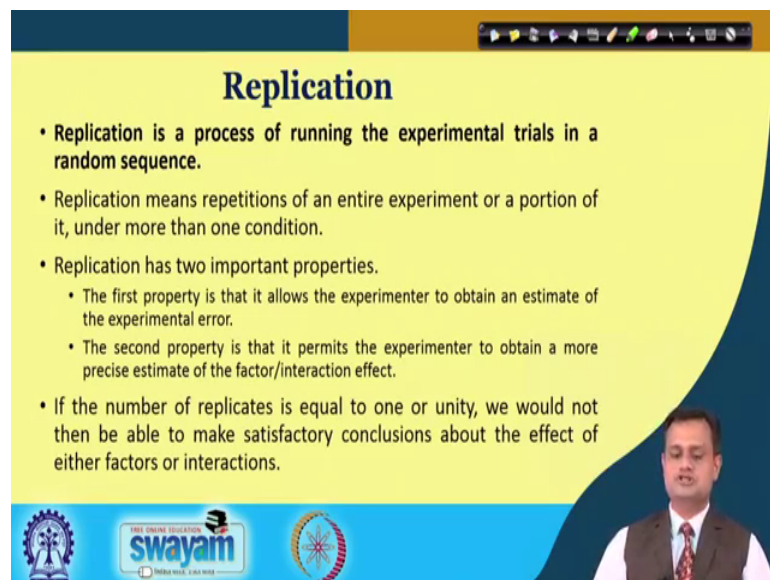
Tips to apply Randomization

- What is the cost associated with change of factor levels?
- Have we incorporated any noise factors in the experimental layout?
- What is the set up time between trials?
- How many factors in the experiment are expensive or difficult to control?
- Where do we assign factors whose levels are difficult to change from one to another level?

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

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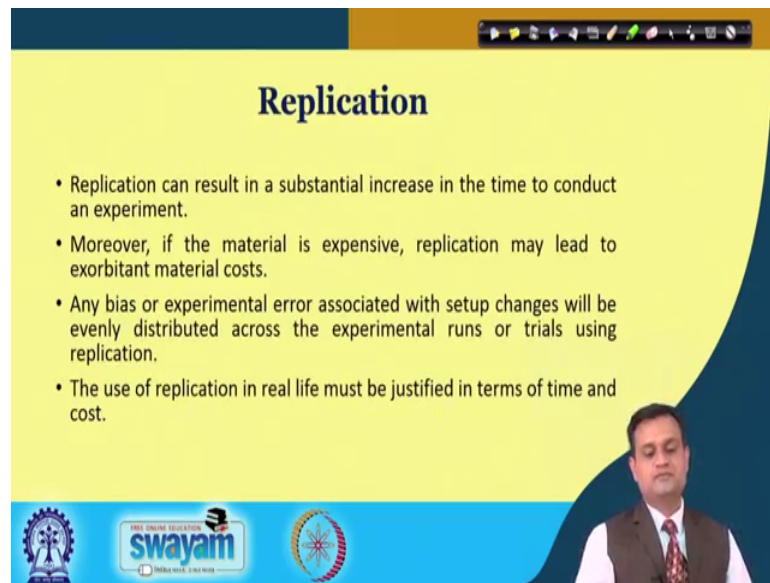
Replication

- Replication is a process of running the experimental trials in a random sequence.
- Replication means repetitions of an entire experiment or a portion of it, under more than one condition.
- Replication has two important properties.
 - The first property is that it allows the experimenter to obtain an estimate of the experimental error.
 - The second property is that it permits the experimenter to obtain a more precise estimate of the factor/interaction effect.
- If the number of replicates is equal to one or unity, we would not then be able to make satisfactory conclusions about the effect of either factors or interactions.

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

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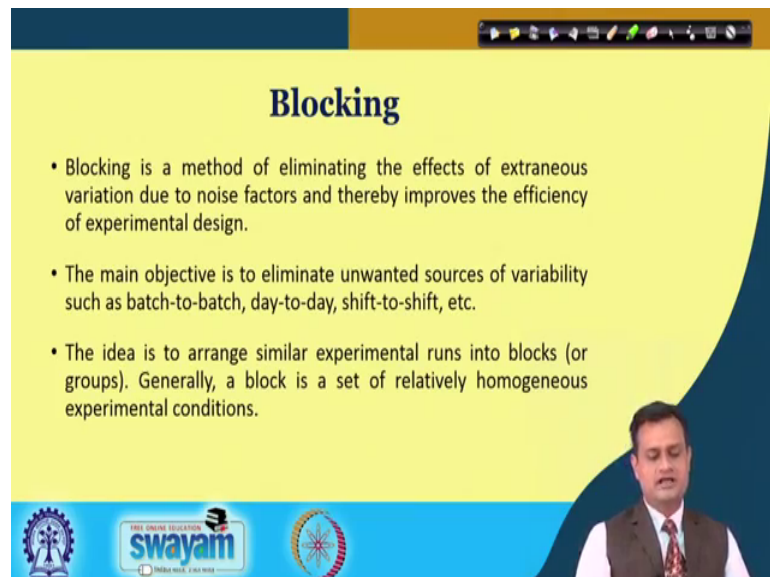
Replication

- Replication can result in a substantial increase in the time to conduct an experiment.
- Moreover, if the material is expensive, replication may lead to exorbitant material costs.
- Any bias or experimental error associated with setup changes will be evenly distributed across the experimental runs or trials using replication.
- The use of replication in real life must be justified in terms of time and cost.

The slide features a yellow background with a dark blue header and footer. The header contains a navigation bar with icons. The footer includes the logos of the Indian Institute of Space Science and Technology (IIST), the Swayam platform, and the Ministry of Education, Government of India. A video feed of a male presenter in a suit and tie is visible in the bottom right corner.

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

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Blocking

- Blocking is a method of eliminating the effects of extraneous variation due to noise factors and thereby improves the efficiency of experimental design.
- The main objective is to eliminate unwanted sources of variability such as batch-to-batch, day-to-day, shift-to-shift, etc.
- The idea is to arrange similar experimental runs into blocks (or groups). Generally, a block is a set of relatively homogeneous experimental conditions.

The slide features a yellow background with a dark blue header and footer. The header contains a navigation bar with icons. The footer includes the logos of the Indian Institute of Space Science and Technology (IIST), the Swayam platform, and the Ministry of Education, Government of India. A video feed of a male presenter in a suit and tie is visible in the bottom right corner.

And blocking. So, there are many factors we will see this concept in detail later on that batch to batch production shift to shift production day to day production, I need to block them; otherwise if the homogeneity is not maintain then my experimentation result will

drastically be affected. So, many a times suppose I am purchasing the material from different vendor. And 1 vendor is not capable to supply the entire material; then I have to block this effect I am running the production in shift 1 to n free. And suppose I proved the null hypothesis, that produce of shift 1 in terms of quality is not equal to shift 2 and shift 3. Then I need to block this factor.

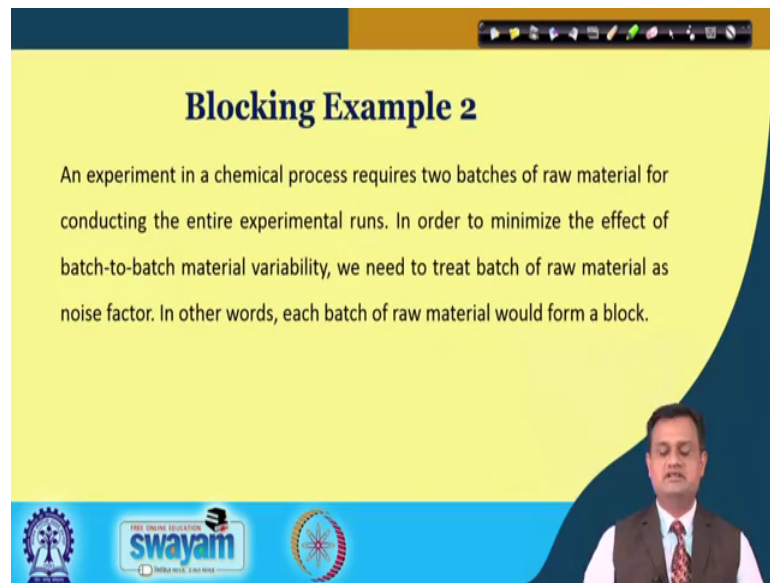
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Blocking Example 1

A metallurgist wants to improve the strength of a steel product. Four factors are being considered for the experiment, which might have some impact on the strength. It is decided to study each factor at 2 levels (i.e. a low setting and high setting). An eight trial experiment is chosen by the experimenter but only four trials are possible to run per day. Here each day can be treated as a separate block.

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

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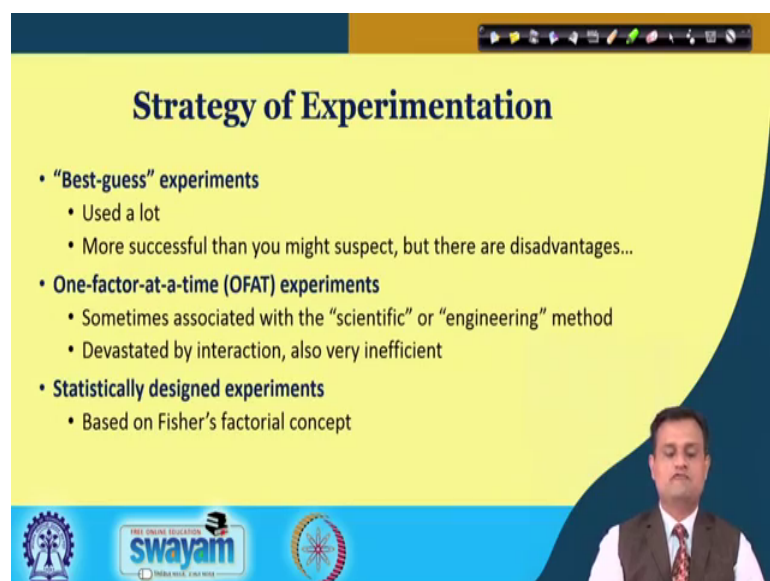


Blocking Example 2

An experiment in a chemical process requires two batches of raw material for conducting the entire experimental runs. In order to minimize the effect of batch-to-batch material variability, we need to treat batch of raw material as noise factor. In other words, each batch of raw material would form a block.

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Strategy of Experimentation

- **"Best-guess" experiments**
 - Used a lot
 - More successful than you might suspect, but there are disadvantages...
- **One-factor-at-a-time (OFAT) experiments**
 - Sometimes associated with the "scientific" or "engineering" method
 - Devastated by interaction, also very inefficient
- **Statistically designed experiments**
 - Based on Fisher's factorial concept

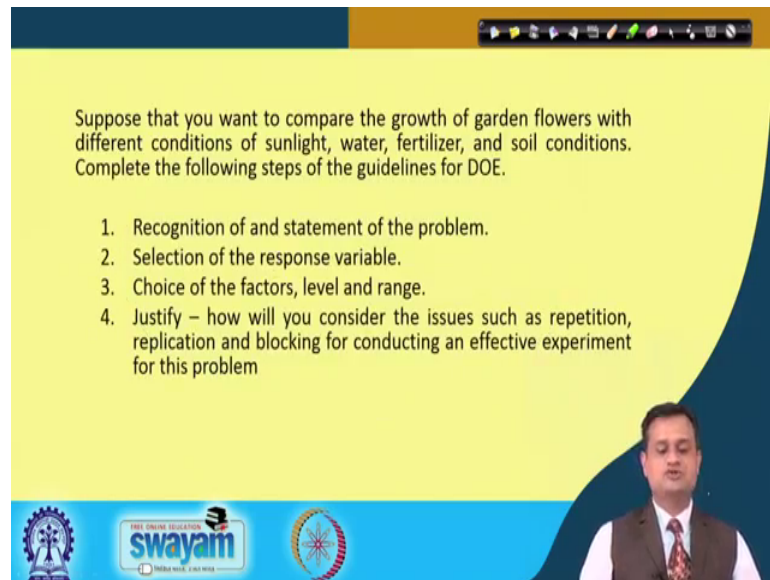
The slide features a yellow background with a dark blue curved border on the right. At the bottom, there is a blue banner with logos for IIT Bombay, Swayam, and IIT Madras. A small video inset of a man in a suit is visible in the bottom right corner.

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

Let us say factor 2 to higher by keeping the first factor at the initial setting that is low level similar way when you are changing the first factor to higher level keep the other

factor at the low level that is the initial setting and this is called one factor at a time. And then you have Fisher's approach. So, there is a big say world of design of experiment and this is what we are interested in.

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Suppose that you want to compare the growth of garden flowers with different conditions of sunlight, water, fertilizer, and soil conditions. Complete the following steps of the guidelines for DOE.

1. Recognition of and statement of the problem.
2. Selection of the response variable.
3. Choice of the factors, level and range.
4. Justify – how will you consider the issues such as repetition, replication and blocking for conducting an effective experiment for this problem

swayam

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

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References

- Montgomery, D C. Design and Analysis of Experiments, Wiley.
- Mitra, Amitava. Fundamentals of Quality Control and Improvement, Wiley India Pvt Ltd.
- T. M. Kubiak, Donald W. Benbow, The Certified Six Sigma Black Belt Handbook, Pearson Publication.
- Forrester W. Breyfogle III, Implementing Six Sigma, John Wiley & Sons, INC.

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

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Conclusion

- **Design of experiments (DOE)** is a systematic method to determine the relationship between factors affecting a process and the output of that process.
- Many experiments involve holding certain factors constant and altering the levels of another variable. This One-Factor-at-a-Time (or OFAT) approach to process knowledge is, however, inefficient when compared with changing factor levels simultaneously.

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