Introduction to Experiments

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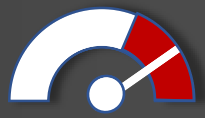
You will learn

Learn about the role of experiments in performance improvement

Level of Difficulty



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Need for Experimentation

- Find which factors impact the output
- Understand the nature of relationship between them
- Quantify impact on Y
- Discover if two or more factors jointly have an impact on output
- Find out their Optimal Settings

Traditional

- Trial & error method to make inferences
- Only one factor varied to study impact

Structured

- Structured & statistically valid method
- More than one factor varied at a given time to study impact

Structured experimentation

is more efficient than

traditional experimentation

Design Of Experiment

Study effect of ***multiple variables*** at

Low effort, Cost & Time

Considerations for DoE

- Able to change process setting without impacting live process or customer
- Necessary resources
- Maintain experimental conditions
- Data collection with different settings not possible without experiments

DoE in Service Sector

- **Process & Product Designs**
  - UI Design
  - Campaign Designs
  - Customer Touch point Design
- **Optimize Performance**
  - Role Performance
  - Sales Performance – Up-selling, Cross-selling, etc
  - C-Sat improvement

Phases of Experiments

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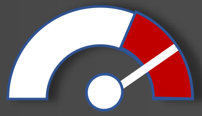
Learn about the different phases of experiments

Level of Difficulty



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Experimental Phase

1. Planning phase
2. Screening phase
3. Optimization phase
4. Verification phase

Planning Phase

- Goal Definition (Objectives)
- Experimental Plan (Factors & Conditions)
- Process and measurement systems are in control

Screening Phase

- 2-level full and factional factorial designs
- Plackett-Burman designs
- Full factorial designs

Optimization Phase

Optimization experiments can then be done to determine the best settings and define the nature of the curvature.

Verification Phase

Experiment at the predicted optimal conditions to confirm the optimization results.

Terms in DOE

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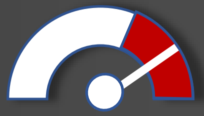
Learn about of basic terms associated with DOE

Level of Difficulty



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DOE Terms

1. Factors
2. Level
3. Runs
4. Settings
5. Experimental design

Response

- A variable measured/observed as the outcome in an experiment

Example:

Soy Oil Yield in %

Factors

- Usually Xs or inputs are considered as ‘factors’
- Can be controlled to study how they influence output in an experiment
- Can either be categorical or continuous variables

Example

- Factor 1 – Feed rate (Kgs/min)
- Factor 2 – Solvent Quantity (%)
- Factor 3 – Rolling Speed (RPM)
- Factor 4 – Temperature(Deg F)
- Factor 5 – Solvent Concentration (%)

Levels

- Set of values that a factor may take through the course of an experiment
- Can be either quantitative or qualitative
- Usually levels are defined by the experimenter based on experimental objectives & other constraints

Example

- Factor 1 – Feed rate = 10 -15 Kgs/min
- Factor 2 – Solvent Quantity = 1 - 2 %

- Particular combination of factor levels while studying their influence on responses
- Treatment combination - set of levels for each factor in an experiment

Example:

		Feed Rate	
		10 kgs/min	15 kgs/min
Solvent Quantity	1 %	I	II
	2 %	III	IV

Performing Full Factorial DOE

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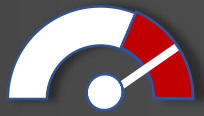
Objective

Learn how to perform full factorial DOE

Level of Difficulty



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How to Perform DOE

1. Define the experimental objective
2. Select response variable, Y
3. Choose Xs to be tested
4. Think about inference space & choose levels for all Xs
5. Select an experimental design & set it up in Minitab
6. Run the experiment
7. Analyse the experiment
8. Confirm the results

2. Select Response Variable Y

- Yield of a production process is measured in ‘% Extracted’

3. Choose the Xs to test

- Factor 1 – Feed rate (Kgs/min)
- Factor 2 – Solvent Quantity (%)
- Factor 3 – Rolling Speed (RPM)
- Factor 4 – Temperature(Deg F)
- Factor 5 – Solvent Concentration (%)

4. Inference space & levels for Xs

Through brainstorming and using good prior knowledge

- Factor 1 – Feed rate = 10 & 15 Kgs/min
- Factor 2 – Solvent Quantity = 1 & 2 %
- Factor 3 – Rolling Speed = 100 & 120 RPM
- Factor 4 – Temperature = 140 & 180°F
- Factor 5 – Solvent Concentration = 3 & 6 %

No. of experiments trials needed:

$$2 \times 2 \times 2 \times 2 \times 2 = 32$$

Full Factorial Experimental Design

Levels

$$2^k$$

Factors

Analysis of Fractional Factorial Experiment

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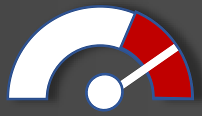
Learn how to analyse fractional factorial DOE

Level of Difficulty



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Confirm the Results

Results of analysis can be studied as follows:

1. Graphical review of Interaction plots followed by Main Effect plots
2. Pareto Diagram to screen significant factors
3. Re-run analysis with significant factors

Additional DOE Terms

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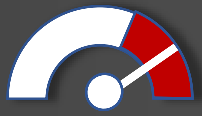
Learn about additional terms involved in DOE

Level of Difficulty



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Advanced DOE Terms

1. Randomization
2. Centre Point
3. Blocking
4. Replication
5. Repetitions

Randomization

1. Practice of conducting trials of an experiment in a random manner to reduce experimental error
2. Ensures experimentation is unbiased
3. Helps balance/eliminate impact of extraneous, unknown or uncontrollable conditions on results of an experiment

Center Point

1. When a non-linear relationship is suspected between Y and Xs, then we may need more than just 2 data points to detect that non-linear relationship.

2. This additional point is called center point.

Blocks

1. An experimental design method where a given factor can be changed from one level to another only once during an entire experiment
2. This prevents a given factor from being changed for each experimental run
3. Enables to perform the series of experiments at low cost

Repetition

1. A method of repeating the same treatment combination consecutively under the same conditions
2. In simple words, two trials performed for same experimental set-up
3. Performed to study experimental variations
4. Inexpensive method of adding marginal costs to improve experimental accuracy

Replication

- Method of conducting experimental trials of same treatment combinations that are not consecutive
- Estimate variance/experimental faults caused by various conditions
- Identify sources of variation
- Minimize errors & increase precision & reliability of result

Run	Order	A	B	AB	Y
1	(1)	-1	-1	1	40.7
2	a	1	-1	-1	74.2
3	b	-1	1	-1	44.1
4	ab	1	1	1	72.6

Run	Order	A	B	AB	Y
5	(1)	-1	-1	1	38.6
6	a	1	-1	-1	68.4
7	b	-1	1	-1	42.1
8	ab	1	1	1	86

Fractional Factorial Experiments - II

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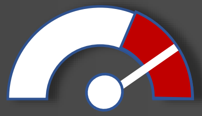
Learn how to perform fractional factorial DOE

Contd. from previous lecture…

Level of Difficulty



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In the Soya Experiment, only 16 trials can be conducted to be resource constraint, instead of 32.

How to run the experiment?

What can we do when..

1. Number of factors are more
2. Higher-order interactions are negligible
3. Main Effects and Low-order interactions more important for us
4. When we want to have fewer runs

- They can study more factors
- Higher Level of interactions are omitted
- Hence have manageable number of runs

But….

- We compromise on the resolution

Number of Factors in the experiment

Size of the Fraction

Number of Levels for each Factor

$$\mathbf{2}^{k\text{-}p}$$

½ Fraction

$\frac{1}{2} * 2^{5} = 2^{5-1}$

5 factors in 32/2 = 16 runs

1/4 Fraction

$\frac{1}{4} * 2^{5} = 2^{5-2}$

5 factors in 32/4 = 8 runs

Resolution

It is the ability to discriminate between effects in a fractional factorial experiment.

1. We can choose the resolution for an experiment while designing the study
2. Higher the resolution, better it is!
3. Standard convention uses roman numerals to show resolution

Resolution III Design

We have some main factors effects mixed –up with some two-way interactions

Resolution IV Design

- We have some main factor effects mixed-up with some three-way interactions
- We have some two-way interactions mixed-up with some other two-way interactions

Resolution V Design

- We have some main factor effects mixed-up with some four-way interactions
- We have some two-way interactions mixed-up with some three-way interactions

Confounding

1. Confounding occurs when a fractional factorial design is run
2. It just means that some factors effects are mixed up or confused with other factor effects of different levels
3. In order to know exactly which factors are confounded with which other factors, we need to know the 'Alias Structure

Steps to Conduct a DOE

1. **Define the experimental objective.**
2. **Select the response variable, Y.**
3. **Choose the Xs to test.**
4. **Think about the inference space and choose the levels for the Xs**
5. Select an experimental design and set it up in Minitab.
6. Run the experiment.
7. Analyze the experiment.
8. Confirm the results.

Alias Structure

1. Identity is used to define the Alias Structure.
2. Identity is the product of main factors.,
3. Alias Structure will provide information on which factors are confounding
4. Alias of a given factor is that factor which is confounding with it

Alias Structure Rules

1. I = ABC (Product of all main factors)
2. I = 1
3. BI = ABC*B
4. B = AC

(Any factor multiplied by itself = 1 (1*1))

How is Alias Structure useful

Using a 2^{4-1} or 2^3 design, we can achieve the required 8 runs.

How do we determine the settings for the fourth factor?

	A	B	C	AB	AC	BC	~~ABC~~ D
1	-1	-1	-1	1	1	1	-1
2	1	-1	-1	-1	-1	1	1
3	-1	1	-1	-1	1	-1	1
4	1	1	-1	1	-1	-1	-1
5	-1	-1	1	1	-1	-1	1
6	1	-1	1	-1	1	-1	-1
7	-1	1	1	-1	-1	1	-1
8	1	1	1	1	1	1	1

Type of Experiments

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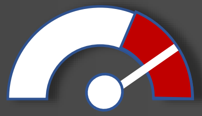
Learn how to perform full factorial DOE

Level of Difficulty



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Types of Designs

1. Screening designs
2. Factorial designs
3. Response surface designs
4. Mixture designs
5. Taguchi designs

Screening Designs

1. Factional Factorial Experiments
2. Plackett-Burman Experiments
3. Definitive Screening Experiments

Plackett-Burman Experiments

1. Plackett-Burman designs are resolution III, 2-level designs
2. Minitab generates designs for up to 47 factors
3. Can be used to test large number of factors at same time

Definitive Screening Experiments

1. Definitive designs are resolution IV, 2-level designs
2. Minitab generates designs for up to 48 factors
3. Can be used for screening curvature (square terms)
4. Can be used to test large number of factors at same time

Types of Designs

1. Screening designs
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3. Response surface designs
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Definitive Screening Experiments

1. Definitive designs are resolution IV, 2-level designs
2. Minitab generates designs for up to 48 factors
3. Can be used for screening curvature (square terms)
4. Can be used to test large number of factors at same time

Response Surface Designs

1. Used to refine models following screening experiments or factorial experiments
2. Useful when particularly when there is curvature in the response surface

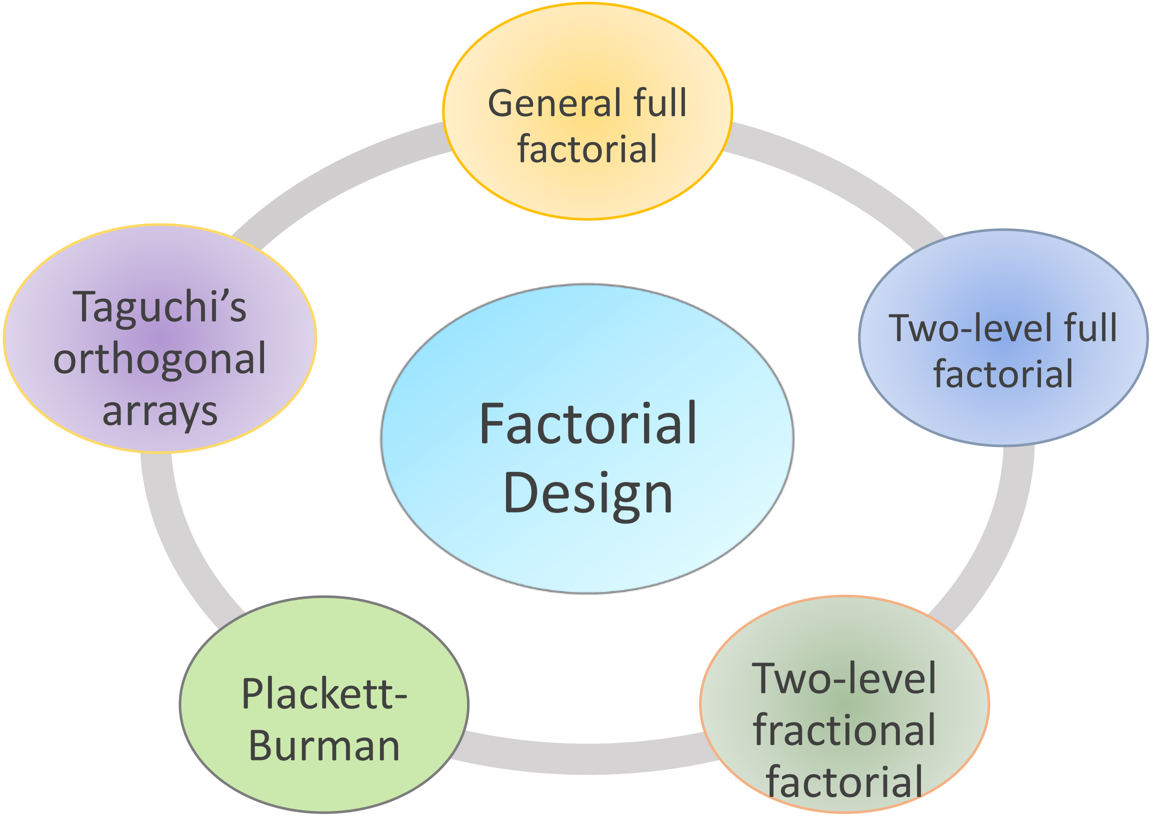
Mixture Designs

1. Used to chemical processes to determine the composition of the ingredients that go into the mixture
2. Mixture experiments are a special class of response surface experiments

Taguchi Designs

1. Developed by Dr. Taguchi
2. Focus in on reducing Taguchi Loss Function
3. Can be used to obtain optimal setting with reduced Variance & On-target
4. Uses a Balanced Design called as "Orthogonal Arrays" (OA)
5. Computes Signal to Noise Ratio

Types of Factorial Design



Example : Response Surface Design

- A full factorial DOE on 'Yield 'of soy oil production process has identified temperature of 180 deg C to be significant
- A response surface design was performed to optimize yield around 180 deg C
- The team identified that 184 deg C is when maximum yield can be obtained