



Design of Experiments Essentials (DOE^2)

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JMP® Statistical Discovery

JMP® is statistical discovery software from the SAS® Institute.

- JMP® provides scientists, engineers and analysts with a visual and interactive tool
 - to explore data,
 - design experiments,
 - improve processes,
 - solve problems quickly,
 - and share results...





Bass Masri

Don't count the days. Make the days count!

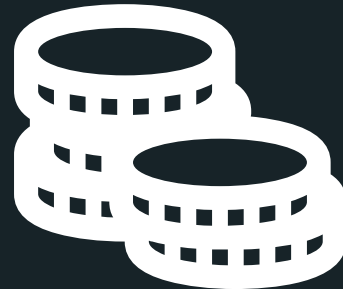


- A passion for analytics and statistics with more than 20 years of work experience in engineering, science and process improvement.
- Tertiary education includes a Bachelor Degree in Science and Masters in Applied Statistics from Macquarie University, Sydney Australia.

Agenda

Design of Experiments Essentials (DOE^2)

- Design of experiments is a structured approach for collecting data and making important discoveries.
- In this reactor case study, we demonstrate how a response can be efficiently optimized for five factors using a design of experiment.
- Today, we focus on why we use DoE, the process workflow, experimental designs and design diagnostics ...



Why use design of experiments?

Quality, Delivery, Cost. In that order!

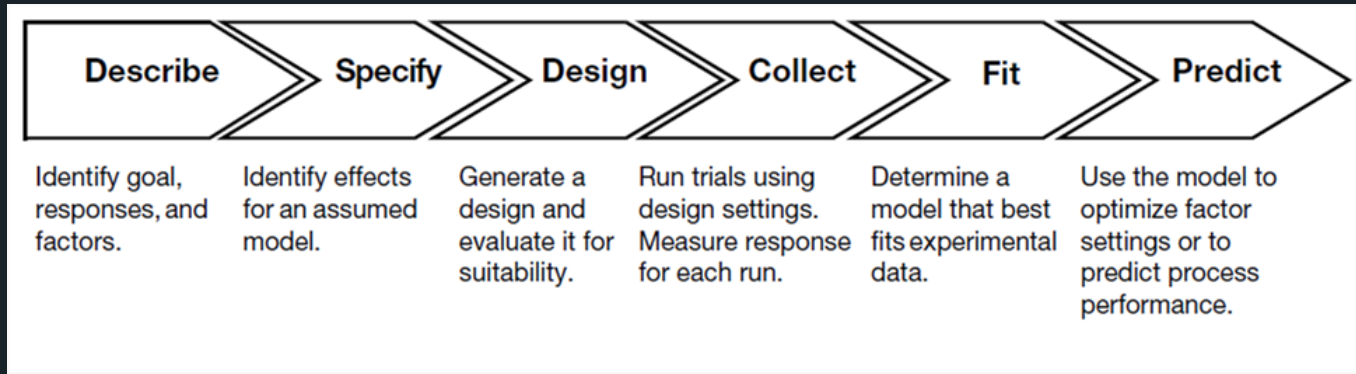
- Design of experiments can be used to improve products and processes by identifying the factors that are important.
- Unlike studying one factor at a time, with a limited number of trials, you can learn a lot about a process.
- Ultimately you improve process performance through better decisions around: Quality, Delivery, Cost.



Process Workflow

Everything is a process!

- This six-step framework provides the structure for designing an experiment, running the experimental trials and analyzing results.




- Source: JMP® Help > Design of Experiments Guide



Design Diagnostics


Power and Sample Size ...

Custom Design



Custom Design

Create a design tailored to meet specific requirements.




Augment Design

Add more runs to an existing data table. Replicate, add centerpoints, fold over, or add model terms.


Definitive Screening

Classical




Screening Design

Sift through many factors to find the few that have the most effect.




Fit Two Level Screening

Analyzes two-level screening designs based on the principle of effect sparsity. This principle assumes that many effects are inactive and helps identify the few effects that have a large impact on the response.




Response Surface Design

Find the best response allowing quadratic effects (curvature).




Full Factorial Design

Generate all possible combinations of the specified factor settings.



Mixture Design


Optimize a recipe for a mixture of several ingredients.



Taguchi Arrays


Make inner and outer arrays from signal and noise factors.

Design Diagnostics




Evaluate Design

Show design diagnostics for any table whether it is a designed experiment or not.



Compare Designs

Make comparisons between experiment designs.



Sample Size and Power

Plot any two of the power to detect an effect, the sample size, and the effect size given the third. Or compute one given the other two.

Consumer Studies

Special Purpose

Sample Size

Prospective Power and Sample Size Calculations

Select Situation for Sample Size or Power calculation

One Sample Mean	Sample Size for testing a mean in a single sample
Two Sample Means	Testing that the means are different across 2 samples
k Sample Means	Testing that the means are different across k samples
One Sample Standard Deviation	Sample Size for detecting a change in the standard deviation.
One Sample Proportion	Sample Size for testing a proportion in a single sample
Two Sample Proportions	Sample Size for testing a proportion across 2 samples
Counts per Unit	Sample Size for detecting change in count per unit, e.g. DPU (defects per unit)
Sigma Quality Level	Calculator for a popular index in terms of defects per opportunity.
Reliability Test Plan	Sample size for reliability studies
Reliability Demonstration	Calculations for planning a reliability demonstration



Design of Experiments

Learning Outcomes and Essential Terms

- Outcome: Design a controlled set of tests to model and explore the relationship between the process inputs and outputs.
- Terminology we will cover
 - factors
 - responses
 - treatments
 - runs
 - effects
 - interactions



Action Plan

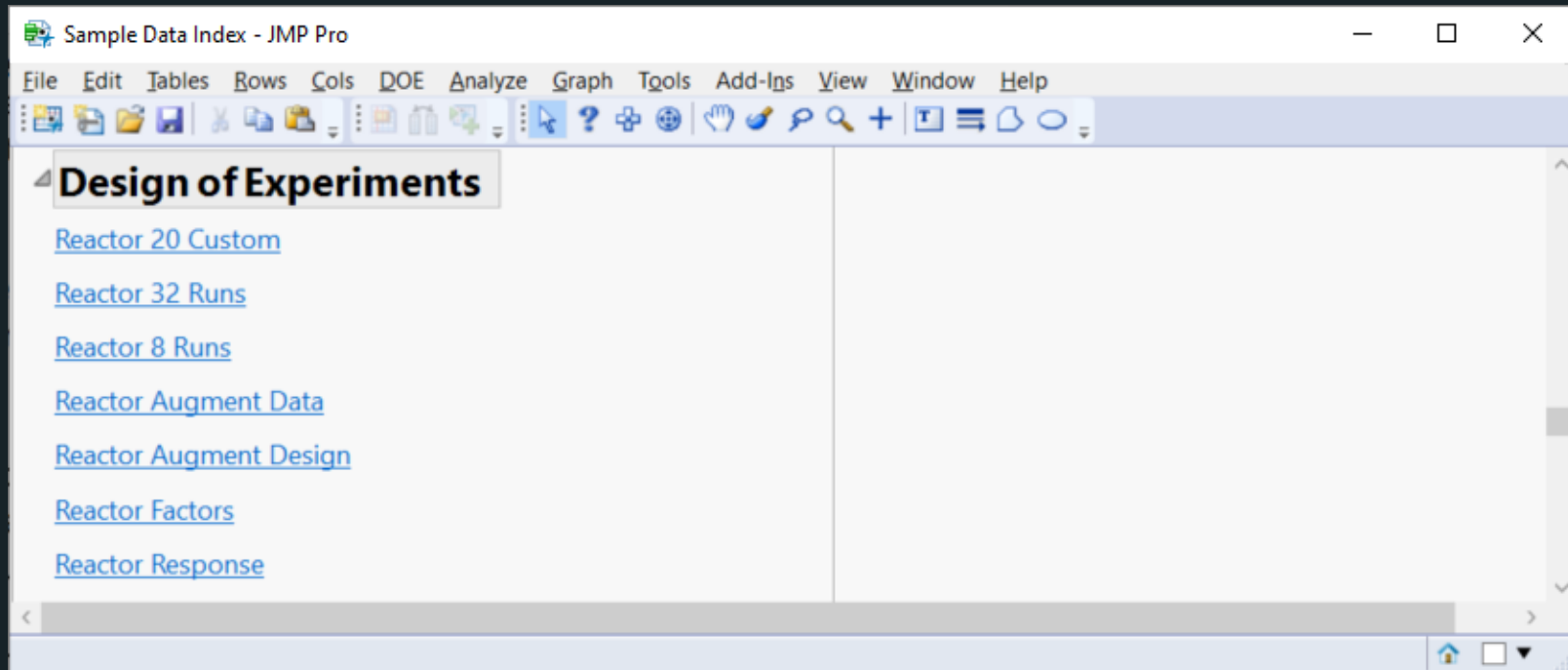
Reactor Case Study

- Situation: You want to study the effects of five two-level factors: Feed Rate, Catalyst, Stir Rate, Temperature and Concentration on the response: Percent Reacted.
- Problem: A higher Percent Reacted ensures higher quality products. In a full factorial design, you perform an experimental run at every combination of the factor levels.
- Impact: The sample size for a full factorial study is 2^K factors, that is 2^5 factorial = $2 \times 2 \times 2 \times 2 \times 2 = 32$ runs. Budget for the design has been allocated and approved.
- Need: You need to determine what factors and 2-way interactions are significant and identify what are the optimal settings to maximize Percent Reacted.



Data Tables

Help > Sample Data > Design of Experiments / Reactor ...



Identify goal, response and factors

Full Factorial Design

Responses

Response Name	Goal	Lower Limit	Upper Limit	Importance
Percent Reacted	Maximize	90	100	1

Factors

Add N Factors: 1

Name	Role	Values
Feed Rate	Continuous	10 15
Catalyst	Continuous	1 2
Stir Rate	Continuous	100 120
Temperature	Continuous	140 180
Concentration	Continuous	3 6

2x2x2x2x2 Factorial

Output Options

Run Order: Randomize

Number of Runs: 32

Number of Center Points: 0

Number of Replicates: 0

The screenshot displays the JMP Pro software interface. The main window shows a table titled 'Reactor Factors' with the following data:

	Feed Rate	Catalyst	Stir Rate	Temperature	Concentration
1	10	1	100	140	3
2	15	2	120	180	6
3	10	1	100	140	3
4	15	2	120	180	6

The interface includes a menu bar (File, Edit, Tables, Rows, Columns, DOE, Analyze, Graph, Tools, Add-Ins, View, Window, Help) and a toolbar. The sidebar on the left shows 'Columns (5/5)' and 'Rows' sections. The 'Columns' section lists 'Feed Rate *', 'Catalyst *', 'Stir Rate *', 'Temperature *', and 'Concentration *'. The 'Rows' section shows 'All rows' (2), 'Selected' (0), and 'Excluded' (0).

Specify

Identify main and interaction effects for the model

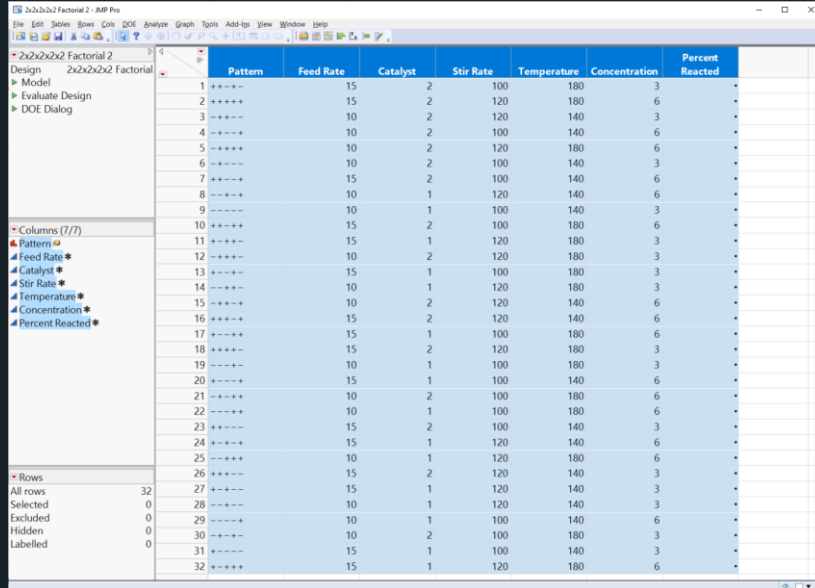
Factors		
Name	Role	Values
Feed Rate	Continuous	10 15
Catalyst	Continuous	1 2
Stir Rate	Continuous	100 120
Temperature	Continuous	140 180
Concentration	Continuous	3 6

Model

Intercept
Feed Rate
Catalyst
Stir Rate
Temperature
Concentration
Feed Rate*Catalyst
Feed Rate*Stir Rate
Catalyst*Stir Rate
Feed Rate*Temperature
Catalyst*Temperature
Stir Rate*Temperature
Feed Rate*Concentration
Catalyst*Concentration
Stir Rate*Concentration
Temperature*Concentration

Design

Generate a design and evaluate



The screenshot shows the JMP Pro interface for a 2x2x2x2 Factorial design. The table contains 32 rows of experimental runs. The columns are: Pattern, Feed Rate, Catalyst, Stir Rate, Temperature, Concentration, and Percent Reacted. The design is a full factorial with 2 levels for each factor.

	Pattern	Feed Rate	Catalyst	Stir Rate	Temperature	Concentration	Percent Reacted
1	1	15	2	100	180	3	*
2	2	15	2	120	180	6	*
3	3	10	2	120	140	3	*
4	4	10	2	100	140	6	*
5	5	10	2	120	180	6	*
6	6	10	2	100	140	3	*
7	7	15	2	100	140	6	*
8	8	10	1	120	140	6	*
9	9	10	1	100	140	3	*
10	10	15	2	100	180	6	*
11	11	15	1	120	180	3	*
12	12	10	2	120	180	3	*
13	13	15	1	100	180	3	*
14	14	10	1	120	180	3	*
15	15	10	2	120	140	6	*
16	16	15	2	120	140	6	*
17	17	15	1	100	180	6	*
18	18	15	2	120	180	3	*
19	19	10	1	100	180	3	*
20	20	15	1	100	140	6	*
21	21	10	2	100	180	6	*
22	22	10	1	100	180	6	*
23	23	15	2	100	140	3	*
24	24	15	1	120	140	6	*
25	25	10	1	120	180	6	*
26	26	15	2	120	140	3	*
27	27	15	1	120	140	3	*
28	28	10	1	120	140	3	*
29	29	10	1	100	140	6	*
30	30	10	2	100	180	3	*
31	31	15	1	100	140	3	*
32	32	15	1	120	180	6	*

Design Diagnostics

D Efficiency	100
G Efficiency	100
A Efficiency	100
Average Variance of Prediction	0.118056
Design Creation Time (seconds)	0

Collect

Run trial using design settings

Reactor 32 Runs - JMP Pro

File Edit Tables Rows Cols DOE Analyze Graph Tools Add-Ins View Window Help

*Reactor 32 Runs
Locked File C:\Program
Design 2x2x2x2x2 Fact
Reference Adapted from
Note Data from a react
► Screening
► Model
► DOE Dialog
► Reduced Model

	Pattern	Feed Rate	Catalyst	Stir Rate	Temperature	Concentration	Percent Reacted
1	++++-	15	2	100	180	3	93
2	+++++	15	2	120	180	6	82
3	-----	10	2	120	140	3	54
4	-----	10	2	100	140	6	70
5	+++++	10	2	120	180	6	81
6	-----	10	2	100	140	3	63
7	+++++	15	2	100	140	6	65
8	-----	10	1	120	140	6	59
9	-----	10	1	100	140	3	61
10	+++++	15	2	100	180	6	77
11	+++++	15	1	120	180	3	60
12	+++++	10	2	120	180	3	95
13	-----	15	1	100	180	3	61
14	-----	10	1	120	180	3	66
15	+++++	10	2	120	140	6	67
16	+++++	15	2	120	140	6	65
17	+++++	15	1	100	180	6	45
18	+++++	15	2	120	180	3	98
19	-----	10	1	100	180	3	69
20	-----	15	1	100	140	6	63
21	+++++	10	2	100	180	6	78
22	+++++	10	1	100	180	6	44
23	-----	15	2	100	140	3	61
24	-----	15	1	120	140	6	55
25	+++++	10	1	120	180	6	49
26	+++++	15	2	120	140	3	61
27	+++++	15	1	120	140	3	56
28	-----	10	1	120	140	3	53
29	-----	10	1	100	140	6	56
30	-----	10	2	100	180	3	94
31	-----	15	1	100	140	3	53
32	+++++	15	1	120	180	6	42

*Columns (7/7)
 Pattern
 Feed Rate
 Catalyst
 Stir Rate
 Temperature
 Concentration
 Percent Reacted

*Rows
 All rows 32
 Selected 0
 Excluded 0

Model Specification

Select Columns
7 Columns
Pattern
Feed Rate
Catalyst
Stir Rate
Temperature
Concentration
Percent Reacted

Pick Role Variables
Percent Reacted

Personality: Standard Least Squares
Emphasis: Effect Screening

☐ Keep dialog open

Construct Model Effects

Degree

2

Attributes

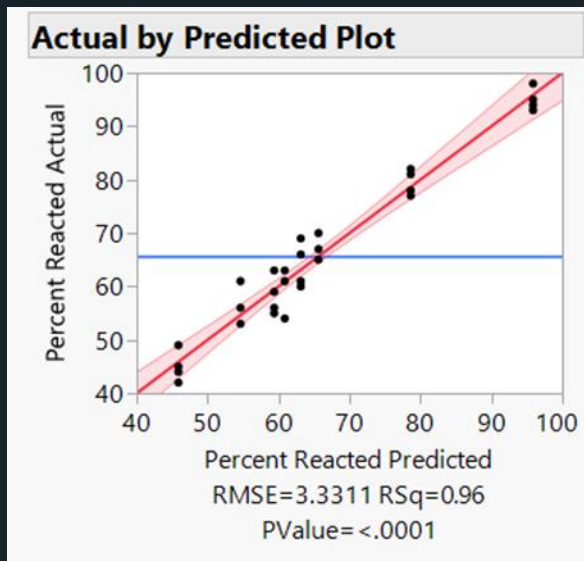
Transform

☐ No Intercept

Feed Rate
Catalyst
Stir Rate
Temperature
Concentration
Feed Rate*Catalyst
Feed Rate*Stir Rate
Catalyst*Stir Rate
Feed Rate*Temperature
Catalyst*Temperature
Stir Rate*Temperature
Feed Rate*Concentration
Catalyst*Concentration
Stir Rate*Concentration
Temperature*Concentration

Fit

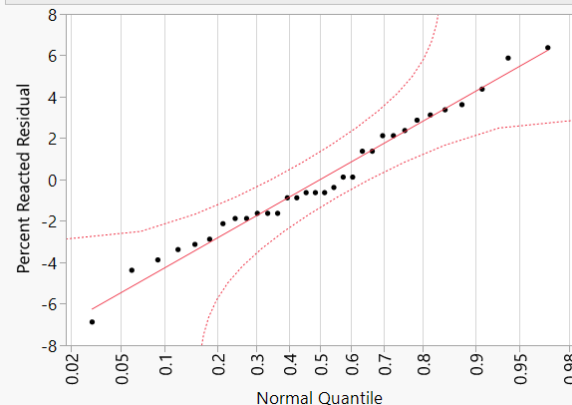
Determine the model that best fits experimental data



Effect Summary

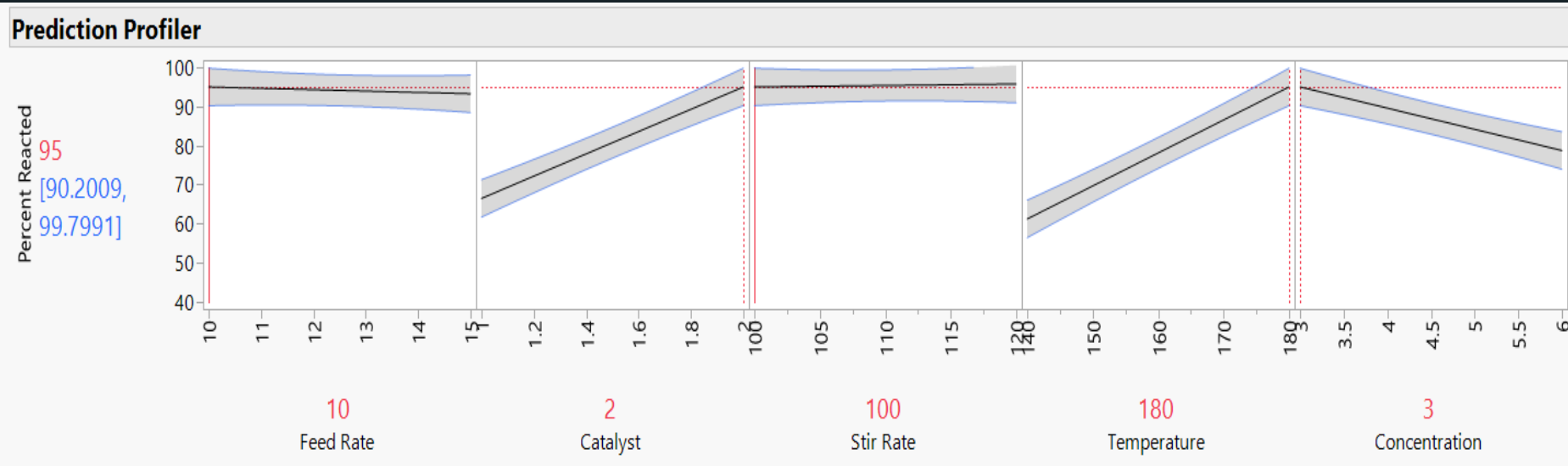
Source	LogWorth	PValue
Catalyst(1,2)	14.602	0.00000
Catalyst*Temperature	10.763	0.00000
Temperature*Concentration	9.065	0.00000
Temperature(140,180)	8.864	0.00000 ^
Concentration(3,6)	4.825	0.00001 ^

Residual Normal Quantile Plot



Predict

Use the model to optimize response



Findings and Summary

Next Steps

- We learnt about experimental designs and the general steps for how to conduct an experiment, including:
 1. Describe response and factors.
 2. Identify effects and specify model.
 3. Generate and evaluate the design.
 4. Conduct experiment and measure response.
 5. Fit model, identify optimal settings and predict performance.



Keen to try?

Download Trial Version

- Keen to give it a go? Try the Design of Experiments Essentials Journal, Sample Data and read the DOE Guide.
- Don't have JMP®? Download a 30-day free trial version from https://www.jmp.com/en_au/download-jmp-free-trial.html



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Design of Experiments

Design of experiments (DOE) is a rigorous methodology that enables scientists and engineers to study the relationship between multiple input variables, or *factors*, on key output variables, or *responses*.

In this module, you will learn why designed experiments are better than trial and error and one-factor-at-a-time approaches to gain an understanding of cause and effect relationships and interactions between factors. You will be introduced to several types of designs such as factorial, response surface and custom designs. Finally, you will learn some DOE guidelines and best practices which will help you succeed with experimentation.

[Enroll now](#)



Design of Experiments

Design of Experiments Overview (1:01)



The Design of Experiments Intro Kit

Complete with individual certificate ...

Adjust the factors that produce an optimal Coffee strength between 1.2 and 1.4, select Brew, then Submit.

Temp Time Charge Grind

200 3.25 2.2

Coarse Medium

Brew

Open Prediction Profiler

Foundation Process Custom Design DOE Designs Tools Experiment

v6.6.8



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Day 1: Introduction to design of experiments

 Monday 22 June 2020 | 10.00 - 10.45 (BST)

What is DoE? From example case studies you will see why this is such an important tool for scientist and engineers.

[VIEW THE RECORDING NOW](#)

Resources

-  [Why design of experiments keeps science in science](#)
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-  [Homework exercises](#)



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JMP is a division of SAS that produces interactive statistical discovery software.



> John Sall

SAS Co-Founder and Executive Vice President John Sall is the creator and chief architect of JMP software.



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Customer success stories by application

Design of Experiments



➤ **AIM Autosport and DMH Racing**
AIM Motorsport and DMH Racing use JMP to fine-tune open wheel race cars.



➤ **Almac**
Almac uses JMP design of experiments to bring new drugs to market faster.



➤ **American Society of Testing and Materials**
The American Society of Testing and Materials uses JMP to design roadwheel tests.



➤ **Amperex Technology Ltd**
Integrated JMP analytics enable engineers to reduce process variation and optimize production.



➤ **Anatune**
Chemists use DOE to design customized robotic solutions for chemical analysis.



➤ **ASM International**
ASM utilizes statistical methods companywide to be more effective and efficient.



➤ **Atotech**
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Lockheed Martin engineers take a statistical approach to aircraft departure noise.



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Synthetic biologists improve experimentation with DOE and robotic automation.



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