Easy DOE - New in JMP 17

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Mastering JMP
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Outline

- Why Easy DOE? – Key Features
- Why DOE?
- 1st example use of Guided Easy DOE
- Review important concepts in the Guided Easy DOE process
- 2nd example use of Guided Easy DOE

Why Easy DOE? - Key Features

JMP 17 makes it easier for everyone to experiment

- End-to-end coverage of every step of experimentation.
- Streamlined experience through tailored elements in a new user interface.
- Guided mode for novice experimenters (default) and Flexible mode for more demanding situations.
- Comprehensive summary report is automatically written based on the current state of the experiment.
- Save your work at any time and return to the same point.
- Easily share experiments with others.

[Developer Tutorial: Easy DOE – Expertly Guiding Users Through Designing an Experiment]

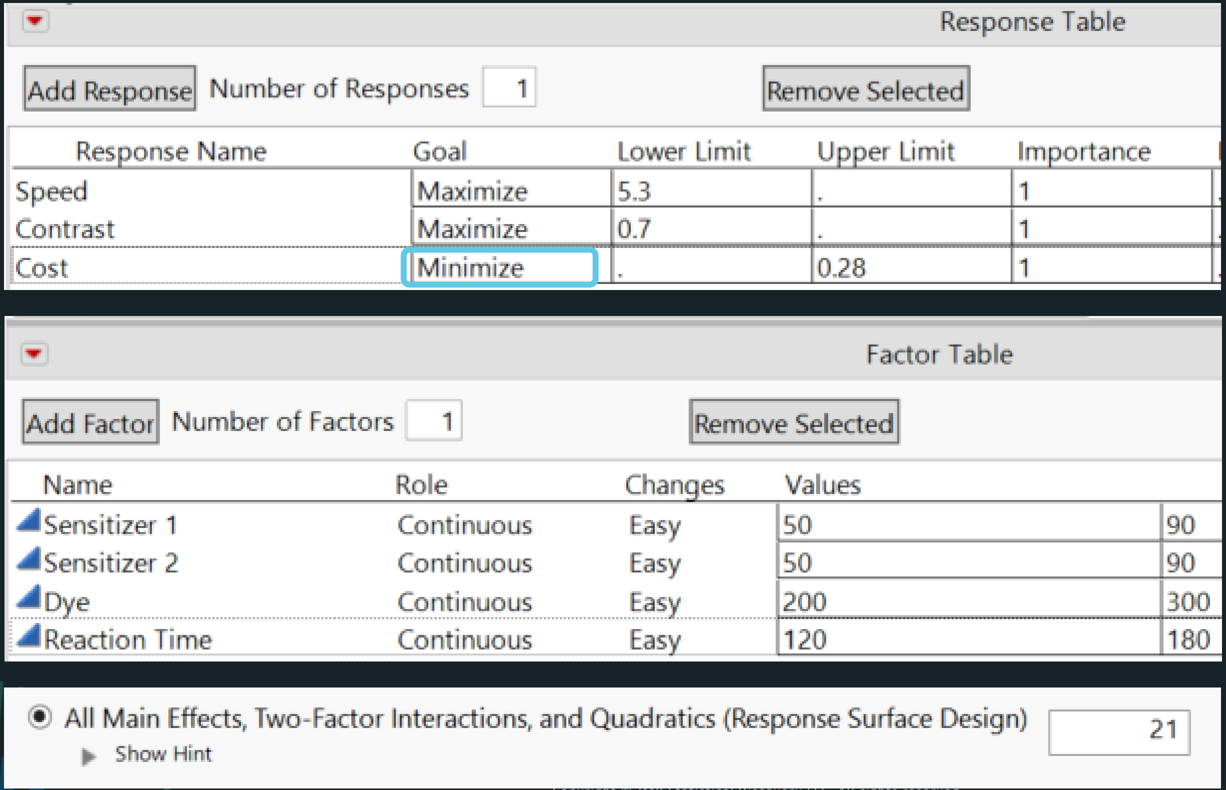
Why use DOE?

QUICKER ANSWERS, LOWER COSTS, SOLVE BIGGER PROBLEMS,
MAKE BETTER INFORMED DECISIONS

- More rapidly answer *“what if?”* questions
- *Identify important factors* when faced with many
- Do *sensitivity* and *trade-space* analysis
- *Optimize* across multiple responses
- By running efficient subsets of all possible combinations, one can – for the same resources and constraints – *solve bigger problems*
- By running sequences of designs one can be as *cost effective as possible* and *run no more trials than needed* to get a useful answer

Use Easy DOE

3-response, 4-factor, trade-space analysis and optimization example



Number of Responses 1

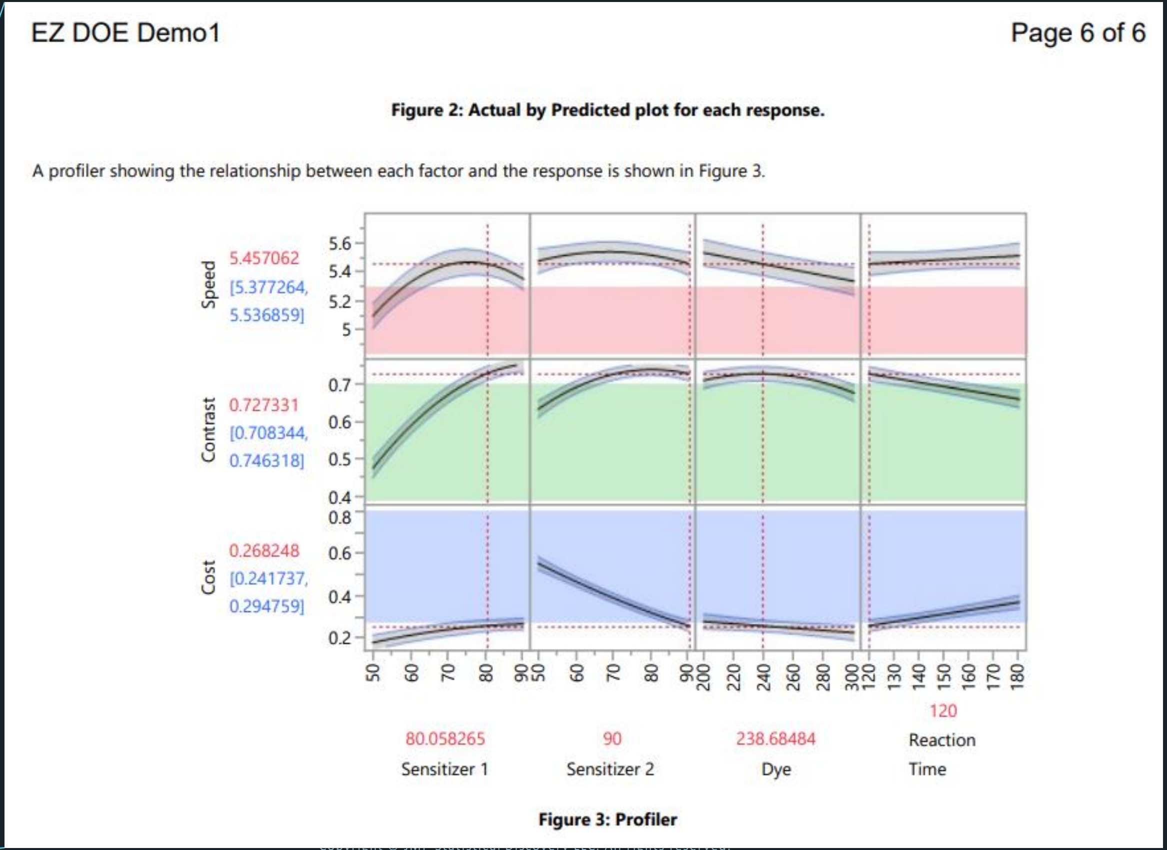
Response Name	Goal	Lower Limit	Upper Limit	Importance
Speed	Maximize	5.3	.	1
Contrast	Maximize	0.7	.	1
Cost	Minimize	.	0.28	1

Number of Factors 1

Name	Role	Changes	Values	
Sensitizer 1	Continuous	Easy	50	90
Sensitizer 2	Continuous	Easy	50	90
Dye	Continuous	Easy	200	300
Reaction Time	Continuous	Easy	120	180

● All Main Effects, Two-Factor Interactions, and Quadratics (Response Surface Design) 21

Last page of Report shows Prediction Profiler after pressing Optimize button & meeting all requirements



EZ DOE Demo1

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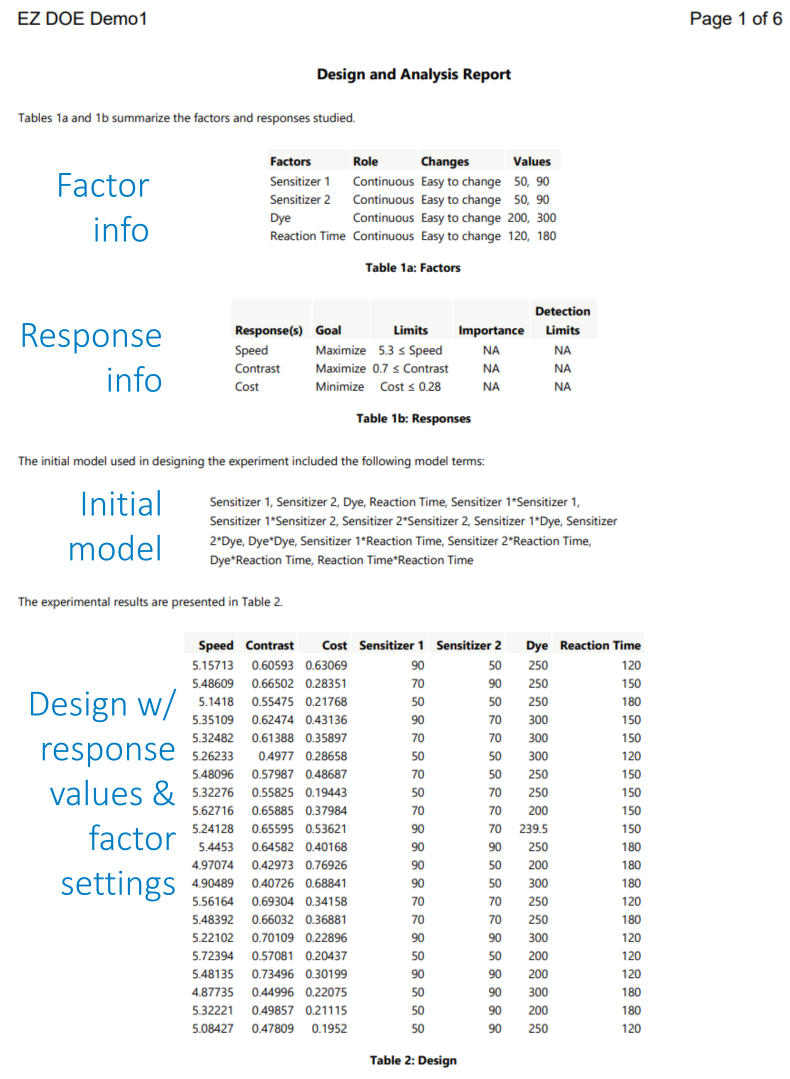
Figure 2: Actual by Predicted plot for each response.

A profiler showing the relationship between each factor and the response is shown in Figure 3.

Figure 3: Profiler



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Design and Analysis Report

Tables 1a and 1b summarize the factors and responses studied.

Factor info

Factors	Role	Changes	Values
Sensitizer 1	Continuous	Easy to change	50, 90
Sensitizer 2	Continuous	Easy to change	50, 90
Dye	Continuous	Easy to change	200, 300
Reaction Time	Continuous	Easy to change	120, 180

Table 1a: Factors

Response info

Response(s)	Goal	Limits	Importance	Detection Limits
Speed	Maximize	5.3 ≤ Speed	NA	NA
Contrast	Maximize	0.7 ≤ Contrast	NA	NA
Cost	Minimize	Cost ≤ 0.28	NA	NA

Table 1b: Responses

The initial model used in designing the experiment included the following model terms:

Initial model

Sensitizer 1, Sensitizer 2, Dye, Reaction Time, Sensitizer 1*Sensitizer 1, Sensitizer 1*Sensitizer 2, Sensitizer 2*Sensitizer 2, Sensitizer 1*Dye, Sensitizer 2*Dye, Dye*Dye, Sensitizer 1*Reaction Time, Sensitizer 2*Reaction Time, Dye*Reaction Time, Reaction Time*Reaction Time

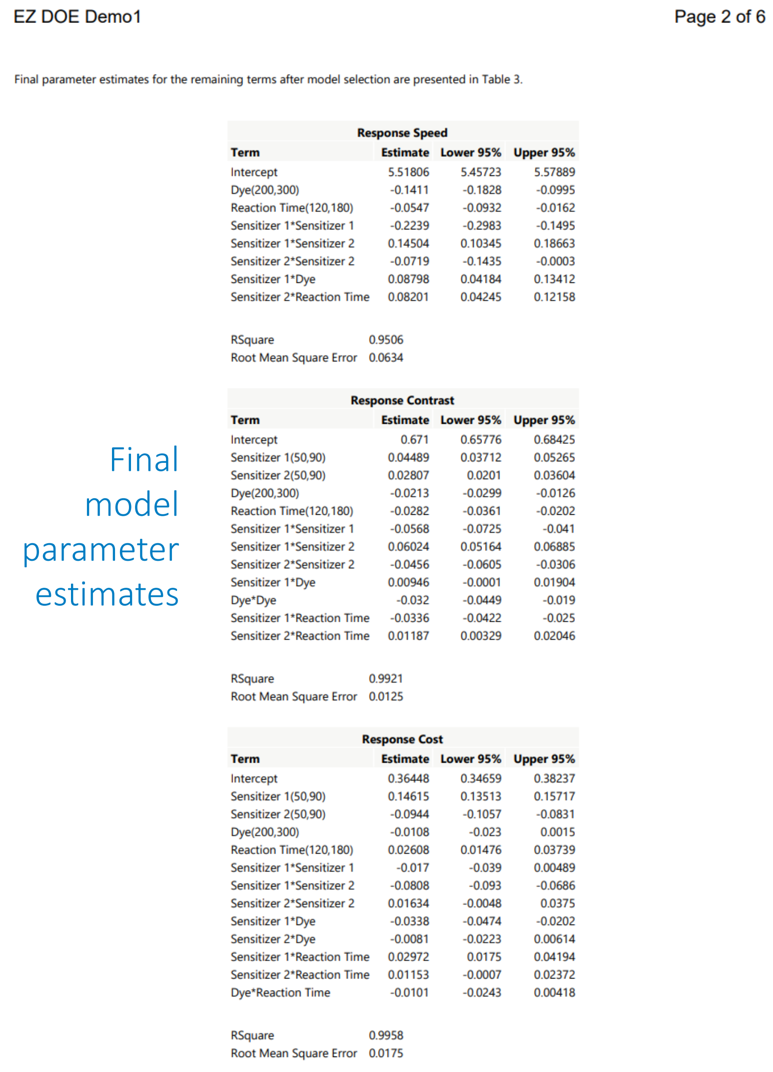
The experimental results are presented in Table 2.

Design w/ response values & factor settings

Speed	Contrast	Cost	Sensitizer 1	Sensitizer 2	Dye	Reaction Time
5.15713	0.60593	0.63069	90	50	250	120
5.48609	0.66502	0.28351	70	90	250	150
5.1418	0.55475	0.21768	50	50	250	180
5.35109	0.62474	0.43136	90	70	300	150
5.32482	0.61388	0.35897	70	70	300	150
5.26233	0.4977	0.28658	50	50	300	120
5.48096	0.57987	0.48687	70	50	250	150
5.32276	0.55825	0.19443	50	70	250	150
5.62716	0.65885	0.37984	70	70	200	150
5.24128	0.65595	0.53621	90	70	239.5	150
5.4453	0.64582	0.40168	90	90	250	180
4.97074	0.42973	0.76926	90	50	200	180
4.90489	0.40726	0.68841	90	50	300	180
5.56164	0.69304	0.34158	70	70	250	120
5.48392	0.66032	0.36881	70	70	250	180
5.22102	0.70109	0.22896	90	90	300	120
5.72394	0.57081	0.20437	50	50	200	120
5.48135	0.73496	0.30199	90	90	200	120
4.87735	0.44996	0.22075	50	90	300	180
5.32221	0.49857	0.21115	50	90	200	180
5.08427	0.47809	0.1952	50	90	250	120

Table 2: Design

Rep



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Final parameter estimates for the remaining terms after model selection are presented in Table 3.

Final model parameter estimates

Response Speed

Term	Estimate	Lower 95%	Upper 95%
Intercept	5.51806	5.45723	5.57889
Dye(200,300)	-0.1411	-0.1828	-0.0995
Reaction Time(120,180)	-0.0547	-0.0932	-0.0162
Sensitizer 1*Sensitizer 1	-0.2239	-0.2983	-0.1495
Sensitizer 1*Sensitizer 2	0.14504	0.10345	0.18663
Sensitizer 2*Sensitizer 2	-0.0719	-0.1435	-0.0003
Sensitizer 1*Dye	0.08798	0.04184	0.13412
Sensitizer 2*Reaction Time	0.08201	0.04245	0.12158

RSquare 0.9506
Root Mean Square Error 0.0634

Response Contrast

Term	Estimate	Lower 95%	Upper 95%
Intercept	0.671	0.65776	0.68425
Sensitizer 1(50,90)	0.04489	0.03712	0.05265
Sensitizer 2(50,90)	0.02807	0.0201	0.03604
Dye(200,300)	-0.0213	-0.0299	-0.0126
Reaction Time(120,180)	-0.0282	-0.0361	-0.0202
Sensitizer 1*Sensitizer 1	-0.0568	-0.0725	-0.041
Sensitizer 1*Sensitizer 2	0.06024	0.05164	0.06885
Sensitizer 2*Sensitizer 2	-0.0456	-0.0605	-0.0306
Sensitizer 1*Dye	0.00946	-0.0001	0.01904
Dye*Dye	-0.032	-0.0449	-0.019
Sensitizer 1*Reaction Time	-0.0336	-0.0422	-0.025
Sensitizer 2*Reaction Time	0.01187	0.00329	0.02046

RSquare 0.9921
Root Mean Square Error 0.0125

Response Cost

Term	Estimate	Lower 95%	Upper 95%
Intercept	0.36448	0.34659	0.38237
Sensitizer 1(50,90)	0.14615	0.13513	0.15717
Sensitizer 2(50,90)	-0.0944	-0.1057	-0.0831
Dye(200,300)	-0.0108	-0.023	0.0015
Reaction Time(120,180)	0.02608	0.01476	0.03739
Sensitizer 1*Sensitizer 1	-0.017	-0.039	0.00489
Sensitizer 1*Sensitizer 2	-0.0808	-0.093	-0.0686
Sensitizer 2*Sensitizer 2	0.01634	-0.0048	0.0375
Sensitizer 1*Dye	-0.0338	-0.0474	-0.0202
Sensitizer 2*Dye	-0.0081	-0.0223	0.00614
Sensitizer 1*Reaction Time	0.02972	0.0175	0.04194
Sensitizer 2*Reaction Time	0.01153	-0.0007	0.02372
Dye*Reaction Time	-0.0101	-0.0243	0.00418

RSquare 0.9958
Root Mean Square Error 0.0175

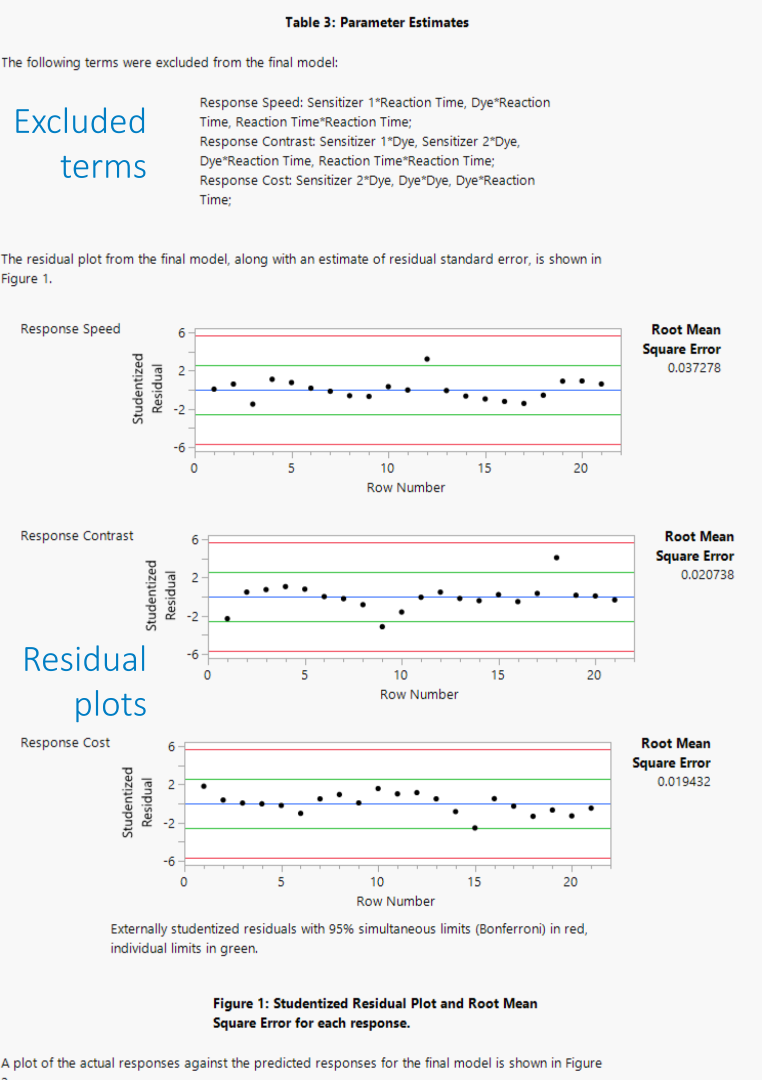


Table 3: Parameter Estimates

The following terms were excluded from the final model:

Excluded terms

Response Speed: Sensitizer 1*Reaction Time, Dye*Reaction Time, Reaction Time*Reaction Time;
Response Contrast: Sensitizer 1*Dye, Sensitizer 2*Dye, Dye*Reaction Time, Reaction Time*Reaction Time;
Response Cost: Sensitizer 2*Dye, Dye*Dye, Dye*Reaction Time;

The residual plot from the final model, along with an estimate of residual standard error, is shown in Figure 1.

Residual plots

Root Mean Square Error 0.037278

Root Mean Square Error 0.020738

Root Mean Square Error 0.019432

Externally studentized residuals with 95% simultaneous limits (Bonferroni) in red, individual limits in green.

Figure 1: Studentized Residual Plot and Root Mean Square Error for each response.

A plot of the actual responses against the predicted responses for the final model is shown in Figure

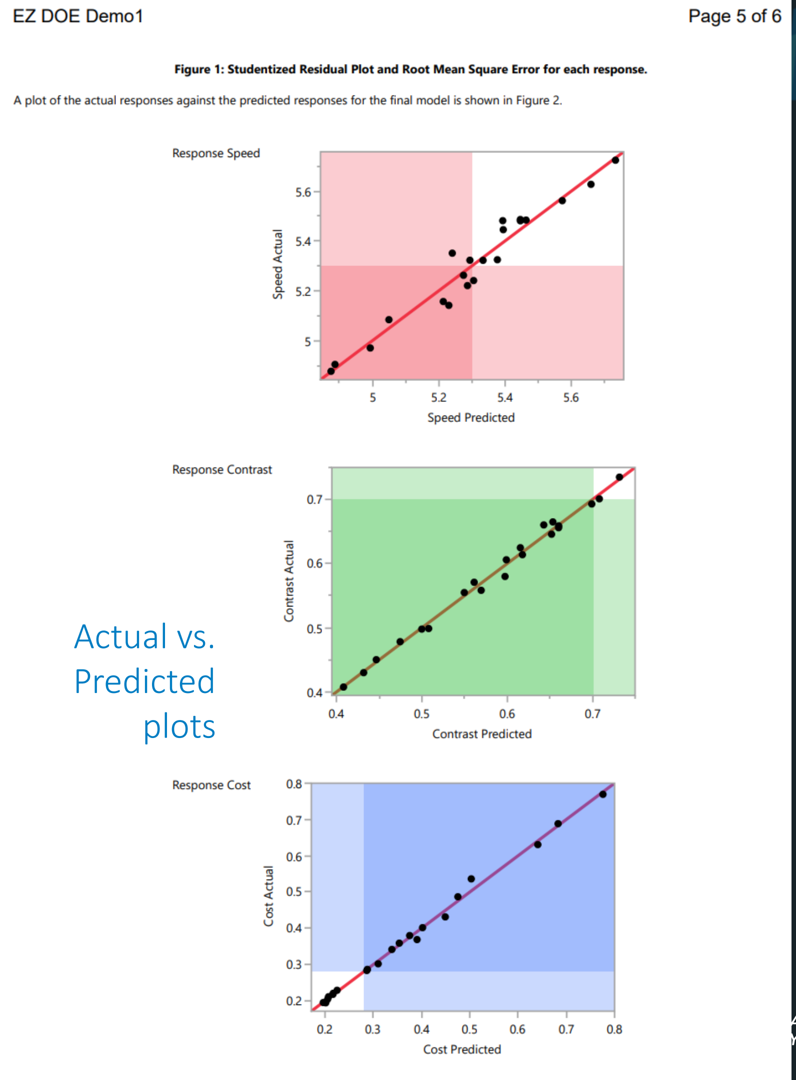


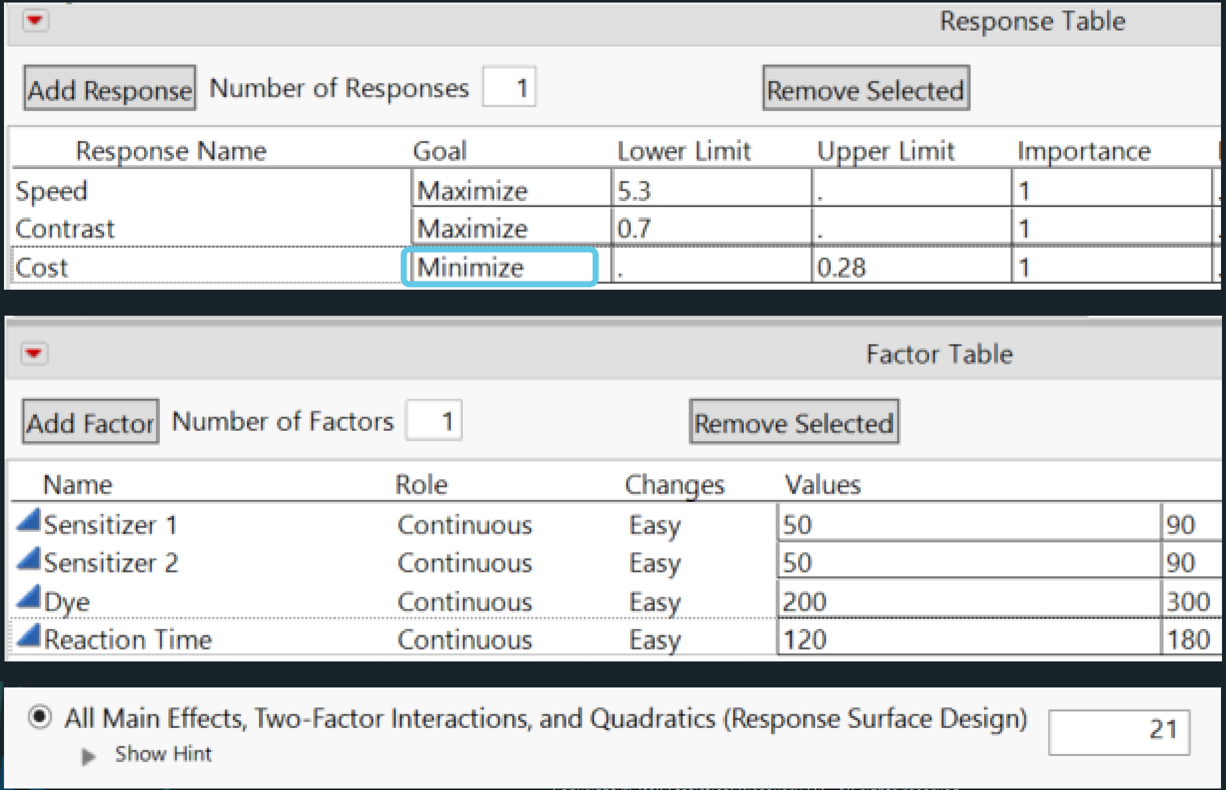
Figure 1: Studentized Residual Plot and Root Mean Square Error for each response.

A plot of the actual responses against the predicted responses for the final model is shown in Figure 2.

Actual vs. Predicted plots

Use Easy DOE

3-response, 4-factor, trade-space analysis and optimization example



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● All Main Effects, Two-Factor Interactions, and Quadratics (Response Surface Design) 21

Go to JMP 17…

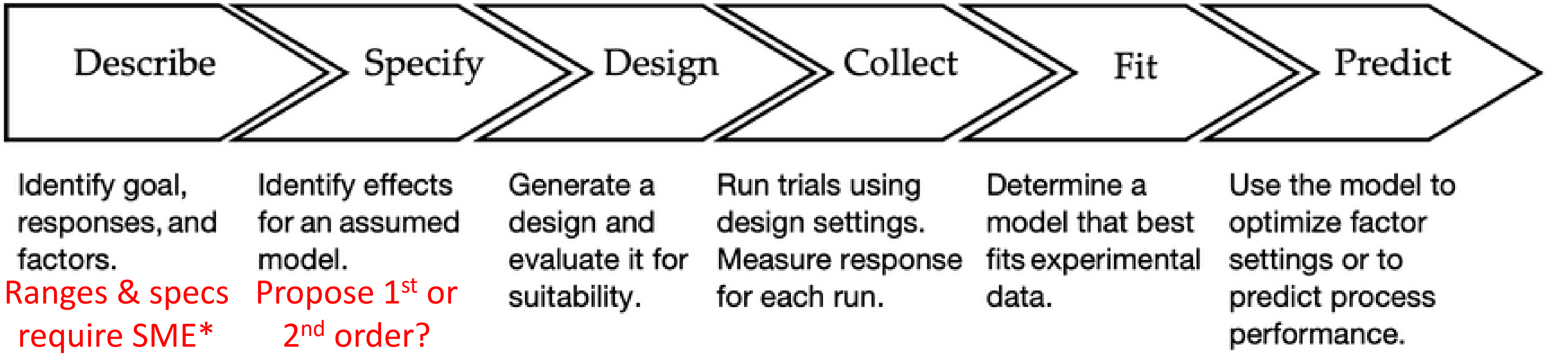
Easy DOE Demo

- ✓ Start with the end…presenting DOE results *interactively* to decision makers
- ✓ Recreate the "Why DOE?" example using Easy DOE platform
- Introduce the 6-step DOE Process implemented in the Easy DOE interface
- Review factor types supported and model choices
- Again, use Guided Easy DOE process for slightly more complex 3-response, 4-factor, trade-space/optimization example using new *.jmpdoe* file.

1. Define
2. Specify
3. Design
4. Data Entry
5. Analyze
6. Predict

Report

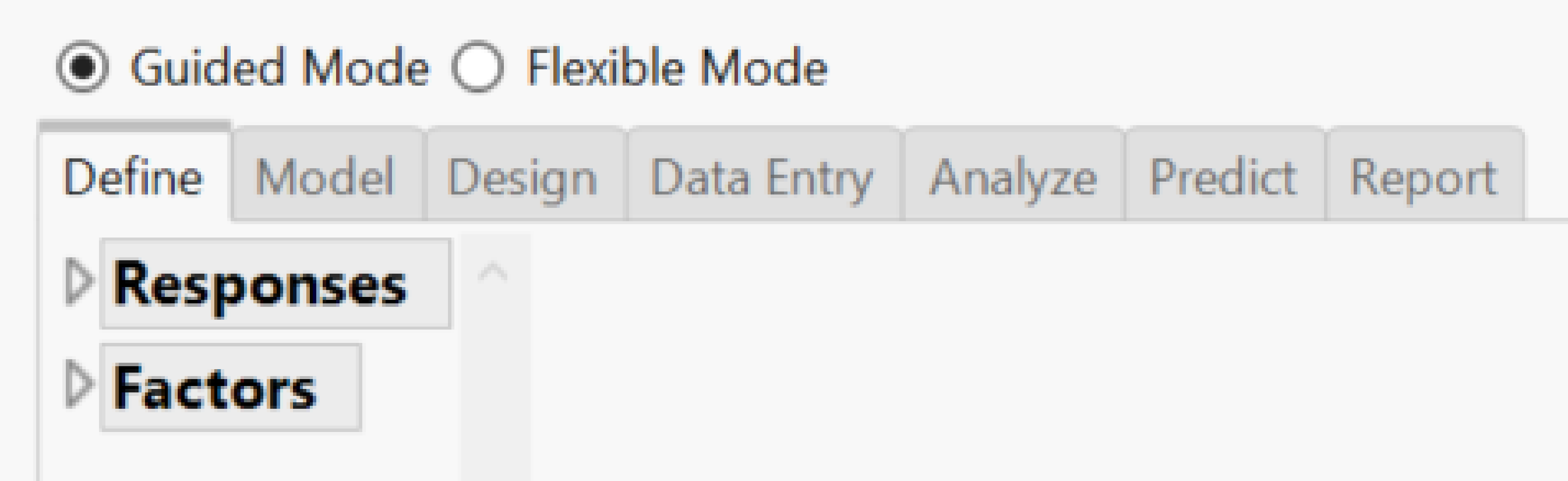
6-Step DOE Process



Describe	Specify	Design	Collect	Fit	Predict
Identify goal, responses, and factors.	Identify effects for an assumed model.	Generate a design and evaluate it for suitability.	Run trials using design settings. Measure response for each run.	Determine a model that best fits experimental data.	Use the model to optimize factor settings or to predict process performance.
Ranges & specs require SME*	Propose 1st or 2nd order?				

Two Modes

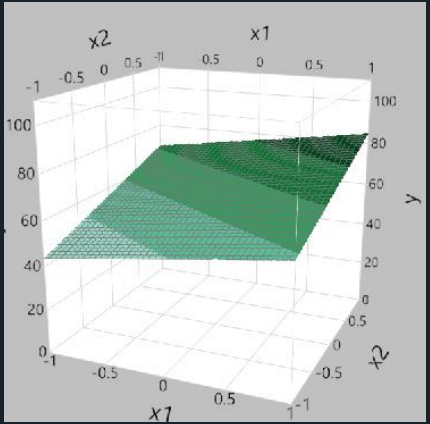
Same 6 Steps plus a *Report*



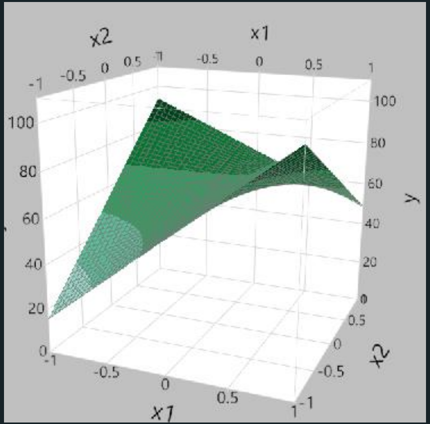
● Guided Mode ○ Flexible Mode

*Subject Matter Expert

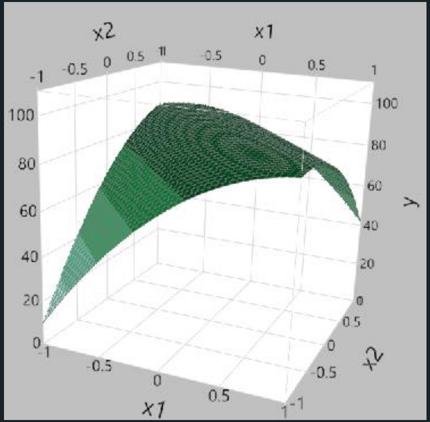
Quadratic model is not much bigger than *Interaction* model. If you have continuous factors, **choose full 2nd order, *Quadratic***



1st Order



2nd Order



2nd Order

$$y = a_0 + a_1x_1 + a_2x_2$$

For k factors there are

k main effects

3-factor Linear Model has 4 terms (8 corners)

6-factor Linear Model has 7 terms (64 corners)

10-factor Linear Model has 11 terms (1K corners)

20-factor Linear Model has 21 terms (1M corners)

$$y = a_0 + a_1x_1 + a_2x_2 + a_{12}x_1x_2$$

For k factors there are

k(k-1)/2 interaction effects

3-f Interaction Model has 7 terms (2X ME)

6-f Interaction Model has 22 terms (3X ME)

10-f Interaction Model has 56 terms (5X ME)

20-f Interaction Model has 211 terms (10X ME)

$$y = a_0 + a_1x_1 + a_2x_2 + a_{12}x_1x_2 + a_{11}x_1^2 + a_{22}x_2^2$$

For k factors there are

k squared effects

3-f Quadratic Model has 10 terms (2.5X ME)

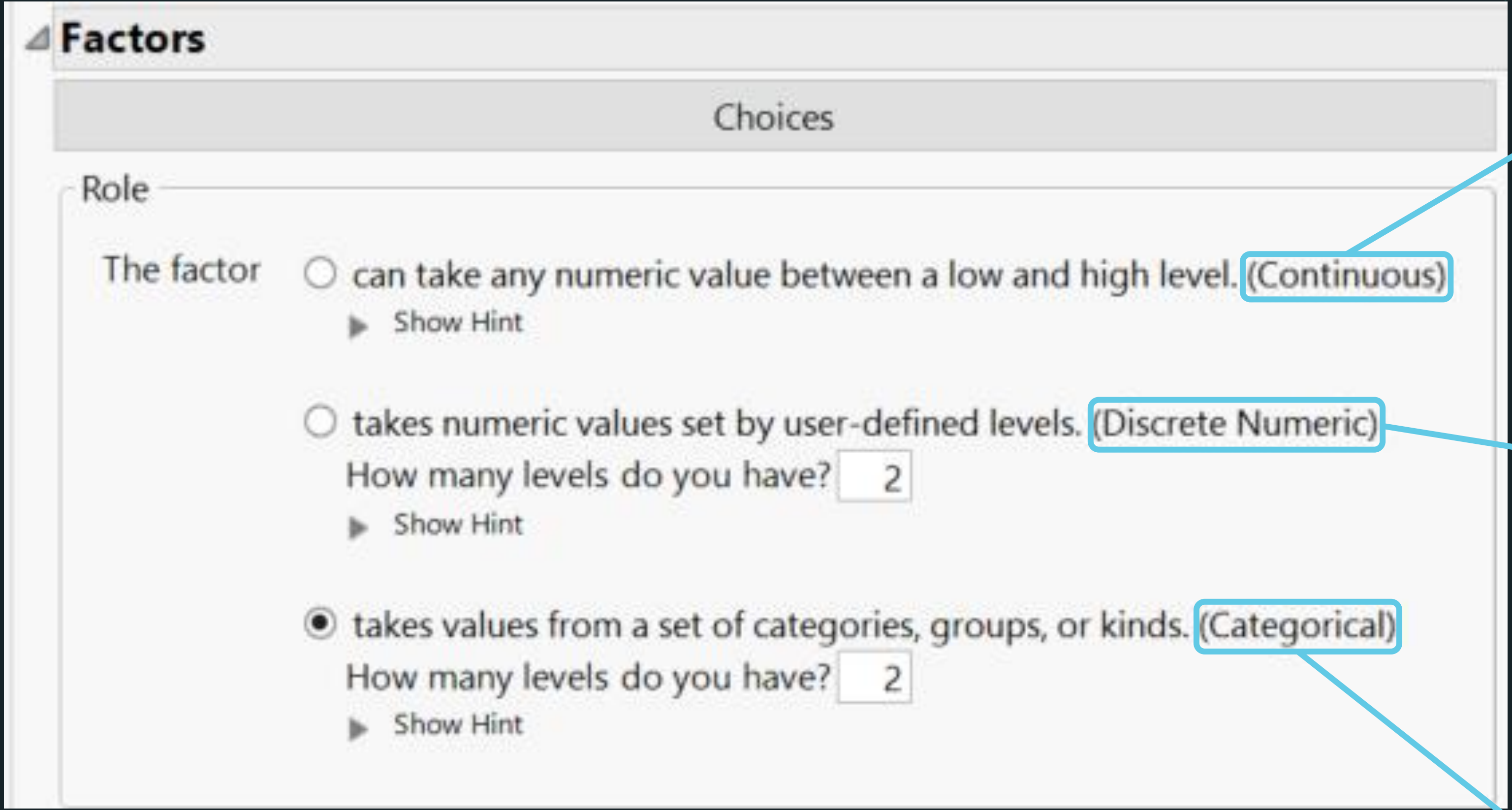
6-f Quadratic Model has 28 terms (4X ME)

10-f Quadratic Model has 66 terms (6X ME)

20-f Quadratic Model has 231 terms (11X ME)

If no squared terms, then optimum can ONLY be a corner!

jmp STATISTICAL DISCOVERY



Factors

Choices

Role

The factor ○ can take any numeric value between a low and high level. (Continuous)

▶ Show Hint

○ takes numeric values set by user-defined levels. (Discrete Numeric)

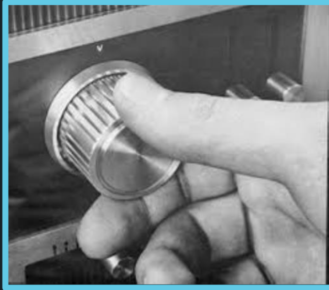
How many levels do you have? 2

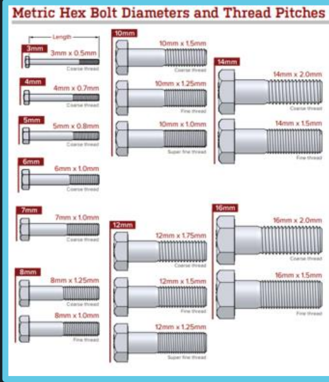
▶ Show Hint

● takes values from a set of categories, groups, or kinds. (Categorical)

How many levels do you have? 2

▶ Show Hint

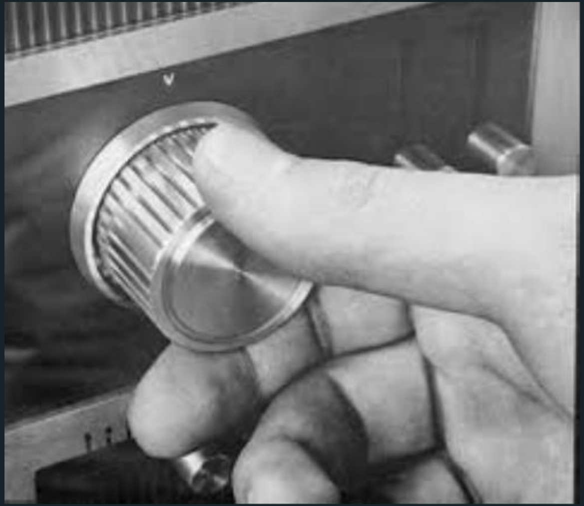




AA ANCHOR BOLT, INC.

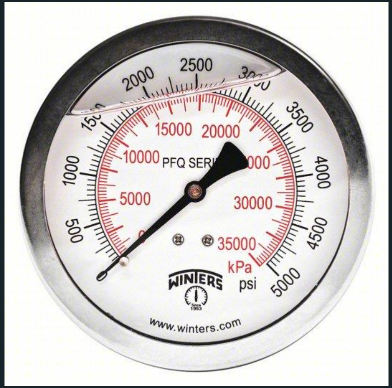
BMB Fasteners, Inc.

CHAMPION BOLT & SUPPLY INC.



Continuous Factors are infinitesimally adjustable over a range. One can finely turn a control knob to adjust the setting.

Examples (Clockwise) are ***Time***, ***Temperature***, ***Speed***, ***RPM***, and ***Pressure***



Categorical Factor: ***Vendor***

Order doesn't matter.

Interpolation makes no sense.

L1

AA ANCHOR BOLT, INC.

L2

BMB Fasteners, Inc.

L3

CHAMPION BOLT & SUPPLY INC.

Categorical Factor: ***Vendor***

Order doesn’t matter.

Interpolation makes no sense.

L1

BMB®
Fasteners, Inc.

L2

CHAMPION
BOLT & SUPPLY INC.

L3

AA ANCHOR
BOLT, INC.

Categorical Factor: *Vendor*

Order doesn't matter.

Interpolation makes no sense.

L1 BMB Fasteners, Inc.

L2 CHAMPION BOLT & SUPPLY INC.

L3 AA ANCHOR BOLT, INC.

Categorical Factor: *Grade of Stainless Steel*

Order potentially matters

Ordinal Ranking makes sense

L1 304 Stainless Steel Pros and Cons

The main benefit is that 304 stainless steel is usually considered to be one of the strongest of the mild steels available on the market. It boasts a respectable level of resistance to corrosion and is much easier to mold than its 316 stainless steel alternative. However, like 18-8 grade stainless steel it is vulnerable to corrosion when exposed to salt water.

L2 18-8 Stainless Steel Pros and Cons

As already mentioned, 18-8 grade stainless steel is celebrated for its superior corrosion resistance. However, it is known to show signs of corrosion when exposed to chlorides, such as salt. Therefore, it is not the ideal stainless steel to use for marine applications. On the upside, 18-8 grade stainless steel properties include the fact that it can be bent and molded without it having an effect on its overall strength and durability. This type of stainless steel is also not only extremely budget-friendly, but it also requires little to no maintenance. 18-8 stainless steel yield strength is also impressive.

L3 316 Stainless Steel Pros and Cons

316 stainless steel boasts a higher strength and durability than 304 stainless steel. It also has a higher level of corrosion resistance, including when exposed to salt water. It performs well against pitting and is also resistant to caustic chemicals. As mentioned above, however, 316 stainless steel is less malleable than 304 stainless steel. It is also substantially more expensive.

Categorical Factor: ***Vendor***

Order doesn't matter.

Interpolation makes no sense.

L1 BMB Fasteners, Inc.

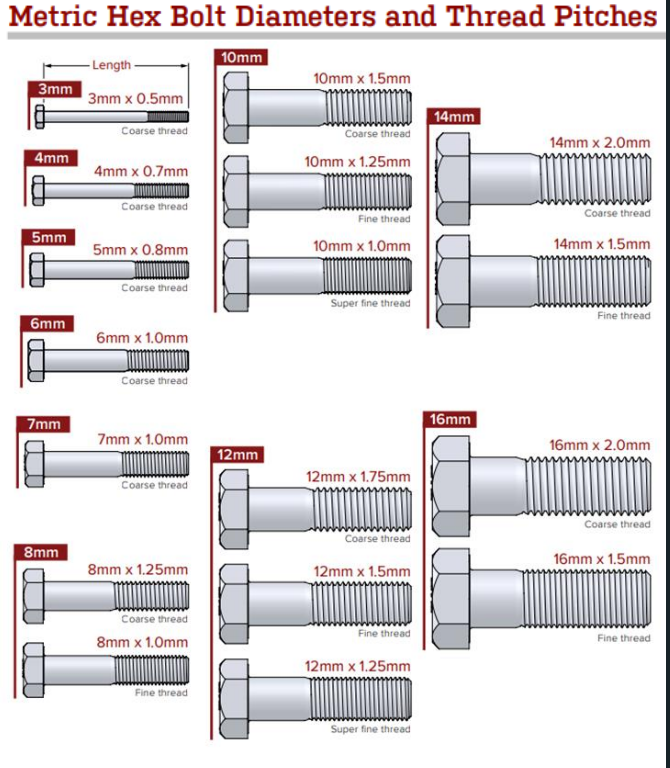
L2 CHAMPION BOLT & SUPPLY INC.

L3 AA ANCHOR BOLT, INC.

Discrete Numeric Factor: ***Diameter***

Order does matter.

Interpolation makes sense.



Designs like a *categorical* factor, but models as *continuous*

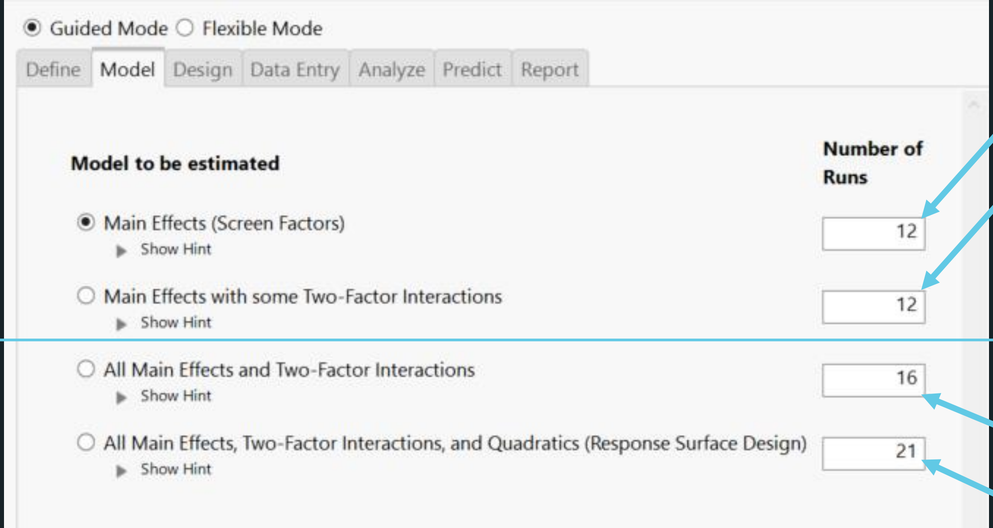
Bolt diameters are only available in whole millimeters between 3 & 16, with no option for 9, 11, 13, & 15 mm.

For range of 7 to 10, mid point is ~~8.5~~. Only "mid" level is 8 mm which is unevenly spaced between ends.

For range of 10 to 16, mid point is ~~13~~. Only "mid" levels are evenly spaced, 12 & 14 mm.

Model Choices in Easy DOE

As complexity supported increases, so do the number of runs



● Guided Mode ○ Flexible Mode

Model to be estimated	**Number of Runs**
● Main Effects (Screen Factors)	12
○ Main Effects with some Two-Factor Interactions	12
○ All Main Effects and Two-Factor Interactions	16
○ All Main Effects, Two-Factor Interactions, and Quadratics (Response Surface Design)	21

SCREENING

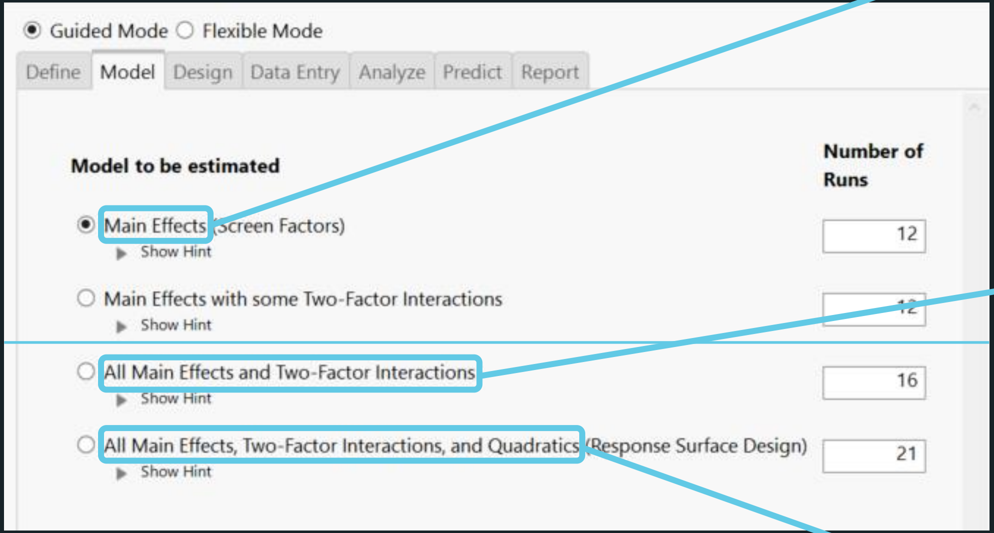
- Less complex (fewer runs)
- More robust (usually ≈1.5X runs)
  - *When conditions are appropriate –* designs for this choice include mid-levels for continuous factors

PREDICTION

- Less complex (fewer runs)
- More robust (1.3X or fewer runs)
  - Design will have mid-levels for continuous factors supporting optima that are not in corners!

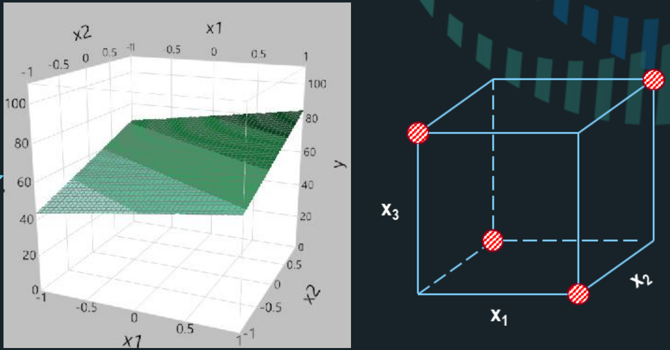
Model Choices in Easy DOE

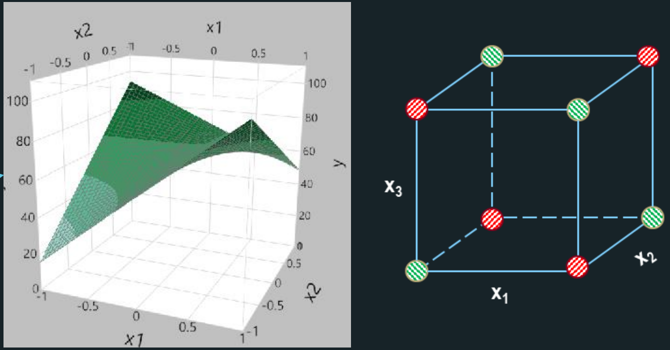
As complexity supported increases, so do the number of runs

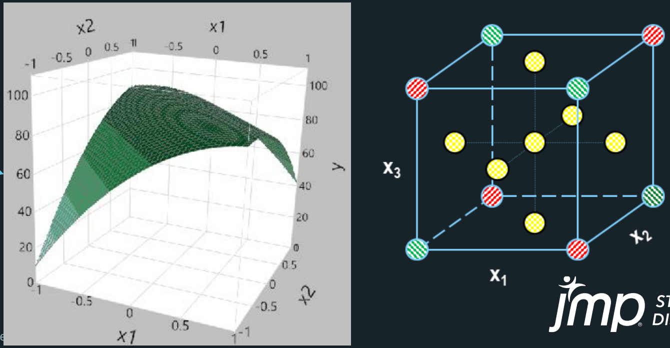


● Guided Mode ○ Flexible Mode

Model to be estimated	Number of Runs
● Main Effects (Screen Factors) ▶ Show Hint	12
○ Main Effects with some Two-Factor Interactions ▶ Show Hint	12
○ All Main Effects and Two-Factor Interactions ▶ Show Hint	16
○ All Main Effects, Two-Factor Interactions, and Quadratics (Response Surface Design) ▶ Show Hint	21





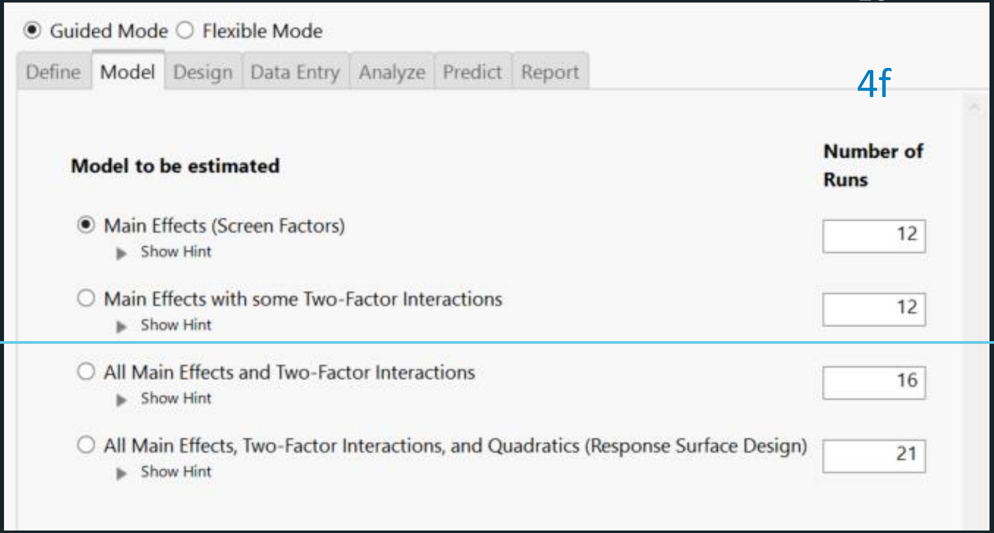


Model Choices in Easy DOE

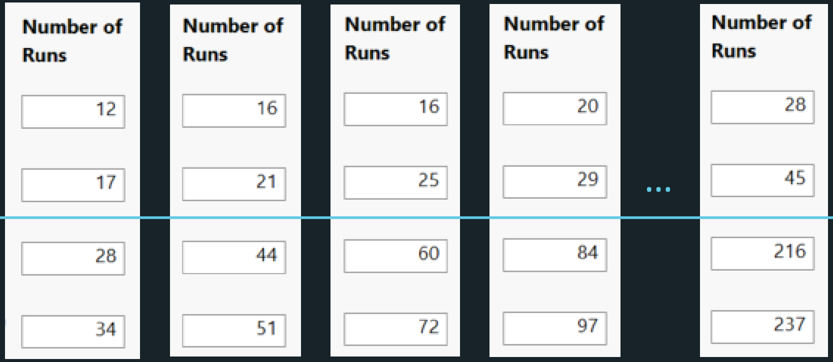
Number of runs for increasing numbers of continuous factors

Number of corners in design space

Number of corners in design space	16	64	256	1024	4096	…	1M+
	4f	6f	8f	10f	12f	…	20f



● Guided Mode ○ Flexible Mode

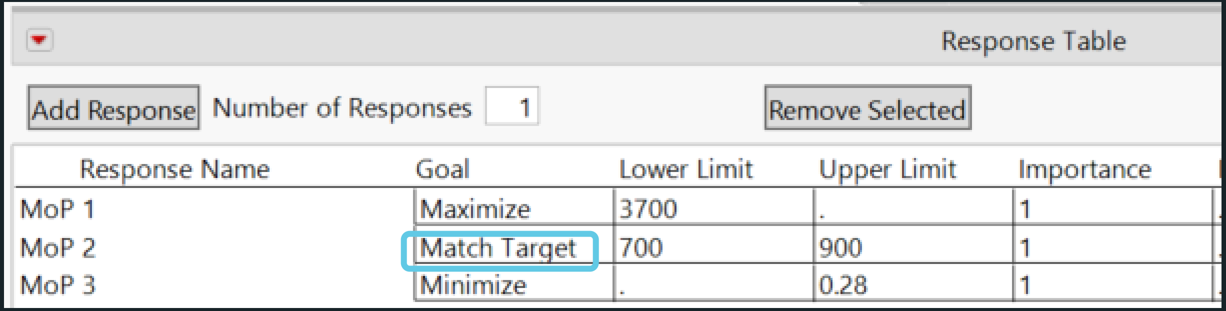


Model to be estimated	4f Number of Runs	6f Number of Runs	8f Number of Runs	10f Number of Runs	12f Number of Runs	…	20f Number of Runs
● Main Effects (Screen Factors)	12	12	16	16	20		28
○ Main Effects with some Two-Factor Interactions	12	17	21	25	29	…	45
○ All Main Effects and Two-Factor Interactions	16	28	44	60	84		216
○ All Main Effects, Two-Factor Interactions, and Quadratics (Response Surface Design)	21	34	51	72	97		237

NOTE: Number of factors need not be even

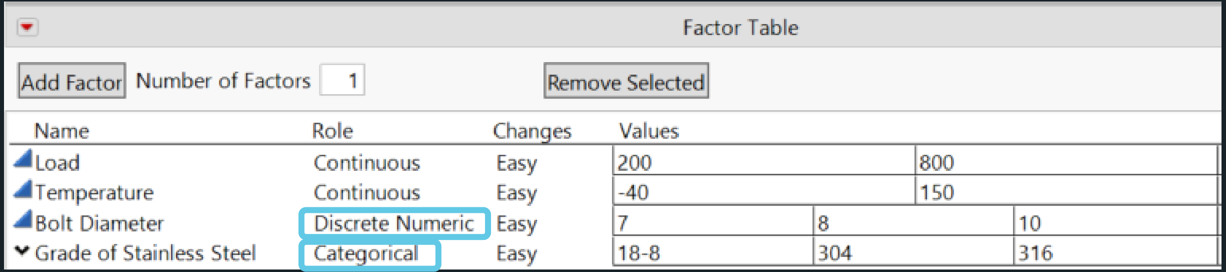
Use Easy DOE Second Time with a few Changes

3-response, 4-factor, trade-space analysis and optimization example



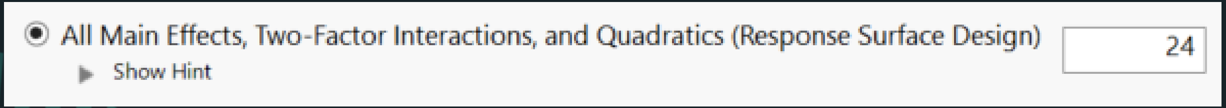
Number of Responses 1

Response Name	Goal	Lower Limit	Upper Limit	Importance
MoP 1	Maximize	3700	.	1
MoP 2	Match Target	700	900	1
MoP 3	Minimize	.	0.28	1



Number of Factors 1

Name	Role	Changes	Values		
Load	Continuous	Easy	200	800	
Temperature	Continuous	Easy	-40	150	
Bolt Diameter	Discrete Numeric	Easy	7	8	10
Grade of Stainless Steel	Categorical	Easy	18-8	304	316



● All Main Effects, Two-Factor Interactions, and Quadratics (Response Surface Design) 24

MoP = Measure of Performance

Go to JMP 17…

Key Features of Easy DOE

JMP 17 makes it easier for everyone to experiment

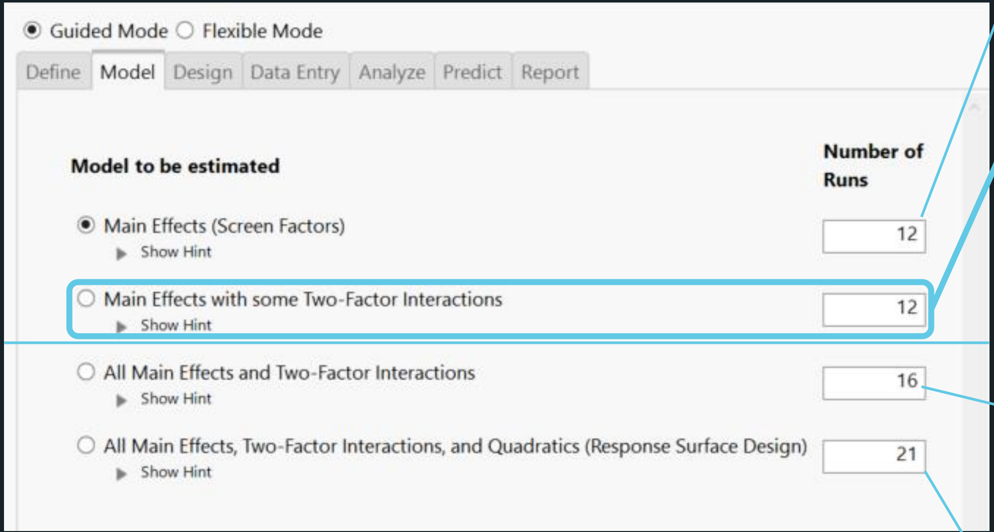
- End-to-end coverage of every step of experimentation.
- Streamlined experience through tailored elements in a new user interface.
- Guided mode for novice experimenters (default) and Flexible mode for more demanding situations.
- Comprehensive summary report is automatically written based on the current state of the experiment.
- Save your work at any time and return to the same point.
- Easily share experiments with others.

[Developer Tutorial: Easy DOE – Expertly Guiding Users Through Designing an Experiment]

Backup Slide

Model Choice #2 in Easy DOE

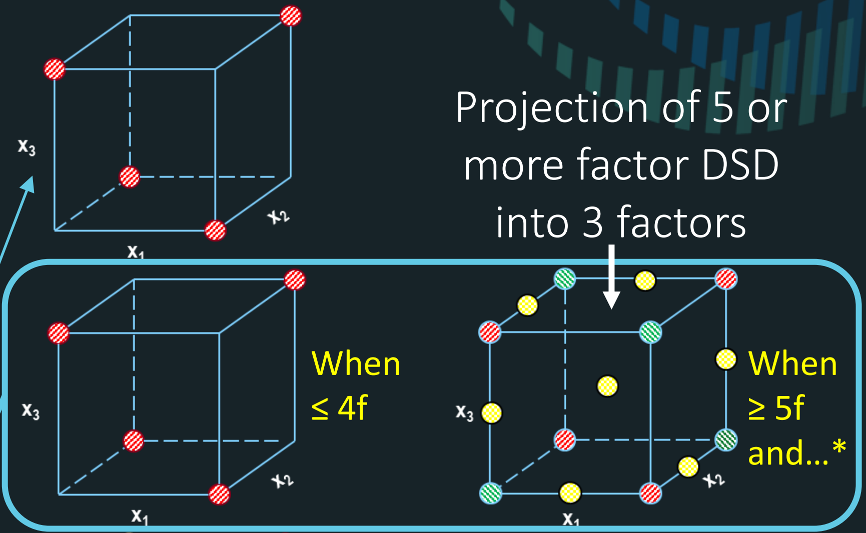
applies an algorithm to factor choices & generates a DSD *when appropriate* *



● Guided Mode ○ Flexible Mode

Define | Model | Design | Data Entry | Analyze | Predict | Report

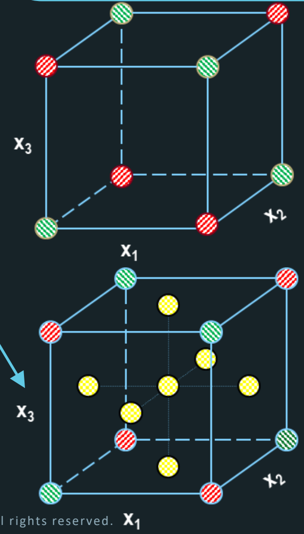
Model to be estimated	**Number of Runs**
● Main Effects (Screen Factors) ▶ Show Hint	12
○ Main Effects with some Two-Factor Interactions ▶ Show Hint	12
○ All Main Effects and Two-Factor Interactions ▶ Show Hint	16
○ All Main Effects, Two-Factor Interactions, and Quadratics (Response Surface Design) ▶ Show Hint	21



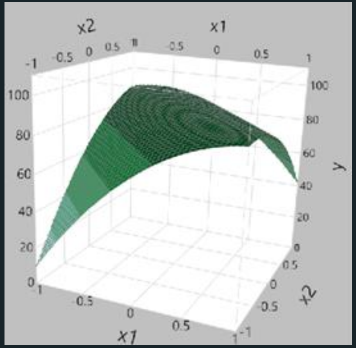
Projection of 5 or more factor DSD into 3 factors

When ≤ 4f

When ≥ 5f and…*



DSD has potential to support a response surface model if only a few factors are important.



* Definitive Screening Design is created for as few as 5 factors, provided that at least 3 are continuous, and no more than 3 are categorical at 2-levels. If a categorical at ≥ 3-levels or a discrete numeric factor is used, then design will NOT be a DSD.

STATISTICAL DISCOVERY