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## Design of Experiments Example: A Response Surface Design with Flexible Blocks

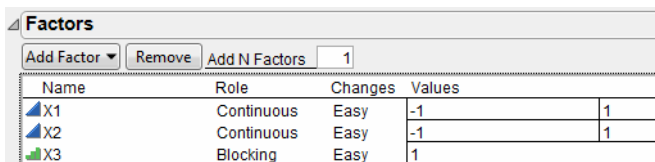
When optimizing a process, you might need to include qualitative factors in your experiment as well as continuous factors. You might need to block by qualitative factors such as batch or day, or include qualitative factors such as machine or delivery mechanism. But the Response Surface Design platform supports only continuous factors. To obtain a response surface design with a qualitative factor, you can replicate the design over each level of the factor. However, this is inefficient. The Custom Design platform constructs an optimal design with fewer runs.

In this example, you construct a response surface design that accommodates two continuous factors and a blocking factor with four runs per block. You can include categorical or discrete numeric factors in a similar fashion.

1. Select **DOE > Custom Design**.
2. Type 2 next to **Add N Factors**.
3. Click **Add Factor > Continuous**.
4. Click **Add Factor > Blocking > 4 runs per block**.

Notice that only one level appears under Values. This is because the number of blocks cannot be determined until the number of runs is determined.

**Figure 1** Factors Outline with Two Continuous Factors and a Blocking Factor



Name	Role	Changes	Values
X1	Continuous	Easy	-1   1
X2	Continuous	Easy	-1   1
X3	Blocking	Easy	1

5. Click **Continue**.

The Default number of runs is 12. The Factors outline updates to show three levels for the Blocking factor, X3. Because you required X3 to have four runs per block, the 12 runs allow three blocks.

6. Click **RSM**.

An informational JMP Alert window reminds you that the blocking factor cannot appear in interaction or quadratic terms. JMP adds only the appropriate RSM terms to the list.

7. Click **OK** to dismiss the message.

Quadratic and interactions terms for X1 and X2 are added to the model. Because you added RSM terms, the Recommended optimality criterion changes from D-Optimal to I-Optimal. You can see this later in the Design Diagnostics outline.

**Figure 2** Model Outline with Response Surface Effects

The screenshot shows the 'Model' window in JMP. At the top, there are buttons for 'Main Effects', 'Interactions', 'RSM', 'Cross', 'Powers', and 'Remove Term'. Below these buttons is a table with two columns: 'Name' and 'Estimability'.

Name	Estimability
Intercept	Necessary
X1	Necessary
X2	Necessary
X3	Necessary
X1*X1	Necessary
X1*X2	Necessary
X2*X2	Necessary

**Note:** Setting the Random Seed in step 8 and Number of Starts in step 9 reproduces the exact results shown in this example. In constructing a design on your own, these steps are not necessary.

8. (Optional) From the Custom Design red triangle menu, select **Set Random Seed**, type 1415408414, and click **OK**.
9. (Optional) From the Custom Design red triangle menu, select **Number of Starts**, type 21, and click **OK**.
10. Click **Make Design**.
11. Open the **Design Evaluation > Design Diagnostics** outline.

**Figure 3** Design Diagnostics Outline

The screenshot shows the 'Design Diagnostics' window in JMP. It contains a table with the following data:

I Optimal Design	
D Efficiency	50.85382
G Efficiency	77.32187
A Efficiency	37.51264
Average Variance of Prediction	0.49973
Design Creation Time (seconds)	0

The first line in the Design Diagnostics outline identifies the optimality criterion being used. This design is I-optimal.

12. Click **Make Table**.

Figure 4 Design Table with Blocking Factor

	X1	X2	X3	Y
1	0	-1	1	•
2	0	0	1	•
3	1	1	1	•
4	-1	0	1	•
5	1	0	2	•
6	0	-1	2	•
7	0	0	2	•
8	-1	1	2	•
9	0	1	3	•
10	1	-1	3	•
11	0	0	3	•
12	-1	-1	3	•

Because the default Run Order was Randomize within Blocks, the levels of the blocking factor (X3) are sorted.

- In the Tables panel of the design table, click the red triangle next to **Model** and select **Run Script**.

Figure 5 Fit Model Window

**Model Specification**

Select Columns: 4 Columns (X1, X2, X3, Y)

Pick Role Variables: Y (optional)

Weight: optional numeric

Freq: optional numeric

Validation: optional

By: optional

Personality: Standard Least Squares

Emphasis: Effect Screening

Buttons: Help, Run, Recall, Remove, Keep dialog open

Construct Model Effects:

Add: X1 & RS, X2 & RS

Cross: X3

Nest: X1\*X1, X1\*X2

Macros: X2\*X2

Degree: 2

Attributes:  Attributes

Transform:  Transform

No Intercept

Notice the following:

- The blocking factor (X3) is entered as an effect.
- No interactions involving X3 are included.
- The other five effects define a response surface model for X1 and X2.

