Example - The Coffee Strength Experiment

This example contains the following processes:

1. Define the Study and Goals
2. Create the Design
3. Run the Experiment
4. Analyze the Data

1. Define the Study and Goals

- Your employer is a local mid-size coffee roaster. You need to address the strength of individually brewed twelve ounce cups of coffee. Your goal is to determine which factors have an effect on coffee strength and to find optimal settings for those factors.

Response

- The response is coffee Strength. It is measured as total dissolved solids, using a refractometer.
- The coffee is brewed using a single cup coffee dripper and measured five minutes after the liquid is released from the grounds.
- Previous studies indicate that a strength reading of 1.3 is most desirable, though the strength is still acceptable if it falls between 1.2 and 1.4.

Factors

- Four factors are identified for the study: Grind, Temperature, Time, and Charge. Coffee is brewed at three stations in the work area. To account for variation due to brewing location, Station is included in the study as a blocking factor. The following describes the factors:

- Grind is the coarseness of the grind. Grind is set at two levels, Medium and Coarse.
- Temperature is the temperature in degrees Fahrenheit of the water measured immediately before pouring it over the grounds. Temperature is set at 195 and 205 degrees Fahrenheit.
- Time is the brewing time in minutes. Time is set at 3 or 4 minutes.
- Charge is the amount of coffee placed in the cone filter, measured in grams of coffee beans per ounce of water. Charge is set at 1.6 and 2.4.
- Station is the location where the coffee is brewed. The three stations are labeled as 1, 2, and 3.

Factors and Range of Settings for Coffee Experiment

Factor	Role	Range of Settings		
Grind	Categorical	Medium	Coarse	
Temperature	Continuous	195	205	
Time	Continuous	3	4	
Charge	Continuous	1.6	2.4	
Station	Blocking	1	2	3

Coffee Factors.jmp

All factors can be varied and reset for each run. There are no hard-to-change factors for this experiment.

Note the following:
- Grind is categorical with two levels.
- Temperature, Time, and Charge are continuous.
- Station is a blocking factor with three levels.

- The apparatus used in running the coffee experiment is shown in Figure. This is the setup at one of the three brewing stations. The two other stations have the same type of equipment.

Number of Runs

- Based on the resources and time available, you determine that you can conduct 12 runs in all.
- Since there are three stations, you conduct 4 runs at each station.

2. Create the Design

Create the design following the steps in the design workflow process outlined in "The DOE Workflow: Describe, Specify, Design"

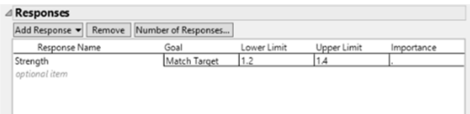
1. "Define Responses and Factors"
2. "Specify the Model"
3. "Generate the Design"
4. "Evaluate the Design"
5. "Make the Table"

2-1. Define Responses and Factors

- In the first outlines that appear, enter information about your response and factors.

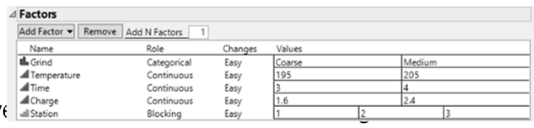
<u>Responses</u>

- Select DOE > Custom Design.



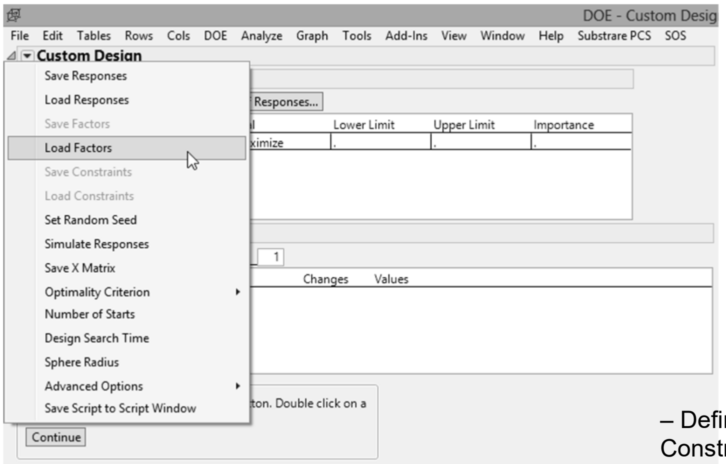
<u>Factors</u>

- Enter factors either manually or from a pre-existing table that contains the factors and settings. If you are designing a new experiment, you must first enter the factors manually.



- Once you have save[illegible]rs option, you can load them using the saved table.

▪ **Entering Factors Using Load Factors**

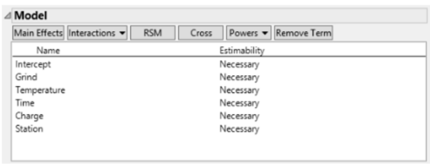


– Define Factor Constraints (not used in this example)
– Model
– Alias Terms
– Design Generation

2-2. Specify the Model

Model Outline

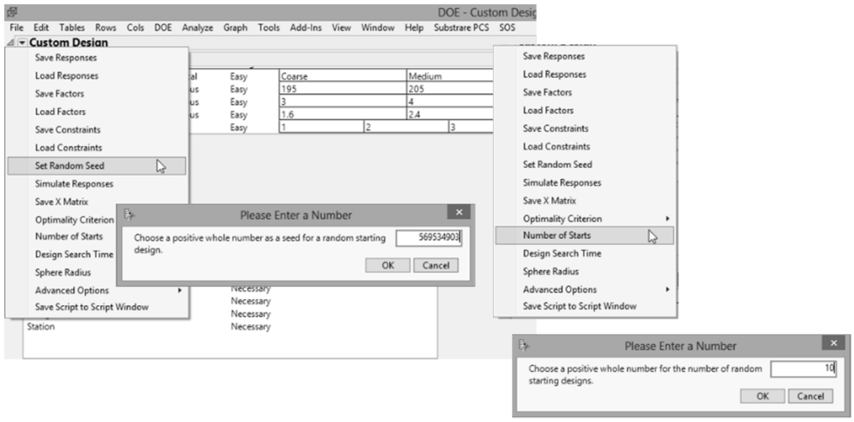
- all main effects as Necessary, indicating that the design is capable of estimating all main effects.



Because your main interest at this point is in the main effects of the factors, you do not add any effects to the Model outline.

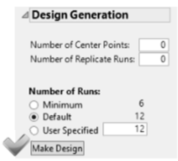
Steps to Duplicate Results (Optional)

- To obtain a design with exactly the same runs and run order, perform the following steps before generating your design:



2-3. Generate the Design

- In the Design Generation outline, you can enter additional details about the structure and size of your design. The Default design is shown as having 12 runs. Recall that your design budget allows for 12 runs.

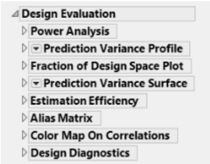


Design

Run	Grind	Temperature	Time	Charge	Station
1	Coarse	195	3	1.6	1
2	Medium	195	4	2.4	2
3	Medium	195	4	1.6	3
4	Medium	205	4	2.4	1
5	Coarse	205	3	2.4	2
6	Medium	205	3	2.4	3
7	Medium	205	3	1.6	1
8	Coarse	205	4	1.6	2
9	Coarse	205	4	1.6	3
10	Coarse	195	4	2.4	1
11	Medium	195	3	1.6	2
12	Coarse	195	3	2.4	3

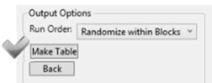
2-3. Evaluate the Design

- The Design Evaluation outline provides various ways to evaluate your design. This is an important topic, but for simplicity, it is not covered in the context of this example

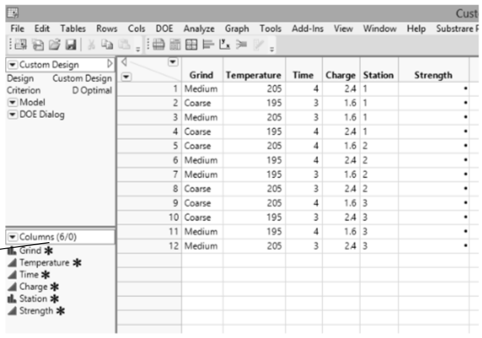


2-4. Make the Table

- Specify the order of runs in your data table using the Output Options panel. The default selection, Randomize within Blocks, is appropriate. This selection arranges the runs in a random order for each Station.



Note the asterisks in the Columns panel to the right of the factors and response. These indicate column properties that have been saved to the columns in the data table. These column properties are used in the analysis of the data.

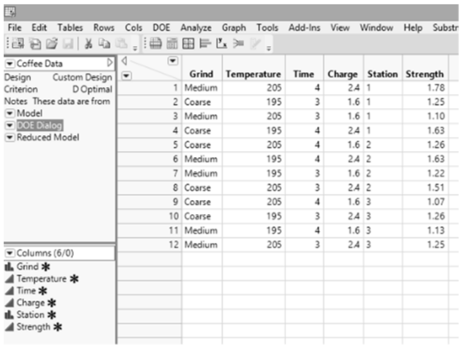


3. Run the Experiment

- At this point, you perform the experiment. At each Station, four runs are conducted in the order shown in the design table. Equipment and material are reset between runs. The Strength measurements are recorded.

• Your design and the experimental results for Strength are given in the **Coffee Data.jmp** sample data table, located in the Design Experiment folder.

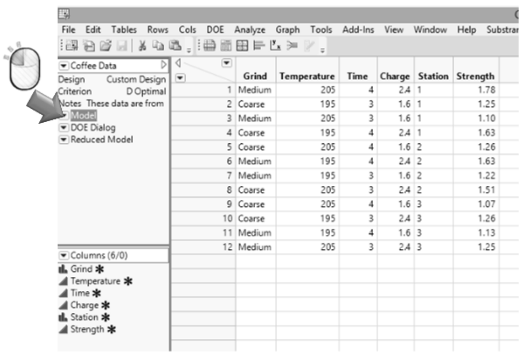
Coffee Data.jmp



	Grind	Temperature	Time	Charge	Station	Strength
1	Medium	205	4	2.4	1	1.78
2	Coarse	195	3	1.6	1	1.25
3	Medium	205	3	1.6	1	1.10
4	Coarse	195	4	2.4	1	1.63
5	Coarse	205	4	1.6	2	1.26
6	Medium	195	4	2.4	2	1.63
7	Medium	195	3	1.6	2	1.22
8	Coarse	205	3	2.4	2	1.51
9	Coarse	205	4	1.6	3	1.07
10	Coarse	195	3	2.4	3	1.26
11	Medium	195	4	1.6	3	1.13
12	Medium	205	3	2.4	3	1.25

4. Analyze the Data

- The Custom Design platform facilitates the task of data analysis by saving a Model script to the design table that it creates. Run this script after you conduct your experiment and enter your data. The script opens a Fit Model window containing the effects that you specified in the Model outline of the Custom Design window



	Grind	Temperature	Time	Charge	Station	Strength
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3	Medium	205	3	1.6	1	1.10
4	Coarse	195	4	2.4	1	1.63
5	Coarse	205	4	1.6	2	1.26
6	Medium	195	4	2.4	2	1.63
7	Medium	195	3	1.6	2	1.22
8	Coarse	205	3	2.4	2	1.51
9	Coarse	205	4	1.6	3	1.07
10	Coarse	195	3	2.4	3	1.26
11	Medium	195	4	1.6	3	1.13
12	Medium	205	3	2.4	3	1.25

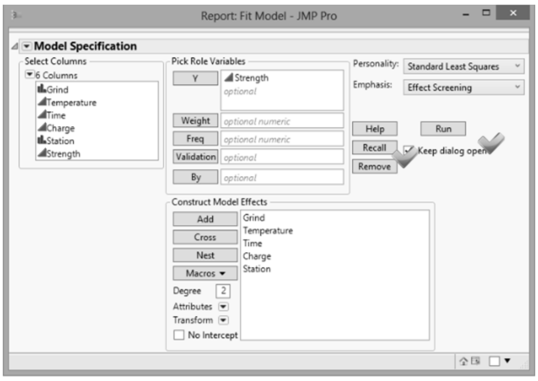
4-1. Fit the Model

1. Select Help > Sample Data Library and open Design Experiment/**Coffee Data.jmp**.

   In the Tables panel, notice the **Model** script created by Custom Design

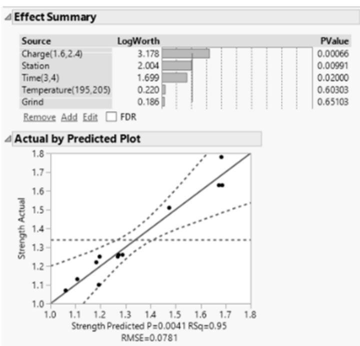
2. Click the red triangle next to Model and select **Run Script**

   The Model Specification window shows the effects that you specified in the Model outline



4-2. Analyze the Model

- The Effect Summary and Actual by Predicted Plot reports give high-level information about the model.



Note the following:

- The Actual by Predicted Plot shows no evidence of lack of fit.
- The model is significant, as indicated by the Actual by Predicted Plot. The notation P = 0.0041, shown below the plot, gives the significance level of the overall model test.
- The Effect Summary report shows that Charge, Station, and Time are significant at the 0.05 level.
- The Effect Summary report also shows that Temperature and Grind are not significant.

4-3. Reduce the Model

- Because Temperature and Grind appear not to be active, they contribute random noise to the model. Refit the model without these effects to obtain more precise estimates of the model parameters associated with the active effects.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	0.57493333	0.143733	29.8040
Error	7	0.03375833	0.004823	Prob > F
C. Total	11	0.60869167		0.0002*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.3408333	0.020047	66.88	<.0001*
Time(3,4)	0.0758333	0.020047	3.78	0.0069*
Charge(1.6,2.4)	0.1691667	0.020047	8.44	<.0001*
Station[1]	0.0991667	0.028351	3.50	0.0100*
Station[2]	0.0641667	0.028351	2.26	0.0580

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Time(3,4)	1	1	0.06900833	14.3093	0.0069*
Charge(1.6,2.4)	1	1	0.34340833	71.2078	<.0001*
Station	2	2	0.16251667	16.8494	0.0021*

Scaled Estimates

Nominal factors expanded to all levels

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.3408333	0.020047	66.88	<.0001*
Time(3,4)	0.0758333	0.020047	3.78	0.0069*
Charge(1.6,2.4)	0.1691667	0.020047	8.44	<.0001*
Station[1]	0.0991667	0.028351	3.50	0.0100*
Station[2]	0.0641667	0.028351	2.26	0.0580
Station[3]	-0.163333	0.028351	-5.76	0.0007*

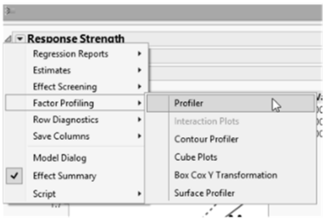
Note the following:

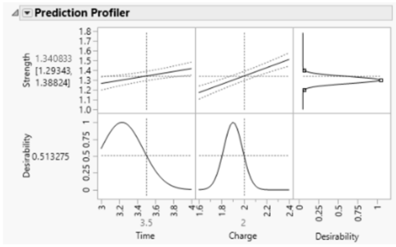
- The Effect Tests report shows that all three effects remain significant.
- The Scaled Estimates report further indicates that the Station[1]and Station[3] means differ significantly from the average response of Strength.

- Note that the Estimates that appear in the Parameter Estimates report are identical to their counterparts in the Scaled Estimates report. This is because the effects are coded.
- The estimate of the Station[3] effect only appears in the Scaled Estimates report, where nominal factors are expanded to show estimates for all their levels.
- The Parameter Estimates report gives estimates for the model coefficients where the model is specified in terms of the coded effects.

4-4. Explore the Model

- The Prediction Profiler appears at the bottom of the report.
- Recall that, in designing your experiment, you set a response Goal of Match Target with limits of 1.2 and 1.4. JMP uses this information to construct a desirability function to reflect your specifications.

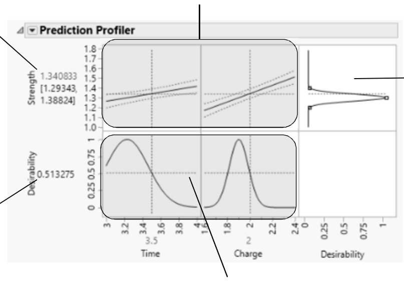




The values to the left of the top row of plots give the Predicted Strength (in red) and a confidence interval for the mean Strength for the selected factor settings.

The first two plots in the top row of the graph show how Strength varies for one of the factors, given the setting of the other factor. For example, when Charge is 2, the line in the plot for Time shows how predicted Strength changes with Time.

The right-most plot in the top row shows the desirability function for Strength. The desirability function indicates that the target of 1.3 is most desirable. Desirability decreases as you move away from that target. Desirability is close to 0 at the limits of 1.2 and 1.4

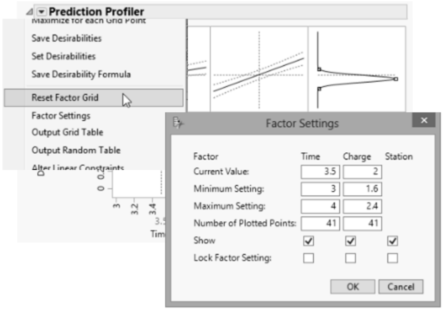


The value to the left of the bottom row of plots gives the Desirability of the response value for the selected factor settings.

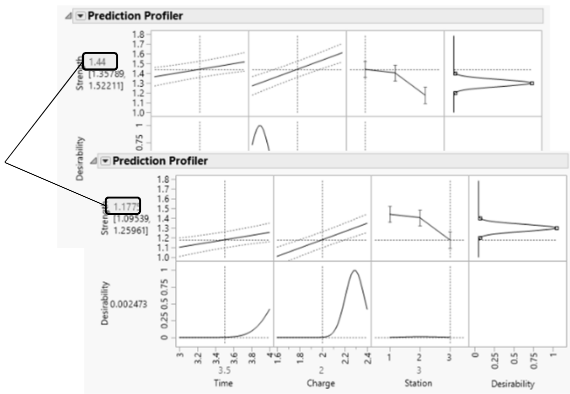
The plots in the bottom row show the desirability trace for each factor at the setting of the other factor

- Explore various factor settings by dragging the red dashed vertical lines in the columns for Time and Charge. Since there are no interactions in the model, the profiler indicates that increasing Charge increases Strength. Also, Strength seems to be more sensitive to changes in Charge than to changes in Time.

- Since Station is a blocking factor, it does not appear in the Prediction Profiler. However, you might like to see how predicted Strength varies by Station. To include Station in the Prediction Profiler, follow these steps:



The predicted Strength in the center of the design region for Station 1 is 1.44.
For Station 3, the predicted Strength is about 1.18.
The magnitude of the difference indicates that you need to address Station variability.
Better control of Station variation should lead to more consistent Strength.



Once Station consistency is achieved, you can determine common optimal settings for Time and Charge.