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Advanced Mixture DOE for Formulators

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Making the most of this learning opportunity

Hide the Control Panel
Mute your line

To prevent audio disruptions, all attendees will be muted.

Questions can be posted in the **Question** area. If they are not addressed during the webinar, I will reply via email afterwards.

Questions may also be sent to stathelp@statease.com. Please provide your company name and, if you are using Design-Expert, the serial number (found under Help, About).

Note: The slides and a recording of this webinar will be posted on the Webinars page of the Stat-Ease website within a few days.

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Stat-Ease Latest News

Released **October 2021!**

Preview at the end of this course.

Live Web Mixture DOE Workshop

May 22-25, 2023 and
Sept 18-21, 2023

Mixture Design for Optimal Formulations (DL)

Find the sweet spot and optimize your formulations by mastering mixture designs in this 1-week (4 half-day sessions) instructor-led online course. 10:00am - 1:30pm (USA Central Time)

Agenda

- **Mixture DOE Recap**
- Advanced Tips for Designing Mixture Experiments
- Other Tips and Tricks
- Conclusion
- Preview of Stat-Ease® 360

What is a Mixture Experiment?

Consider this experiment:

- Suppose we are deciding what cheese to put on a pizza.
- We can blend three cheeses to make up the blend (A) **mozzarella** (B) **provolone** and (C) **white cheddar**.
- We try various combinations of the three cheeses. Each pizza that we cook will be topped with a total of 6 ounces of cheese.

mozzarella:	0 to 6 ounces
provolone:	0 to 6 ounces
white cheddar:	0 to 6 ounces

- **Notice:** **mozzarella** **+** **provolone** **+** **white cheddar** = 6 ounces

What is a Mixture Experiment?

- The responses we measure will be:
  1. **appearance**
  2. **taste**
  3. **texture** (soft & oozy **versus** hard & chewy)
  4. **cost**
- In this situation the components of the cheese blend **cannot** be set independently of one another. For example, if we put 2 ounces of mozzarella cheese into the blend, we must put a total of 4 ounces of the other two cheeses into the blend.
- This is a typical **mixture experiment**.

CRITICAL!

mozzarella **+** **provolone** **+** **white cheddar** **=** 6 ounces

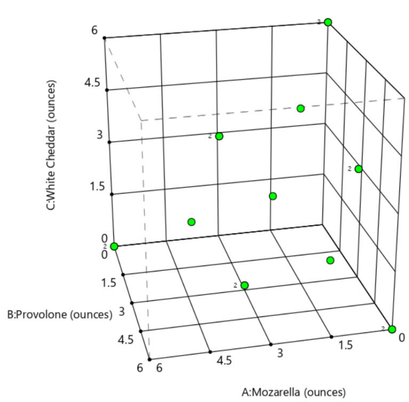
What is a Mixture Experiment?

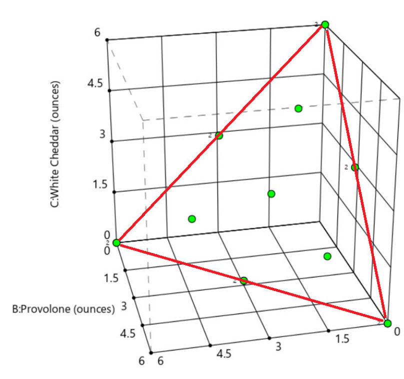
- A typical mixture DOE would look something like this:

Run	Component 1 A:Mozarella ounces	Component 2 B:Provolone ounces	Component 3 C:White Cheddar ounces	Response 1 appearance	Response 2 taste	Response 3 texture	Response 4 cost
1	0	3	3				
2	4	1	1				
3	3	0	3				
4	0	6	0				
5	2	2	2				
6	1	1	4				
7	6	0	0				
8	1	4	1				
9	0	0	6				
10	3	0	3				
11	3	3	0				
12	0	6	0				
13	3	3	0				
14	0	3	3				
15	6	0	0				
16	0	0	6				

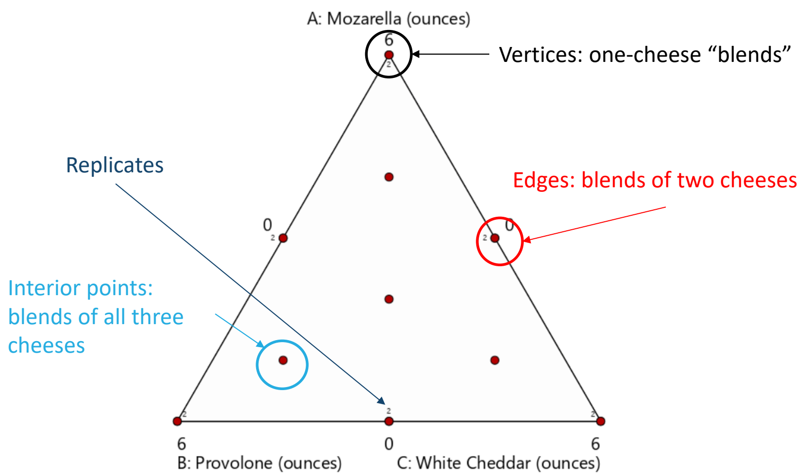
- Note that the **sum of the three cheeses = 6** in each run!

What is a Mixture Experiment?





What is a Mixture Experiment?



Identifying a Mixture Experiment

- Blending experiments should usually be set up as a mixture DOE, but not always.
  - If you are varying concentration or amounts of the components, rather than varying the weight %, volume %, or proportion of total, you may have a response surface experiment.
- The key to verifying whether you need a mixture design is to determine if any of the columns in the design plan **add up to a fixed total** in each run of the experiment.
- Part of an experiment may be a mixture (e.g. a cake formulation) and you may have non-mixture factors as well (e.g. temperature of the oven). This is called a **mixture-process combined design**.

Types of Mixture Designs

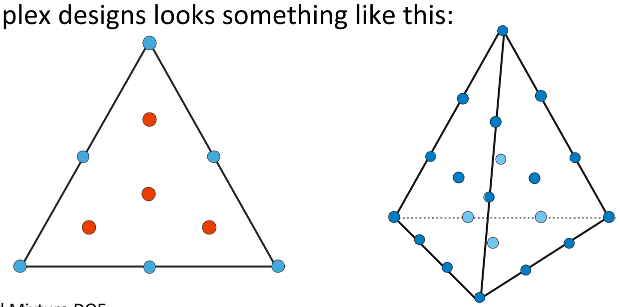
There are two basic categories of mixture DOEs:

- **Simplex**-based designs (canned)
- **Optimal** computer-generated designs

In practice, most of the designs I use are optimal designs due to their flexibility.

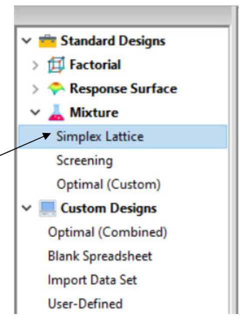
Simplex-Based Designs

- Simplex designs are **canned** and straightforward.
- In order to use a simplex design, one of the following conditions must hold true:
  - All the components have ranges 0 to 100%.
  - All the components must have the same range.
- Simplex designs looks something like this:



Simplex-Based Designs

- Simplex designs are incredibly restrictive and limited purpose.
- It **rarely** makes sense for all components to go from 0% to 100% of the mixture (100% yeast in a bread dough formulation?)
- It's also somewhat rare that all the components have the same range.
- **Do not** force all your components to have the same range so you can use a simplex design!!
- A better option is an **optimal computer-generated** design.



Simplex designs in our software.

Optimal Design

- Suppose you have the following set of constraints:

Single component

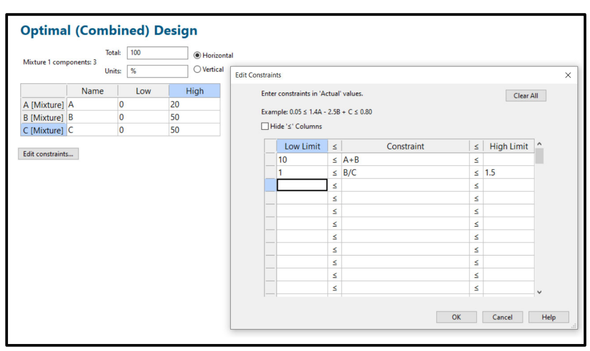
- 0% ≤ **A** ≤ 20%
- 0% ≤ **B** ≤ 50%
- 0% ≤ **C** ≤ 50%

Multicomponent

- **A** + **B** ≥ 10%
- 1 < **B**/**C** < 1.5

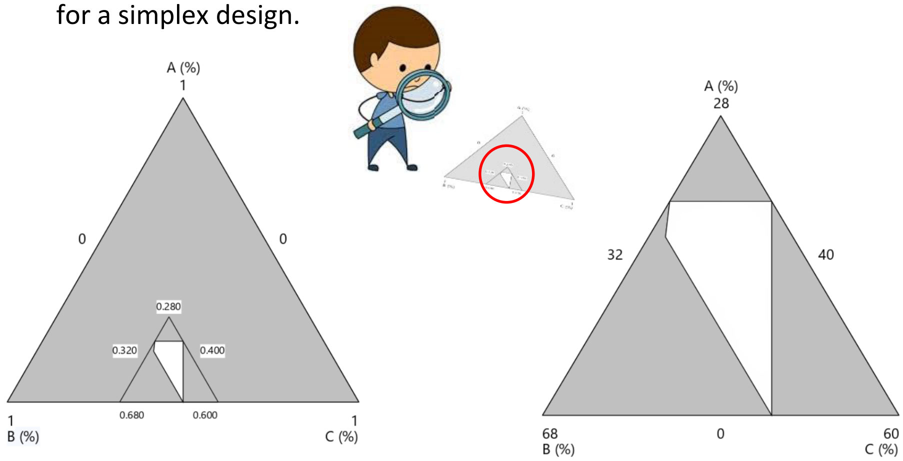
Equality constraint

- **A** + **B** + **C** = 100%



Optimal Design

- This is what the experimental design space looks like. Not a great fit for a simplex design.



Advanced Mixture DOE 15

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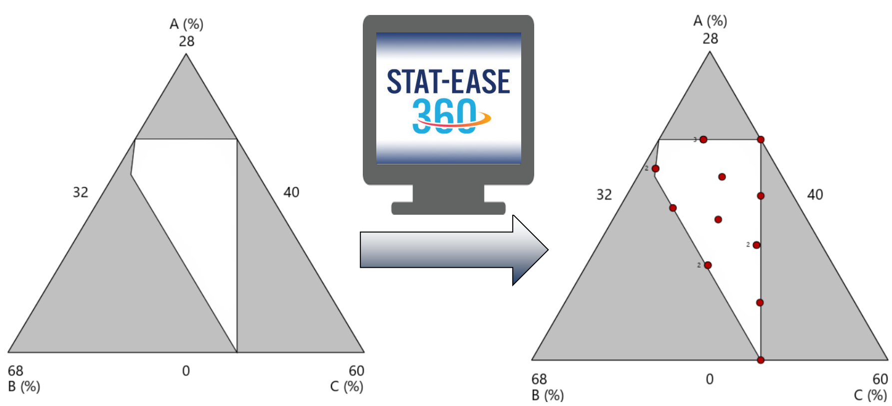
Optimal Design

- Here's what an **optimal computer-generated** design looks like for this complicated design space.



Advanced Mixture DOE 16

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Agenda

- Mixture DOE Recap
- **Advanced Tips for Designing Mixture Experiments**
- Other Tips and Tricks
- Conclusion
- Preview of Stat-Ease® 360

Optimal Design

Now we will go through several advanced Mixture DOE topics in greater detail. We will focus on **building** the designs – analysis is usually straightforward and there are plenty of resources of available:

- Optimal Design Deep Dive
- Space-Filling Designs
- Mixture-Process Designs
- Other Designs

Optimal Design Deep Dive

The general flow for building an **optimal design** is:

1. Choose your mixture **components** and set their ranges
2. Determine the **model** of interest (linear, quadratic, etc.)
3. Choose the **number of runs** in the experiment and define the properties of these runs
4. Set the remaining **build parameters**
5. Define your **responses**
6. Generate the design

Optimal Design Deep Dive

Demo: A fruit punch is being formulated. It consists of 5 possible juices we can blend:

- Grape
- Watermelon
- Orange
- Apple
- Pineapple

Each juice blend can be independently formulated and will be tested and rated by a panel of experts. If we have a budget of 40 runs, how can we build an optimal design?

Optimal Design Deep Dive

Let's go through the workflow:

- Choose your mixture **components** and set their ranges:

0 ≤ **Grape** ≤ 10%

20 ≤ **Watermelon** ≤ 60%

10 ≤ **Orange** ≤ 40%

10 ≤ **Apple** ≤ 20%

5 ≤ **Pineapple** ≤ 15%

The total of the 5 juices must sum to 100%.

Optimal Design Deep Dive

Let's go through the workflow:

- Determine the **model** of interest (linear, quadratic, etc.)

Linear mixture models can only detect linear blending properties (e.g. the weighted average of two or more components). The food scientists had reason to believe there was non-linear blending in the mixture, so they chose a **quadratic** mixture model.

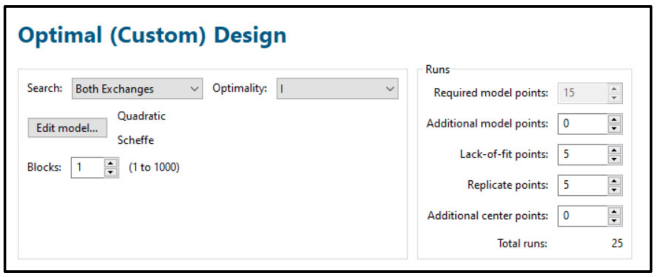
- Choose the **number of runs** in the experiment and define the properties of these runs.

The run budget was determined to be 40 runs. The experimenters decided to do 30 runs in the first pass of the experiment.

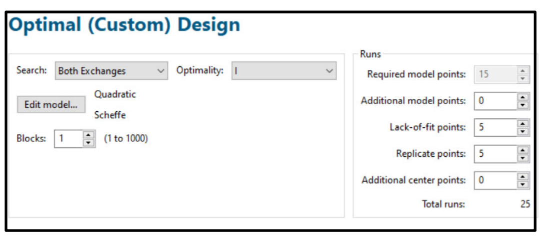
Optimal Design Deep Dive

Let’s go through the workflow:

- Choose the **number of runs** in the experiment and define the properties of these runs.
- Set the remaining **build parameters**.



Optimal Design Deep Dive



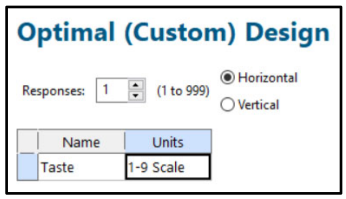
Details:

- Optimality
- Additional model points
- Lack-of-fit points
- Replicate points
- Additional center points

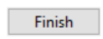
Optimal Design Deep Dive

Let's go through the workflow:

- Define your **responses**.



- Generate the design.



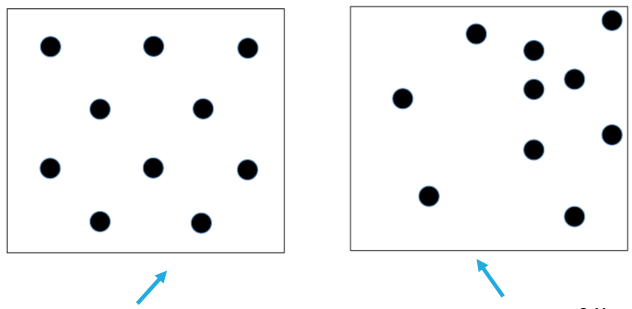
Optimal Design Deep Dive

Tips and Tricks for Run Size:

- The software defaults are fairly "safe". If you have no strong feelings towards a particular design size, the defaults are a good start.
- If you need to cut runs, lower the replicates and lack-of-fit points. A minimum of 3 for each is recommended. If you cannot afford any, set them both to 0. You could also consider lowering the model order.
- If you have lots of extra runs, consider increasing the model order before adding extra model points, replicates, or lack-of-fit points.
- Use the FDS to guide you in sizing your design. An FDS scores of 80% is recommended.

Space-Filling Designs

- **Space-Filling Designs** are another category of mixture designs. They aim to “fill” a design space – evenly distribute points, leave no large gaps, etc.



Space-filling

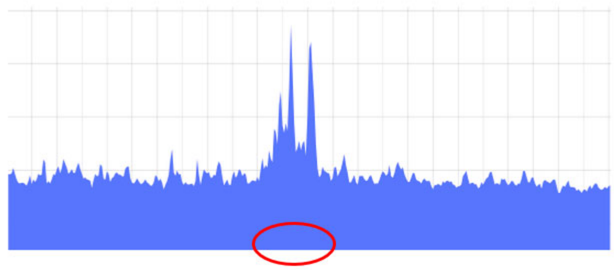
Not space-filling

Space-Filling Designs

Space-Filling Designs (SFDs) can be used in a wide variety of cases:

- They are especially useful in **computer experiments** where the response of interest is generated by a simulation rather than a physical experiment. These responses are deterministic with no error, so it makes no sense to do replicates. A space-filling design will give maximum information in this case.
- SFDs can be used in **exploratory studies**, where there is much uncertainty about the design space. SFDs include more unique points than other optimal designs, giving you more information about a new experimental design space.
- If you expect a sharp **peak** in your response, a SFD has a better chance of catching that peak since there are more unique design points that are nicely spread apart.

Space-Filling Designs



We want some runs here to detect the spikes

Space-Filling Designs

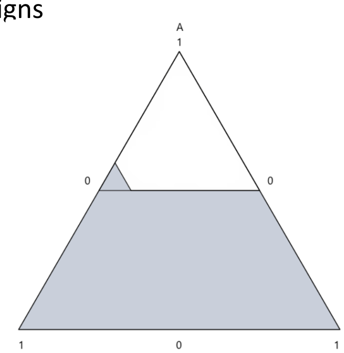
Demo: Space-Filling Designs vs. Optimal designs

We'll look at a three-component example:

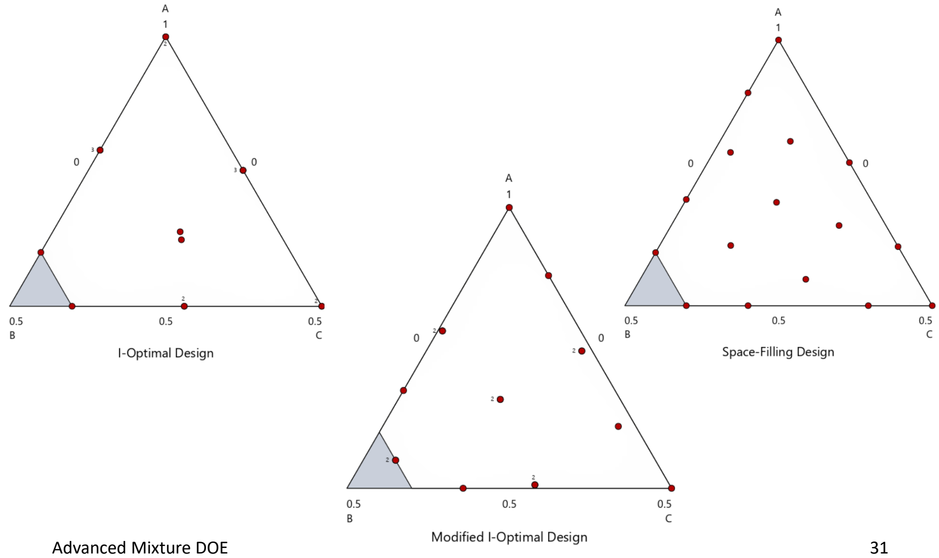
- 0.5 ≤ **A** ≤ 1
- 0 ≤ **B** ≤ 0.4
- 0 ≤ **C** ≤ 0.5

Three different designs will be compared:

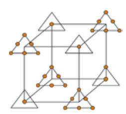
- Space-filling design
- Modified I-optimal design
- I-optimal design



Space-Filling Designs



Mixture-Process Designs



- In some experiments, a formulation may be processed under various conditions. For example, a cake batter formulation could be baked at several different temperatures.
- Historically, this type of experiment would be done in two stages:
  - **Step 1**: find the optimal formulation under the “middle” setting of the process parameters.
  - **Step 2:** take the formulation from the previous step and tweak the process parameters to try to improve the results.
- There is a better way to do this type of experiment: use a mixture-process design.

Mixture-Process Designs

- One disadvantage of the two-stage approach in the previous slide is that the ideal mixture often depends on the process parameters and vice versa. Essentially, the mixture interacts with the process parameters.
- A mixture-process design models the effects of the mixture, the effects of the process parameters, and the interaction between the two, giving you a complete picture of what's going on.
- Mixture-process designs are almost always built as computer-generated optimal designs.

Mixture-Process Designs

Demo: 3 components of a cake batter formulation were varied, and then the cake was baked at a pre-specified temperature in the oven.

- The three components were
  - 10g ≤ **Sugar** ≤ 50g
  - 1g ≤ **Vanilla** ≤ 1.5g
  - 2g ≤ **Raspberry Juice** ≤ 3g
- The three components sum to 50g, although each cake weighs 200g.
- The oven temperature ranged from 350F to 400F.
- **Note:** A mixture-amount experiment is an example of a combined design (e.g. fertilizer blend with differing amounts applied).

Other Designs

Some other designs to be aware of:

- **Double mixture designs**

  Two separate mixtures are part of the experiment. For example, a cake batter formulation + a frosting formulation. The two mixtures may depend on one another.

- **Split-plot (restricted randomization) designs**

  Formulations must be prepared in batches, or several independent formulations must be processed at the same time (e.g. in an oven). Full randomization not possible or feasible.

- **Mixture of mixtures design**

  Several mixtures are blended together to form a final mixture.

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Tips and Tricks (Recap)

Here are a few **tips and tricks** from the Mixture DOE crash course. The recording of this can be found on our YouTube page:

1. Don't use factorial designs.
2. Don't convert to ratios so that you can use factorial or response surface designs.
3. Spend a lot of time choosing the components and the ranges.
4. Experiment iteratively, especially in new problems.
5. Master building optimal designs.

Tips and Tricks **(Advanced)**

Here some more tips and tricks for advanced DOE practitioners:

1. If possible, analyze mixture-process experiments as a single experiment, rather than as two separate experiments.
2. Use KCV models for mixture-process designs whenever possible to save runs.
3. Fully randomize a mixture experiment. If it's not possible, use a split-plot design!
4. When in doubt, start small and build up. Do not deplete your entire run budget in one pass if possible.
5. Use FDS plots to "right-size" your design.

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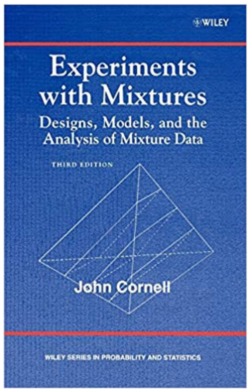
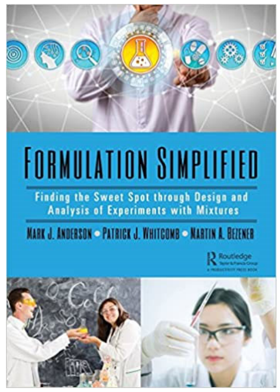
Conclusion

- Mixture DOE is a **very powerful** tool that unfortunately does not receive much attention.
- Design-Expert and Stat-Ease® 360 software contains all the **latest and greatest** tools for building and analyzing basic and advanced mixture experiments.
- The key to recognizing a mixture experiment is determining if there is an **equality constraint**. There may also be process parameters in a mixture experiment.
- If you enjoyed this presentation and found it useful, consider taking our 4-day distance-learning workshop that dives into more detail on all the topics I discussed, including software use.

Resources





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Regular price $945.

Online
April 25 - 28

REGISTER   LEARN MORE

Agenda

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- Other Tips and Tricks
- Conclusion
- **Preview of Stat-Ease® 360**

Stat-Ease® 360 Exclusive Preview

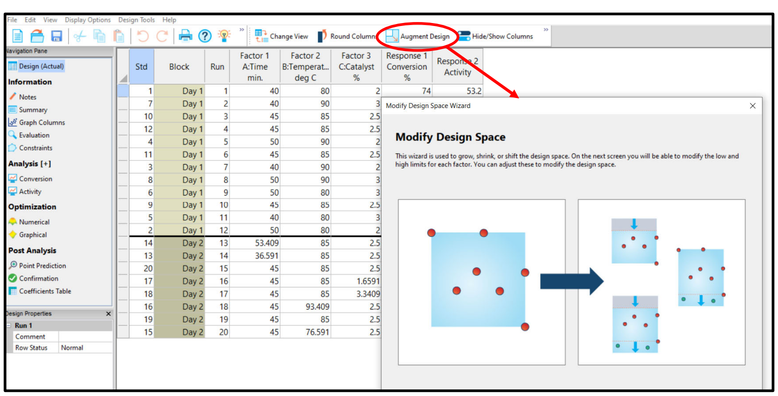
Just Released **October 2021!**

Many new, user-requested features!

- **Modify Design Space Wizard**
- **Round Columns**
- **Python Scripting (SE360)**
- Space-Filling Designs & Gaussian Process Models (SE360)

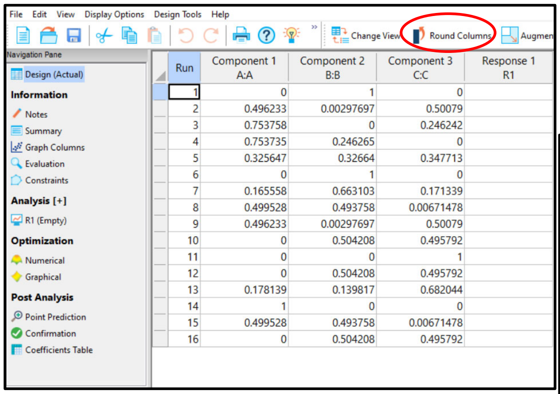
Stat-Ease® 360 Preview

Modify Design-Space Augment Wizard



Stat-Ease® 360 Preview

Round Columns



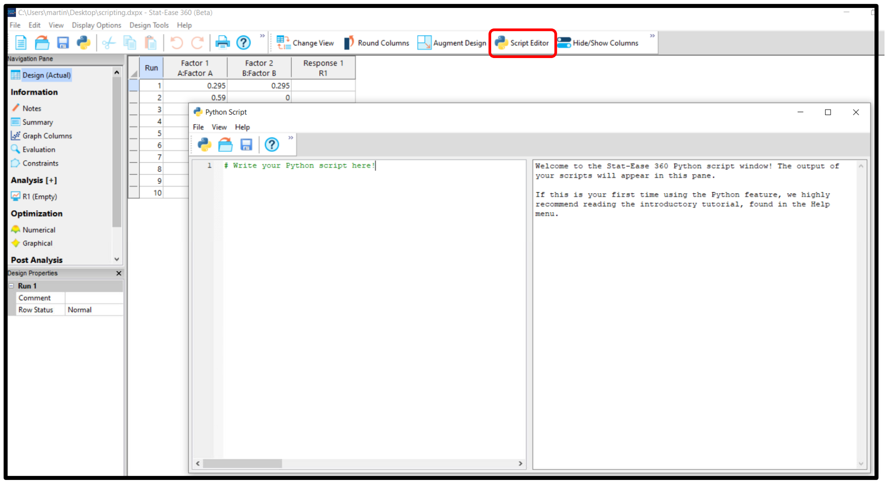
Run	Component 1 A:A	Component 2 B:B	Component 3 C:C	Response 1 R1
1	0	1	0	
2	0.496233	0.00297697	0.50079	
3	0.753758	0	0.246242	
4	0.753735	0.246265	0	
5	0.325647	0.32664	0.347713	
6	0	1	0	
7	0.165558	0.663103	0.171339	
8	0.499528	0.493758	0.00671478	
9	0.496233	0.00297697	0.50079	
10	0	0.504208	0.495792	
11	0	0	1	
12	0	0.504208	0.495792	
13	0.178139	0.139817	0.682044	
14	1	0	0	
15	0.499528	0.493758	0.00671478	
16	0	0.504208	0.495792	

Run	Component 1 A:A	Component 2 B:B	Component 3 C:C
1	0	1	0
2	0.5	0	0.5
3	0.75	0	0.25
4	0.75	0.25	0
5	0.32	0.33	0.35
6	0	1	0
7	0.17	0.66	0.17
8	0.5	0.49	0.01
9	0.5	0	0.5
10	0	0.5	0.5
11	0	0	1
12	0	0.5	0.5
13	0.18	0.14	0.68
14	1	0	0
15	0.5	0.49	0.01
16	0	0.5	0.5

Python Scripting Capabilities

- Here is just a small sampling of what you will be able to do:
  - Write scripts to automate routine processes
  - Create simulations
  - Combine features of Stat-Ease 360 with features from relevant Python packages
  - Create infinitely customizable plots and graphs
  - Facilitate import/export of data between Stat-Ease 360 and other software

Python Scripting Capabilities



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Make the most from every experiment!℠

Thanks for listening!

martin@statease.com