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Masterful experiment delivers delectable chocolate chip cookies

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Maximizing this educational opportunity

Welcome everyone! To make the most from this webinar:

- Attendees on mute
- Chat not opened until afterwards
- Address questions to mark@statease.com
- Slides posted to www.statease.com/webinars/ with link to
- Video uploaded to the Stat-Ease YouTube channel

Please press the raise-hand button if you are with me.

The WIIFM (What's in it for me)

This presentation spells out a fun kitchen experiment that:

- Illustrates the application of a split plot to deal with hard to change (HTC) baking factors combined with easy-to-change (ETC) mixture components.
- Demonstrates how KCV models minimize the number of runs in mixture-process designs while retain the ability to detect synergistic or antagonistic component-factor combinations.
- Incorporates blocking to conveniently divide the experiment into two days to avoid overwhelming production or sensory evaluation.

Background

Project by student of Greg Hutto

Greg Hutto, Adjunct Professor, Northwest Florida Campus, University of Arkansas, asked me to help him advise his Industrial Experiments student Jessica Keel. Using a “cakey chocolate chip cookies” recipe by Martha Steward Test Kitchen as the basis, she wanted to vary the relative amounts of butter, granulated and brown sugar, and vanilla—baked at differing temperatures and times.

This provided a prime opportunity to put a mixture-process split plot and KCV modeling to good use.

Home-made Chocolate Chip Cookies

Challenge for kitchen scientists

Optimizing cookies involves a tricky combination of mixture components and process factors. Furthermore, adhering to a gold standard for valid statistical studies—randomization—presents great difficulties. For each run in the combined design, the experimenter must mix one cookie according to the specified recipe and then bake it at the stated time and temperature.

It's much simpler to make a trayful of cookies with varying ingredients and bake them all at once. This can be accommodated by a specialized DOE called a "split plot".

Let's get into a few details on this 'flavor' of DOE.

Split-Plot Designs

Problem

Often in designed experiments some of the factors are more difficult or expensive to vary than others. In some cases, conducting a completely randomized design isn't practical.

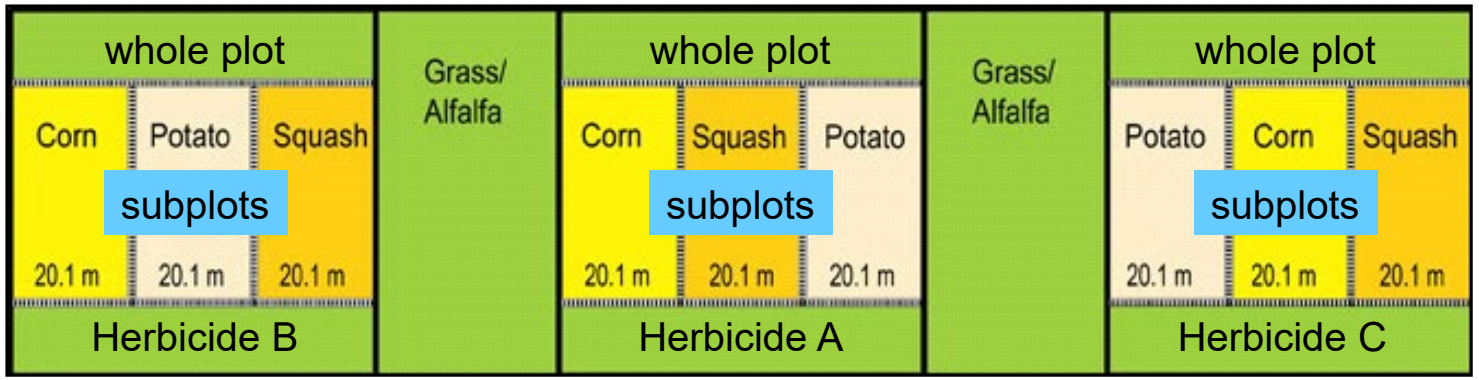
Solution

Restrict the randomization so it is practical to conduct the design. If you must sort a factor to make a DOE easier to run, this restriction in randomization results in a "split-plot" design.

Split-Plot Designs

Restricting randomization for convenience

The “split-plot” design originated in the field of agriculture. Agronomists applied one treatment (*e.g., herbicide*) to a large area of land, called a “whole plot”, and other treatments (*e.g., crop*) to smaller areas of land within the whole plot, called a “subplot”.



Split-Plot Designs

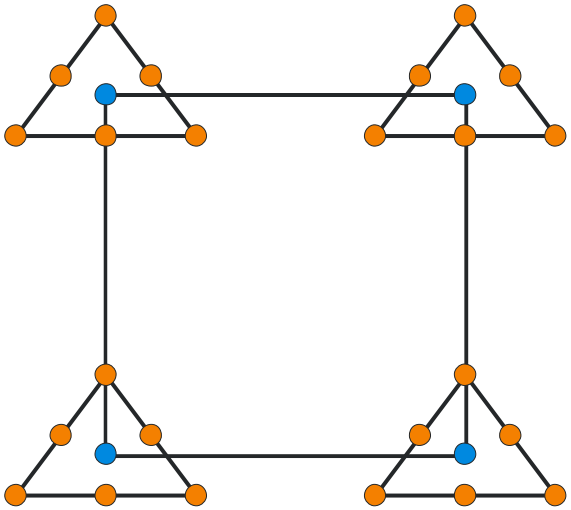
Combining mixture and process variables

In combined designs it's common that either the process factors or the mixture components are hard to change (HTC), e.g., mixing and baking chocolate-chip cookies, which could go either way.

<u>Process Factors HTC</u>

Mix each cookie at random (ETC)

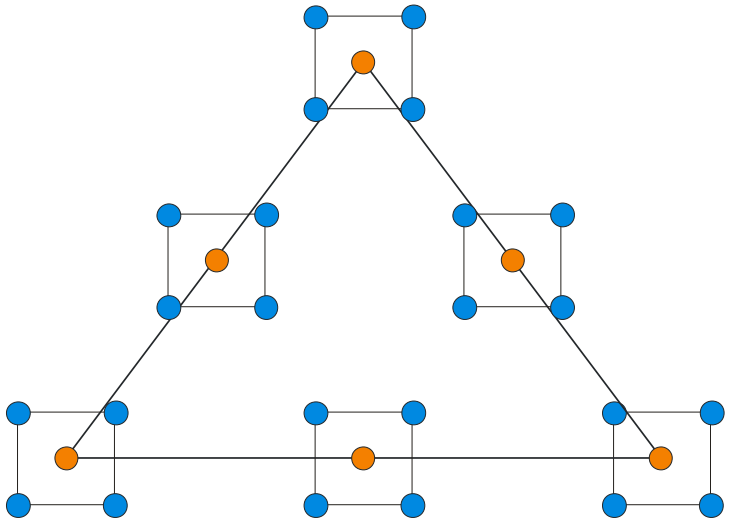
Bake a bunch on a tray.



<u>Mixture Components HTC</u>

Mix up a batch.

Bake one cookie at a time (ETC).

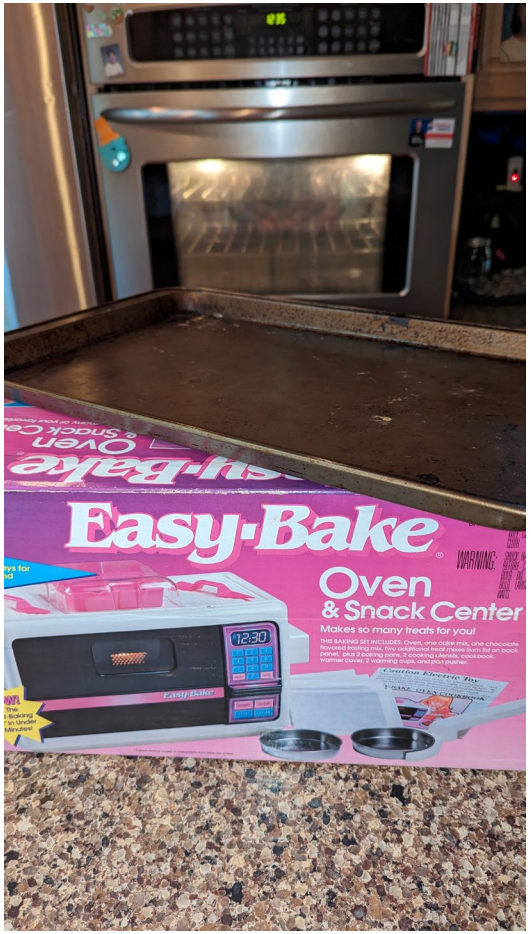


Split-Plot Designs

Bake cookies one at a time, or on a tray?

The test kitchen (unlike mine) not being equipped with an Easy Bake Oven (and even if so, not wanting to spend the time), we decided to make up a tray of cookies made by varying recipes, and then bake them grouped on trays.

The next big question:
How to design an optimal experiment with many variables that could be done over two weekend days in a reasonable amount of time per day?



KCV Modeling

A good compromise for mixture-process designs

Problem:

Standard crossed models generate far more terms than needed to detect likely interactions between mixture and process variables.

Elegant Solution:

Kowalski, Cornell and Vining (KCV) simplified the equation by only crossing the linear models; adding mixture and process terms beyond that. This streamlined approach saves many runs, yet it detects probable combination effects between components and factors.

KCV makes mixture-process combined designs far more practical!

KCV Models

Big savings vs completely crossed models

Mixture Components	Process Factors	Crossed Q by Q	KCV
2	2	18	10
3	2	36	15
4	2	60	21
3	3	60	21
4	3	100	28
5	3	150	36
4	4	150	36
5	4	225	45
6	4	315	55

Design & Analysis of Chocolate Chip Cookie DOE

Stat-Ease software up to the challenge

Full disclosure: Putting all the elements—split plot, blocking, combining process and mixture—into a do-able experiment put me, Greg and the program to the task. But with a lot of patience for the long builds, we finally succeeded. Kudos to Greg's student Jessica for actually pulling it off (and doing some clever testing) !

1. *Open "Chocolate chip cookies" and go over the design layout by day, group, inputs, responses (note the wide range for taste).*
2. *Rebuild only to D-optimal screen. (Too long to create.)*
3. *Discuss options: blocks, groups, model points, etc.*
4. *Show combined QxQ vs KCV model terms.*
5. *Cancel, re-open, optimize on taste.*

Conclusions*

Cookies made to taster's choice

Focusing on taste alone, this combined mixture-process experiment led to a recipe—heavy on butter, vanilla free—that, when baked at the ideal conditions—325 deg F for 18 minutes—scores near perfect.

Furthermore, by adjusting the recipe (mixture component levels) along with the baking temperature and time (process factor settings), cookies can be made either soft or crispy, depending on what people like.

Now that you know all the DOE tricks, set up your own optimal mixture-process experiment to 'level up' your homemade chocolate chip cookies. Yum!

* "Chocolate Chip Cookie Mixture", Jessica Keel, University of Arkansas, INEG 5333: Design of Industrial Experiments Term Project: Spring 2023 (submitted to Professor Greg Hutto). Posted at www.statease.com/case-studies/chocolate-chip-cookie-mixture/

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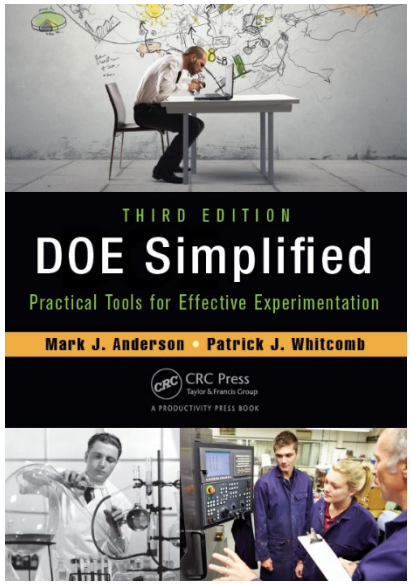
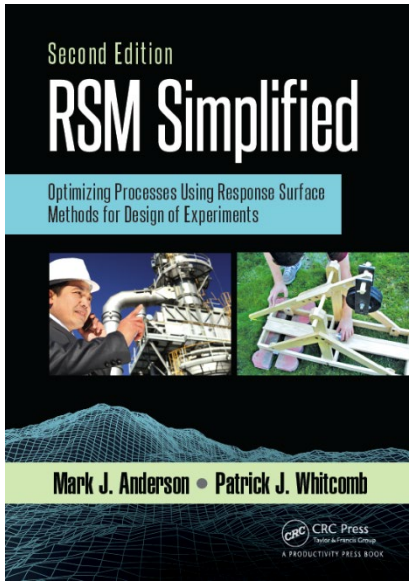
Did you enjoy this talk and learn a few things? I hope so!

References*

3rd edition 2015



2nd edition 2016



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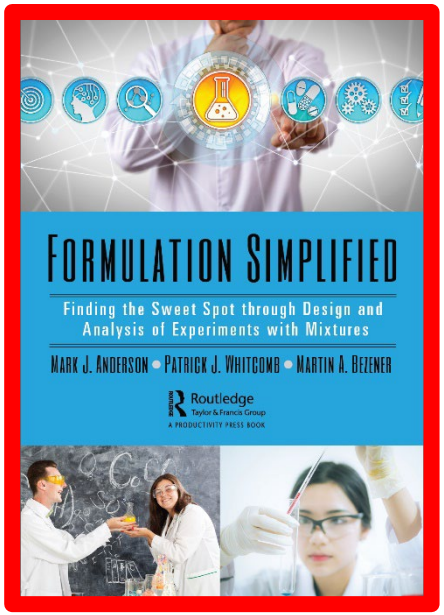

* *Taylor & Francis/CRC/ Productivity Press New York, NY.*

Other relevant educational resources

- Stat-Ease software tutorial “Combined Split-Plot Lady Baltimore” available via program Help or www.statease.com/docs/latest/tutorials/combined-split-plot/
- Geoff Vining’s 2/21/20 blog “Background on the KCV Designs” www.statease.com/blog/background-kcv-designs/
- My webinar on “How to Unveil Breakthrough Synergisms Between Mixture and Process Variables” www.statease.com/webinars/how-to-unveil-breakthrough-synergisms-between-mixture-and-process-variables/
- Report by Jessica Keel on her Chocolate Chip Cookie Mixture

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