Camo Analytics

Design of Experiments Made Easy

Before we begin

- All attendees will be muted during the webinar.
- Please send questions to mark@statease.com who will answer questions after the webinar.
- The webinar will be available for viewing after the presentation.

Synergies between design of experiments and multivariate analysis: Sum is larger than the parts

Design of experiments

- Systematic testing of effects
- Optimised sampling plans to solve defined problem
- Number of experiments larger than number of factors
- Hypothesis checking

Multivariate analysis

- Description of data – data driven
- Identifying main variation sources in data
- Handles interaction among factors and among responses
- Hypothesis generation

synergy
noun
The interaction or cooperation of two or more organizations, substances, or other agents to produce a combined effect greater than the sum of their separate effects.

https://en.oxforddictionaries.com/definition/synergy

DESIGNEXPERT

Unscrambler
by Camo Analytics

Camo Analytics

Together we cover the whole process from design to pilot to production

Design of experiments (DOE)

Multivariate analysis (MVA)

Process Analytical Technology (PAT)

DESIGNEXPERT

Unscrambler by Camo Analytics

Process Pulse by Camo Analytics

Camo Analytics

StatEase®
statistics made easy®
Make the most from every experiment!℠

Design of Experiments (DOE) Made Easy *(<u>and</u> more powerful)* with Version 12 of Design-Expert® Software

By Mark J. Anderson, PE, CQE
Stat-Ease, Inc., Minneapolis, Minnesota, USA

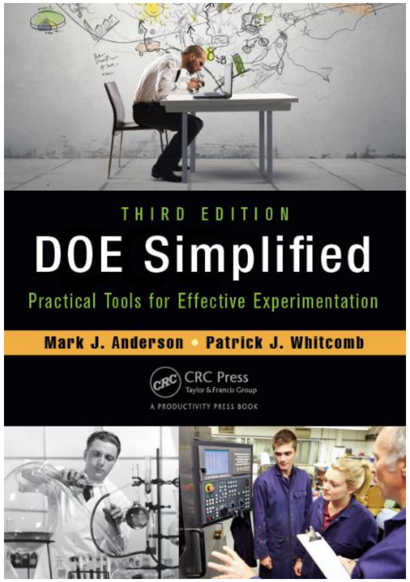
Hosted by

Camo Analytics

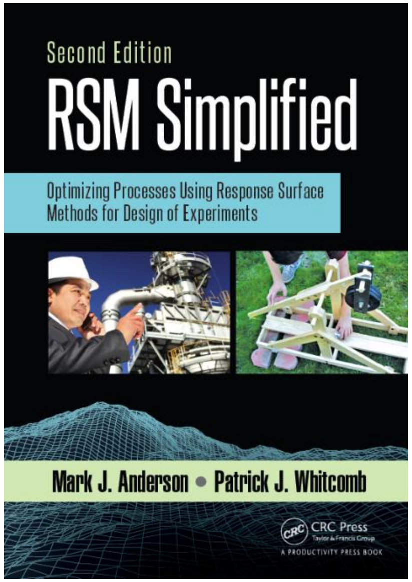
To prevent audio disruptions, all must be muted.
Please address questions to mark@statease.com.

References*

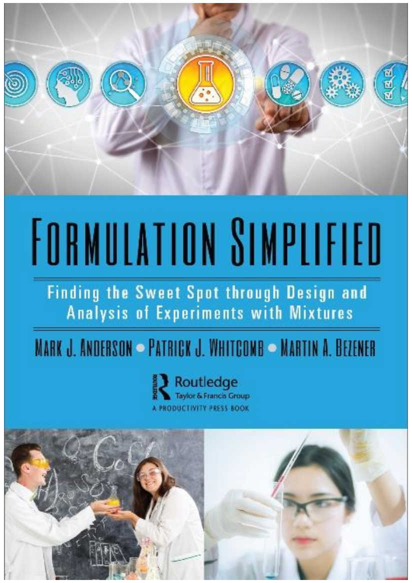
3rd edition 2015



2nd edition 2016



1st edition 2018



If you see me, please press the raise hand button.

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

The WIIFM* for this Webinar

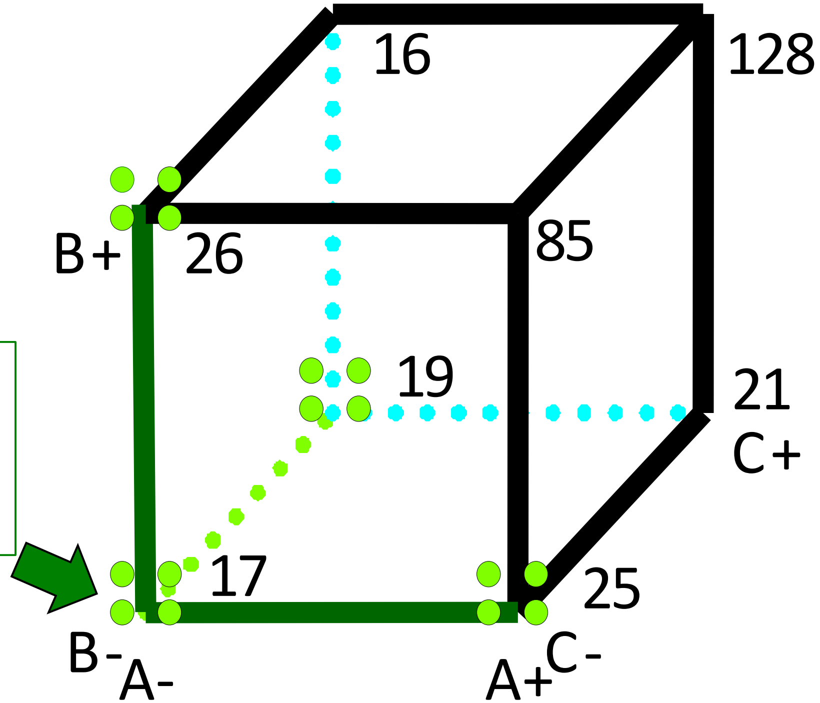
**(What's in it for me)*

This demonstration ('demo') of Design-Expert features an array of powerful DOE tools for quickly converging on the 'sweet spot'—the most desirable combination of process parameters and product attributes.

Some WIFFMs for you to take home will be:

- Appreciation for multifactor testing.
- A tried-and-true strategy of experimentation.
- Inspiration to use stat tools that can greatly accelerate your research.

Multi-Factorial (VS OFAT)
(life from accelerated test)



Start point for One Factor at a Time (OFAT)

Relative efficiency = 16/8

⇨ 2 to 1!

"To make knowledge work productive will be the great management task of this century."
-- Peter Drucker

Screening/Characterization

Purpose: Quickly sift through a large number of potential factors to discard the trivial many. Then follow-up with an experiment that focuses on the vital few.

Tool: Two-level factorial designs:

1. Medium resolution fractional for screening main effects in minimal runs.
2. High resolution full (or less fractional) to resolve two-factor interactions.

Screening/Characterization Case Study

The biggest client of a large pie-maker confronted them with of unsightly pitting on the bottom crust. Their food scientists ran a trouble-shooting study on these six factors via a two-level fractional design:

A. Dough temperature,
B. Amount of shortening,
C. Shortening temperature,
D. Rework,
E. Aging,
F. Conditioner.

They expected the factors to interact. However, time being of the essence, the experiment could not exceed 24 runs.

Standard (Classical) Two-Level Designs

Only can afford a screening (yellow) design on 6 factors, which resolves main effects, not interactions. ☹

Factors

Runs	2	3	4	5	6	7	8	9	10	11	12	13	14	15
4	Full	1/2 Fract.												
8		Full	1/2 Fract.	1/4 Fract.	1/8 Fract.	1/16 Fract.								
16			Full	1/2 Fract.	1/4 Fract.	1/8 Fract.	1/16 Fract.	1/32 Fract.	1/64 Fract.	1/128 Fract.	1/256 Fract.	1/512 Fract.	1/1024 Fract.	1/2048 Fract.
32				Full	1/2 Fract.	1/4 Fract.	1/8 Fract.	1/16 Fract.	1/32 Fract.	1/64 Fract.	1/128 Fract.	1/256 Fract.	1/512 Fract.	1/1024 Fract.
64					Full	1/2 Fract.	1/4 Fract.	1/8 Fract.	1/16 Fract.	1/32 Fract.	1/64 Fract.	1/128 Fract.	1/256 Fract.	1/512 Fract.
128						Full	1/2 Fract.	1/4 Fract.	1/8 Fract.	1/16 Fract.	1/32 Fract.	1/64 Fract.	1/128 Fract.	1/256 Fract.
256							Full	1/2 Fract.	1/4 Fract.	1/8 Fract.	1/16 Fract.	1/32 Fract.	1/64 Fract.	1/128 Fract.

Design-Expert to the rescue with modern DOE options!

Modern Minimum-Run Designs (up to 50 factors)

Considerable savings over standard fractions

Characterization

Factors	Std Res V	MR5*
6	32	22 ☺
7	64	30
8	64	38
9	128	46
10	128	56
11	128	68
12	256	80
13	256	92
14	256	106

Screening

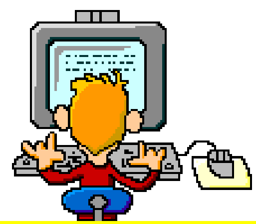
Factors	Std Res IV	MR4**
9	32	18
10	32	20
11	32	22
12	32	24
13	32	26
14	32	28
15	32	24
16	32	26
17	64	28

* Oehlert & Whitcomb, “Small, Efficient, Equireplicated Resolution V Fractions of 2^k designs …”, Fall Technical Conference, 2002: www.statease.com/pubs/small5.pdf

** Anderson & Whitcomb, “Screening Process Factors In the Presence of Interactions,” Annual Quality Congress, American Society of Quality, Toronto, 2004: www.statease.com/pubs/aqc2004.pdf

Screening/Characterization Case Study

Using Design-Expert® software let’s rebuild this MR5 design so you can see how it’s done, re-open the file to collect the data, analyze it and, finally, search out the optimal settings (aka “sweet spot”) to minimize pitting (most important!), raw spot and bake shrink (not very important) to less than 20, 15 and 1.5; respectively.

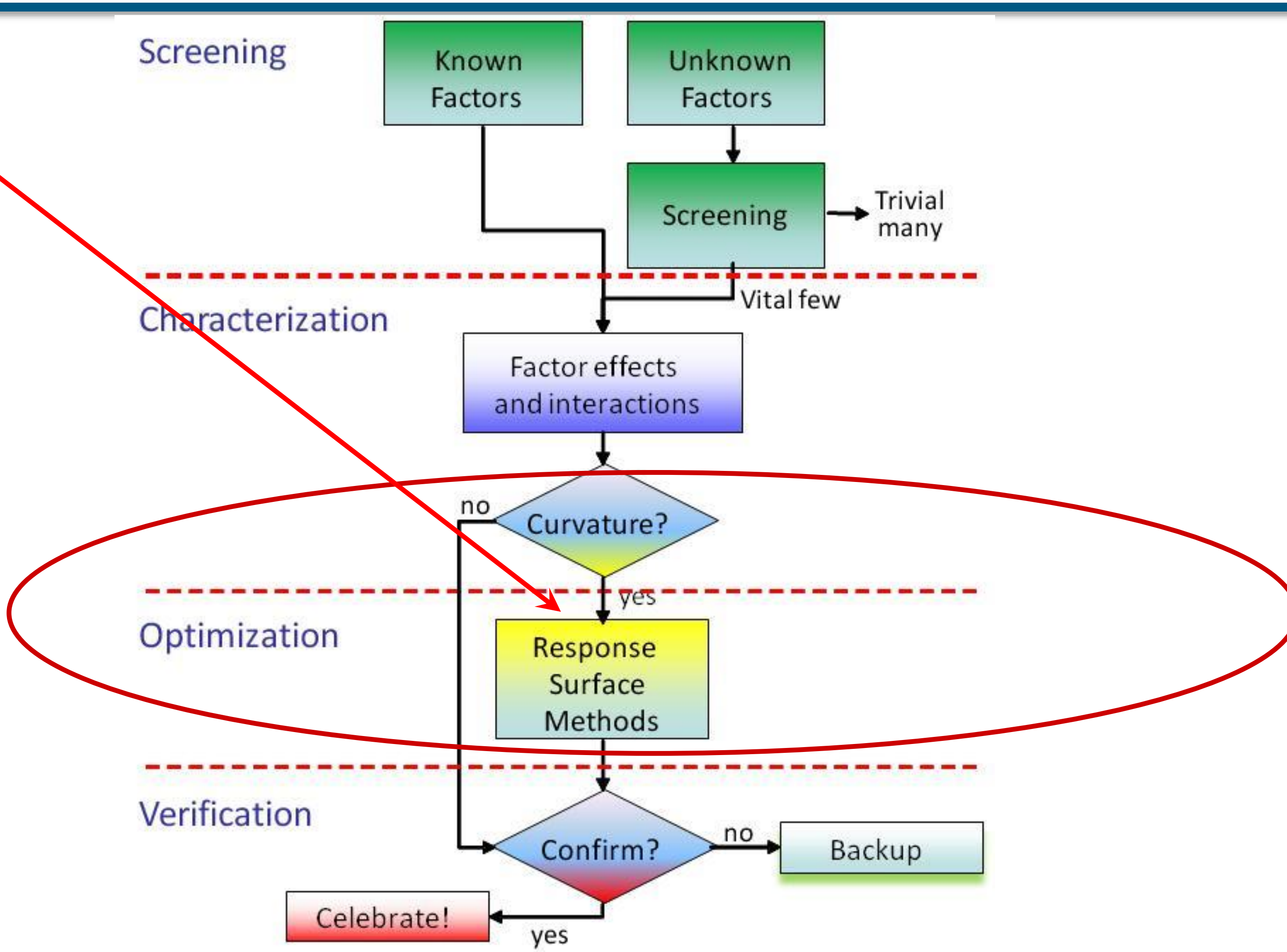


⇒ *Hide Presenter View (blocks DX projection)*

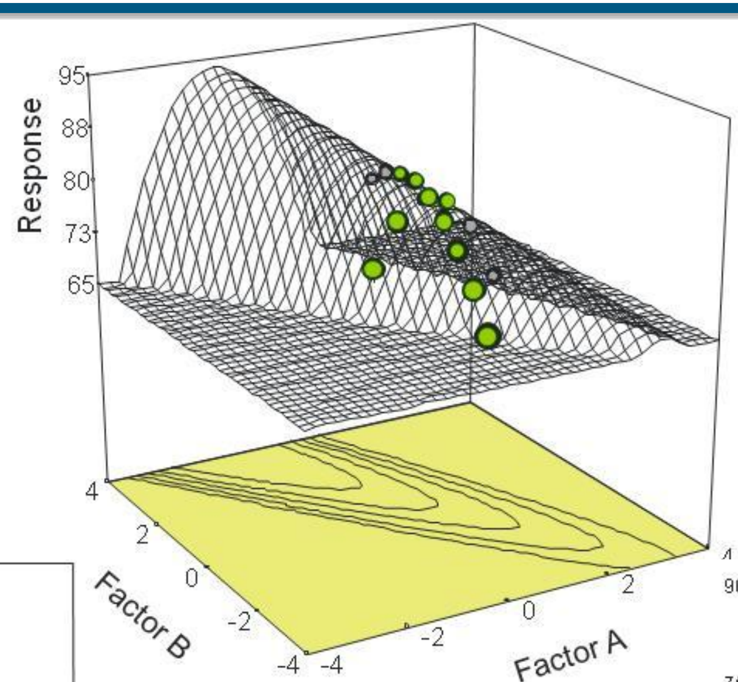
Pies-a
Rebuild, note transformatons, show cube for pitting
Optimize

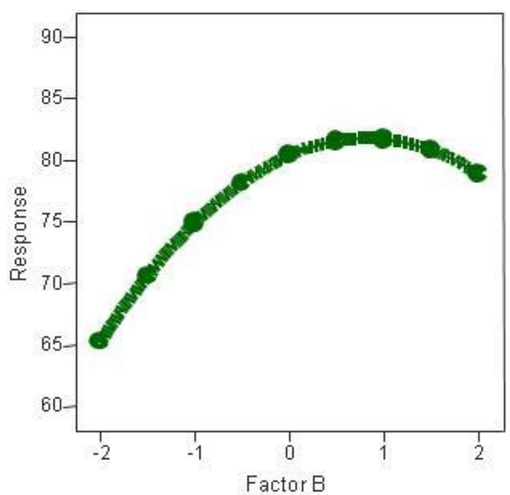
Strategy of Experimentation

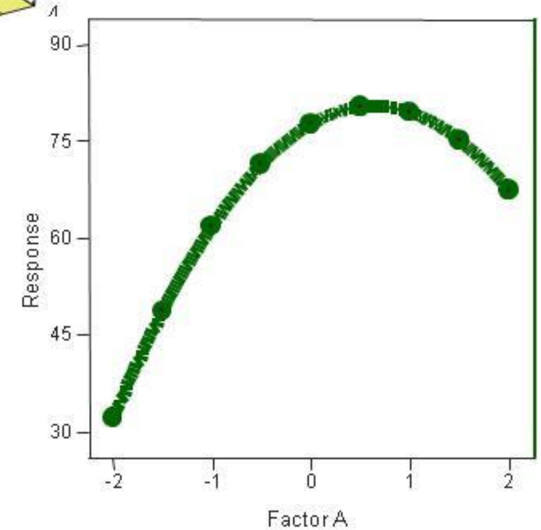
RSM



RSM vs OFAT


Response
95
88
80
73
65
4
2
0
-2
-4
Factor B
-4
-2
0
2
Factor A

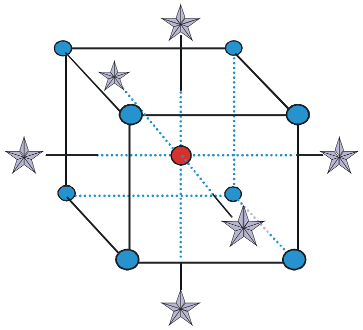

Response
90
85
80
75
70
65
60
-2
-1
0
1
2
Factor B


Response
90
75
60
45
30
-2
-1
0
1
2
Factor A

RSM Case Study

A chemist studied three process factors:

A. Time (minutes)
B. Temperature (degrees C)
C. Catalyst (percent)

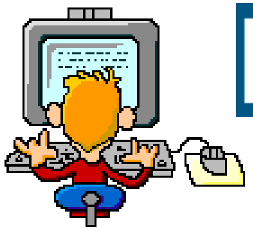


To optimize two key responses:

1. Conversion (%) => Maximize (80% or better)
2. Activity => Target 63 (± 3 allowable)

For convenience, the experiment is run in two blocks via a "central composite design" (CCD):

1. Two-level factorial with center points.
2. Axial runs (star points) plus more center points.



RSM
Rebuild—Show CCD layout
Optimize & Confirm

Mixture Design*

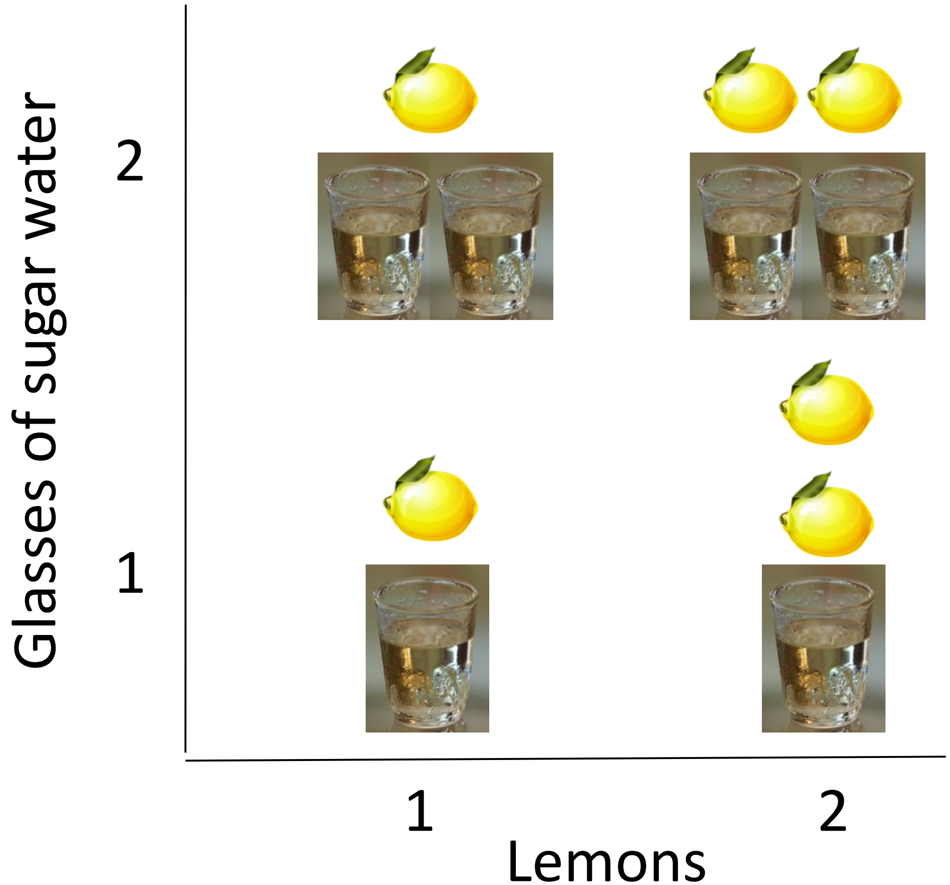
Considerations:

- Factors are ingredients of a mixture.
- The response is a function of proportions, not amounts.
- Given these two conditions, fixing the total (an equality constraint) facilitates mixture modeling as a function of component proportions.

Let's try forcing a factorial design onto a mixture.

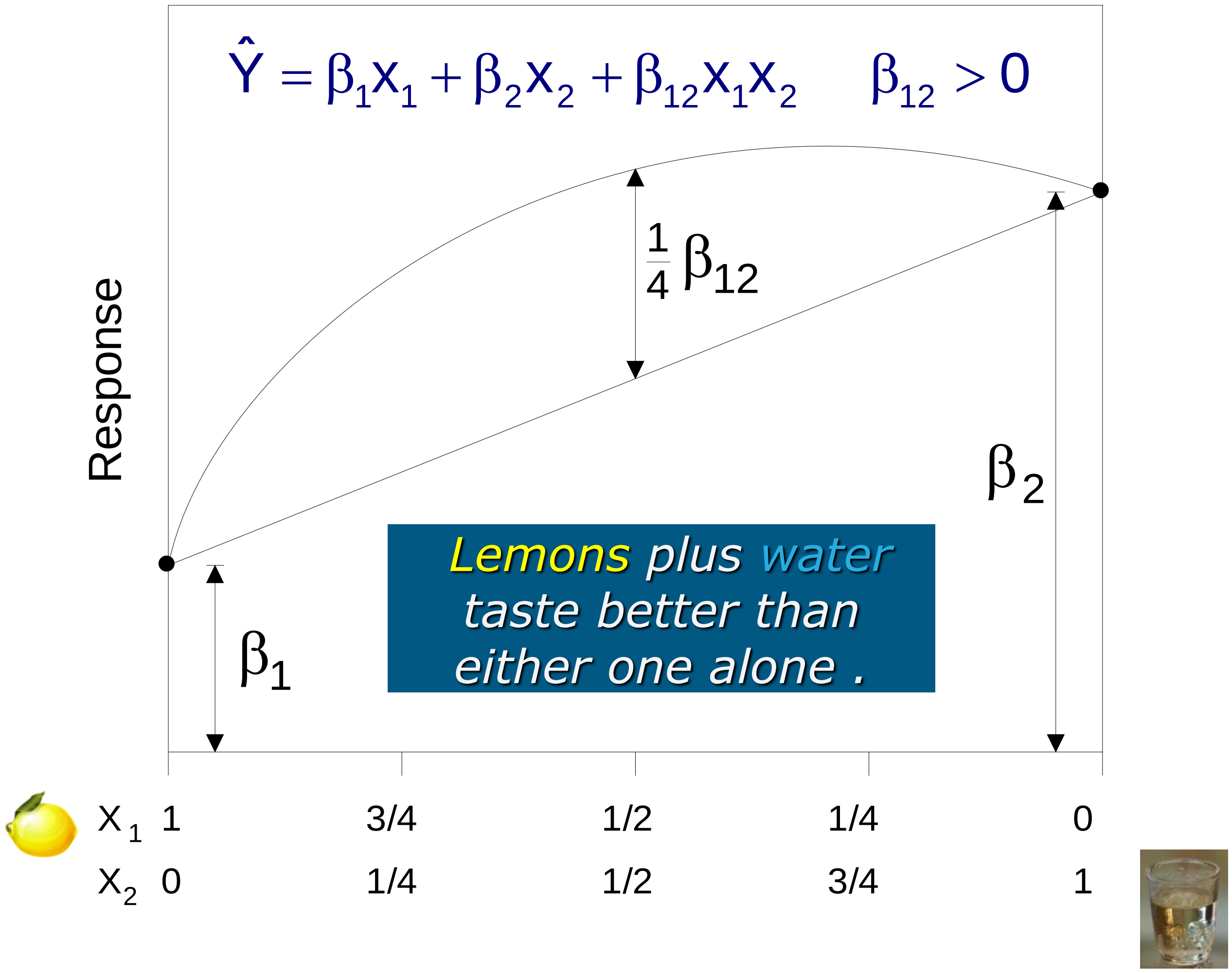
*(Pioneered by Henry Scheffé, U Cal., 1957)

Forcing (squeezing?) factorial design on a mixture: Lemonade

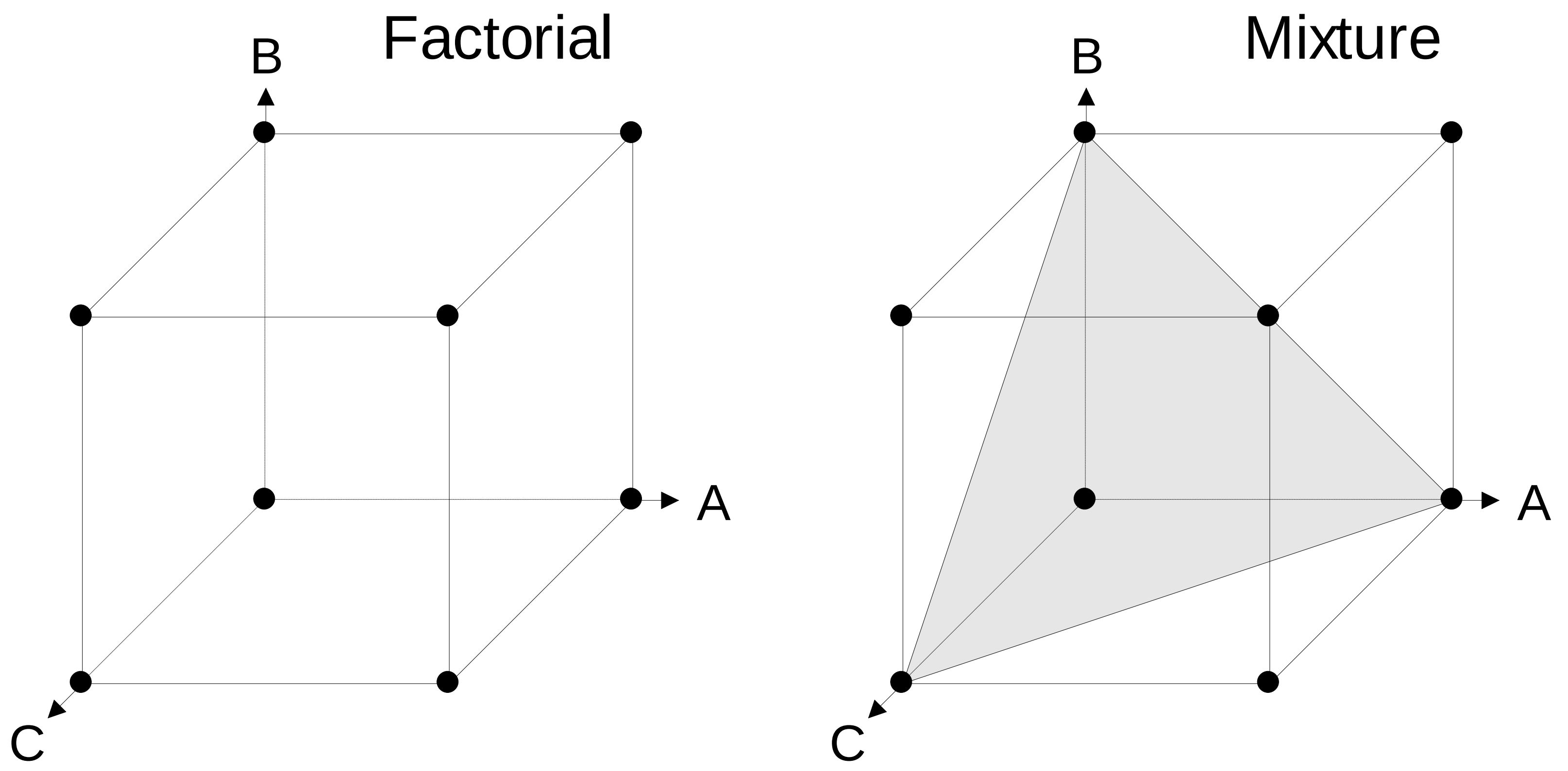


Mixture Design and Modeling (sweet!)

Two components: Quadratic (synergistic)



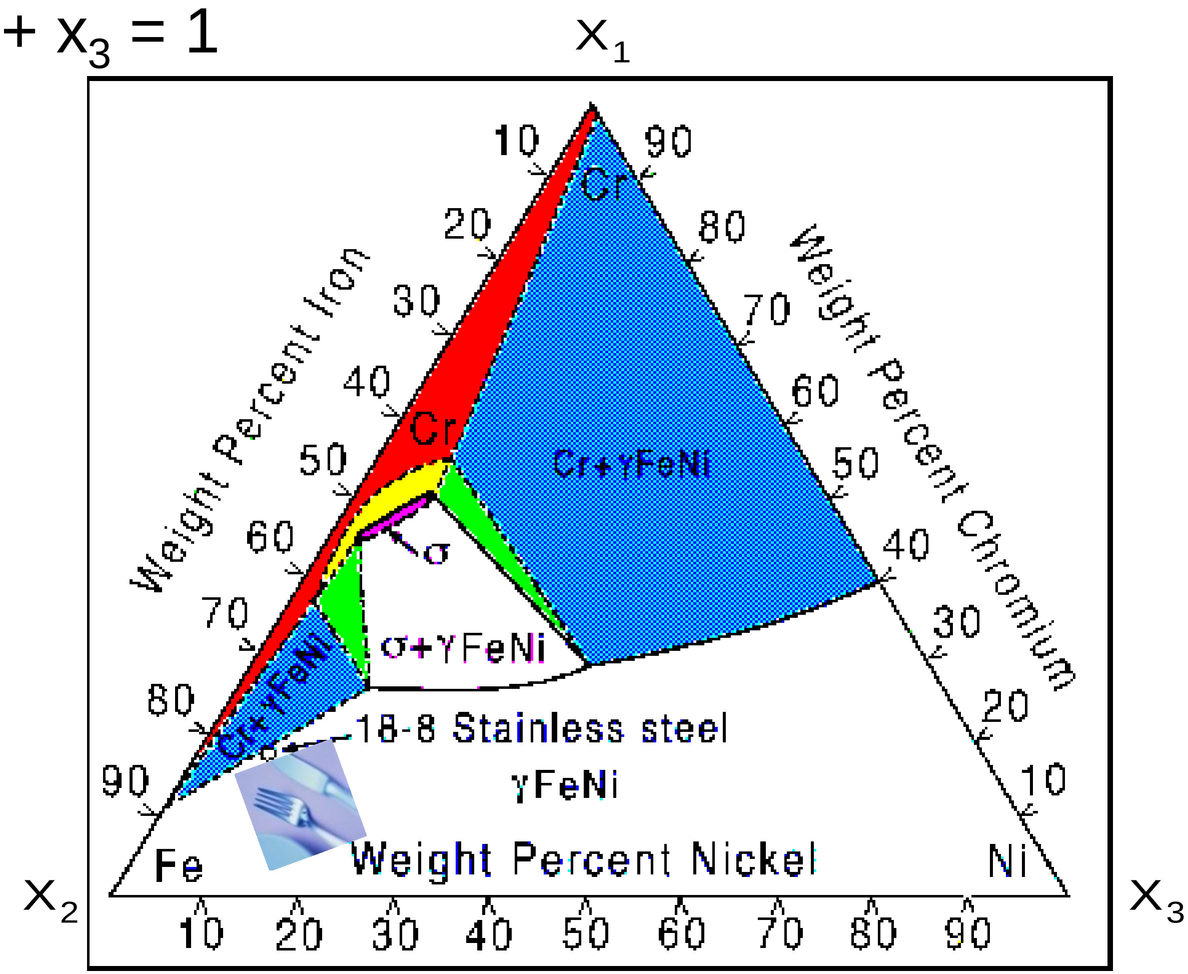
Three-Component Mixture



Raise hand if you have used a triangular (ternary) graph.

Ternary Diagram for Mixture Composition
(for example, stainless steel flatware)

$x_1 + x_2 + x_3 = 1$

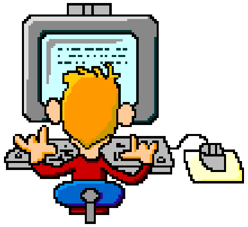


Mixture Case Study

Hoping to hit their target for viscosity, while keeping their product from becoming cloudy (low turbidity), detergent chemists varied three components:

A. Water, 3-5%
B. Alcohol, 2-4%
C. Urea, 2-4%

constraining the total of these active components to 9% while holding the 91% of other ingredients constant.



Mix-a
Rebuild, Run, Analyze, Optimize Numerical & Graphical

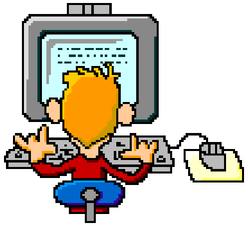
Optimal (Custom) Design

In this study a paint chemist working for an automobile manufacturer was tasked to choose:

- Monomer vendor M1 or M2.
- Crosslinker type CL1, CL2 or CL3.
- The optimal mix of
  A. Monomer, 5 - 20 %
  B. Crosslinker, 25 - 40 %
  C. Resin, 55 - 70 %

With these goals for two key response measures:

1. Knoop hardness > 10.
2. Solids content > 50%.



Autocoat
Rebuild, Run, Analyze, Optimize Numerical & Graphical

Conclusion

- **Trim out the OFAT!**
  By making use of multifactor design of experiments (DOE) starting with simple two-level factorials and graduating to response surface methods (RSM) for processes and products (mixture design), you will greatly accelerate product development and process optimization. That's the key.

- **Design-Expert® software makes DOE easy, yet powerful.**
  Experimenters do well by this DOE dedicated tool versus a general statistical package. Why use a Swiss Army Knife when you need a screwdriver?

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Make the most from every experiment!℠

Much appreciation to Camo Analytics for hosting and thank you for listening!

Mark

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