Statistical Discovery.™ From SAS.

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PART I

Author Request - The following author(s) request authority to disclose the following presentation at the MORS Event below with subsequent publication in the MORS Event Report and posting on the MORS website if applicable.

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Date: 3 June 2021

MORS Event: 89th MORSS

Event Date(s): 21-24 June 2021

Presentation Type ☐ Plenary ☐ Course ■ Tutorial ☐ Special Session ☐ Poster ☐ Demonstration
☐ Working/Composite/Distributed or Focus Group List All ☐ Other

Title of Presentation: Custom DOE – Making Your Experimental Design Fit the Problem

Presentation ID (if assigned): 56937

Classification ☐ SECRET ☐ SECRET//REL TO FVEY ☐ CONFIDENTIAL ☐ CONFIDENTIAL//REL TO FVEY
■ UNCLASSIFIED ☐ UNCLASSIFIED W/FOUO ☐ Other

Distribution Statement ■ A (Publicly Releasable) ☐ B ☐ C ☐ D ☐ E (see side 2 for definitions)

A.	This work was performed in connection with a government contract.	☐ YES (Complete Parts I, II & III)
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CUSTOM DESIGN OF EXPERIMENTS (DOE) - MAKING YOUR EXPERIMENTAL DESIGN FIT THE PROBLEM

89TH MORSS
WEBCAST TUTORIAL 56937
JUNE 21, 2021

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Technical Questions, Getting Started, Tutorials, Mentoring…

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AGENDA

- Multiple Response Optimization

  Trade-Space Analysis – Why we do DOE
- Review of Classic DOE
- Real-World Experimental Issues – Custom DOE is all about

  Making Designs Fit the Problem –

  NOT Making Problems Fit the Designs!
- Two Example Designs
  - Four continuous factors, three responses, 2nd order RSM model
  - Continuous, discrete numeric, categorical, and hard-to-change factors

    \- with constraints – 2nd order RSM model
- Specialized DOE Solutions

WHY USE DOE?

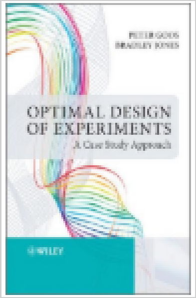
QUICKER ANSWERS,
LOWER COSTS,
SOLVE BIGGER PROBLEMS

- More rapidly answer “what if?” questions
- Do sensitivity and trade-space analysis
- Optimize across multiple responses
- By running efficient subsets of all possible combinations,
  one can – for the same resources and constraints –
  solve bigger problems
- By running sequences of designs
  one can be as ***cost effective as possible*** and
  run no more trials than needed to get a useful answer

Agent Fate 10,000+, USAF Sim Study 648

DOE BOOKS

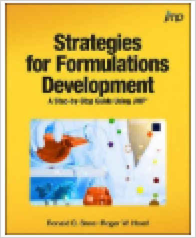
WWW.JMP.COM/BOOKS



› Optimal Design of Experiments: A Case Study Approach

by Peter Goos and Bradley Jones

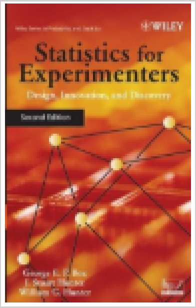
2011 (John Wiley Sons Inc.)



› Strategies for Formulations Development: A Step-by-Step Guide Using JMP

by Ronald Snee and Roger Hoerl

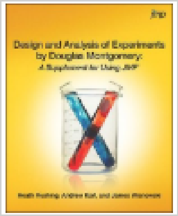
2016 (SAS Institute)



› Statistics for Experimenters: Design, Innovation, and Discovery, 2nd Edition

by George E. P. Box, J. Stuart Hunter, and William G. Hunter

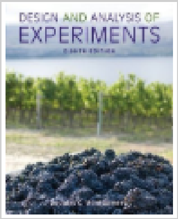
2005 (Wiley)



› Design and Analysis of Experiments by Douglas Montgomery: A Supplement for Using JMP

by Heath Rushing, James Wisnowski, and Andrew Karl

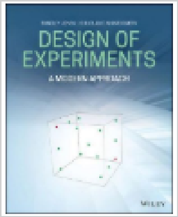
2013 (SAS Institute)



› Design and Analysis of Experiments, 8th Edition

by Douglas C. Montgomery

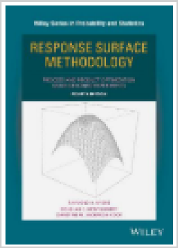
2012 (Wiley)



› Design of Experiments: A Modern Approach

by Bradley Jones and Douglas C. Montgomery

2019 (SAS Institute)

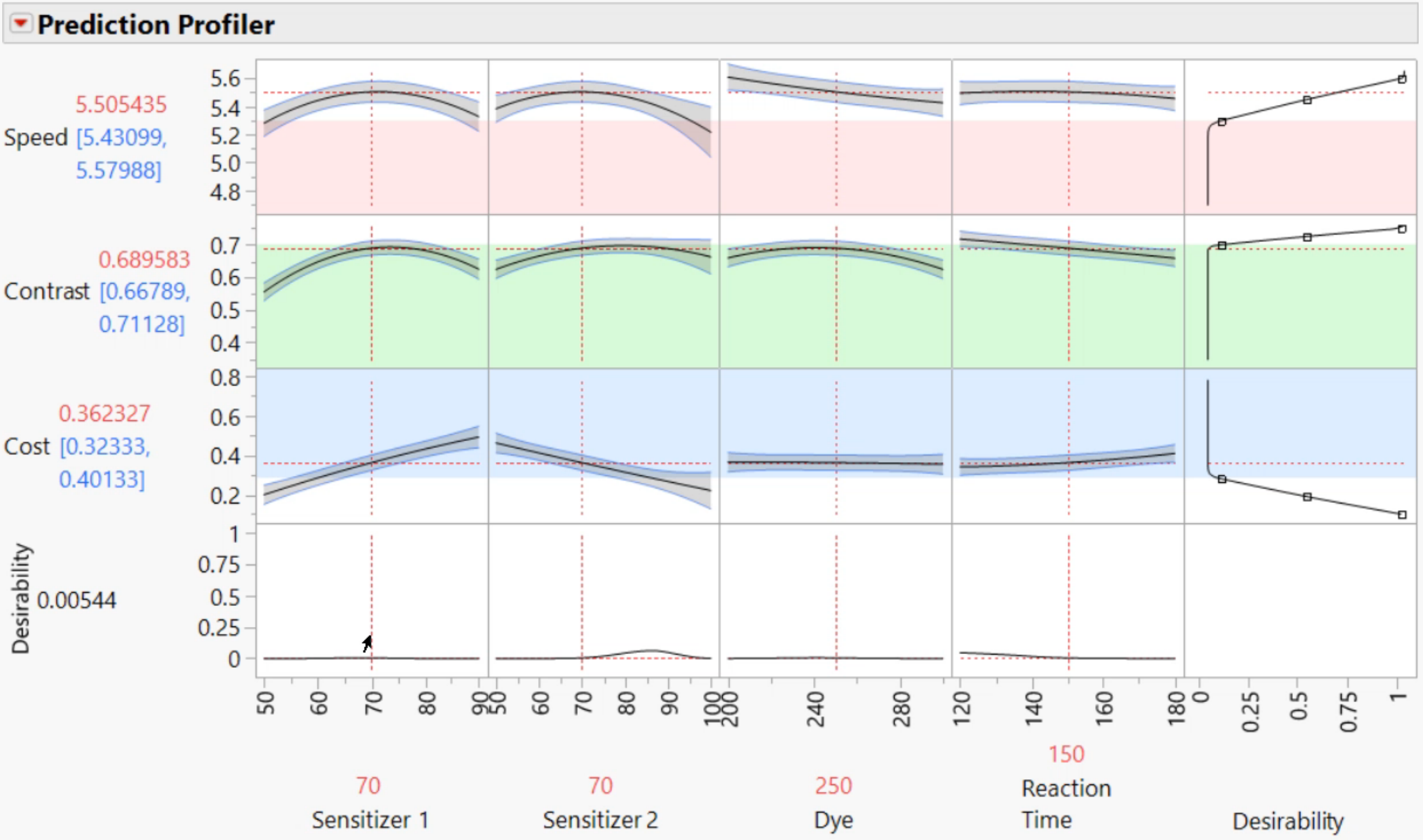


› Response Surface Methodology: Process and Product Optimization Using Designed Experiments, 4th Edition

by Raymond H. Myers, Douglas C. Montgomery, and Christine M. Anderson-Cook

2016 (Wiley)

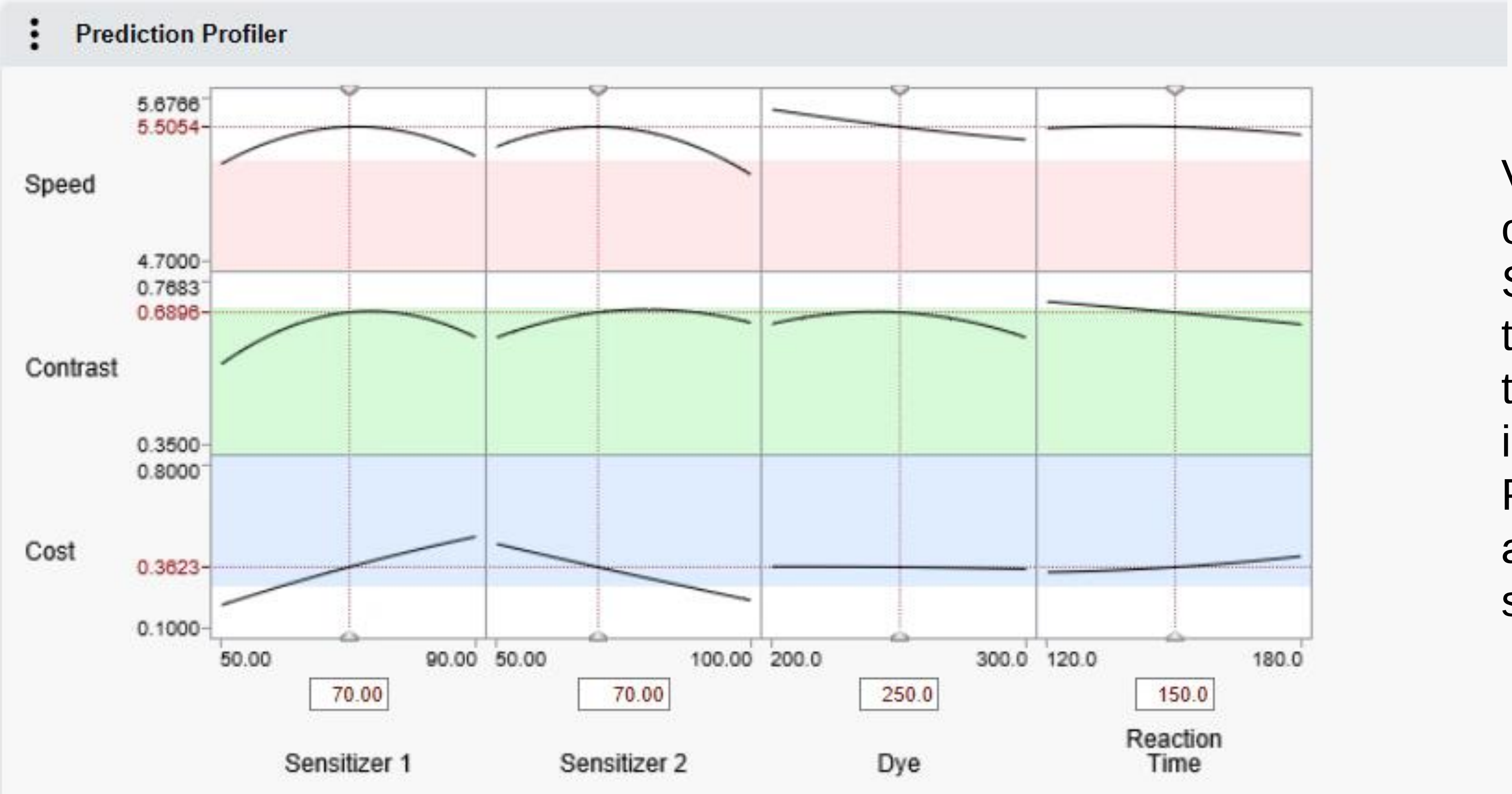
USE JMP TRADE-OFF AND OPTIMIZATION



Remembered Settings

Setting	Sensitizer 1	Sensitizer 2	Dye	Reaction Time	Speed	Contrast	Cost	Desirability
Equal Importance Opt	80.753574	91.269729	250.57625	120	5.3542877	0.7466933	0.2504014	0.347702
Mid Point Settings	70	70	250	150	5.5054353	0.6895831	0.3623274	0.004875
Cost 6X Speed & Contrast	84.016038	93.725925	283.02514	120	5.2902084	0.72549	0.1991539	0.214425
Opt Spd3X-Cntr1X-Cost6X	81.958309	90.706277	286.82246	120	5.3269582	0.7177857	0.2211116	0.264298

SHARE RESULTS ON JMP PUBLIC OR JMP LIVE



Remembered Settings

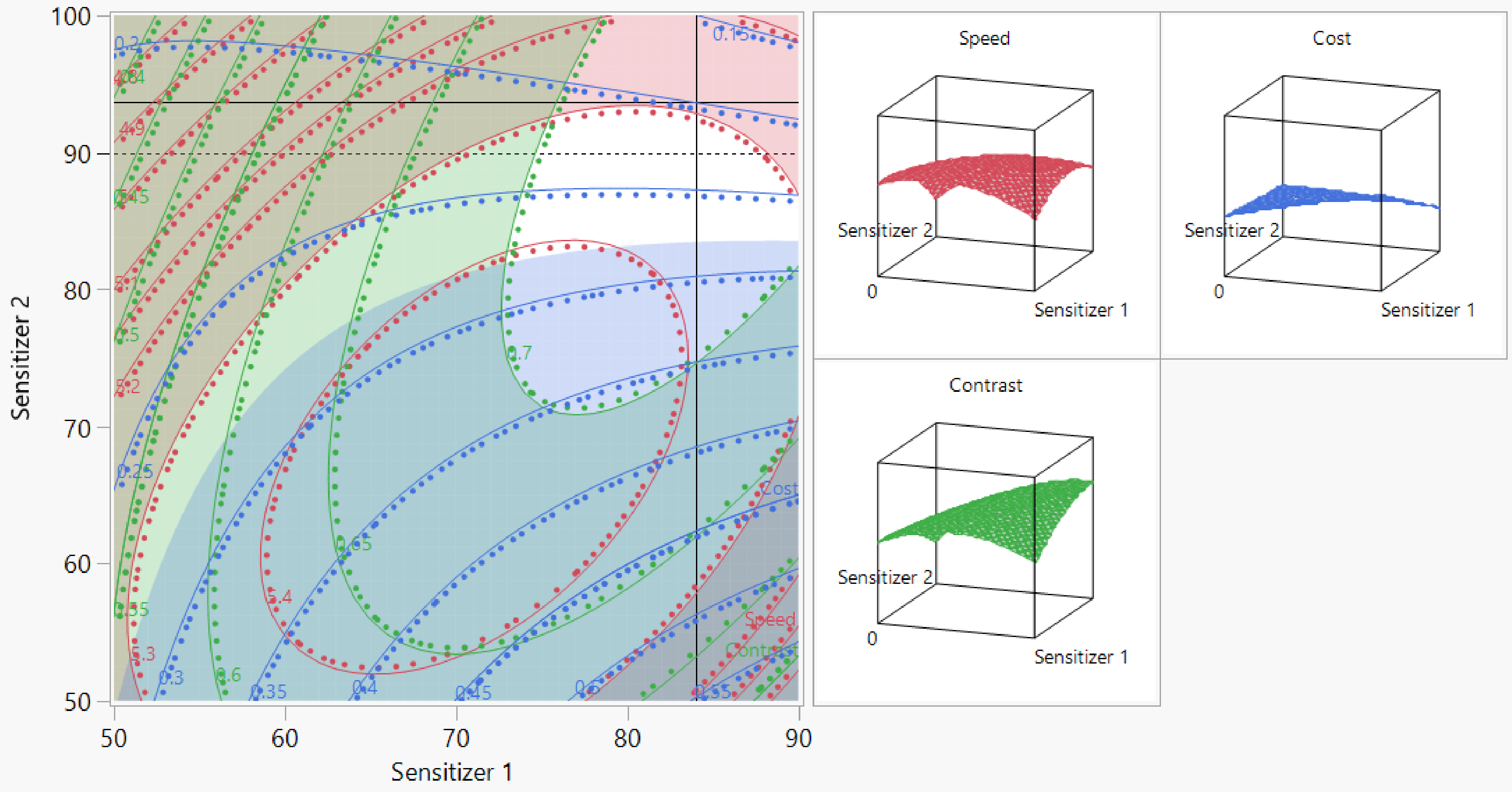
	Setting	Sensitizer 1	Sensitizer 2	Dye	Reaction Time	Speed	Contrast	Cost
Apply	Equal Importance Opt	80.753574	91.269729	250.57625	120	5.3542877	0.7466933	0.2504014
Apply	Mid Point Settings	70	70	250	150	5.5054353	0.6895831	0.3623274
Apply	Cost 6X Speed & Contrast	84.016038	93.725925	283.02514	120	5.2902084	0.72549	0.1991539
Apply	Opt Spd3X-Cntr1X-Cost6X	81.958309	90.706277	286.82246	120	5.3269582	0.7177857	0.2211116

View optimizations on your phone. Scan the QR code to launch browser, then use finger to interact with the Prediction Profiler and to “Apply” saved settings.

TRADE-OFF & OPTIMIZATION

COST RESPONSE GIVEN 6X THE IMPORTANCE OF SPEED & CONTRAST

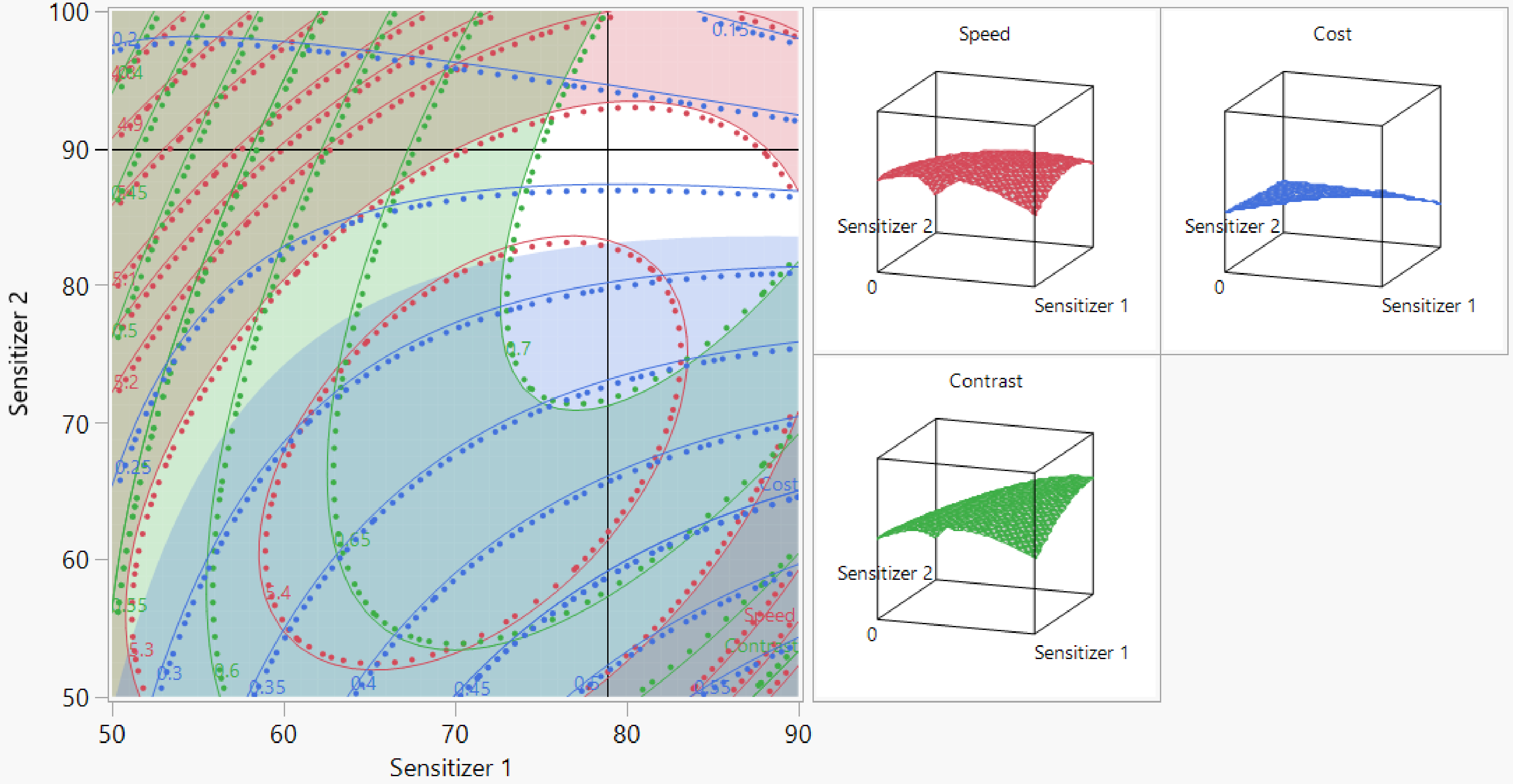
Response	Contour	Current Y	Lo Limit	Hi Limit
Speed	5.15	5.2902084	5.3	.
Contrast	0.55	0.72549	0.7	.
Cost	0.45	0.1991539	.	0.28



TRADE-OFF & OPTIMIZATION

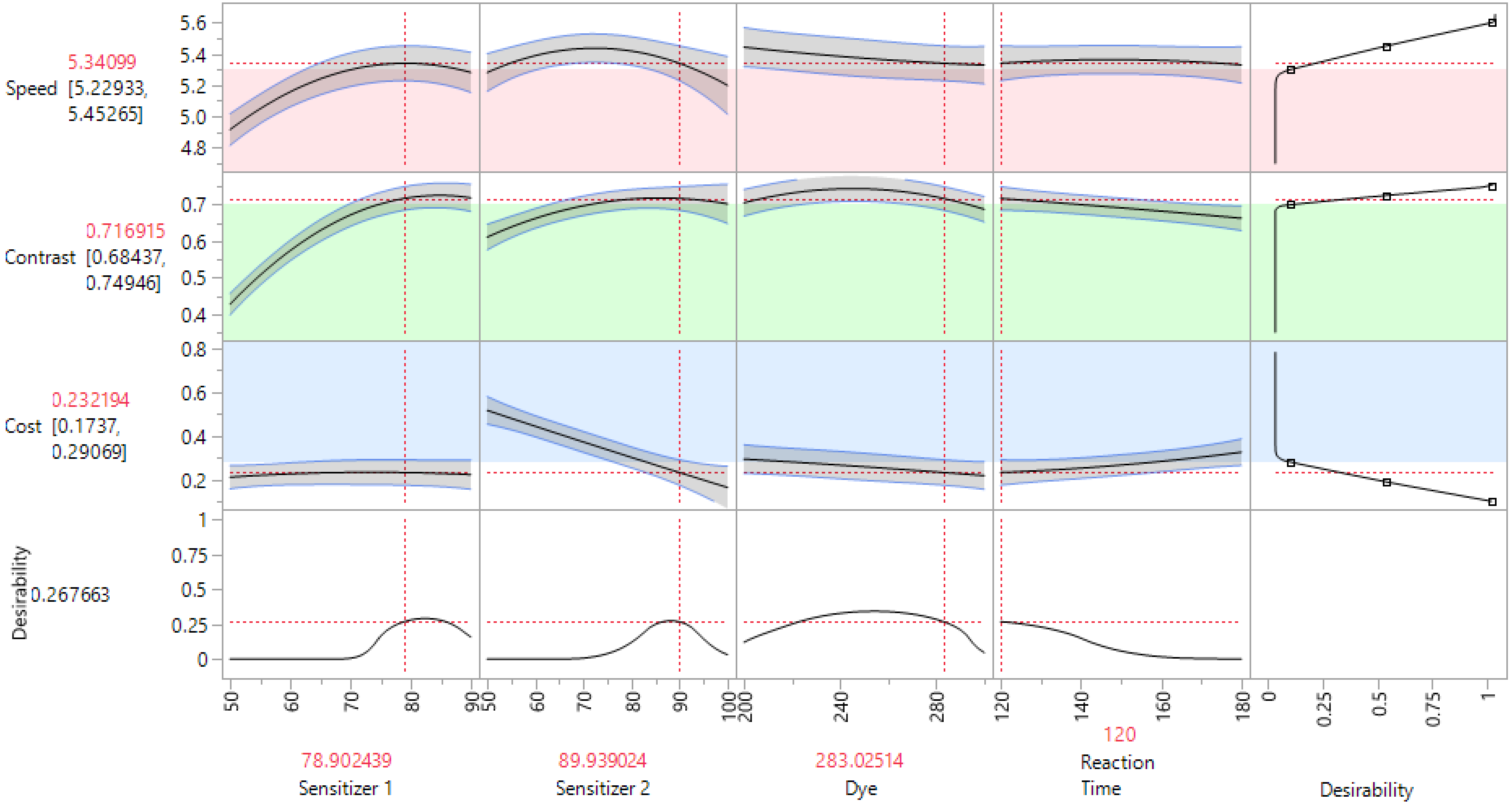
AFTER SELECTING LOCATION IN THE ACCEPTABLE WHITE REGION OF THE CONTOUR PLOT

Response	Contour	Current Y	Lo Limit	Hi Limit
Speed	5.15	5.3409902	5.3	.
Contrast	0.55	0.7169151	0.7	.
Cost	0.45	0.2321944	.	0.28

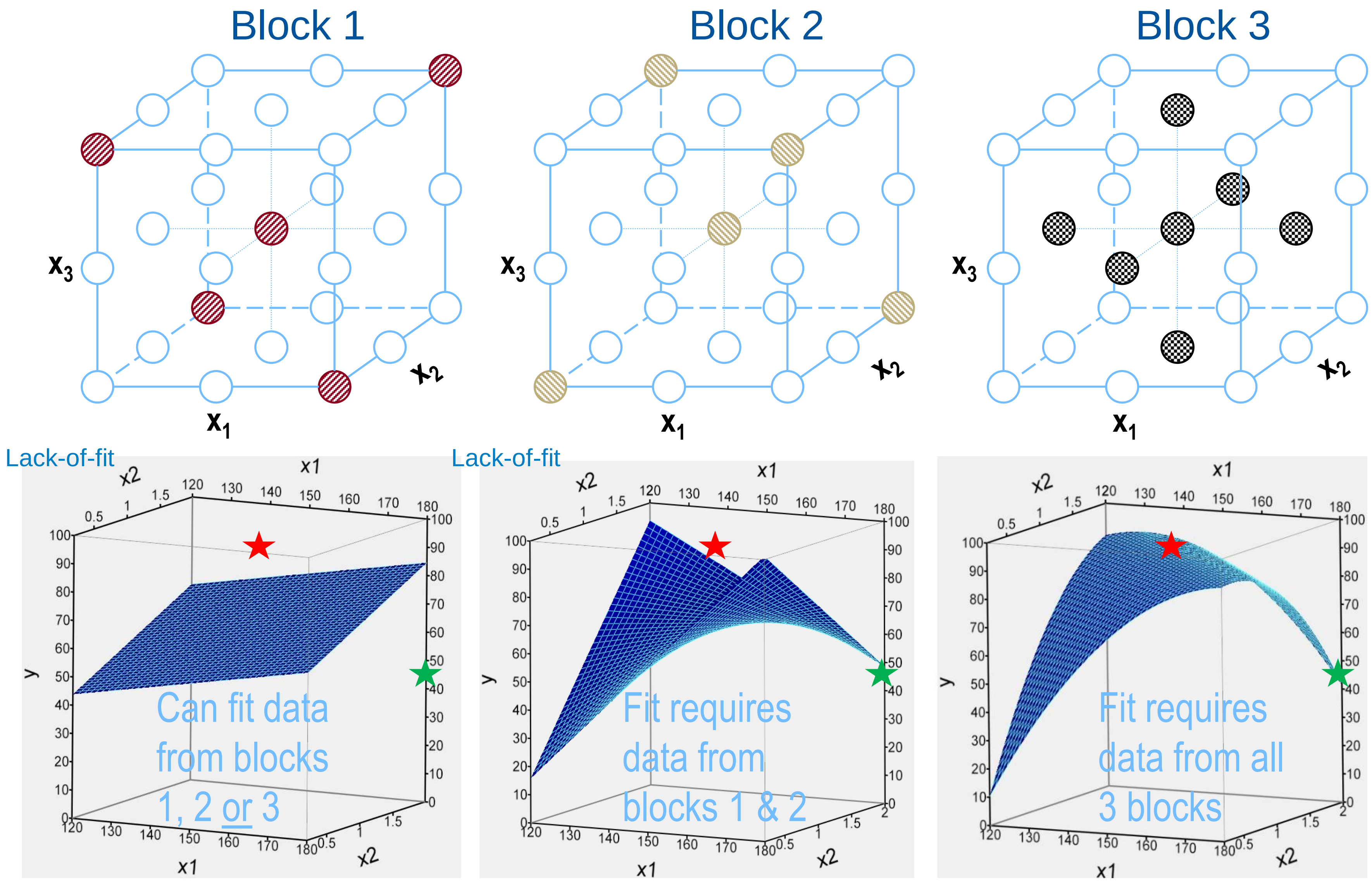


TRADE-OFF & OPTIMIZATION

PROFILER AFTER CENTERING IN ACCEPTABLE ZONE IN CONTOUR PLOT

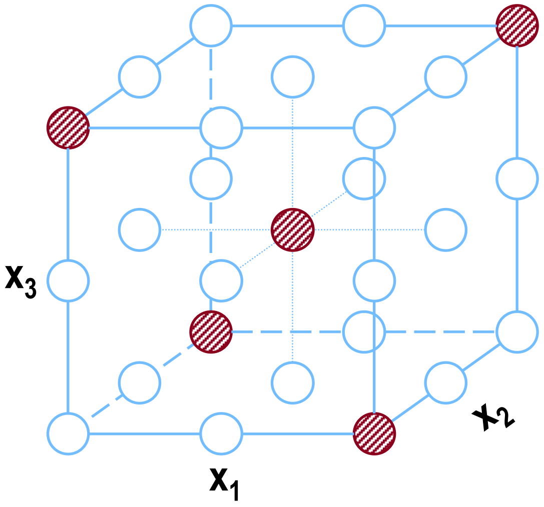


CLASSIC RESPONSE-SURFACE DOE IN A NUTSHELL



POLYNOMIAL MODELS USED TO CALCULATE SURFACES

Block 1

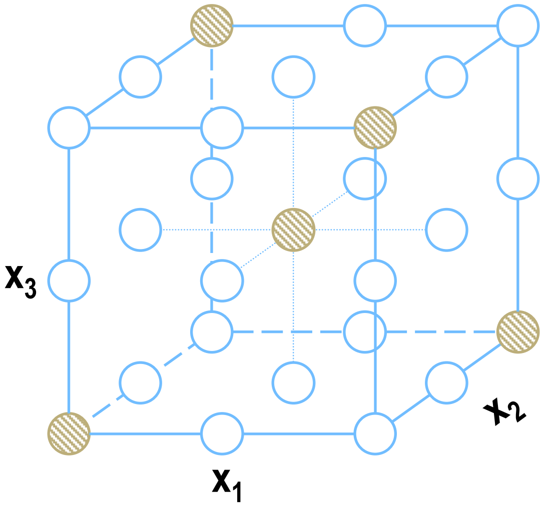


$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3$

Run this block 1st to:

(i) estimate the main effects*
(ii) use center point to check for curvature.

Block 2



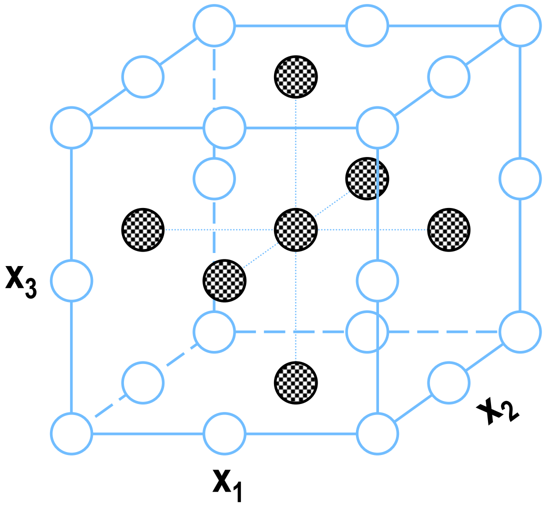
$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3$

$+ a_{12}x_1x_2 + a_{13}x_1x_3 + a_{23}x_2x_3$

Run this block 2nd to:

(i) repeat main effects estimate,
(ii) check if process has shifted
(iii) add interaction effects to model <u>if needed.</u>

Block 3



$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3$

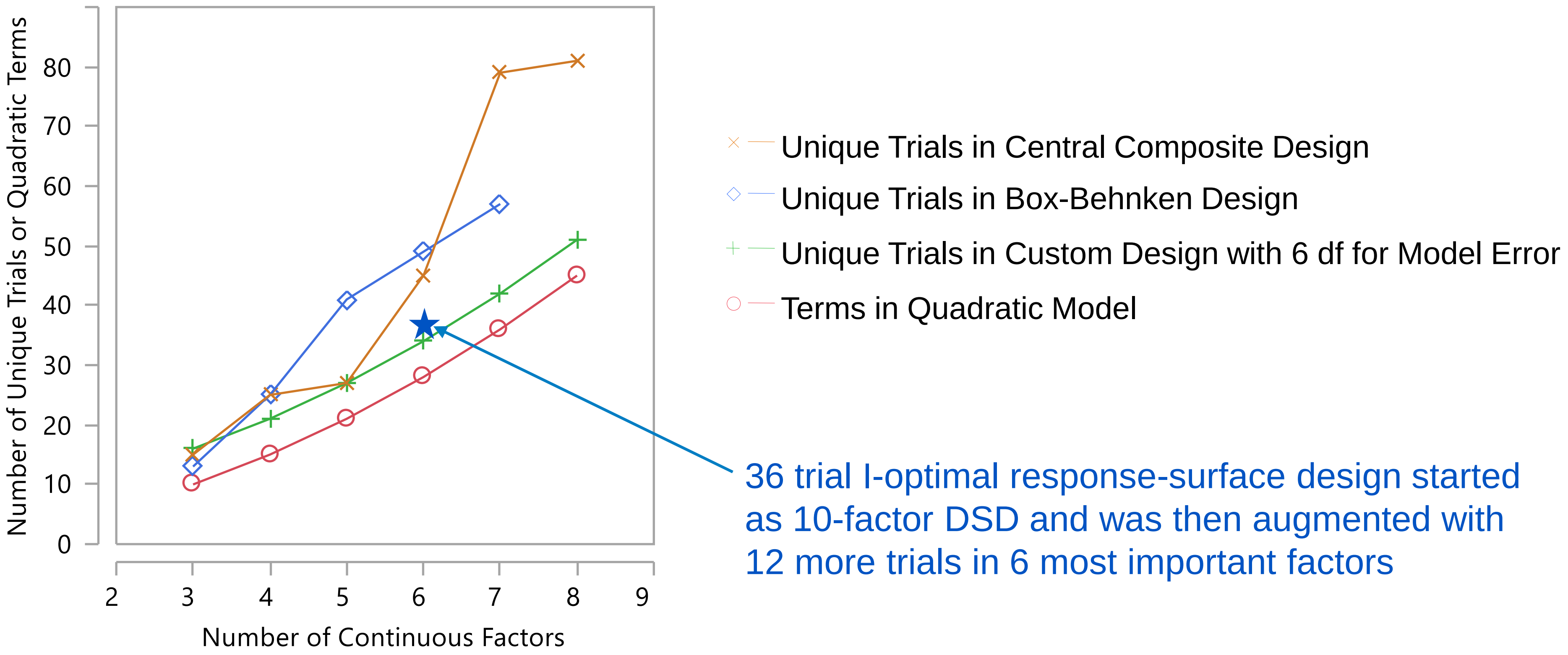
$+ a_{12}x_1x_2 + a_{13}x_1x_3 + a_{23}x_2x_3$

$+ a_{11}x_1^2 + a_{22}x_2^2 + a_{33}x_3^2$

Run this block 3rd to:

(i) repeat main effects estimate,
(ii) check if process has shifted
(iii) add curvature effects to model <u>if needed.</u>

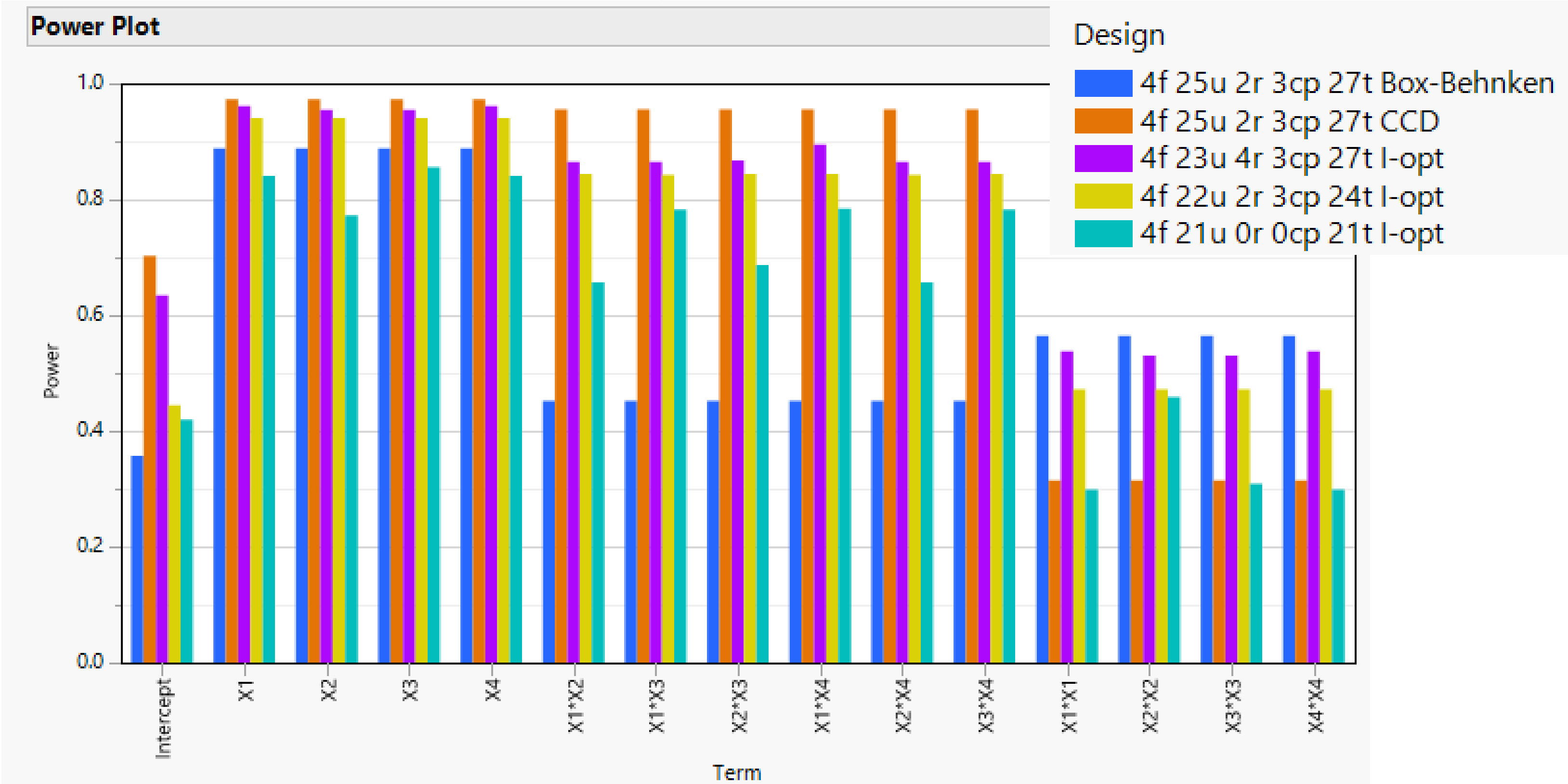
NUMBER OF UNIQUE TRIALS FOR 3 RESPONSE-SURFACE DESIGNS AND NUMBER OF QUADRATIC MODEL TERMS VS. NUMBER OF CONTINUOUS FACTORS

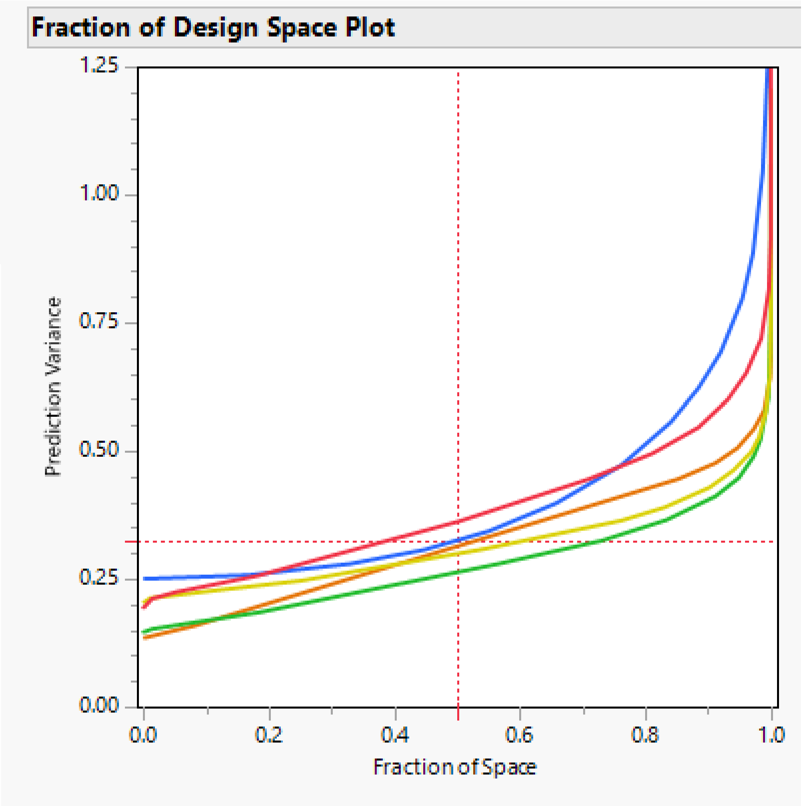


If generally running 3, 4 or 5-factor fractional-factorial designs…

1. How many interactions are you not investigating?
2. How many more trials needed to fit curvature?
3. Consider two stages: Definitive Screening + Augmentation

COMPARISON FOR SAME SIZED, 27-TRIAL 4-FACTOR DESIGNS: BOX-BEHNKEN, CENTRAL COMPOSITE, I-OPTIMAL, AND SMALLER 24-TRIAL & 21-TRIAL I-OPTIMAL DESIGNS





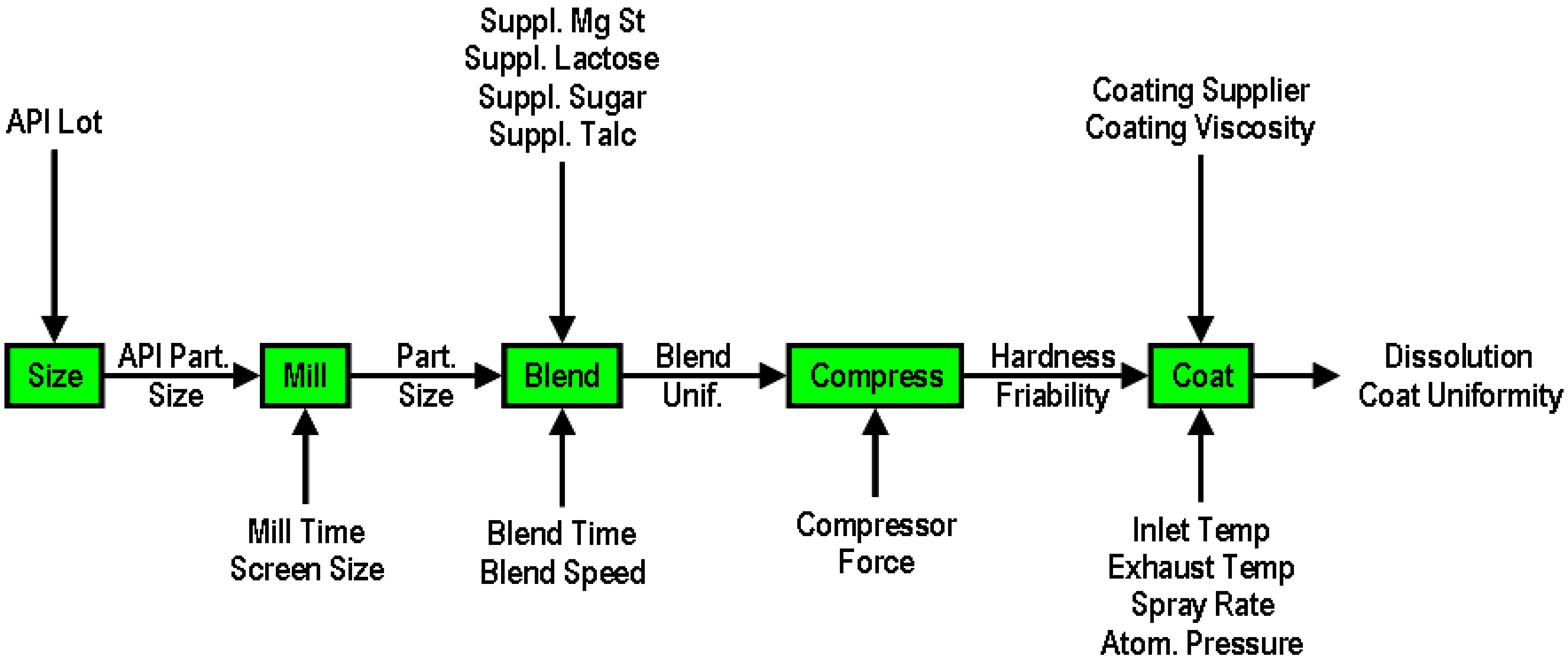
BB best for Quadratics
CC best for Main Effects & Interactions
IO-27 strong second for ALL
IO-24 nearly as good

BB highest Prediction Variance
CC lower and flatter than BB
IO-27 lowest & flattest Prediction Variance
IO-24 nearly as good

Recording

CLASSIC DEFINITION OF DOE

PURPOSEFUL CONTROL OF THE INPUTS (FACTORS) IN SUCH A WAY AS TO DEDUCE THEIR RELATIONSHIPS (IF ANY) WITH THE OUTPUT (RESPONSES).



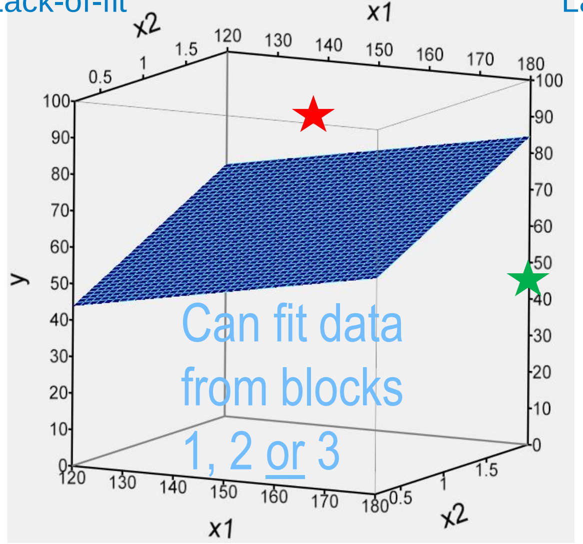
ALTERNATIVE DEFINITION OF DOE

A DOE IS THE SPECIFIC COLLECTION OF TRIALS RUN TO SUPPORT A PROPOSED MODEL.

- If proposed model is ***simple***, e.g. just main effects or ***1st order*** effects (x_1 , x_2 , x_3, etc.), the design is called a ***screening*** DOE
  - Goals include **rank factor importance** or **find a "winner" quickly**
  - Used with many (> 6?) factors at start of process characterization
- If the proposed model is ***more complex***, e.g. the model is ***2nd order*** so that it includes two-way interaction terms (x_1x_2 , x_1x_3, x_2x_3, etc.) and in the case of continuous factors, squared terms (x_1^2, x_2^2, x_3^2 , etc.), the design is called a ***response-surface*** DOE
  - Goal is generally to develop a **predictive model** of the process
  - Used with a few (< 6?) factors after a screening DOE

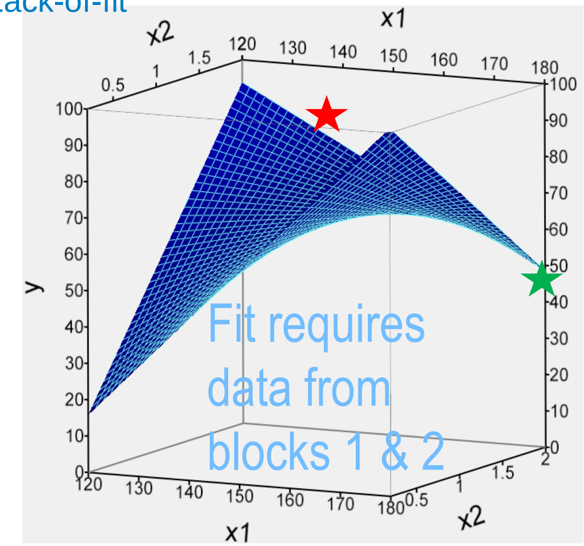
QUADRATIC MODEL NOT THAT MUCH BIGGER THAN INTERACTION MODEL

Lack-of-fit

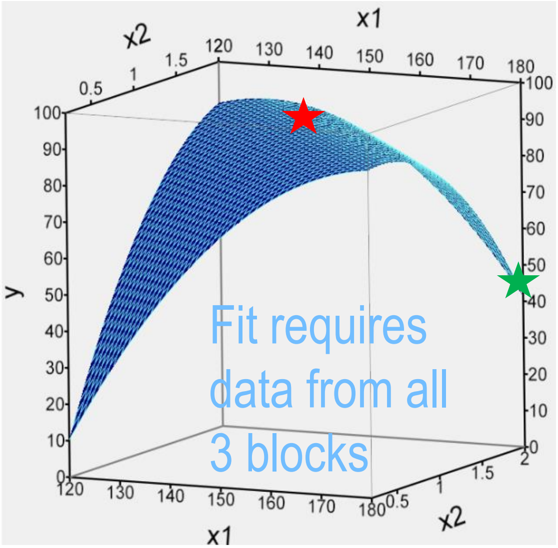


1st Order

Lack-of-fit



2nd Order



2nd Order

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3$$

For k factors there are k main effects

For 3 factors Linear Model has 4 terms

For 6 factors Linear Model has 7 terms

For 10 factors Linear Model has 11 terms

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3$$
$$+ a_{12}x_1x_2 + a_{13}x_1x_3 + a_{23}x_2x_3$$

For k factors there are k(k-1)/2 interaction effects

For 3 factors Interaction Model has 7 terms

For 6 factors Interaction Model has 22 terms

For 10 factors Interaction Model has 56 terms

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3$$
$$+ a_{12}x_1x_2 + a_{13}x_1x_3 + a_{23}x_2x_3$$
$$+ a_{11}x_1^2 + a_{22}x_2^2 + a_{33}x_3^2$$

For k factors there are k squared effects

For 3 factors Quadratic Model has 10 terms

For 6 factors Quadratic Model has 28 terms

For 10 factors Quadratic Model has 66 terms

If no squared terms, then optimum can ONLY be a corner!

REAL-WORLD DESIGN ISSUES

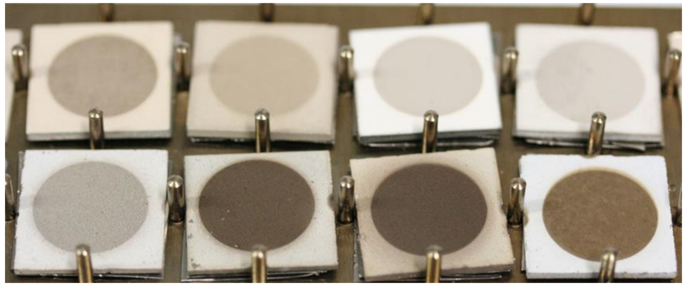
How many experimenters have any of these issues?
Most of these are NOT well treated by classic DOE

- Work with these different kinds of control variables/factors:
  - **Continuous/quantitative?** (Finely adjustable like *temperature*, *speed*, *force*)
  - **Categorical/qualitative?** (Comes in types, like material = *rubber*, *polycarbonate*, *steel* with mixed # of levels; 3 chemical agents, 4 decontaminants, 8 coupon materials…)
  - **Mixture/formulation?** (Blend different amounts of *ingredients* and the process performance is dependent on the *proportions* more than on the amounts)
  - **Blocking?** (e.g. "lots" of the same raw materials, multiple "same" machines, samples get processed in "groups" – like "eight in a tray," run tests over multiple days – i.e. variables for which there *shouldn't* be a causal effect
- Work with **combinations of these four kinds** of variables?
- Certain **combinations cannot be run**? (too costly, unsafe, breaks the process)
- Certain factors are **hard-to-change** (temperature takes a day to stabilize)
- Would like to **add onto existing trials**? (really expensive/time consuming to run, or by adding constraints can repair broken design)

CATEGORICAL FACTORS AND RESPONSES

- Agents
  - Agent 1
  - Agent 2
  - Agent 3
- Decontaminants
  - Decon 1
  - Decon 2
  - Decon 3
  - Decon 4

- Materials
  - Steel
  - Aluminum
  - Glass
  - Polycarbonate
  - CARC (Paint)
  - Viton
  - Kapton
  - Silicone



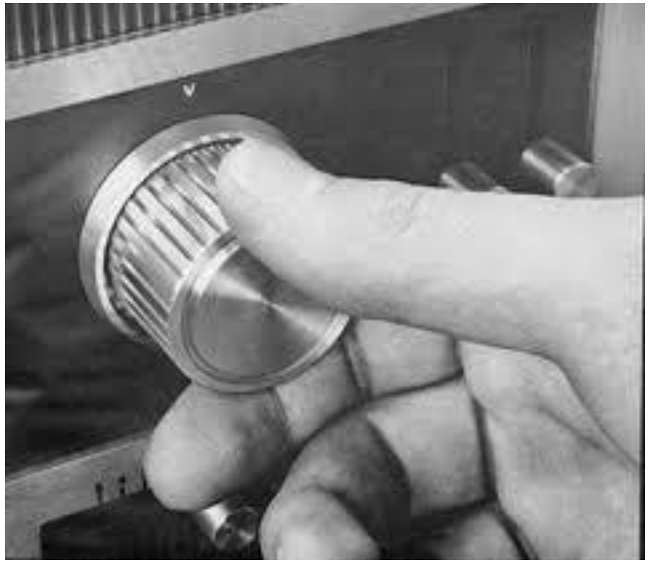
Responses

- Pass/Fail
- Yes/No
- Not Cracked/Cracked
- Safe/Caution/Unsafe
- Not Corroded/ Moderately Corroded/ Severely Corroded

CONTINUOUS FACTORS AND RESPONSES

- Factors
  - Time
  - Temperature
  - Amount of Agent/Unit Area
  - Wind Speed
  - Humidity

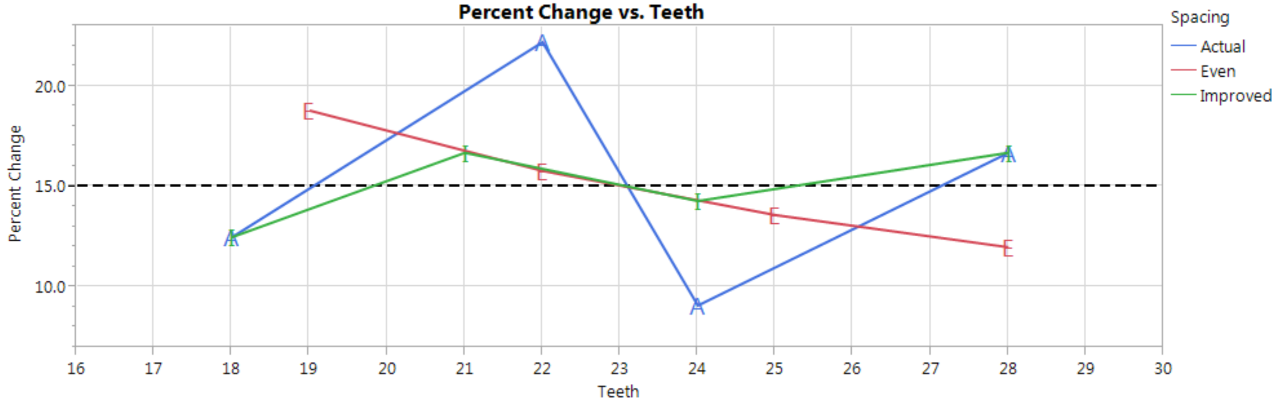
- Responses
  - Evaporation Rate
  - Absorption
  - Adsorption
  - Residual Concentration



DISCRETE NUMERIC VARIABLE

Example: Number of Teeth on Bicycle Sprockets

Designs like a categorical factor
Models like a continuous factor



18

22

16 24 28

Evenly Spaced					
Teeth	16	19	22	25	28
Delta		3	3	3	3
% Change		18.8%	15.8%	13.6%	12.0%

Actual Spacing					
Teeth	16	18	22	24	28
Delta		2	4	2	4
% Change		12.5%	22.2%	9.1%	16.7%

Improved Spacing					
Teeth	16	18	21	24	28
Delta		2	3	3	4
% Change		12.5%	16.7%	14.3%	16.7%

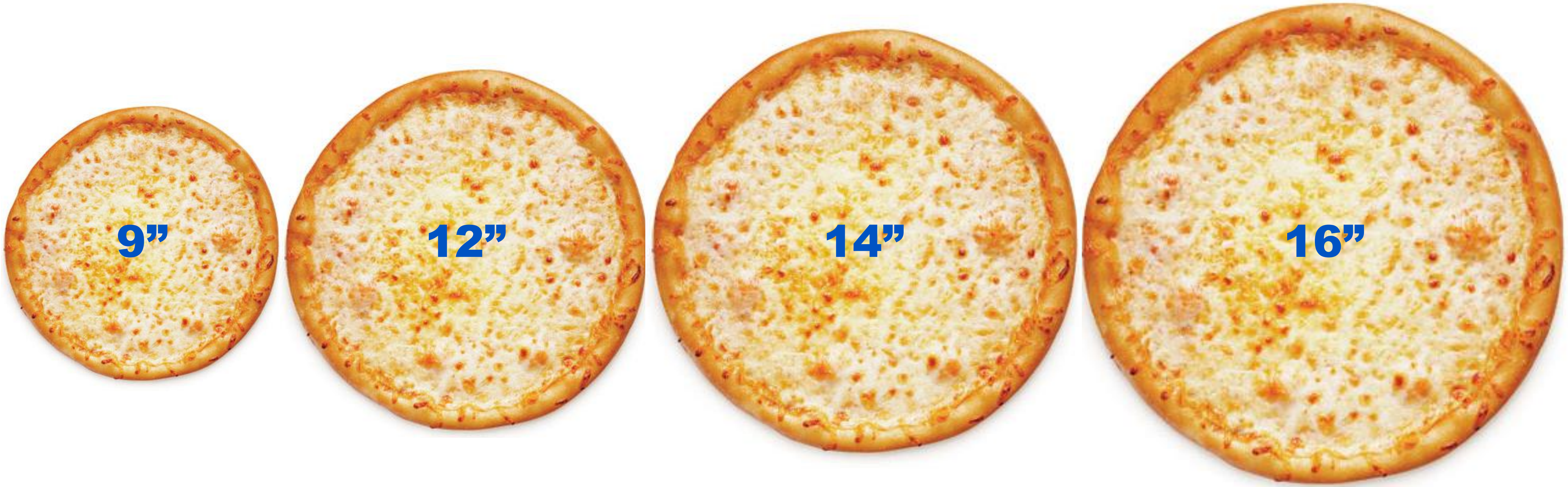
DISCRETE NUMERIC VARIABLE

Sell four sizes of pizza: 9”, 12”, 14” & 16”

Mid-point of full range is 12.5” diameter.

Corresponding areas in sq. in. are: 64, 113, 154 & 201

Mid-point of full range is 133 sq. in., or 13” diameter.



MIXTURE VARIABLES

SIMPLE MIXTURE – MAKING SALAD DRESSING

- Relative ***proportions*** of factors or components is more important than actual quantity
- Three liquid components - Oil, Water, and Vinegar
- 8 oz. in Cruet vs. 4 gal. in Jug

5 oz.	"O"	320 oz.	5/8
1 oz.	"W"	64 oz.	1/8
2 oz.	"V"	128 oz.	1/4

- To study these mixture components in a DOE use ranges that are proportions:

O:	0.500 to 0.750	(½ to ¾)
W:	0.000 to 0.250	(0 to ¼)
V:	0.125 to 0.375	(⅛ to ⅜)

- Sum of proportions ***constrained*** to equal 1.

100.0%

37.5%

25.0%

0%

$1 = O + W + V$ so therefore…

$W = 1 – (O + V)$, $O = 1 – (V + W)$, & $V = 1 – (O + W)$

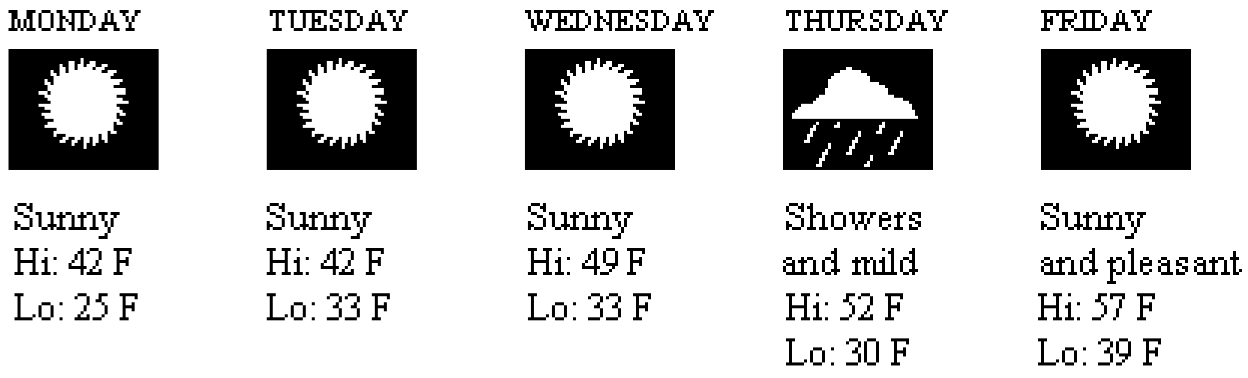
RECORDINGS AT WWW.JMP.COM/FEDGOV

These 12 videos primarily cover Design of Experimenst (DOE) topics.

Custom DOE - JMP 13 (not 14) Make the Design Fit Your Problem (Link to Mastering JMP)	Screening Designs Classic FF & PB, and Modern D-Optimal, Supersaturated, DSD, & Alias-Optimal	Compare Designs How to Choose Better Designs on Multiple Criteria
Advanced Custom DOE - JMP 13 (not 14) Augmentation, Broken Design Repair, & Design from a Candidate Set	Definitive Screening Designs (DSD) Creation & Augmentation	Data Transformations Get Rid of L-o-F, Predictions Make Physical Sense (Link to Mastering JMP)
Mixture DOE Efficiently Blending Ingredients to Optimize a Process (Link to Mastering JMP)	Analyzing DSD DOEs Graphical Methods and Fit Definitive Screening Platform	Power Calculation via MC Simulation Binary Responses & Split-Plot Designs
Efficient M&S Using DOE How to Run Fewer Computer Simulations	Exploratory Data and Root Cause Analyses What to Do When You Don't Have a DOE	Covering Arrays - Rapid Fault Detection in Software & Systems

https://community.jmp.com/t5/US-Federal-Government-JMP-Users/Mixture-DOE-JMP-14/ta-p/69546

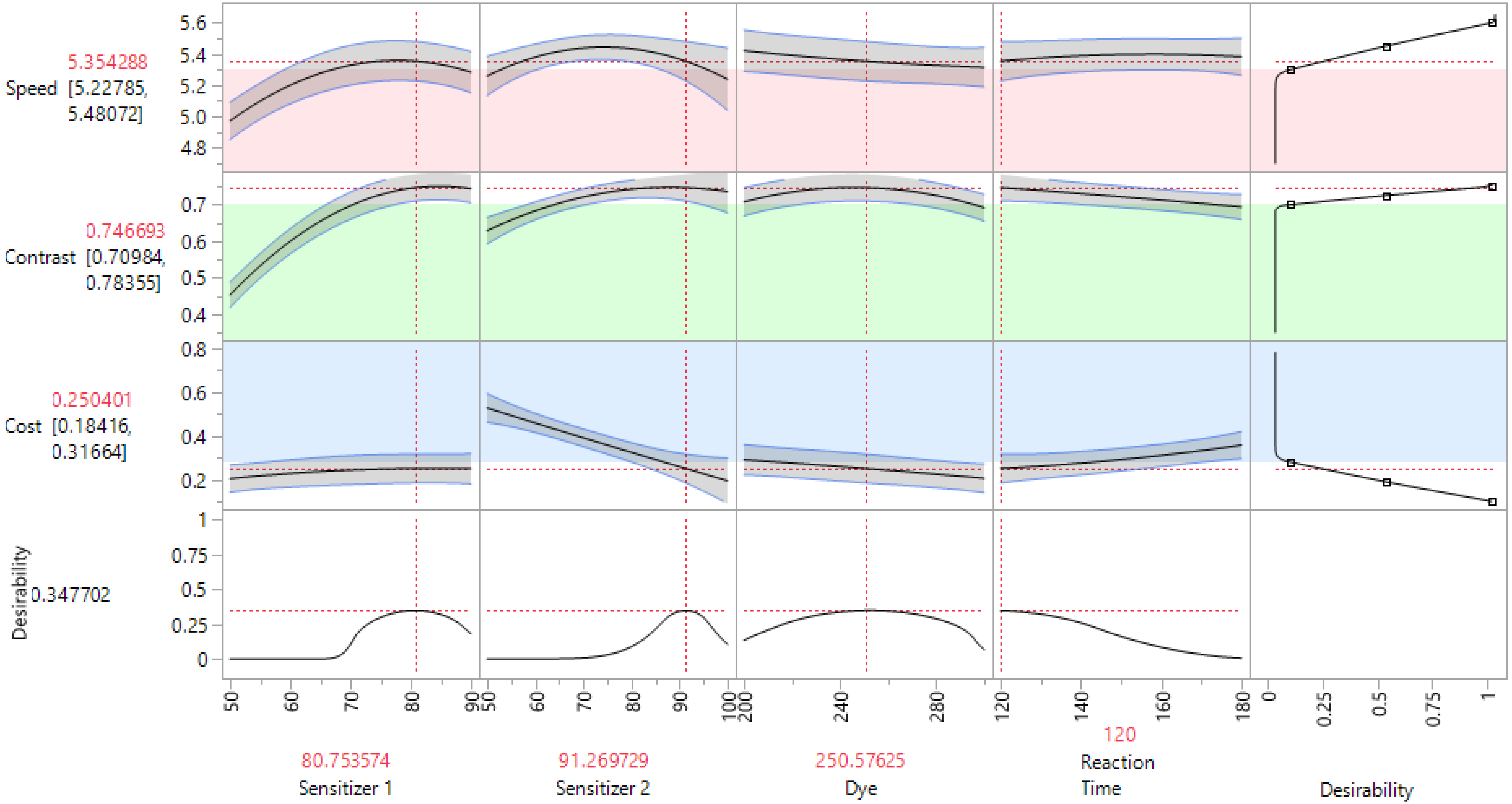
BLOCKING FACTOR LIKE "DAY" OR "BATCH"



- A design run over 5 days that is sensitive to humidity might SHIFT on Thursday
  - But what if because of the rain the tester from days 1, 2, 3 & 5 didn't make it to work?
  - What if that day the power went out briefly? Or, dept. meeting "paused" the work? Or…?
- The block variable doesn't tell you the cause of the effect -
  just that a shift has been detected among blocks.
- Hoping block variable has no effect. If it does then how can we reliably predict other blocks? If significant, it probably means we are missing a factor.
- The only way to be sure that no "unknown" factor has crept into the experiment, is to test for it - and "blocking" your design is inexpensive.
- Block variable is a categorical factor having only 1-way effects (no interactions)

FOUR CONTINUOUS FACTOR RSM DESIGN

MAKE THE DOE FOR THIS ANALYSIS



VISUALIZE DESIGN BALANCE

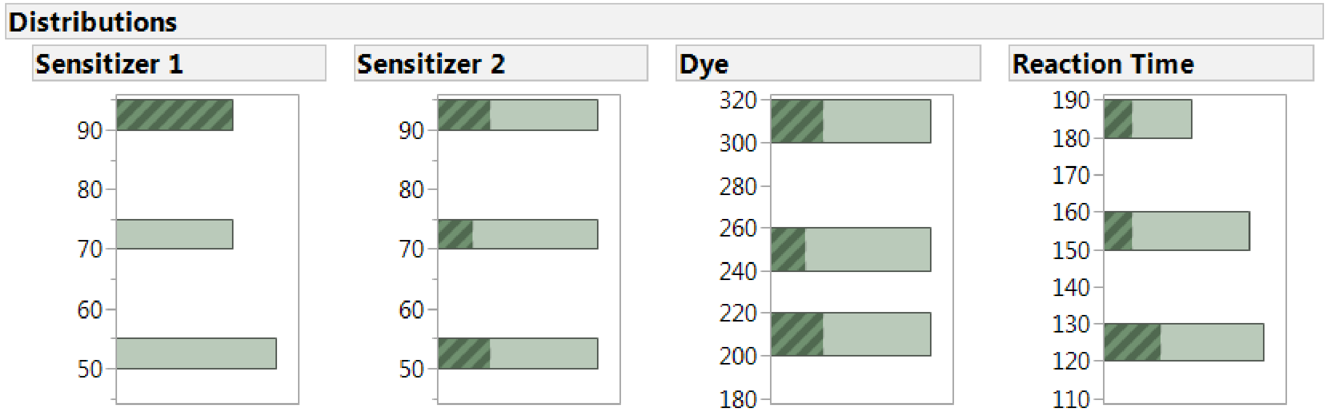
DISTRIBUTION OF DESIGN TRIALS
PROJECTIONS OF DESIGNS TRIALS IN 2-D & 3-D

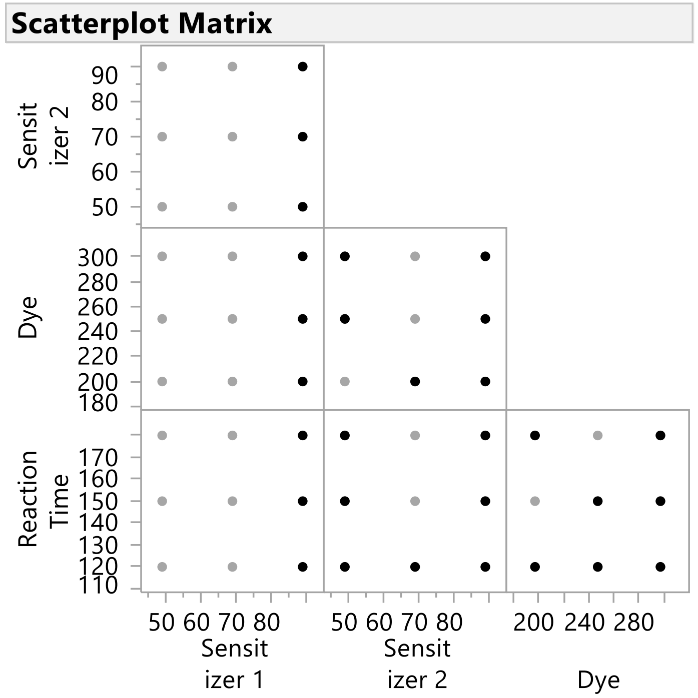
Photo_Cost27 - JMP Pro [3]

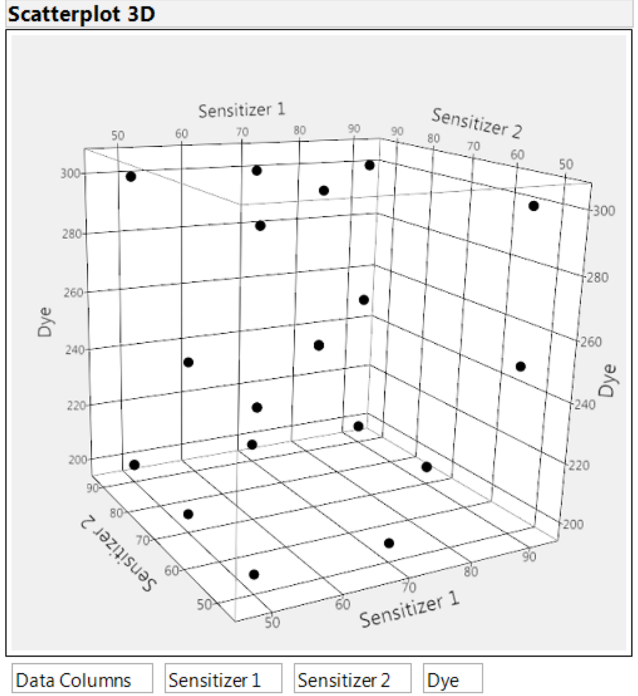
File Edit Tables Rows Cols DOE Analyze Graph Tools Add-Ins View Window Help

7/4 Cols
27/0

	Sensitizer 1	Sensitizer 2	Dye	Reaction Time	Speed	Contrast	Cost
1	50	50	250	120	5.36	0.616	0.198
2	50	50	200	180	5.39	0.537	0.175
3	90	70	200	120	5.31	0.623	0.447
4	50	90	200	150	5.13	0.431	0.177
5	70	70	250	180	5.37	0.643	0.445
6	50	90	300	120	4.79	0.375	0.231
7	90	90	200	180	5.45	0.626	0.471
8	90	50	250	150	5.00	0.470	0.670
9	50	50	300	150	5.22	0.478	0.283
10	70	90	200	120	5.41	0.668	0.226
11	90	90	250	120	5.33	0.734	0.310
12	50	50	250	120	5.32	0.574	0.257
13	70	50	200	150	5.49	0.596	0.456
14	50	70	250	180	5.22	0.558	0.166
15	70	70	250	150	5.57	0.689	0.390
16	90	90	300	150	5.26	0.653	0.226
17	70	70	250	150	5.47	0.688	0.356
18	70	70	300	120	5.42	0.657	0.337
19	50	70	200	120	5.43	0.518	0.222
20	50	50	300	150	5.15	0.505	0.287
21	90	70	200	120	5.33	0.661	0.457
22	50	90	300	120	4.97	0.411	0.191
23	90	50	300	120	5.09	0.492	0.588
24	90	50	300	180	5.03	0.358	0.733
25	70	70	250	150	5.59	0.707	0.318
26	70	90	300	180	5.25	0.605	0.290
27	50	90	200	150	5.24	0.476	0.177

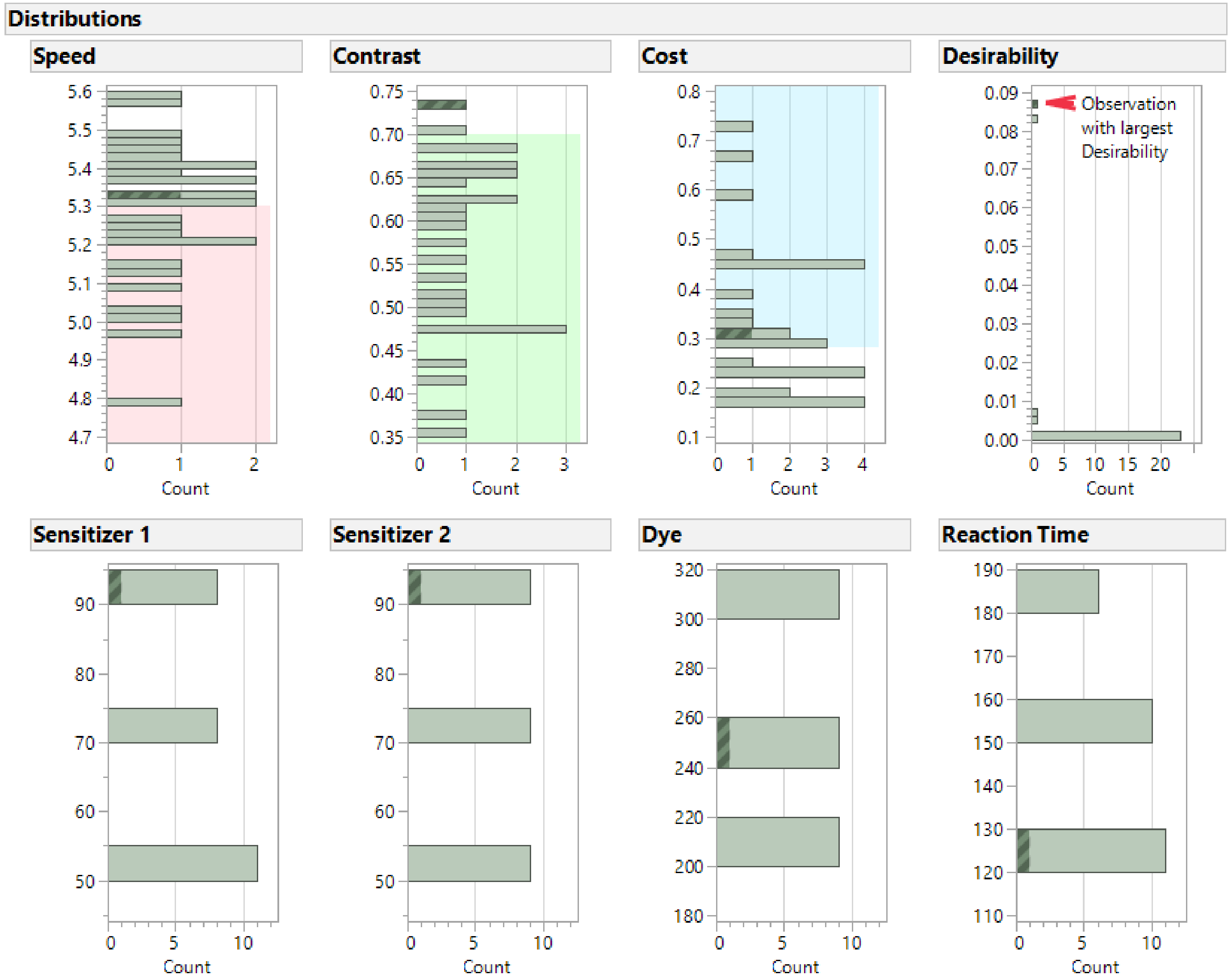






DISTRIBUTIONS OF RESPONSES AND FACTORS

CAN FIND OBSERVATION WITH HIGHEST DESIRABILITY



3 DIFFERENT FACTOR TYPES PLUS 2 CONSTRAINTS

CREATE DOE FOR A REAL-WORLD PIZZA PROCESS

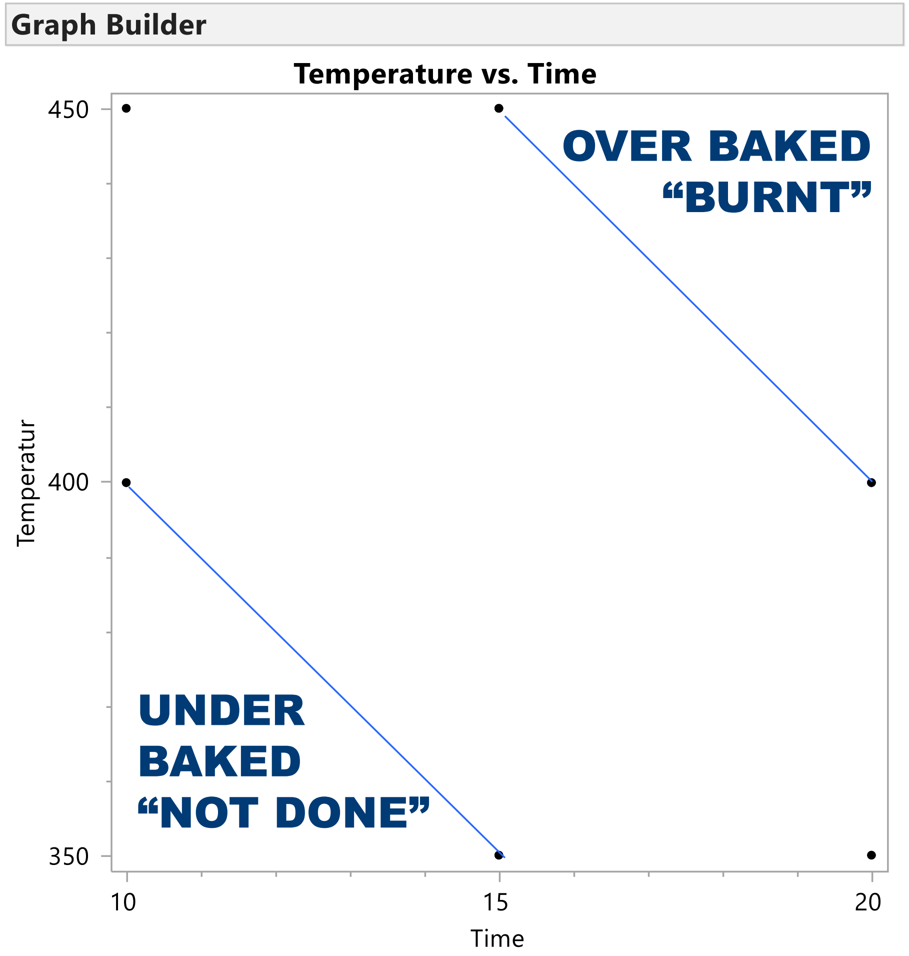
Continuous
- Time: 10 20 (easy)

Continuous
- Temp: 350 450 (hard-to-change)

Discrete Numeric 4 levels
- Pizza Size: 9, 12, 14, & 16

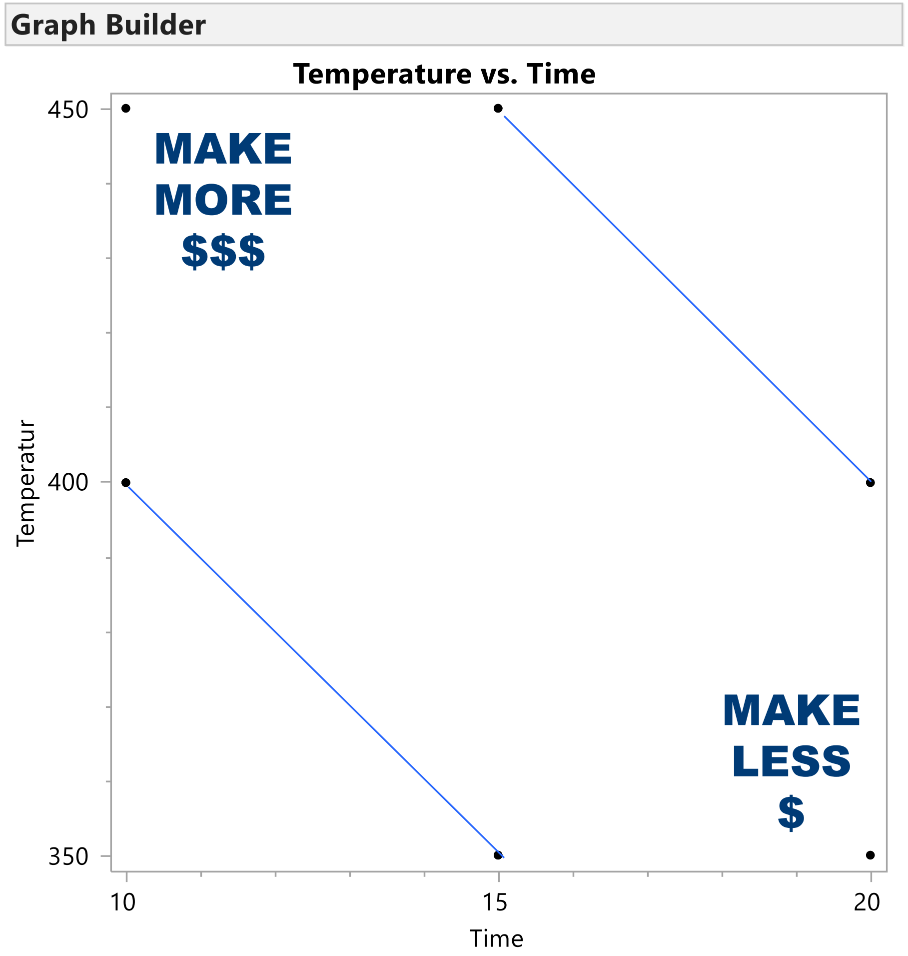
Categorical 3 levels
- Pizza Type
  - Cheese
  - Meats
  - Veggies

- Hi + Hi = "Burnt"
- Lo + Lo = "Not Done"

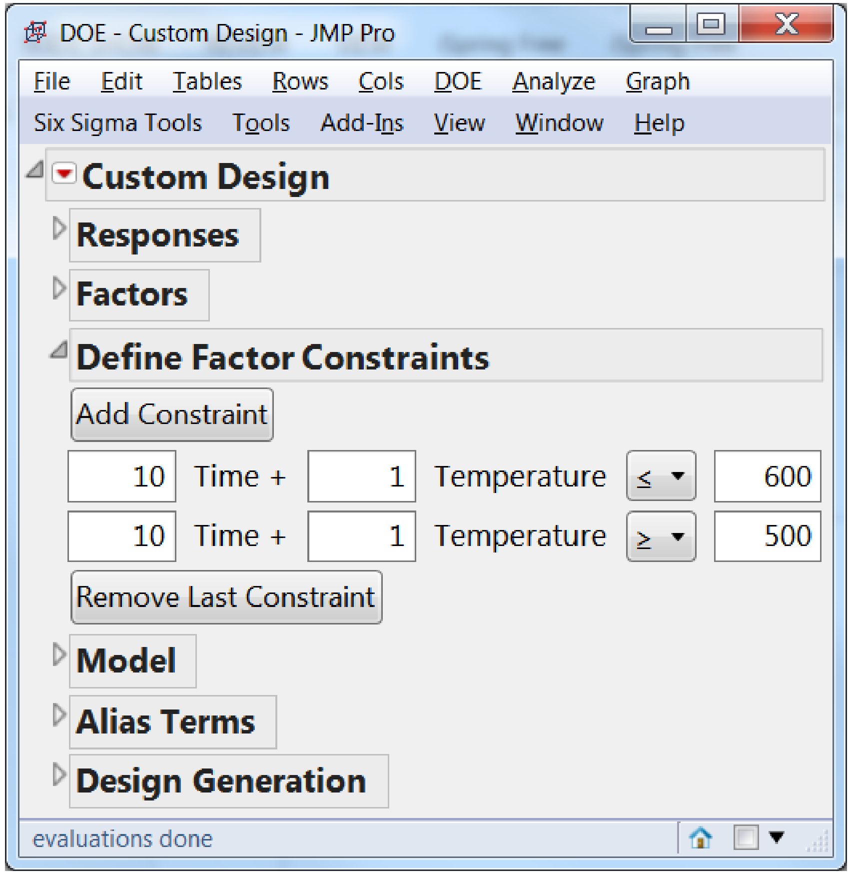


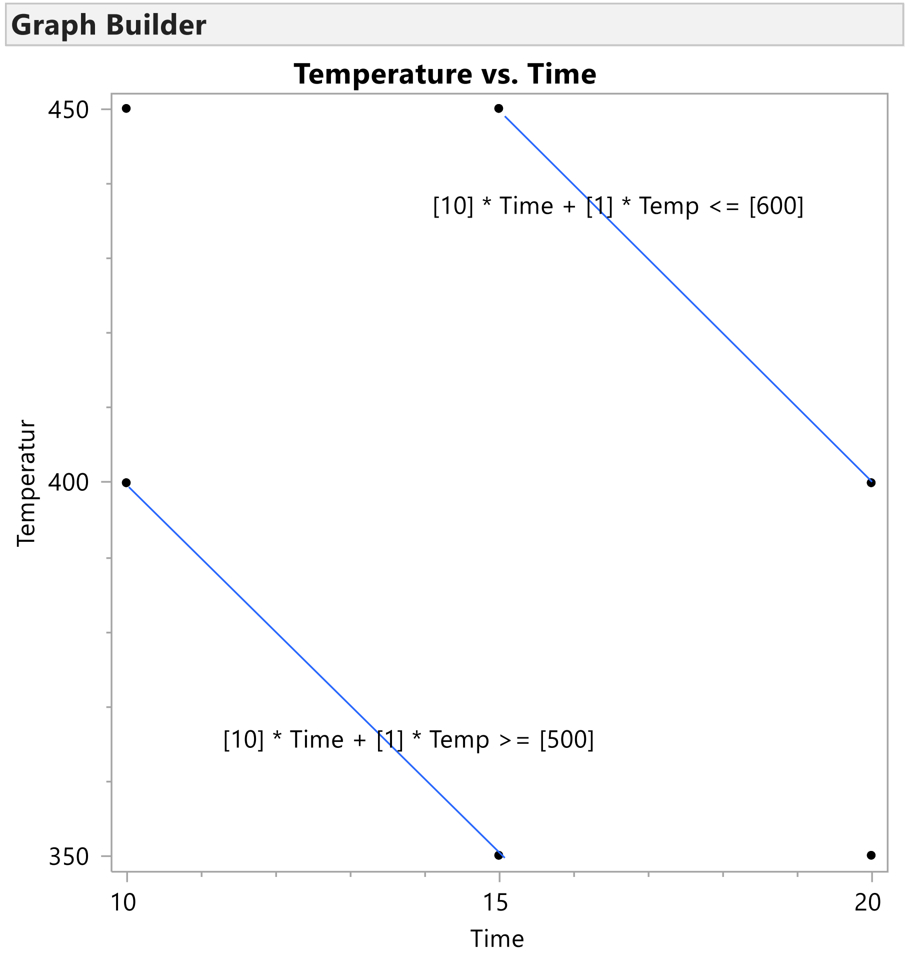
TIME AND TEMPERATURE CONSTRAINTS UNCODED

- Shorter times means more product produced per hour
- Make most of our money in a few hours each evening
- *“No pizza shall take more than 7 minutes!”* – Mgmt.

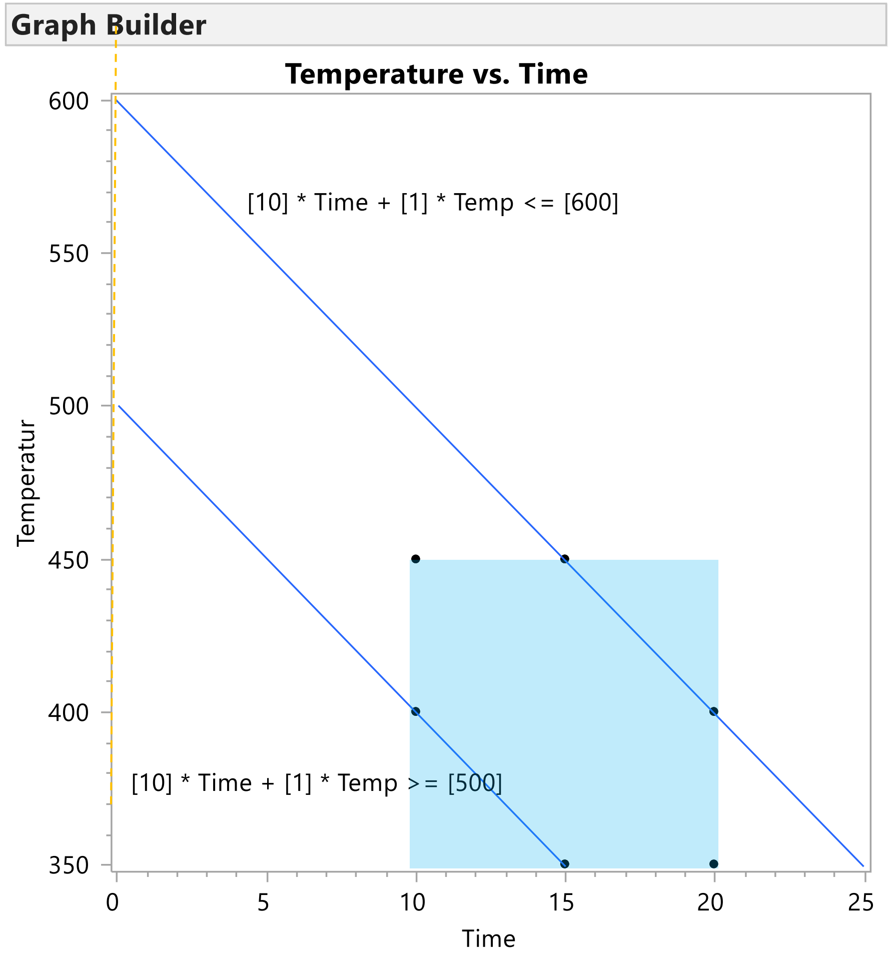


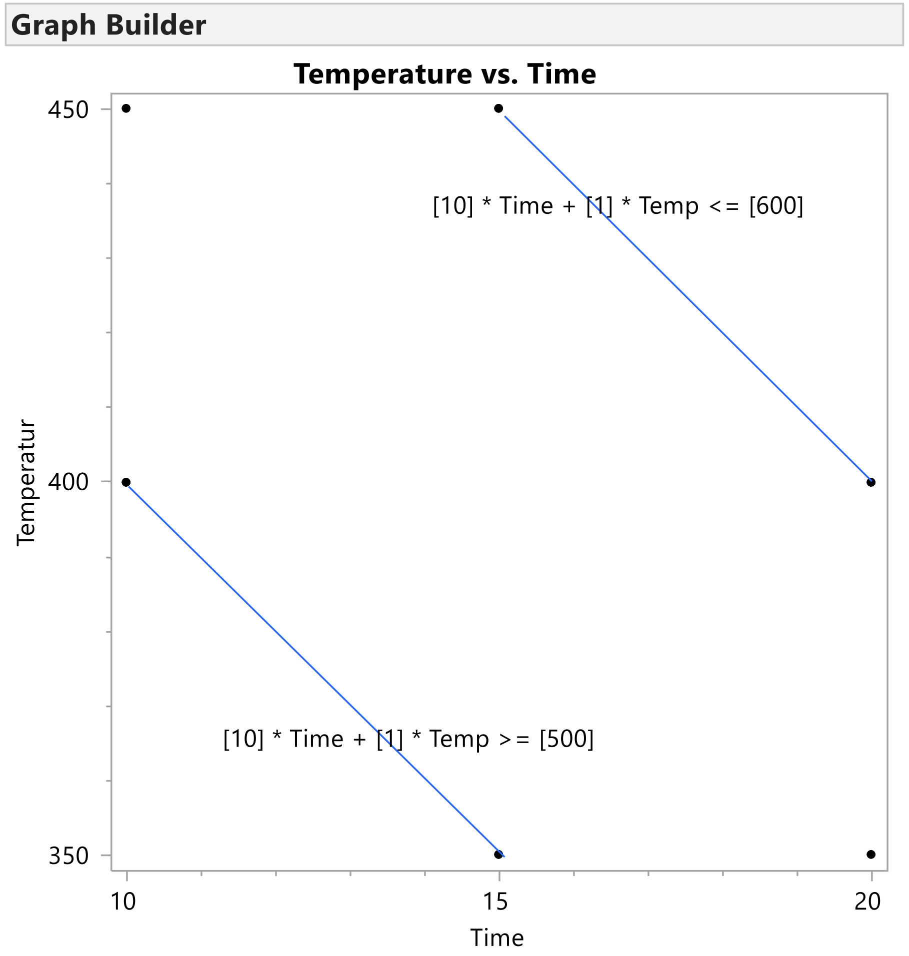
TIME AND TEMPERATURE CONSTRAINTS UNCODED





TIME AND TEMPERATURE CONSTRAINTS UNCODED

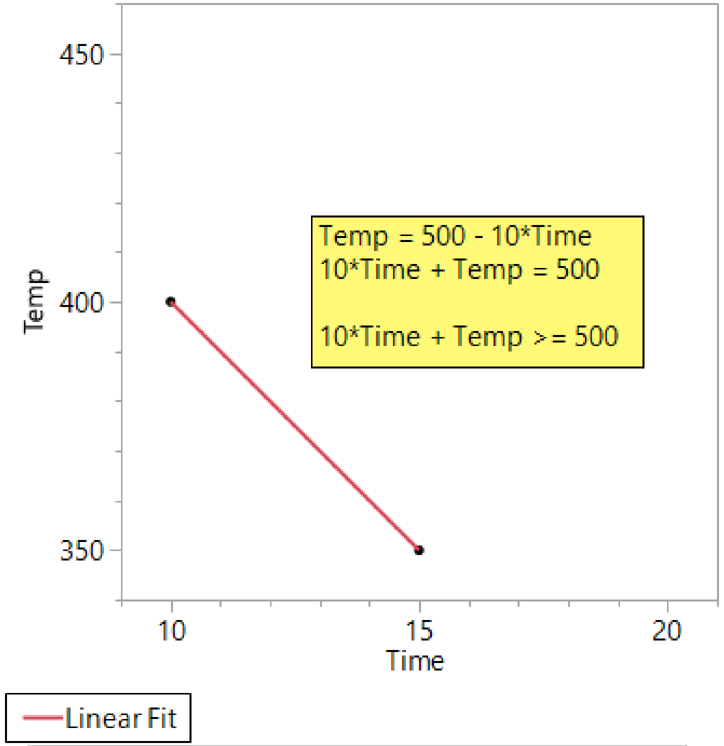




TIME AND TEMPERATURE CONSTRAINTS UNCODED

	Time	Temp	Constraint Location
1	15	450	Upper
2	20	400	Upper
3	15	350	Lower
4	10	400	Lower

Bivariate Fit of Temp By Time Constraint Location=Lower



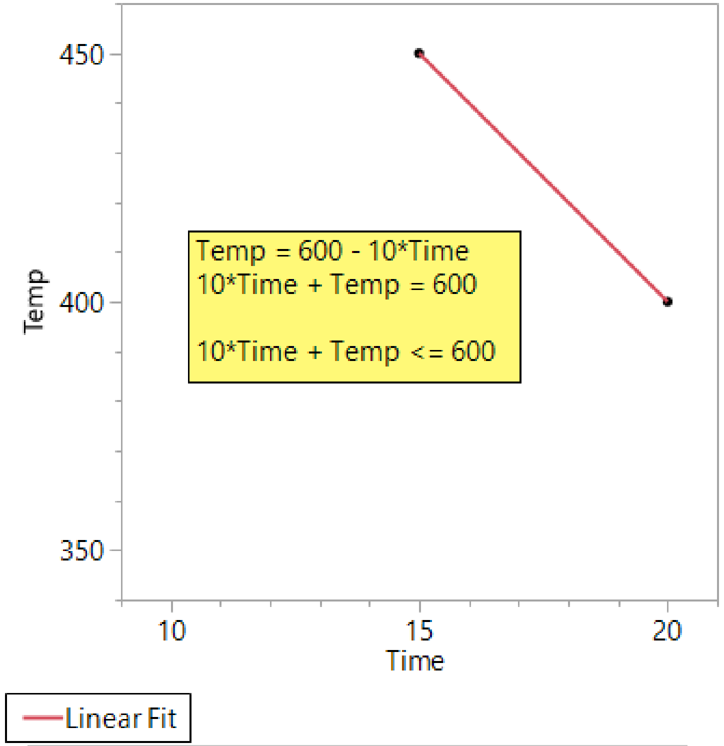
Linear Fit

Temp = 500 - 10*Time

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	500	.	.	.
Time	-10	.	.	.

Bivariate Fit of Temp By Time Constraint Location=Upper



Linear Fit

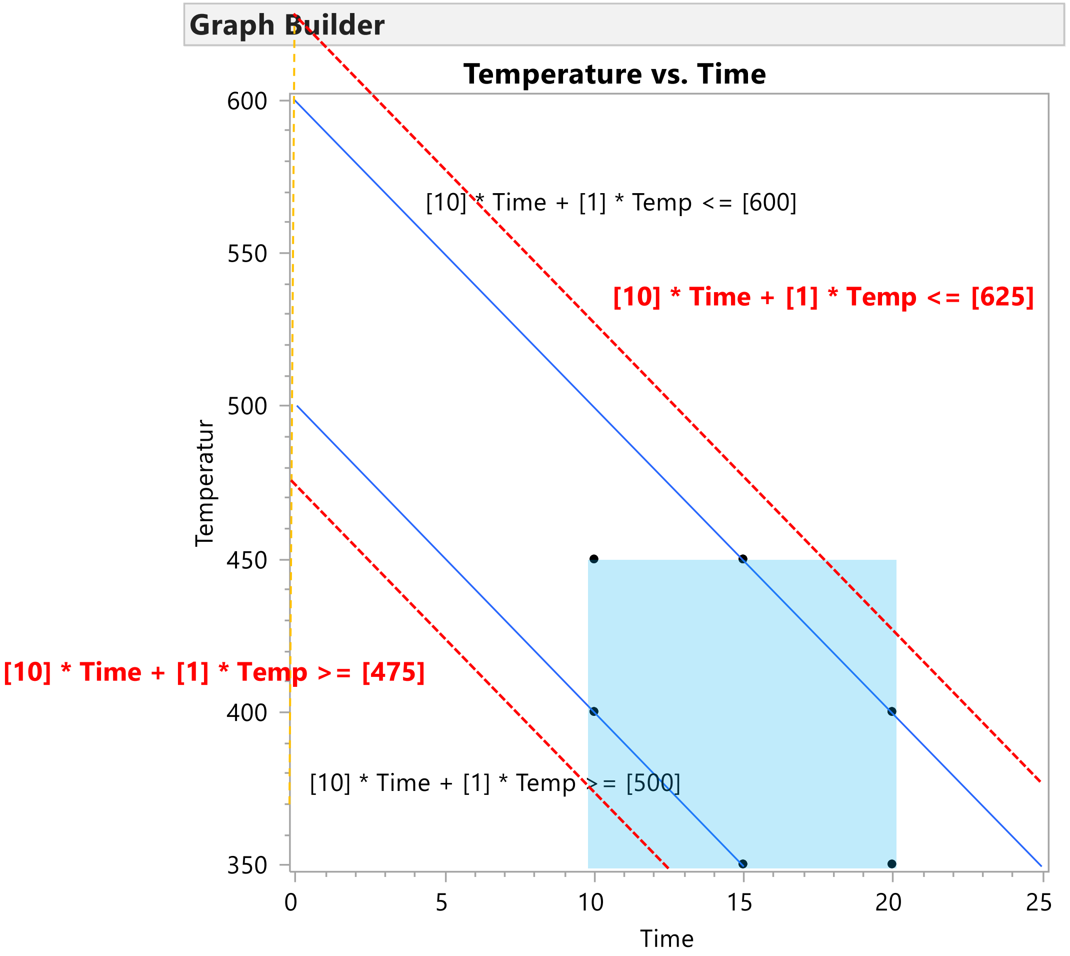
Temp = 600 - 10*Time

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	600	.	.	.
Time	-10	.	.	.

TIME AND TEMPERATURE CONSTRAINTS UNCODED

Slope = m = rise/run = -150/15; m = -10
Intercept = b = *y* when *x* = zero; b = 625



y = mx + b
Temp = m*Time + b
[1]*Temp = [-10]*Time + [625]
[10]*Time + [1]*Temp = [625]

[10]*Time + [1]*Temp <= [625]

y = mx + b
Temp = m*Time + b
[1]*Temp = [-10]*Time + [475]
[10]*Time + [1]*Temp = [475]

[10]*Time + [1]*Temp >= [475]

3 DIFFERENT FACTOR TYPES
1 IS HARD-TO-CHANGE
PLUS 2 CONSTRAINTS

CREATE DOE FOR A PIZZA PROCESS

Factors

Add Factor | Remove | Add N Factors 1

Name	Role	Changes	Values			
Time	Continuous	Easy	10	20		
Temperature	Continuous	Hard	350	450		
Pizza Size	Discrete Num	Easy	9	12	14	16
Pizza Type	Categorical	Easy	Cheese	Veggies	Meats	

Define Factor Constraints

- None
- Specify Linear Constraints (selected)
- Use Disallowed Combinations Filter
- Use Disallowed Combinations Script

Linear Constraints

Add

10 Time + 1 Temperature ≤ 625

10 Time + 1 Temperature ≥ 475

Remove Last Constraint

Check Constraints

Model

Main Effects | Interactions | RSM | Cross | Powers | Remove Term

Name	Estimability
Intercept	Necessary
Time	Necessary
Temperature	Necessary
Pizza Size	Necessary
Pizza Size*Pizza Size	If Possible
Pizza Size*Pizza Size*Pizza Size	If Possible
Pizza Type	Necessary
Time*Time	Necessary
Time*Temperature	Necessary
Temperature*Temperature	Necessary
Time*Pizza Size	Necessary

Design Generation

Number of Whole Plots 6

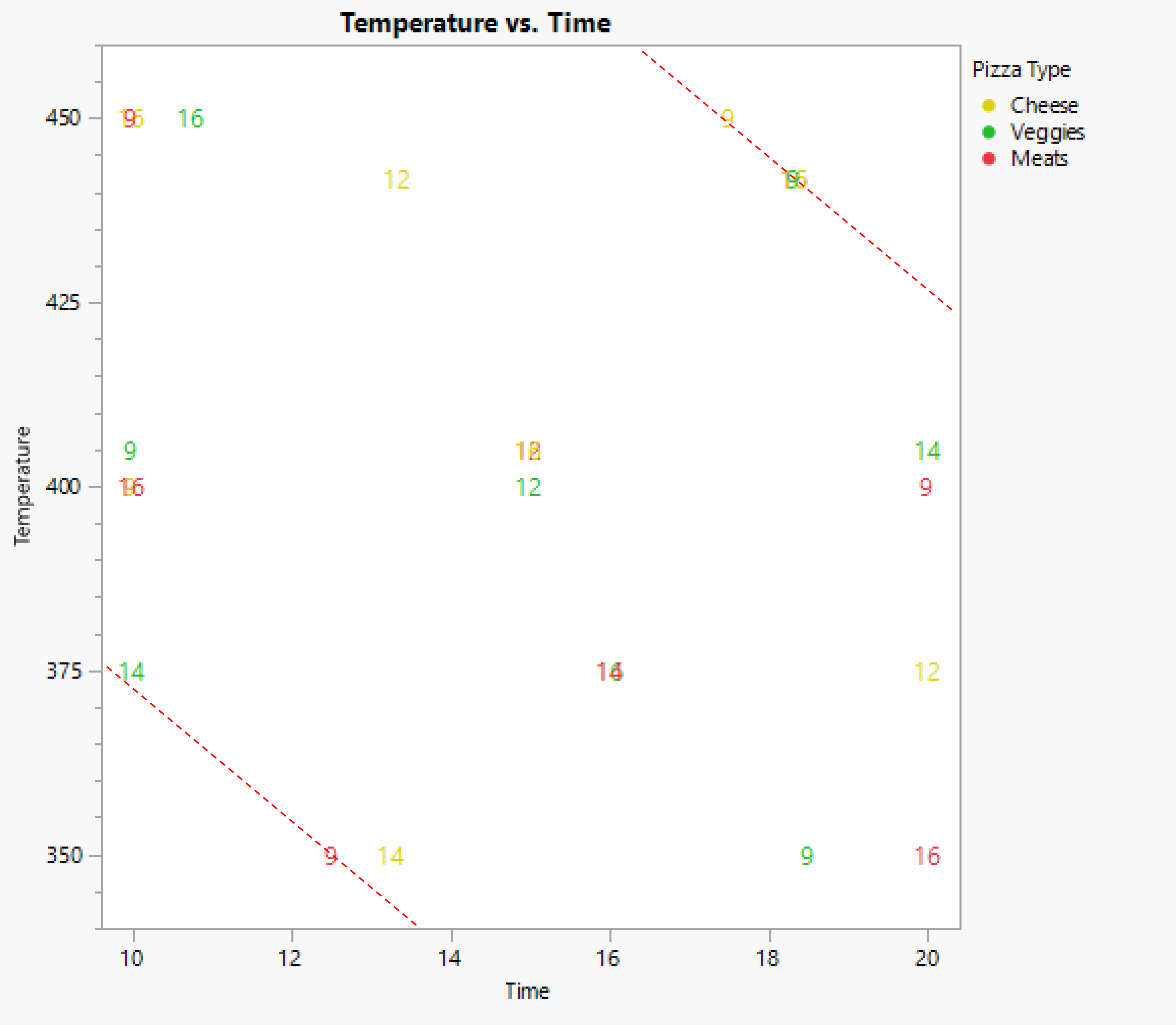
Number of Runs:

- Minimum 17
- Default 24 (selected)
- User Specified 24

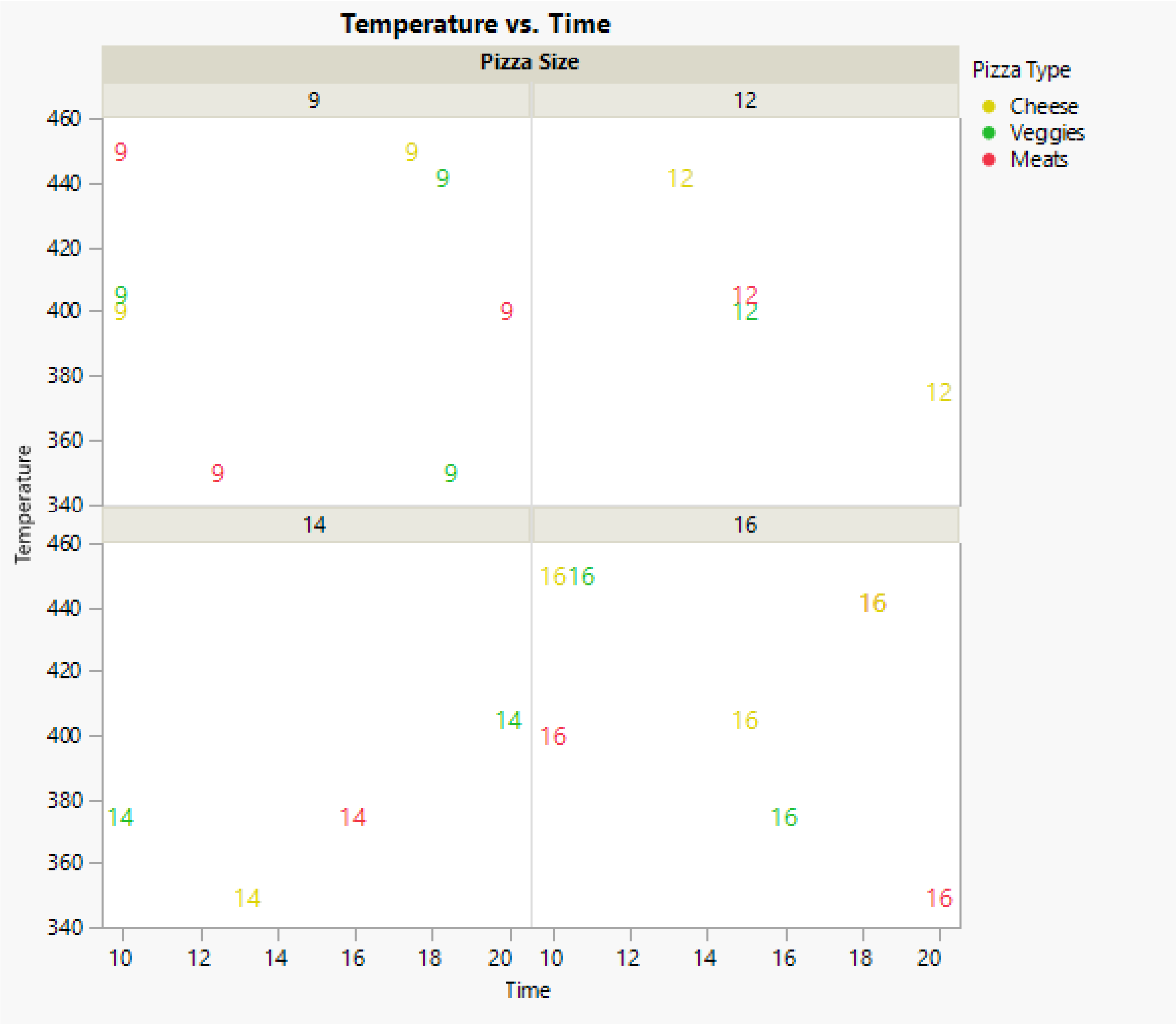
Make Design

	Whole Plots	Time	Temperature	Pizza Size	Pizza Type
1	1	20	375	12	Cheese
2	1	16	375	16	Veggies
3	1	16	375	14	Meats
4	1	10	375	14	Veggies
5	2	20	350	16	Meats
6	2	13	350	9	Meats
7	2	13	350	14	Cheese
8	2	19	350	9	Veggies
9	3	20	405	14	Veggies
10	3	15	405	12	Meats
11	3	15	405	16	Cheese
12	3	10	405	9	Veggies
13	4	18	442	16	Meats
14	4	13	442	12	Cheese
15	4	18	442	16	Cheese
16	4	18	442	9	Veggies
17	5	10	450	16	Cheese
18	5	18	450	9	Cheese
19	5	11	450	16	Veggies
20	5	10	450	9	Meats
21	6	10	400	9	Cheese
22	6	15	400	12	Veggies
23	6	20	400	9	Meats
24	6	10	400	16	Meats

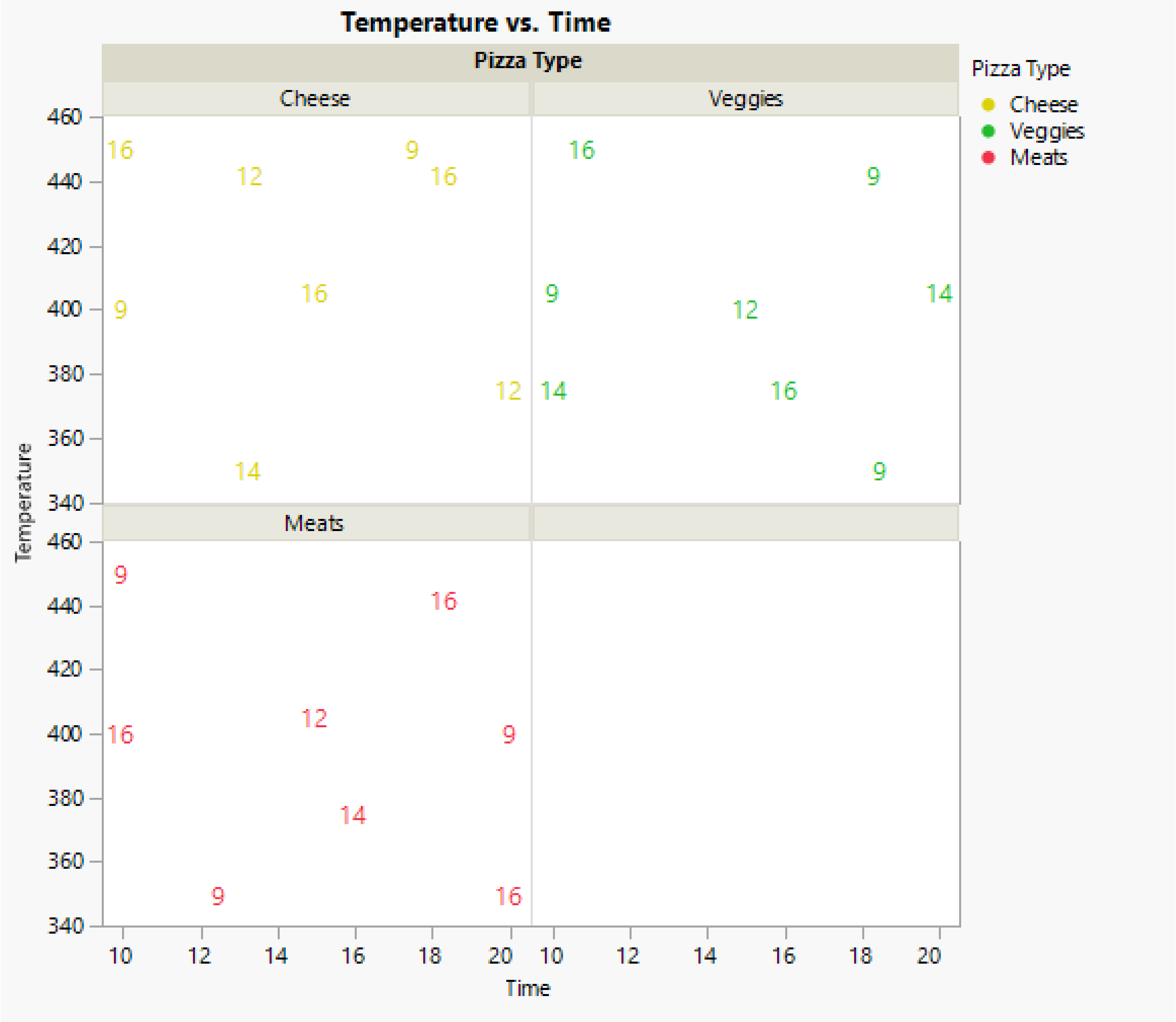
FINAL DESIGN SHOWING CONSTRAINED REGIONS



FINAL DESIGN SHOWING CONSTRAINED REGIONS



FINAL DESIGN SHOWING CONSTRAINED REGIONS



AGENDA

- Multiple Response Optimization

  Trade-Space Analysis – Why we do DOE
- Review of Classic DOE
- Real-World Experimental Issues – Custom DOE is all about

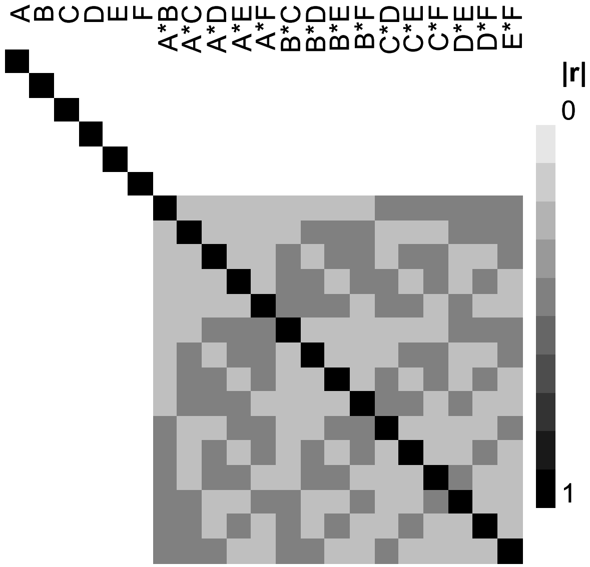
  Making Designs Fit the Problem –

  NOT Making Problems Fit the Designs!
- Two Example Designs
  - Four continuous factors, three responses, 2nd order RSM model
  - Continuous, discrete numeric, categorical and blocking factors - with constraints – 2nd order RSM model
- Specialized DOE Solutions

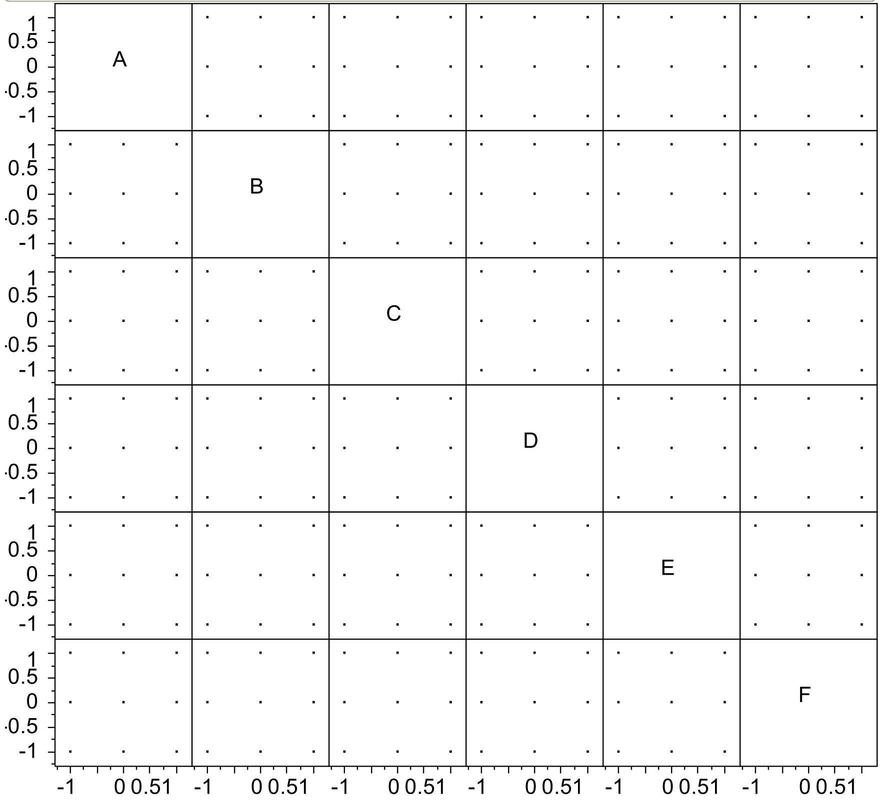
DEFINITIVE SCREENING DESIGN
NEW ALTERNATIVE TO
CLASSIC 2-LEVEL SCREENING DESIGNS

	A	B	C	D	E	F
1	0	1	-1	-1	-1	-1
2	0	-1	1	1	1	1
3	1	0	-1	1	1	-1
4	-1	0	1	-1	-1	1
5	-1	-1	0	1	-1	-1
6	1	1	0	-1	1	1
7	-1	1	1	0	1	-1
8	1	-1	-1	0	-1	1
9	1	-1	1	-1	0	-1
10	-1	1	-1	1	0	1
11	1	1	1	1	-1	0
12	-1	-1	-1	-1	1	0
13	0	0	0	0	0	0

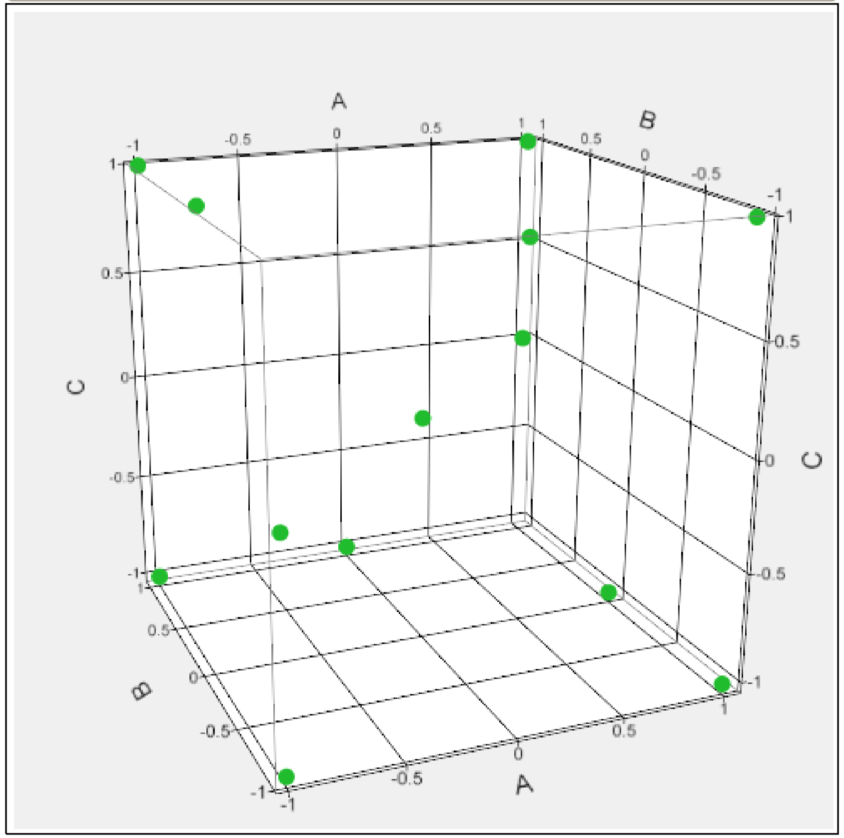
Color Map On Correlations



Scatterplot Matrix



Scatterplot 3D



Data Columns A B C

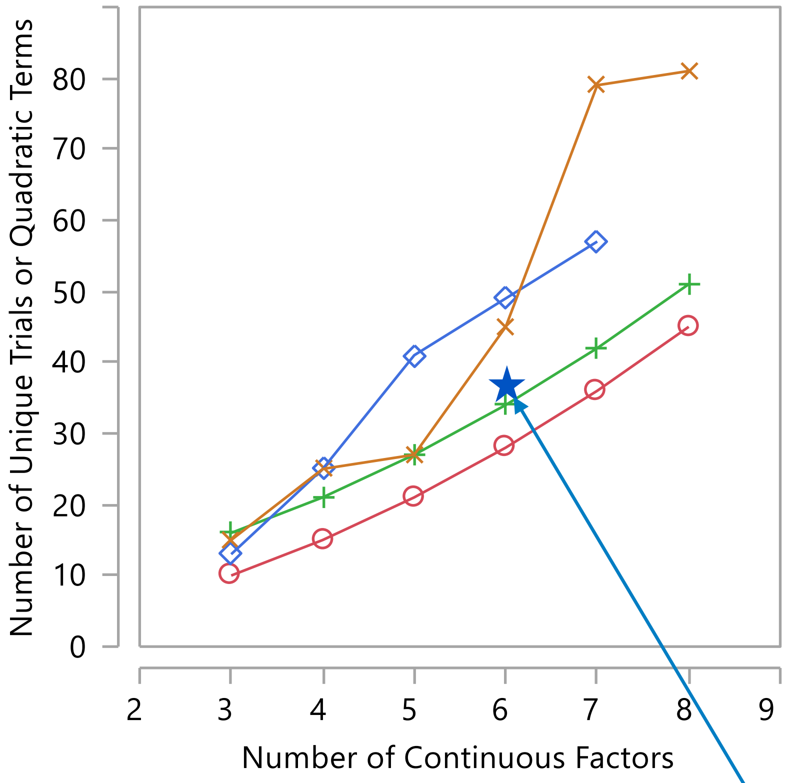
AUGMENTATION VIA CUSTOM DOE

IF MORE THAN A FEW FACTORS ARE SIGNIFICANT FOR DSD, THEN AUGMENT DESIGN TO SUPPORT 2ND ORDER MODEL

	A	B	C	D	F	G	Block	Yield @ Time t
14	0	0	0	0	0	0	1	7.49
15	1	1	-1	1	-1	1	1	0.98
16	1	1	1	-1	-1	0	1	0.86
17	-1	1	-1	-1	1	1	1	1.25
18	1	-1	1	1	-1	-1	1	1.03
19	1	1	0	-1	1	-1	1	1.07
20	0	0	0	0	0	0	1	7.33
21	1	-1	-1	0	1	-1	1	2.61
22	-1	-1	0	1	-1	1	1	11.39
23	-1	0	1	-1	1	1	1	12.96
24	1	1	-1	1	1	1	1	1.18
25	1	0	1	1	-1	1	2	•
26	1	-1	0	1	1	0	2	•
27	1	-1	-1	1	0	1	2	•
28	1	-1	0	-1	0	-1	2	•
29	1	0	-1	-1	1	0	2	•
30	1	1	0	-1	0	1	2	•
31	1	0	1	0	1	-1	2	•
32	-1	-1	0	0	1	1	2	•
33	0	0	1	1	-1	-1	2	•
34	-1	-1	1	0	0	0	2	•
35	0	1	1	0	1	0	2	•
36	0	1	-1	1	1	-1	2	•

NOTE: First 13 rows of original design are not shown.

These 12 trials added onto original 24 trials to support full quadratic model in 6 most important factors plus a block effect between original and augmented trials



36 trial I-optimal response-surface design started as 10-factor DSD and was then augmented with 12 more trials in 6 most important factors

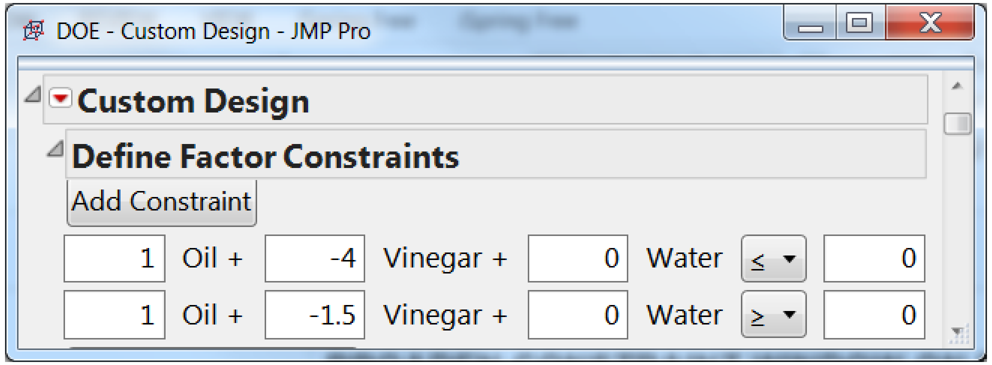
3-COMPONENT MIXTURE DOE WITH CONSTRAINTS

RARELY DO COMPONENTS RANGE FROM 0 TO 1, UNLESS TAKING UP THE SLACK IN A BLEND, LIKE WATER. VERY OFTEN ADDITIONAL CONSTRAINTS

Study mixture components in a DOE use ranges that are proportions:

O:	0.500 to 0.750	(½ to ¾)
W:	0.000 to 0.250	(0 to ¼)
V:	0.125 to 0.375	(⅛ to ⅜)

Sum of proportions ***constrained*** to equal 1.



Ratio of Oil/Vinegar Constrained

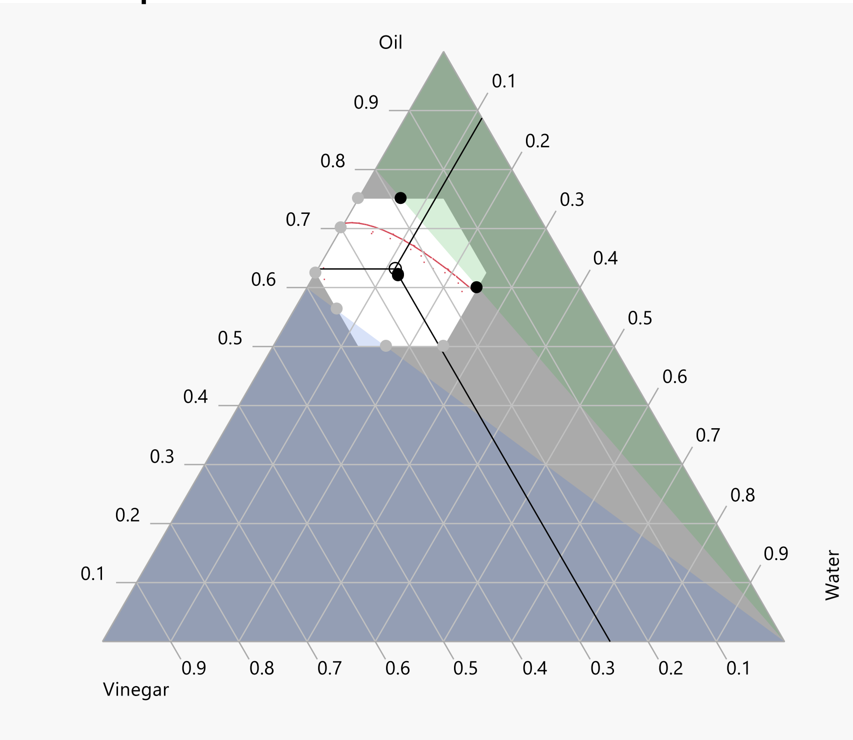
$1.5 \le O/V \le 4$

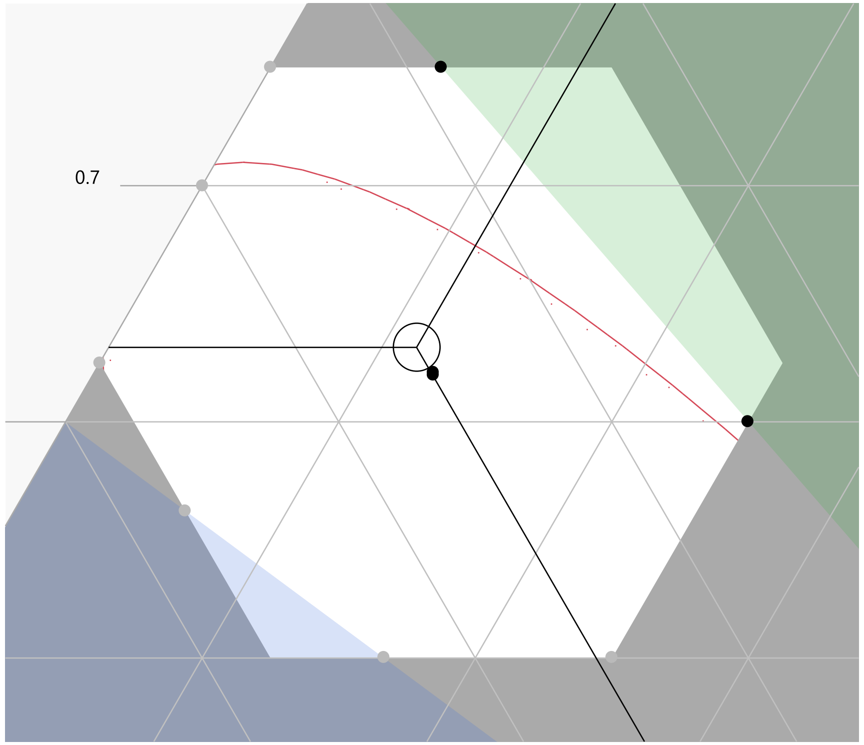
$1 = O + W + V$ so therefore…

$W = 1 - (O + V)$,

$O = 1 - (V + W)$, &

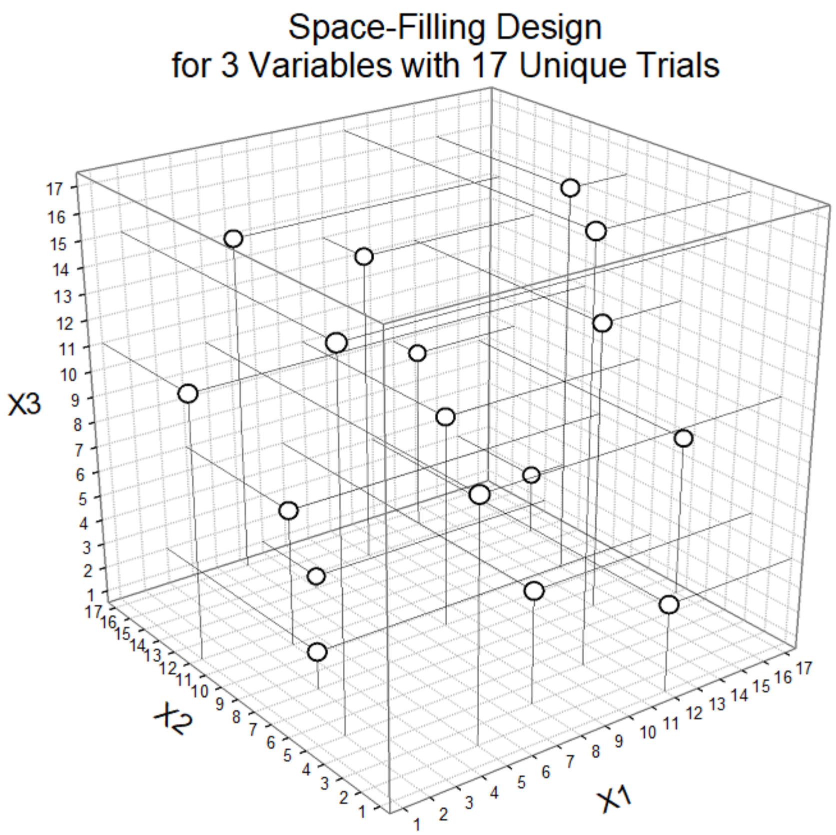
$V = 1 - (O + W)$

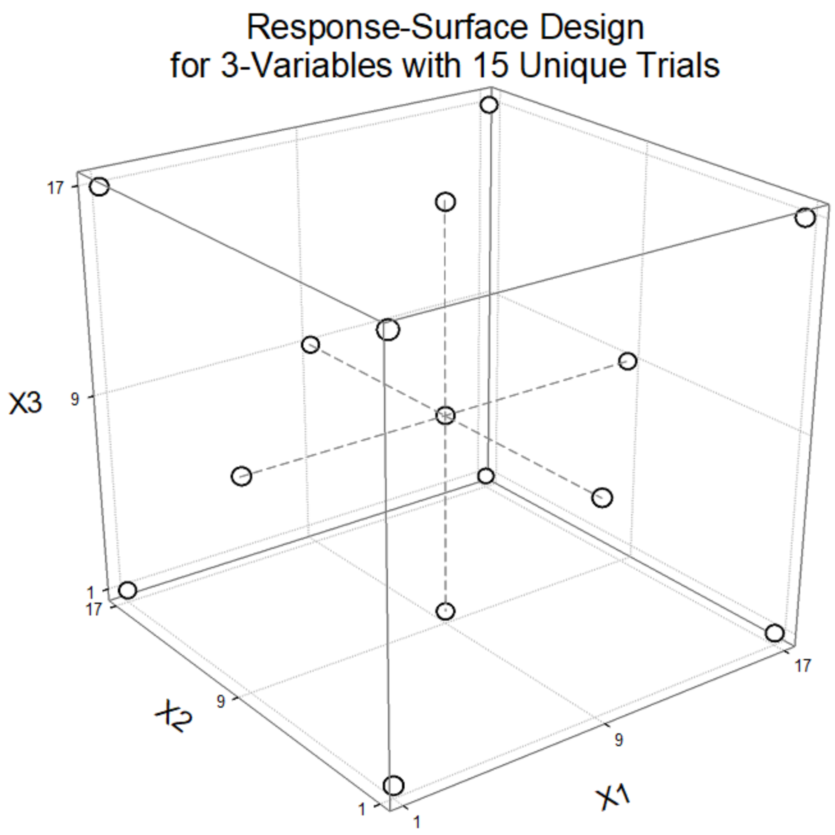




SPACE-FILLING DOE FOR SIMULATIONS

HOW ARE SPACE-FILLING DESIGNS DIFFERENT FROM TRADITIONAL DOE?

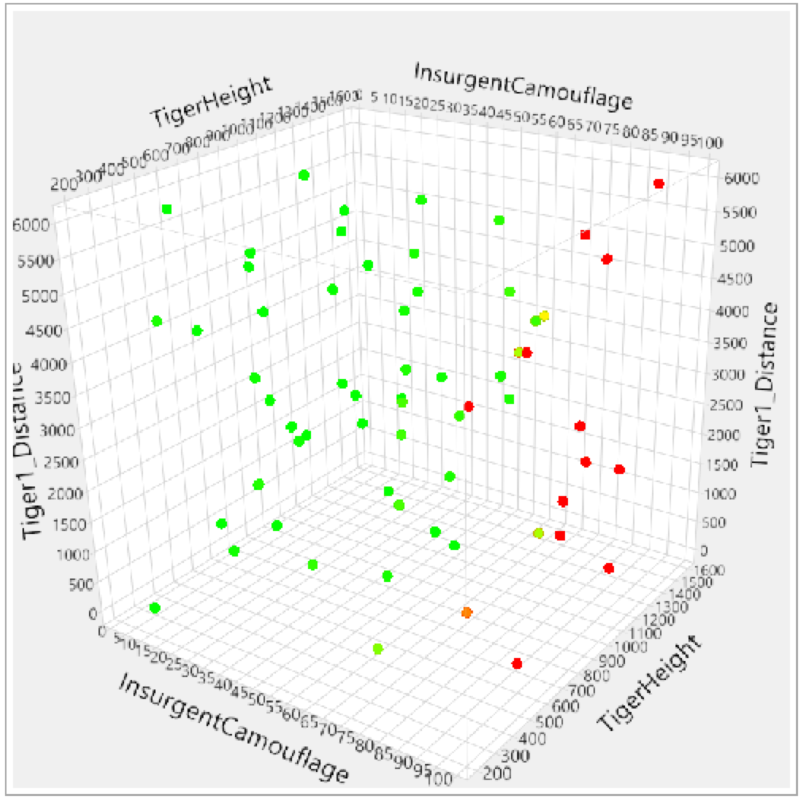


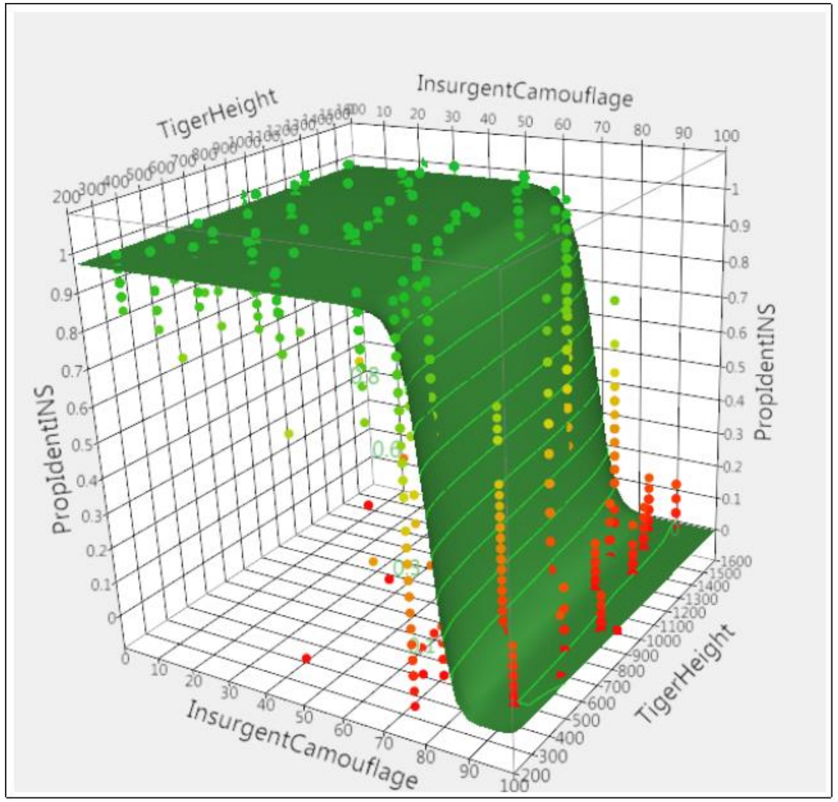


Rather than emphasizing high leverage trials ("corners") for a simple polynomial model, space-filling designs "spread" their trials more uniformly through the space to better capture the local complexities of the simulation model.

SPACE-FILLING DOE FOR SIMULATIONS

SPACE-FILLING DESIGNS ARE BETTER ABLE TO DETECT WHEN A PROCESS FALLS OFF A CLIFF OR HAS A SPIKE

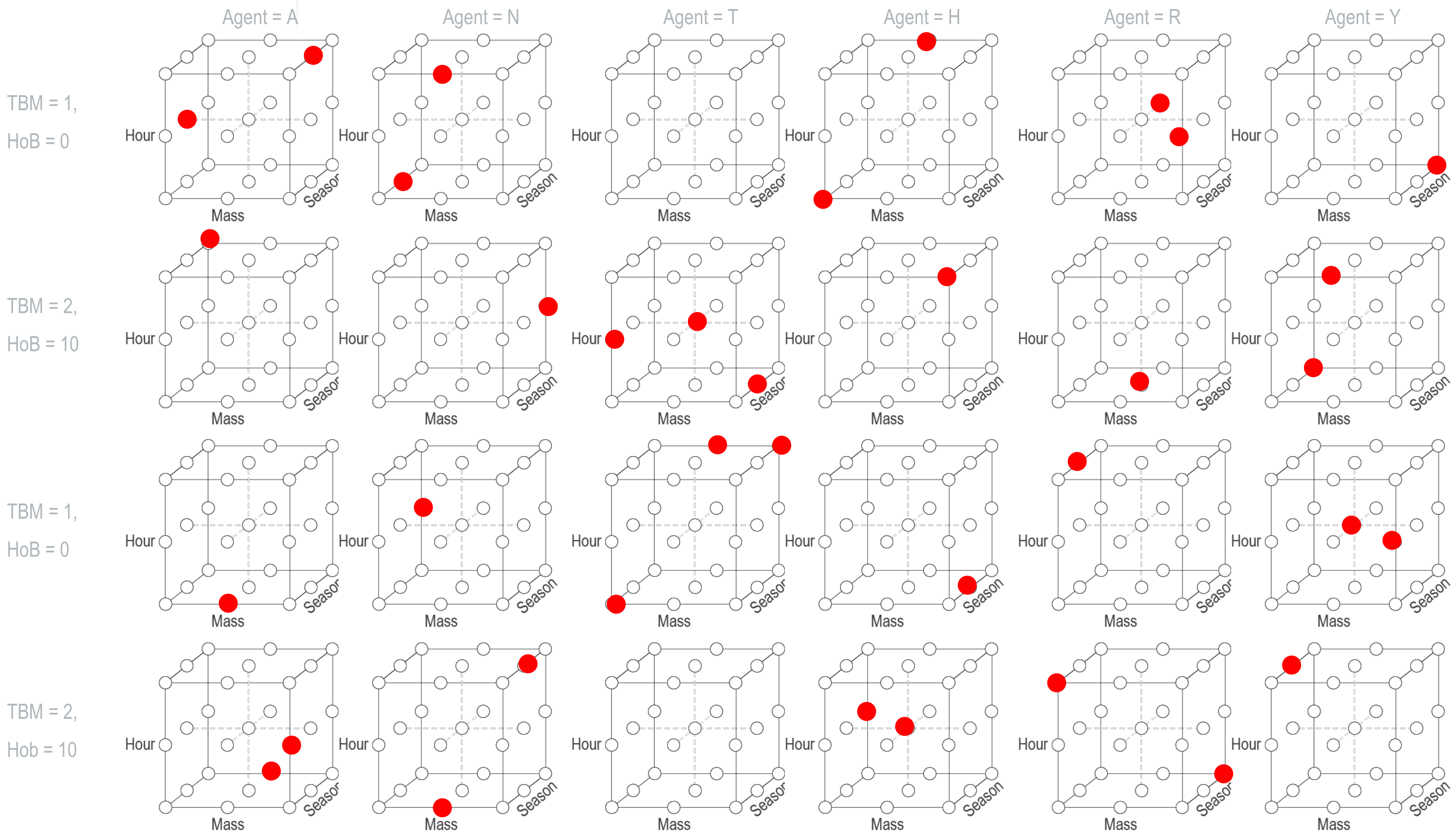




Rather than emphasizing high leverage trials (“corners”) for a simple polynomial model, space-filling designs “spread” their trials more uniformly through the space to better capture the local complexities of the simulation model.

SEQUENTIAL EXPERIMENTATION

36 OF ALL 648 POSSIBLE COMBINATIONS OF SETTINGS FOR 6 VARIABLES (6 X 2 X 2 X 3 X 3 X 3)



Red Dots Mark the 36 Trials (an Orthogonal Array) Analyzed for Stage 1

SEQUENTIAL EXPERIMENTATION

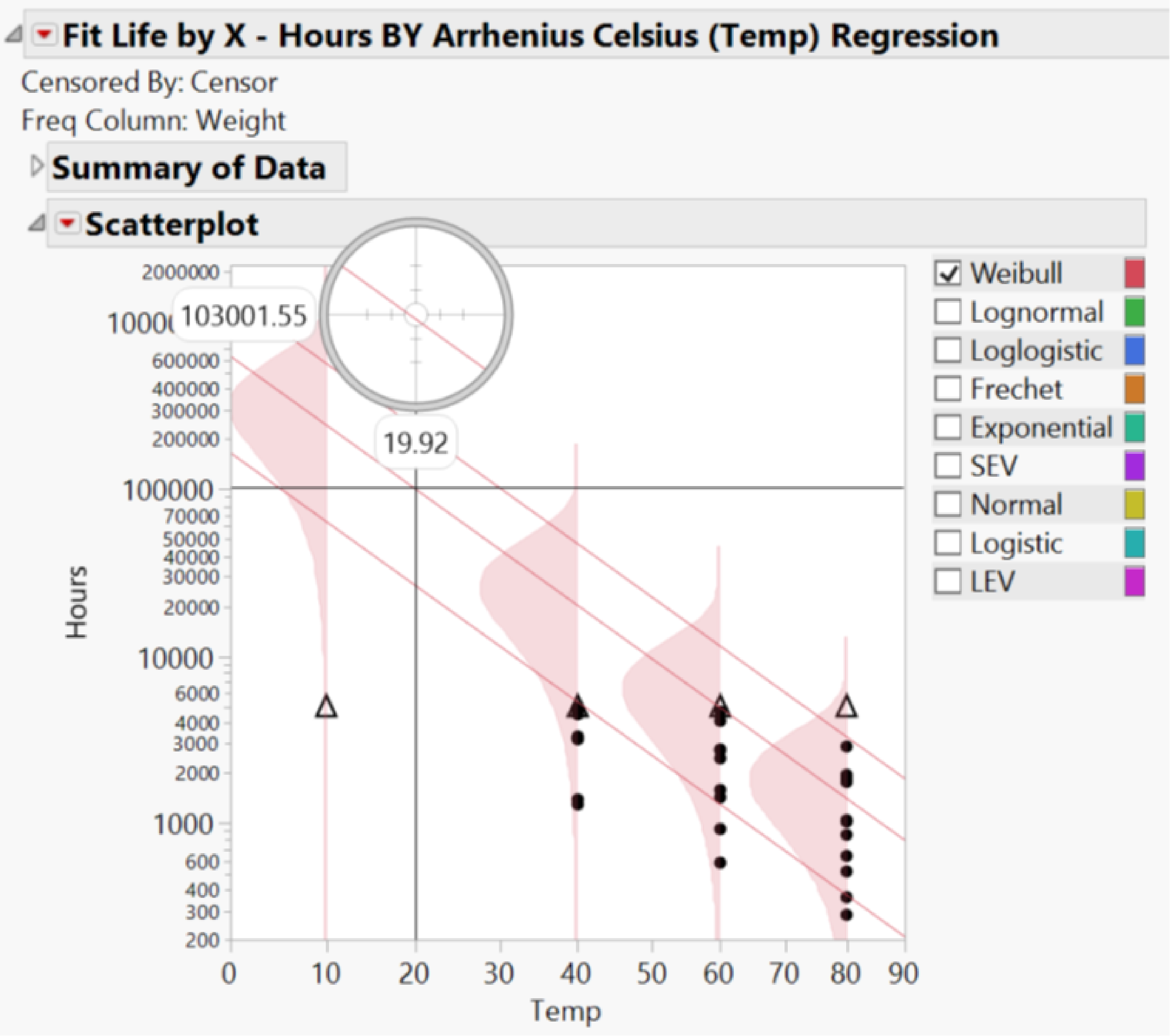
FOUR STAGE DESIGN SUPPORTING INCREASING COMPLEXITY OF MODEL

Stage 1	Stage 2	Stage 3	Stage 4
36 Total Simulations	108 Total Simulations	324 Total Simulations	ALL 648 Simulations
Design 1, 36 trials	Design 1, 36 trials	Design 1, 36 trials	Design 1, 36 trials
	Design 2, 72 trials	Design 2, 72 trials	Design 2, 72 trials
		Design 3, 216 trials	Design 3, 216 trials
Main effects only for ALL variables + some 2-way interactions	Stage 1 effects plus all 2-way interactions + some 3-way interactions	Stage 2 effects plus all 3-way interactions	Stage 3 effects plus ALL remaining 4-way, 5-way and 6-way interactions
5.6% of 648	16.7% of 648	50% of 648	**Design 4, 324 trials** NOTE: Length of this green box should be longer than shown

324 trials in Design 4 used as checkpoints for Designs 1, 2 & 3 →

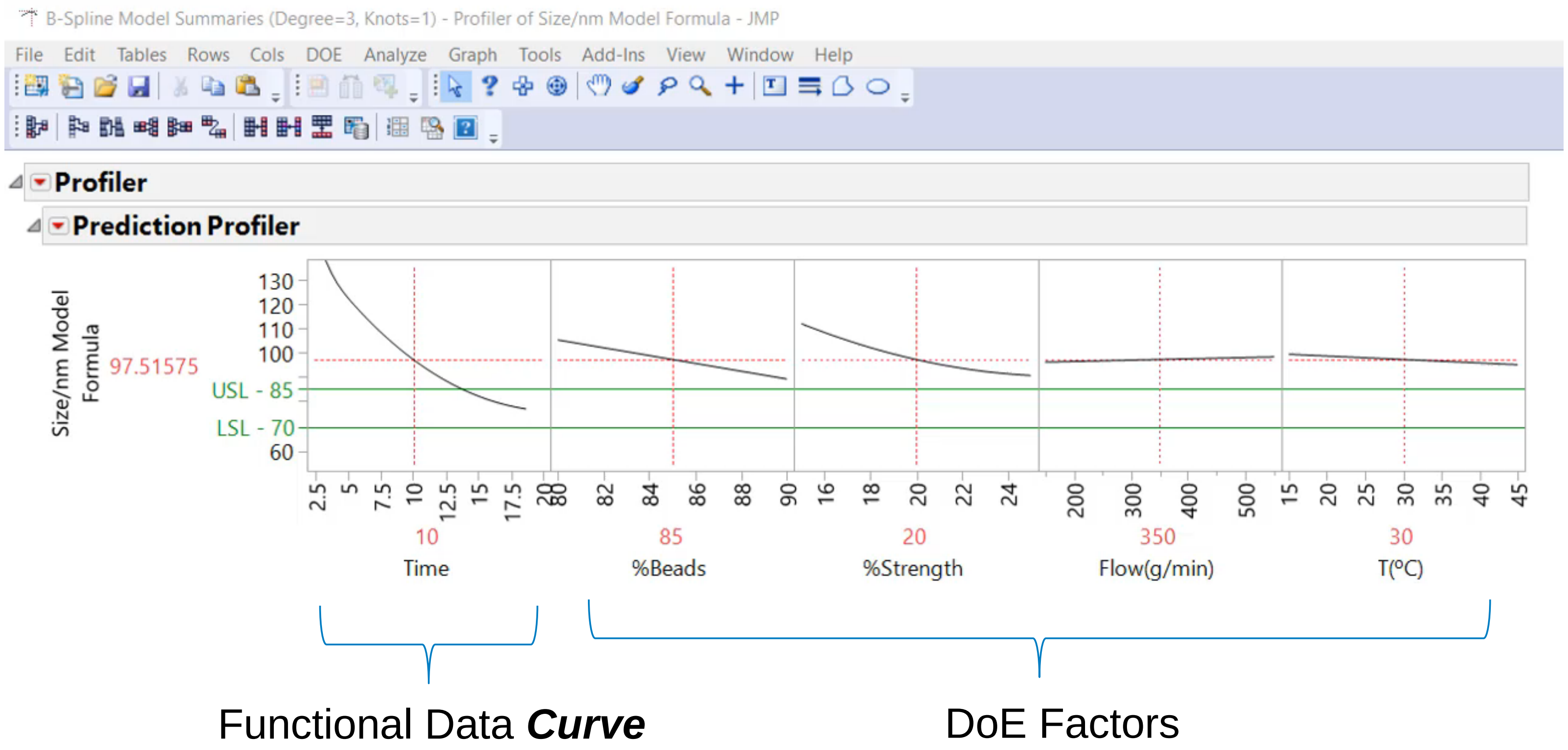
ACCELERATED LIFE TEST DESIGN

TAKE TRIALS WHERE THEY GIVE THE BEST INFORMATION

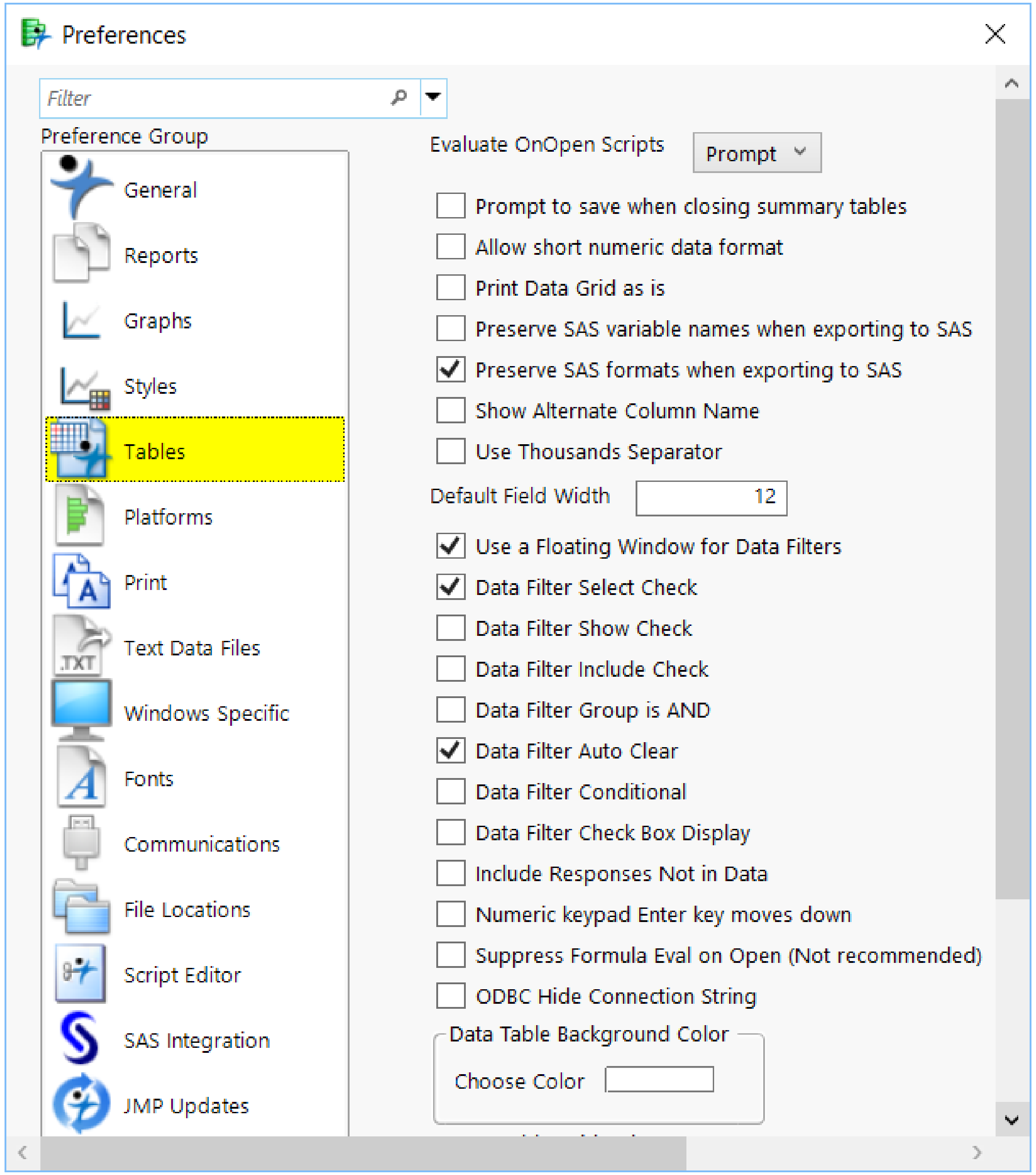


FUNCTIONAL DATA ANALYSIS FOR DOE

MODELING THE "SHAPE" OF A STREAM OF DATA – SHAPE IS THE FUNDAMENTAL UNIT OF OBSERVATION – DIMENSION REDUCTION WITH FUNCTIONAL PCA



COVERING ARRAYS FEWEST TESTS FOR N-WAY COVERAGE



Twenty check boxes in this dialog box

$2^{20} = 1{,}048{,}576$ possible combinations

How many tests to check:

All pairs?

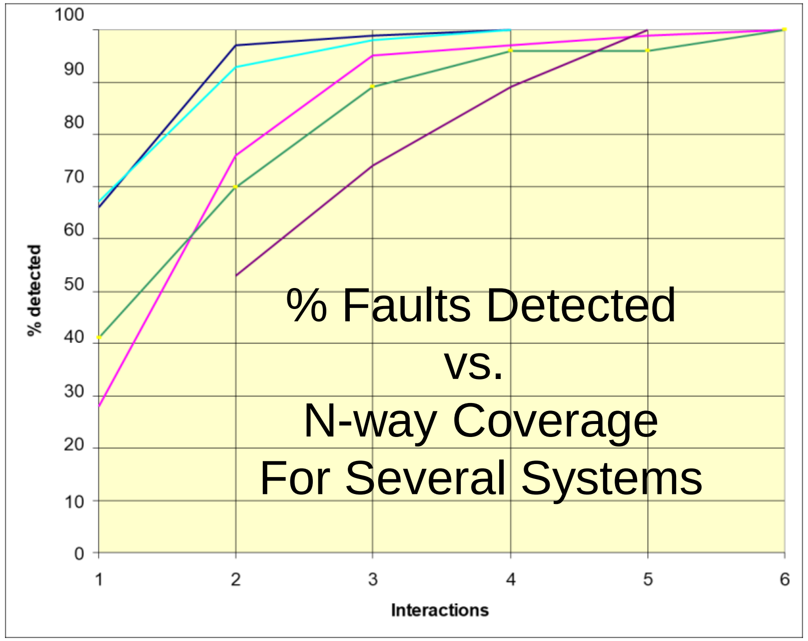
All triples?

All quadruples?

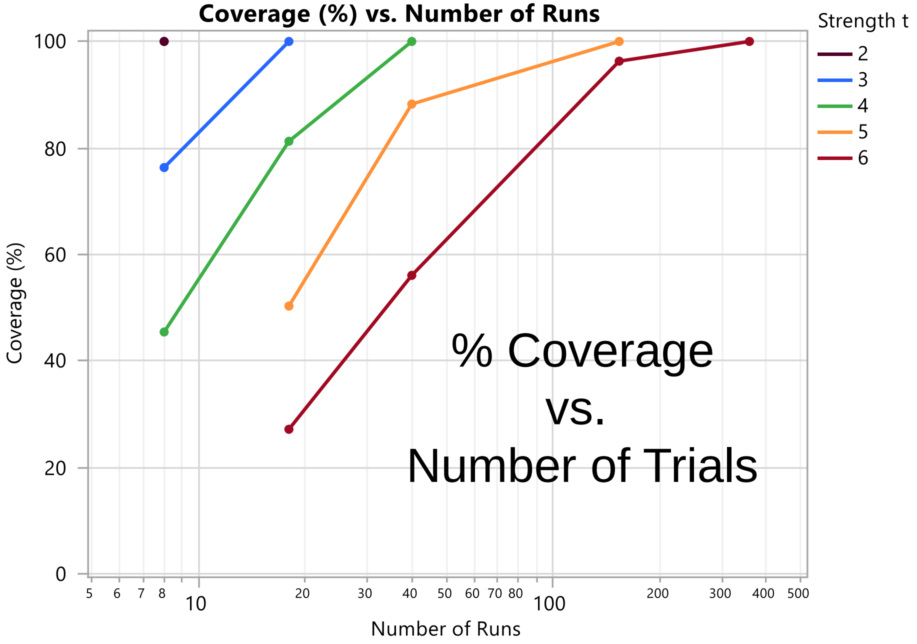
All quintuples?

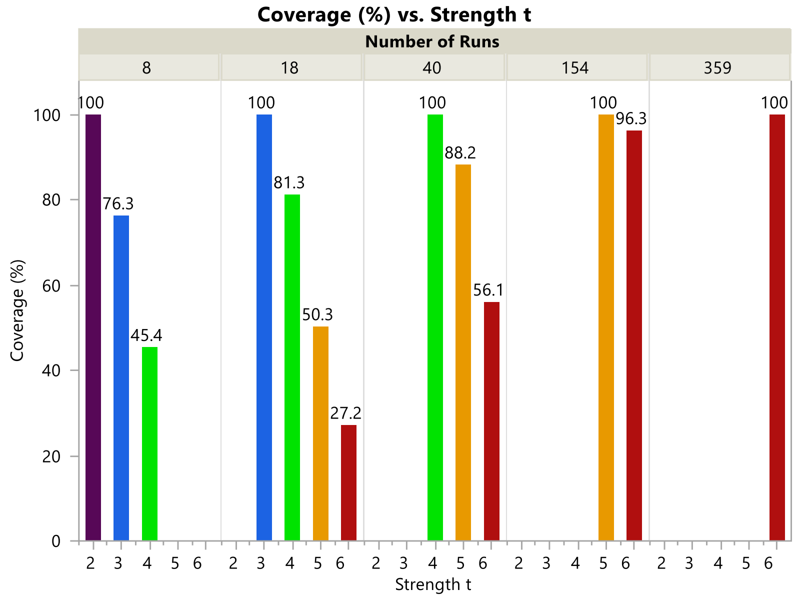
All sextuples?

COVERING ARRAYS FEWEST TESTS FOR N-WAY COVERAGE



Graph courtesy of Rick Kuhn, NIST





Number of Runs: 8

t	Coverage	Diversity
2	100.00	50.00
3	76.32	76.32
4	45.43	90.87

Number of Runs: 18

t	Coverage	Diversity
3	100.00	44.44
4	81.25	72.22
5	50.30	89.42
6	27.16	96.57

Number of Runs: 40

t	Coverage	Diversity
4	100.00	40.00
5	88.24	70.59
6	56.07	89.71

Number of Runs: 154

t	Coverage	Diversity
5	100.00	20.78
6	96.39	40.06

Number of Runs: 359

t	Coverage	Diversity
6	100.00	17.83

REALLY USEFUL "JMP ON AIR" 20-MIN SEGMENTS ON DATA PREP BY THE "DATA DOCTOR," BRADY BRADY

URL Link to April 10th recording of Brady handling data wrangling/clean up/shaping issues:
https://community.jmp.com/t5/JMP-On-Air/Garbage-in-Goodies-out/ta-p/256748#U256748
You will need to join the JMP Community (create a SAS Profile). You can also post questions to the JMP Community to get answers from data geeks that watch for challenging problems.

URL Link to April 3rd recording of the Data Doctor handling date and time issues:
https://community.jmp.com/t5/JMP-On-Air/The-Doctor-Cures-Your-Date-and-Time-Import-Problems/ta-p/255386#U255386

URL Link to April 17th Data Doctor segment on special formula columns
https://community.jmp.com/t5/JMP-On-Air/Special-Formula-Columns/m-p/257371#U257371

This link will take you to the top of the JMP On Air episode lists that you can then drill down to see the segments and links. https://community.jmp.com/t5/JMP-On-Air/tkb-p/jmp-on-air

Here is a link to download Brady's "Data Table Tools Add-in." https://community.jmp.com/t5/JMP-Add-Ins/Data-Table-Tools-Add-in/ta-p/28582 It includes a document of instructions. Really useful.