

Design of Experiments (DOE) Made Easy and More Powerful via Design-Expert® Software

Part 2 – Response Surface Methods (RSM) for Process Optimization*

*Posted at www.statease.com/webinar.html

*To avoid disrupting the Voice over Internet Protocol (VoIP) system, I will mute all. Feel free to press the raise hand feature on GotoWebinar, which I will watch for at intervals during my presentation. If I do not get to you, please accept my apology in advance. Then I'd appreciate you sending me an email after the talk** so we can discuss your issue(s) 'off-line.'* – Mark

**Estimated time of presentation: 60 – 75 minutes.



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software by Stat-Ease

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Mission and Agenda for this Webinar Series



Objective:

Show-and-tell what DOE can do with the aid of dedicated software from Stat-Ease and support of its experts.

Agenda of Webinars:

1. ~~Factorials for discovery, breakthrough and verification (✓*)~~
2. Response surface methods (RSM) for process optimization
3. Mixture design for optimal formulation

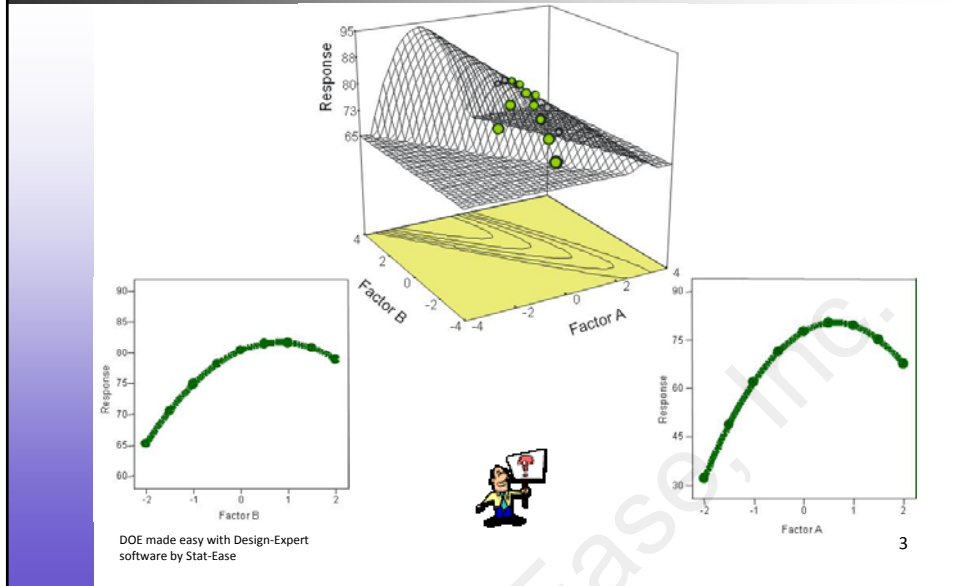
"Theory guides, experiment decides."
-- I. M. Kolthoff

*Posted at www.statease.com/webinar.html

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RSM vs One Factor at a Time (OFAT)



Real-World Headlines

Success with RSM Supported by Stat-Ease



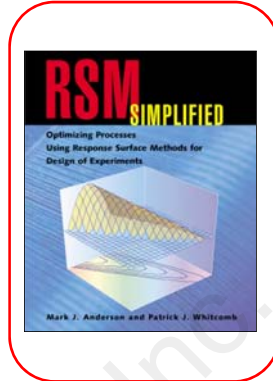
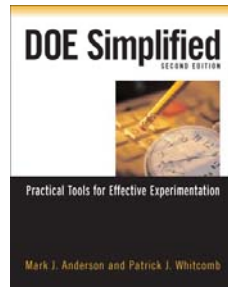
- Inconsistency problems resolved [Pharmaceutical Manufacturing Magazine](#)
- Products developed with a far higher level of certainty in much less time [Military Embedded Systems](#)
- Process Optimized in a Fraction of the Normal Time [Pharmaceutical Processing](#)
- [Semiconductor](#) Made More Robust to Operating Conditions [International SEMATECH Manufacturing Initiative \(ISMI\) Symposium on Manufacturing Effectiveness](#)
- Breakthrough Achieves Critical Design Specification for 3D Printer [Desktop Engineering](#)
- Resource-Minimal Computational Experiments Effectively Model Debris Damage to Space Shuttle's Thermal Protection System [Aerospace Sciences](#)
- Performance of Bioreactor Greatly Enhanced [BioProcess International](#)
- RSM Achieves Design For Six Sigma Goals For [Medical Device](#) Manufacturer -- Doubling Production While Halving Variation of a Key Component [SE Web Exclusive](#)
- Response Surface Methods for Peak Process Performance [Rubber and Plastics News](#)
- Design-Expert Optimizes a Combination of Categorical and Numerical Factors in a Single RSM Design on [Electrical Discharge Machining](#) [SE Web Exclusive](#)
- RSM Yields Improvement In [Biopharmaceutical](#) Separation Process [SE Web Exclusive](#)

Contact mark@statease.com for these and other pubs – *likely some relevant for you.*



Co-author Pat

Now in 2nd edition*!

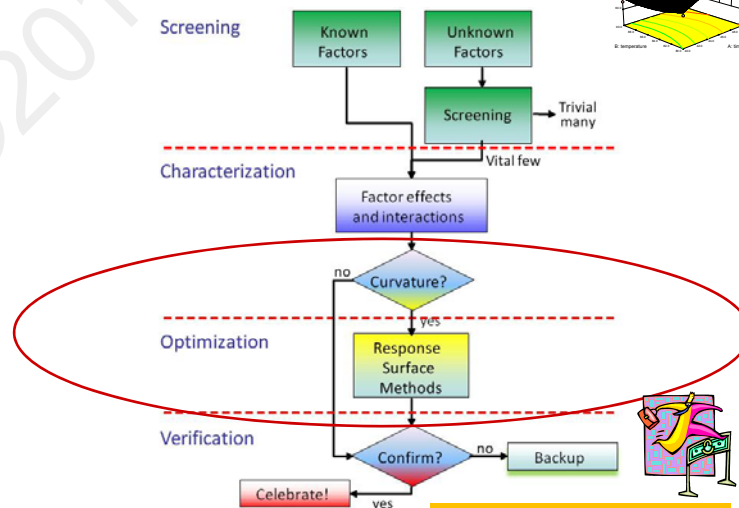
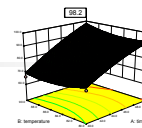


New -- a free intro to *Formulation Simplified* book (under development):

A Primer on Mixture Design: What's In It for Formulators?

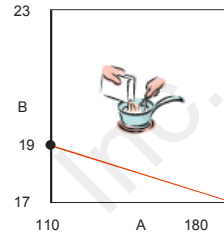
www.statease.com/pubs/MIXprimer.pdf

Strategy of Experimentation: RSM



- Direct setting of discrete (fixed) numeric levels for response surface method designs: *Limit factor settings to reasonable levels, but still produce continuous models.*
- Discrete factor levels adhered to in numeric optimization: *Find the most desirable setting for factors that are not continuous.*
- Constraint calculator: *Simplifies the process for calculating constraint inequalities.**

Low Limit	Constraint	High Limit
775	$\leq +A +35 B$	\leq



- IV-optimal design: *Ideal for optimizing constrained process experiments.**

*For details, refer to <http://statease.info/dx8files/manual/DX8-04F-MultifactorRSM-IVopt.pdf>

See these tools put to use in the following case study.

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	Name	Units	-1 level	+1 level
A	flow rate	ml/min	10	30
B	pressure	kPa	3	10
C	linear speed	inch/sec	0.1	0.5
D	passes	#	1	10

Issues:

- Passes of the coater cannot be incomplete, that is, they must be set at integer values.
- At one extreme (A = 10, B = 3, C = 0.5 and D = 1) insufficient coating is applied by the sprayer.
- At another extreme (A = 30, B = 10, C = 0.1 and D = 10) the sprayer applies too much coating!

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Spray Coating
Discrete (whole) number of passes

Spray - No discrete factor or MLCs

	A [Numeric]	B [Numeric]	C [Numeric]	D [Numeric]
Name	flow rate	pressure	linear speed	passes
Units	ml/min	kPa	inch/sec	#
Type	Continuous	Continuous	Continuous	Discrete
Levels	N/A	N/A	N/A	10
L[1]	10	3	0.1	1
L[2]	30	10	0.5	2
L[3]				3
L[4]				4
L[5]				5
L[6]				6
L[7]				7
L[8]				8
L[9]				9
L[10]				10

“Discrete” is a numeric factor but its values are restricted to the values you define, in this case by simply entering :

- 1 for low
- 10 for high and
- “Tab” to calculate intermediate values

Next: Edit Constraints

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Prevent Insufficient Coating

Define constraint as points on edge of cuboidal space. Determine the setting for each factor that provides adequate coating while all other factors are at their low coating weight level. Here are the constraint points (CP's):

- A (flow rate) ≥ 15 when B = 3, C = 0.5 and D = 1
CP_A = 15 (must spray at a higher rate than this)
- B (pressure) ≥ 6 when A = 10, C = 0.5 and D = 1
CP_B = 6 (must spray at a higher pressure than this)
- C (linear speed) ≤ 0.3 when A = 10, B = 3 and D = 1
CP_C = 0.3 (must spray slower than this)
- D (# passes) ≥ 4 when A = 10, B = 3 and C = 0.5
CP_D = 4 (must spray more times than this)

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Prevent Insufficient Coating

	Name	Low Actual	High Actual	Vertex	< > skip	Constraint Point
A:	flow rate	10	30	10	A >	15
B:	pressure	3	10	3	B >	6
C:	linear speed	0.1	0.5	0.5	C <	0.3
D:	passes	1	10	1	D >	4

On the Add Constraints Tool:

- Choose the vertex to exclude (A=10, B=3, C=0.5, D=1)
 - Look over the inequality column: $A > CP_A$, $B > CP_B$, $C < CP_C$, $D > CP_D$
 - Enter the constraint points: $CP_A=15$, $CP_B=6$, $CP_C=0.3$, $CP_D=4$
- Click "OK" to automatically compute the multilinear constraint.

For details press Help and see "Constraint Tool Examples."

Prevent Over-Coating

	Name	Low Actual	High Actual	Vertex	< > skip	Constraint Point
A:	flow rate	10	30	30	A <	20
B:	pressure	3	10	10	B <	6
C:	linear speed	0.1	0.5	0.1	C >	0.3
D:	passes	1	10	10	D <	5

On the Add Constraints Tool:

- Choose the vertex to exclude (A=30, B=10, C=0.1, D=10)
 - Look over the inequality column: $A < CP_A$, $B < CP_B$, $C > CP_C$, $D < CP_D$
 - Enter the constraint points: $CP_A=20$, $CP_B=6$, $CP_C=0.3$, $CP_D=5$
- Click "OK" to automatically compute the multilinear constraint.



Optimal Design

Search: **Best** Optimality: **IV**

Edit model... Quadratic

Blocks: **1** Options...

Force categoric balance

Model points:	15
To estimate lack of fit:	5
Replicates:	5
Additional center points:	0
Total runs:	25

'Best' will try both Point Exchange and Coordinate Exchange searches of the design space. This could result in some unusual combinations of factors. If you require certain candidates or combinations of factors, switch to Point Exchange.

IV-optimal designs provide lower average prediction variance across your region of experimentation. IV-optimality is desirable for response surface methods (RSM) where prediction is important. The algorithm picks points that minimize the integral of the prediction variance across the design space.



Find conditions that give a thickness of "**9.5 ±0.5**". **"Restrict"** the number of passes to their discrete levels.



Spray - Final

Criteria Solutions Graphs

A: flow rate
B: pressure
C: linear speed
D: passes
thickness

D: passes
Discrete numeric factor

Goal: in range

Lower: Upper:

Limits: 1 10

Weights: 1 1

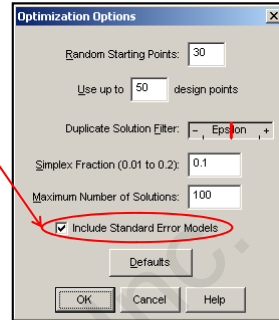
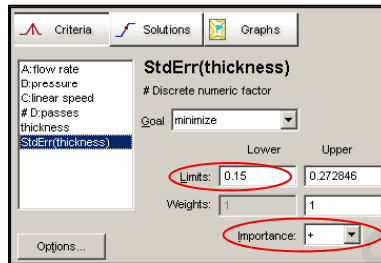
Importance: +++

Restrict Discrete Factor

Options...

Since there are many conditions that yield a thickness of 9.5 let's pick one with less prediction error:

- Click the Options button and check "Include Standard Error Models"
- Minimize standard error. Note: low limit = **0.15** & importance = **+**.



- Smoother color gradations on 2D contours: *More impressive for presentations.*
- Rounded contour values: *More presentable defaults requiring less 'fiddling.'*
- Plant flags on 3D surfaces: *Previously, you could only put flags on 2D contour plots.*
- New and fully configurable mesh option that reflects smooth, lighted colors off your 3D surface: *Dazzle your customers and colleagues.*
- 3D graphs that you can spin with your mouse: *Simply grab and rotate!*

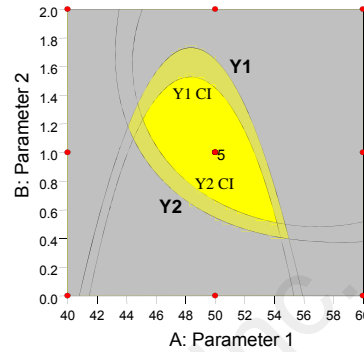


Thickness surface
Spray - Final

New Features for RSM (Bonus with free update to v8.0)



- Graphical optimization now frames the "design space" where all modeled responses fall within confidence, prediction or tolerance intervals (user choice): *Ideal tool for quality by design (QbD).*



Graphical optimization
Granulation



How to get help



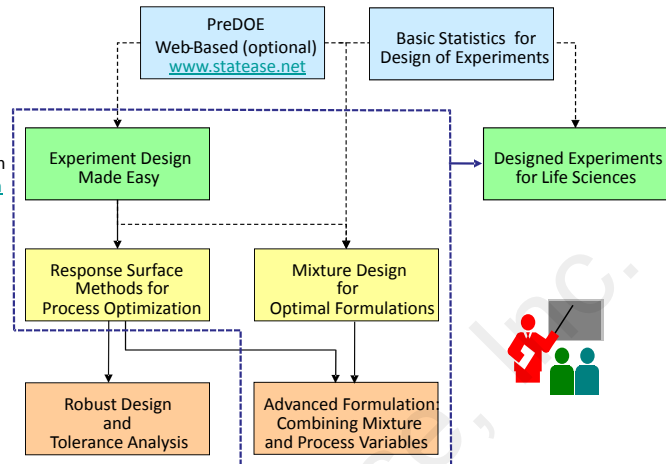
- Search publications posted at www.statease.com.
- In Stat-Ease software press for Screen Tips, view reports in annotated mode, look for context-sensitive Help (right-click) or search the main Help system.
- Explore Experiment Design Forum <http://forum.statease.com> and post your question (if not previously answered).
- E-mail stathelp@statease.com for answers from Stat-Ease's staff of statistical consultants.
- Call 612.378.9449 and ask for "statistical help."



Stat-Ease Training: Computer-Intensive Statistical Workshops



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For all the new features in v8 of Design-Expert software, see
www.statease.com/dx8descr.html



*Best of luck in your
experimenting!
Thanks for listening!*

-- Mark

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