Design of Experiments Using Statgraphics Centurion

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Design of Experiments Wizard

- Phase 1: Creating an experiment
- Phase 2: Analyzing the results
- Phase 3: Further experimentation



Phase 1: Creating an experiment

- Phase 1: Creating an experiment
 - Step 1: Define responses
 - Step 2: Define experimental factors
 - Step 3: Select design
 - Step 4: Specify model
 - Step 5: Select runs
 - Step 6: Evaluate design
 - Step 7: Save design
- Phase 2: Analyzing the results
- Phase 3: Further experimentation



Phase 2: Analyzing the results

- Phase 1: Creating an experiment
- Phase 2: Analyzing the results
 - Step 8: Analyze data
 - Step 9: Optimize responses
 - Step 10: Save results
- Phase 3: Further experimentation



Phase 3: Further experimentation

- Phase 1: Creating an experiment
- Phase 2: Analyzing the results
- Phase 3: Further experimentation
 - Step 11: Augment design
 - Step 12: Extrapolate



Example – from <u>Response Surface</u> <u>Methodology</u> by Myers and Montgomery

Find the settings of *time*, *temperature* and *catalyst* that maximize the *conversion percentage* of a chemical process while keeping the *thermal activity* as close as possible to 57.5.



DOE Wizard – Main Window

🧱 Experimental Design Wizard 💼 💷 🛃											
Step 1:Define responses	Step 3:Select design	Step 5:Select runs	Step 7:Save experiment	Step 9:Optimize responses	Step 11:Augment design						
Step 2:Define exp. factors	Step 4:Specify model	Step 6:Evaluate design	Step 8:Analyze data	Step 10: Save results	Step 12:Extrapolate						
Experimental Design Wi Step 1: Define the response ve You may define between 1 and The StatAdvisor Press the buttons on the DOE	<mark>izard</mark> tiables to be measured t 16 responses. Wizard toolbar in sequer	ice to step through the cr	eation and analysis of yo	ur experiment.							



Step 1: Define responses

Design file: <un Comment: RSM Number of respo Response Name</un 	ntitled> 1 Example onses: 2	Units																		
Comment: RSM Number of respo Response Name	1 Example onses: 2 • e	Units																		
Number of respo Response Name	e	Units																		
Response Name	e	l Inits	Number of responses: 2																	
	version	Oriko	Analyze	Goal			Target	Impact (1-5)	Sensitivity		Minimum	Maximum								
1 conv	(CIGIOIT	%	Mean	• Max	kimize	•	0.5	3.0	Medium	•	80	100								
2 them	mal activity		Mean	• Hitt	target	•	57.5	3.0	Medium	•	55	60								
3 Var_	3		Mean	r Max	kimize	Ŧ	0.5	3.0	Medium	$\overline{\mathbf{v}}$										
4 Var_	4		Mean	r Max	kimize	Ŧ	0.5	3.0	Medium	Ŧ										
5 Var_	5		Mean	r Max	kimize	Ŧ	0.5	3.0	Medium	Ŧ										
6 Var_	6		Mean	r Max	kimize	Ŧ	0.5	3.0	Medium	Ŧ										
7 Var_	.7		Mean	- Max	kimize	Ŧ	0.5	3.0	Medium	Ŧ										
8 Var_	.8		Mean	Max	kimize	Ŧ	0.5	3.0	Medium	-										
9 Var_	9		Mean	Max	kimize	Ŧ	0.5	3.0	Medium	-										
10 Var_	10		Mean	Max	kimize	Ŧ	0.5	3.0	Medium	-										
11 Var_	11		Mean	- Max	kimize	Ŧ	0.5	3.0	Medium	-										
12 Var_	12		Mean	Max	kimize	Ŧ	0.5	3.0	Medium	-										
13 Var_	13		Mean	Max	kimize	Ŧ	0.5	3.0	Medium	-										
14 Var_	14		Mean	Max	kimize	Ŧ	0.5	3.0	Medium	-										
15 Var_	15		Mean	Max	kimize	Ŧ	0.5	3.0	Medium	-										
16 Var_	16		Mean	Max	kimize	Ŧ	0.5	3.0	Medium	-										
	0	К		Cance	el				Help											



Step 2: Define experimental factors

lumbe	er of controllable proc	ess factors: 3 🔄 Nu	umber of controllable mix	ture component:	s: 0	Number of r	Number of noise factors: 0	
actor	Name	Units	Туре	Role	Low	High	Levels	
А	time	minutes	Continuous 💌	Controllable	10	15	1,2,3,4	
В	temperature	degrees C	Continuous 💌	Controllable	170	200	1,2,3,4	
С	catalyst	%	Continuous 💌	Controllable	2	3	1,2,3,4	
D	Factor_D		Continuous 👻		-1.0	1.0	1,2,3,4	
Е	Factor_E		Continuous 👻		-1.0	1.0	1,2,3,4	
F	Factor_F		Continuous 👻		-1.0	1.0	1,2,3,4	
G	Factor_G		Continuous 💌		-1.0	1.0	1,2,3,4	
Н	Factor_H		Continuous 💌		-1.0	1.0	1,2,3,4	
I	Factor_I		Continuous 💌		-1.0	1.0	1,2,3,4	
J	Factor_J		Continuous 💌		-1.0	1.0	1,2,3,4	
к	Factor_K		Continuous 💌		-1.0	1.0	1,2,3,4	
L	Factor_L		Continuous 💌		-1.0	1.0	1,2,3,4	
М	Factor_M		Continuous 💌		-1.0	1.0	1,2,3,4	
Tota	al for controllable mixto	ure components: 1.0				Factors A-M	Factors N-Z	

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Step 3: Select design

esign of Experimer	nts Wizard - Select	Desigr	ı			X	
Design file: <untitle< th=""><th>ed></th><th></th><th></th><th></th><th></th><th>Robust Parameter Design</th><th></th></untitle<>	ed>					Robust Parameter Design	
Comment: RSM Ex	xample					Combined array	
9	Segment	Facto	rs Runs	Blocks	Design	C Crossed array	
Options	Process factors	3	0	0	Press the Options button.		
Options	Mixture components	0	0	0			
Options		0	0	0			
	COMBINED	3	n Desiren for Cont		Construction 1)	
			Designs for Com	inuous o	I Wo-Level Factors	·	
4			 Screening Response S Multilevel Fa Orthogonal a 	urface actorial Array	Cancel	▼	
	ОК		Cance		Rerandomize	Help	
						STATPOI	NT IES,

Step 3: Select design (cont.)

gn of Experir	ments W	Vizard - Se	lect Design							X
esign file: Kur	ntitled>							⊢ Robust I	Parameter Design —	
mment: RSN	1 Exampl	le						T 💿 Cor	mbined array	
1								0.00	vered arrau	
	Segm	ient	Factors	Runs	Blocks	Design			isseu allay	
Options	Proce	ess factors	3	0	0	Press the (Dotions button.			
	ĺ	Response	Surface Desig	n Selection						
Options	Mixtu		-							
Options		Name				Runs	Error d.f.	Largest Blo	ck	
options		Box-Beb	nken design			15	5	15	_	
	COM	Box-Beb	nken design			15	5	15		
		Central	composite d	esign: 213	+ star	16	6	16		
A BLO	ICK	Central	composite b	locked cub	e-star	16	5	9		
		3-level	factorial d	n 3 blocks esign: 3^3		27	17	27		
		3-level	factorial in	n 3 blocks		27	15	9		
		3-level User-sp	factorial is ecified desig	n 9 blocks m		27	9	3		
		🔽 Displa	ay Blocked Desi	gns OK	Cancel	Ba	ick H	lelp		
										► •
	(эк		Canc	el		Rerandomize		Help	

Step 3: Select design (cont.)

Design of Ex	periments Wizard - S	elect Design			8
Design file:	<untitled></untitled>			Robust	Parameter Design
Comment:	RSM Example	~			mbined array
	Segment	Composite Design Options		—X —	ssed array
Options	Process factors	Base Design: Central composite des	ign: 2^3 + star		
Options	Mixture compor	Runs: 20 – Design Characteristics –	Error d.f.: 10	ОК	
Options		 Rotatable 		Cancel	
	COMBINED	C Orthogonal		Generators	
	BLOCK	C Rotatable and Orthogonal		Back	
	r	C Face Centered		Help	=
		Centerpoints	Replicate Design		
		Number:	Number:		
		C Random	🗆 Randomize		
		C First C Last			
•		Axial Distance:	1.68179		
	ОК	Cancel	Rerandomize		Help
				1.2	STATPOIN

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Step 3: Select design (cont.)

Design of Experi	ments Wizard - Select	Design					X
Designifile: Ku	ntitled>					Robust Parameter Design	
Comment: RSI	M Example					Combined array	
,	Segment	Factors	Runs	Blocks	Design	C Crossed array	
Options	Options Process factors 3		20	1	Central composite des	jn: 2^3 + star	
Options	Options Mixture components 0		0	0			
Options		0	0	0			
	COMBINED	3	20	1	Samples per run: 1		
BLO	ICK time		tempe	rature	catalust		
	minute	12	degre	es C	2		
1 1	10.0		170.0		2.0		
2 1	15.0		170.0		2.0		
3 1	10.0		200.0		2.0		
4 1	15.0		200.0		2.0		
5 1	10.0		170.0		3.0		
6 1	15.0		170.0		3.0		
7 1	10.0		200.0		3.0		
8 1	15.0		200.0		3.0		
9 1	8.29552		185.0		2.5		
10 1	16.7045		185.0		2.5		
11 1	12.5		159.773		2.5		
12 1	12.5		210.227		2.5		
13 1	12.5		185.0		1.6591		
14 1	12.5		185.0		3.3409		
15 1	12.5		185.0		25		
•							•
	ОК		Cano	cel	Rerandor	ze Help	
						I STA	

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Datasheet

untitle	d>					
	BLOCK	time	temperature	catalyst	conversion	thermal 🔺
		minutes	degrees C	8	8	
1	1	10.0	170.0	2.0		
2	1	15.0	170.0	2.0		
3	1	10.0	200.0	2.0		
4	1	15.0	200.0	2.0		
5	1	10.0	170.0	3.0		
6	1	15.0	170.0	3.0		
7	1	10.0	200.0	3.0		
8	1	15.0	200.0	3.0		
9	1	8.3	185.0	2.5		
10	1	16.7	185.0	2.5		
11	1	12.5	160	2.5		
12	1	12.5	210	2.5		
13	1	12.5	185.0	1.66		
14	1	12.5	185.0	3.34		
15	1	12.5	185.0	2.5		
16	1	12.5	185.0	2.5		
17	1	12.5	185.0	2.5		
18	1	12.5	185.0	2.5		
19	1	12.5	185.0	2.5		
20	1	12.5	185.0	2.5		
	A B C					



Step 4: Select model

DOE Wizard Model Options		— —
Process Factors Model	Mixture Components Model	OK
C Mean	Mean	Cancel
C Linear (Main Effects)	C Linear	
C 2-Factor Interactions	C Quadratic	Help
Quadratic	C Special Cubic	
C Cubic	C Cubic	
Include: A:time B:temperature C:catalyst AA AB AC BB BC CC	Exclude:	



Step 5: Select runs (D-optimal design only)

🔺 E	LOCK	time temperat	ure	catalyst	conversion	thermal activity
4		minutes degrees	:C	%	%	
1 1	10.0	170.0	2.0			
2	15.0	170.0	2.0			
3 1	10.0	200.0	2.0			
4	15.0	200.0	2.0			
5	10.0	170.0	3.0			
5	10.0	170.0	3.0			
2 1	15.0	200.0	3.0			
9 1	8.3	185.0	2.5			
10 1	16.7	185.0	2.5			
11 1	12.5	160.0	2.5			
12 1	12.5	210.0	2.5			
13 1	12.5	185.0	1.66			
14 1	12.5	185.0	3.34			
15 1	12.5	185.0	2.5			
16 1	12.5	185.0	2.5			
17 1	12.5	185.0	2.5			
18 1	12.5	185.0	2.5			
19 1	12.5	185.0	2.5			
20	12.0	180.0	2.0			
mbor of ru	an desired:		1	D officionau:	CE 00%	
	is desired.	Select runs using forwar	d algorithm	Dremciency.	03.03%	
5		Select runs using backwa	ard algorithm	A-efficiency:	33.47%	
odel coeffic	ients: 10	🔽 Apply exchange algori	ithm at end	G-efficiency:	39.86%	
	ОК	Cancel		Reset	1	Help

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Step 6: Evaluate design

Tables and Graphs		
TABLES	GRAPHS	ОК
 Analysis Summary Design Worksheet 	Prediction Variance Plot	Cancel
ANOVA Table	✓ Prediction Profile	All
Model Coefficients	Variance Dispersion Graph	Store
🔽 Alias Matrix	✓ Fraction of Design Space Plot	Help
Correlation Matrix	Power Curve	
✓ Leverage	🔲 Desirability Plot	
🗖 Desirability	Cverlaid Contour Plots	

Plot of design space



Prediction variance plot











Do the experiment! Then enter the results:

Convers	Conversion & activity.sgx											
	BLOCK	time	temperature	catalyst	conversion	thermal 🔺 activity						
		minutes	degrees C	%	8							
1	1	10.0	170.0	2.0	74	53.2						
2	1	15.0	170.0	2.0	51	62.9						
3	1	10.0	200.0	2.0	88	53.4						
4	1	15.0	200.0	2.0	70	62.6						
5	1	10.0	170.0	3.0	71	57.3						
6	1	15.0	170.0	3.0	90	67.9						
7	1	10.0	200.0	3.0	66	59.8						
8	1	15.0	200.0	3.0	97	67.8						
9	1	8.3	185.0	2.5	76	59.1						
10	1	16.7	185.0	2.5	79	65.9						
11	1	12.5	160	2.5	85	60						
12	1	12.5	210	2.5	97	60.7						
13	1	12.5	185.0	1.66	55	57.4						
14	1	12.5	185.0	3.34	81	63.2						
15	1	12.5	185.0	2.5	81	59.2						
16	1	12.5	185.0	2.5	75	60.4						
17	1	12.5	185.0	2.5	76	59.1						
18	1	12.5	185.0	2.5	83	60.6						
19	1	12.5	185.0	2.5	80	60.8						
20	1	12.5	185.0	2.5	91	58.9						
	Conversion & activity	BC										



Step 8: Analyze data

Design of Experiments Wizard - Analyze Data								
Response	Transformation	Power	Addend					
conversion	None	1.0	0					
thermal activity	None 💌	1.0	0					
	-							
	-							
	-							
		,						
		, 						
		,						
		, 						
ОК	Cancel	, Help	, 					



Step 8: Analyze data (cont.)





ANOVA table

	175.419 0.886557	56.57 0.29	0.0000 0.6045	\neg
1	0.886557	0.29	0.6045	
1	177.007			
1-	67.926	21.91	0.0009	
1	10.0355	3.24	0.1022	
1	1.20125	0.39	0.5476	=
1	0.01125	0.00	0.9532	
1	0.0752541	0.02	0.8793	
1	0.78125	0.25	0.6266	
1	0.0451827	0.01	0.9063	
10	3.10072			
19				
	1 1 1 1 1 1 1 10 19	1 10.0355 1 1.20125 1 0.01125 1 0.0752541 1 0.78125 1 0.0451827 10 3.10072 19	1 10.0355 3.24 1 1.20125 0.39 1 0.01125 0.00 1 0.0752541 0.02 1 0.78125 0.25 1 0.0451827 0.01 10 3.10072 19	1 10.0355 3.24 0.1022 1 1.20125 0.39 0.5476 1 0.01125 0.00 0.9532 1 0.0752541 0.02 0.8793 1 0.78125 0.25 0.6266 1 0.0451827 0.01 0.9063 10 3.10072 19 10



Pareto chart





Exclude effects

Exclude Effects Options							
Include: AC B:temperature BB BC C:catalyst CC	Exclude:						
Ignore Block Numbers							
OK Can	cel Help						



Final models



Standardized Pareto Chart for thermal activity





Step 9: Optimize responses



Step 9: Optimize responses (cont.)



Step 9: Optimize responses (cont.)

📰 Experimental Design Wizard										
Step 1:Defin	e responses	Step 3:Select design Step 5:Se		elect runs	elect runs Step 7:Save experiment		Step 9:Optimize responses	Step 11:Augment design		
Step 2:Define	exp. factors	Step 4:Specify model Step 6:Eva		uate design Step 8:Analyze data		Step 10: Save results	Step 12:Extrapolate			
Step 9: Optimize the Response Values at	Step 9: Optimize the responses									
Response	Optimized	Prediction	Lower 95	5.0% Limit	Upper 95.09	6 Limit	1			
conversion	yes	96.148	87.2221		105.074					
thermal activity	yes	57.5	56.5677		58.4323]			
Desirability 0.807398 1.0										
Optimized desirabili	ity = 0.898553	3								=
Factor Settings at C	ffing									
time 11.	2019									
temperature 210	0.0									
catalyst 2.3	1889									
•		11	1						Þ	



3-D contour plot





Overlaid contour plots





Step 10: Save results





Step 11: Augment design

esign of Experimer	nts Wizard - Augment Des	sign				
BLOCK	time	temperature	catalyst			
	minutes	degrees C	%			
1 1	10.0	170.0	2.0			
2 1	15.0	170.0	2.0			
3 1	10.0	200.0	2.0			
4 1	15.0	200.0	2.0			
5 1	10.0	170.0	3.0			
6 1	15.0	170.0	3.0			
7 1	10.0	200.0	3.0			
8 1	15.0	200.0	3.0			
9 1	8.3	185.0	2.5			
10 1	16.7	185.0	2.5			
11 1	12.5	160.0	2.5			
12 1	12.5	210.0	2.5			
13 1	12.5	185.0	1.66			
Action				1		
Add replicates:	1			Total runs: 20		
Add a fraction	1			Total blocks: 1		
	1					
Clear main effects						
			-			
Clear a factor:	clear time	<u> </u>	<u>~</u>			
A.11.7. 2.7	1					
Add star points						
	OK	Cancel		Reset	Help	
					CTATO	
					SIAIP	
					TECHNOL	OGIES.

Step 12: Extrapolate

Extrapolation Options				
Start at Center of design Best observed design point Best predicted design point Best predicted vertex Derived optimum Other	Disp	lay steps of:		OK Cancel Help
Change time temperature catalyst	Start 11.2019 210.0 2.31889 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.	Low 10.0 2.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0	High 15.0 300 3.0 1.0	More



Step 12: Extrapolate (cont.)

🔚 Exp	🗄 Experimental Design Wizard 💼 🗉 💌								
	Step 1:Define	responses	Step 3:Select design	Step 5:Select runs	Step 7:Save experiment	Step 9:Optimize responses	Step 11:Augment design		
	Step 2:Define exp. factors Step 4:Specify model		Step 6:Evaluate design	Step 8:Analyze data	Step 10: Save results	Step 12:Extrapolate	Ĺ		
				,					
<u>Step I.</u> Evtran	<u>2: Extrapolate i</u> olated Respon	<u>model</u> ise Values							
Step	Desirabiliti	conversi	on thermal activity	7					
	0.898546	96.148	57.4999	1					
1	0.913903	96.7047	57.4999	1					
2	0.929211	97.269	57.4999	1					
3	0.94447	97.8408	57.4999	1					
4	0.959683	98.4202	57.4999	7					
5	0.974853	99.0072	57.4999]					
6	0.989981	99.6017	57.4999						
7	0.99999	100.204	57.4999						
8	0.99999	100.204	57.4999						
L .	a: a. n								
Factor	Settings for E	xtrapolation	astalust						
n n n n n n n n n n n n n n n n n n n	11 2010 2	9100	2 21990						
	11 2019 2	210.0	2.51889						
2	11 2019 2	211.030	2.31889						
3	11 2019 2	211 559	2 31889					Ξ	
4	11.2019 2	212.078	2.31889						
5	11.2019 2	12.598	2.31889						
6	11.2019 2	213.118	2.31889						
7	11.2019 2	213.637	2.31889						
8	11.2019 2	13.637	2.31889						
								Ŧ	
•							•		
								_	



More... (next webinar)

- Creating and using RPDs (Robust Parameter Designs)
- Analyzing designs with both process and mixture components
- Using D-optimal designs to fix a botched experiment



More Information

Go to <u>www.statgraphics.com</u>

Or send e-mail to info@statgraphics.com

