New Developments in Design of Experiments (DOE) for Quality Improvement

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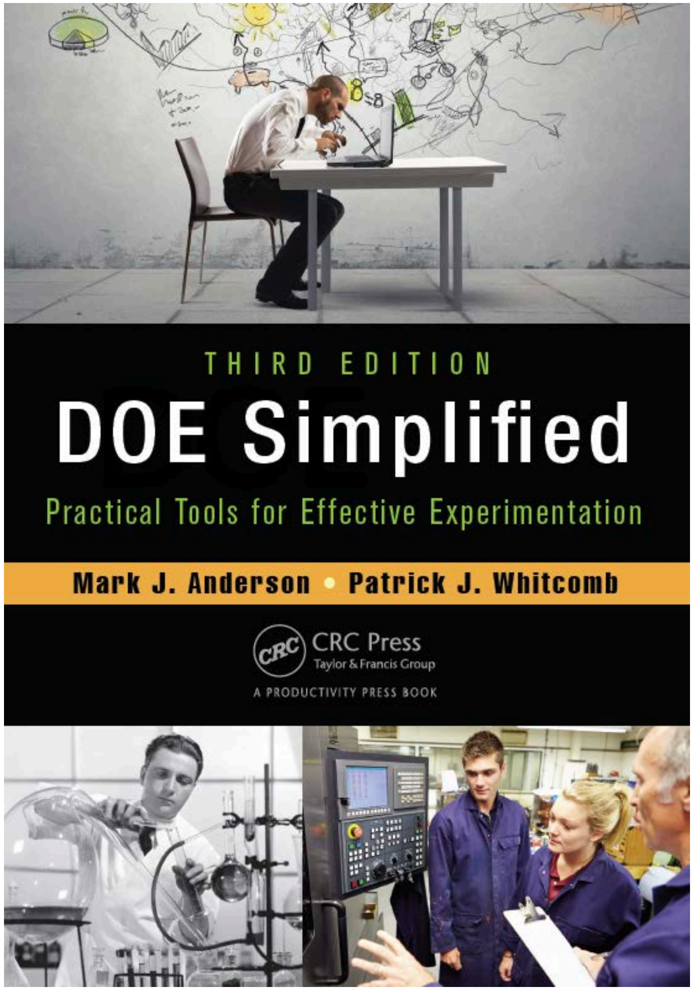
Coming this year!



Objective for this Talk:
Build up your DOE Chops

A short-and-sweet brief on three new DOE tools of particular interest for quality professionals:

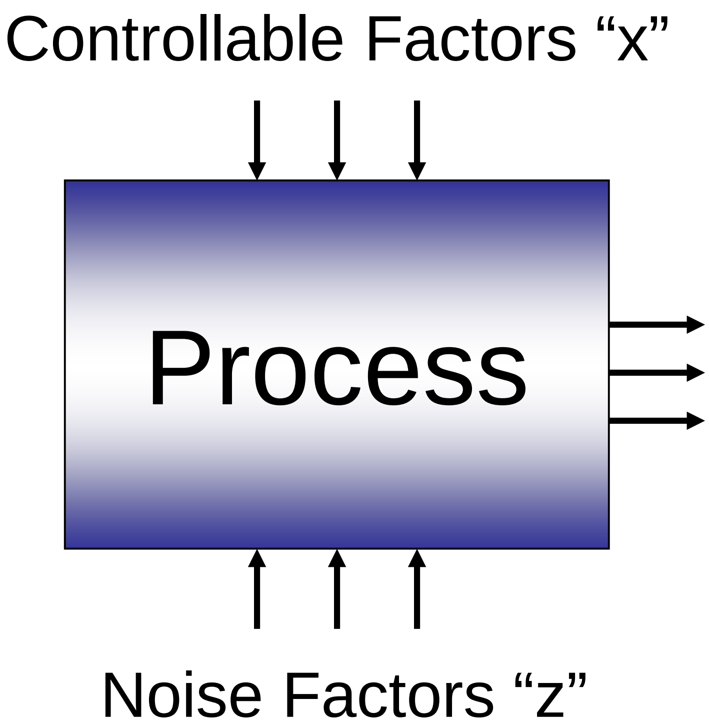
- Minimum-run (MR) screening and characterization designs
- Test plans that handle hard-to-change (HTC) factors
- Definitive screening designs (DSD)

Get up to full speed on the powerful methods of statistically planned experiments that, via the magic of multifactor testing, can quickly lead to quality breakthroughs.

Agenda

- **Overview of DOE**
- Minimum-Run Design—Case Study on Stent
- Factorial Split Plots—Helicopter Experiment
- Definitive Screening Designs
- Conclusion

The Essence of Design of Experiments



DOE (Design of Experiments) is:

“A systematic series of tests,
in which purposeful changes
are made to input factors,

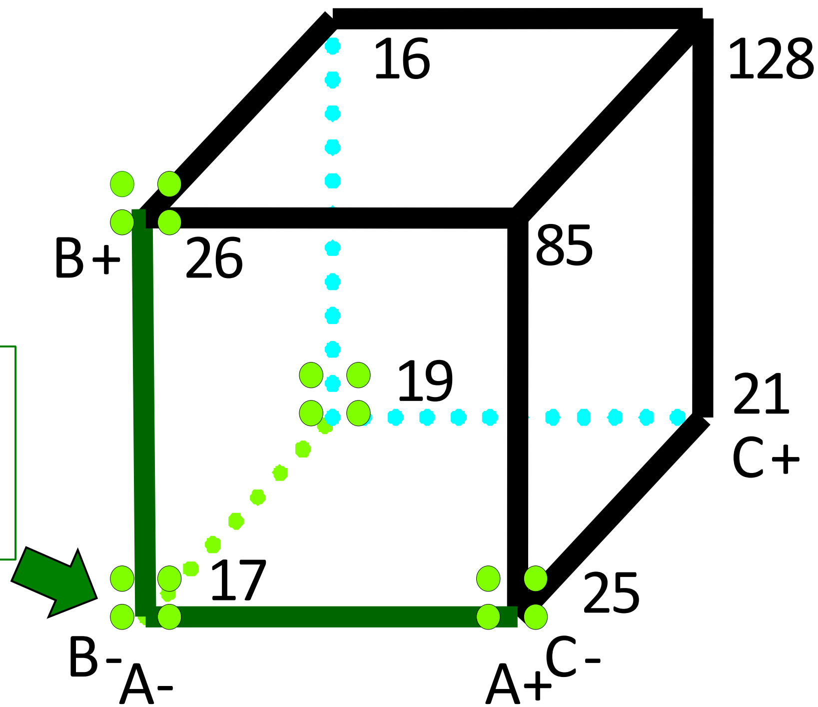
Responses “y”

so that you may identify
causes for significant changes
in the output responses.”

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

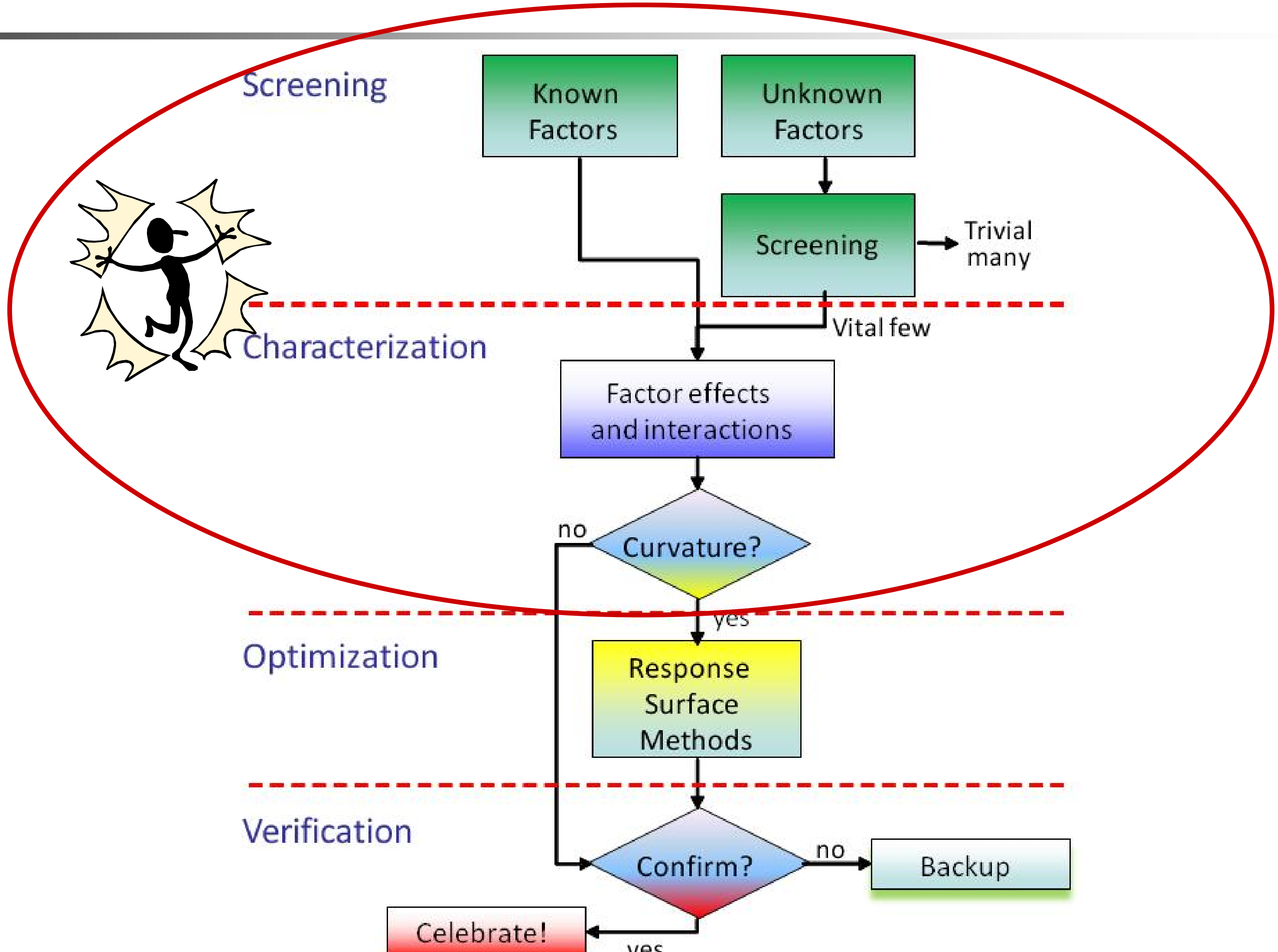
The Rest of the Story

An 8-run multifactor design can work
– if you are both bold and lucky!

Ultimately the engineers (SKF-Sweden) improved bearing life
from 41 million revolutions on average
(already better than any competitors),
to 400 million revs* – nearly a ten-fold improvement!

* “Breaking the Boundaries,” *Design Engineering*, Feb 2000, pp 37-38.

Strategy of Experimentation



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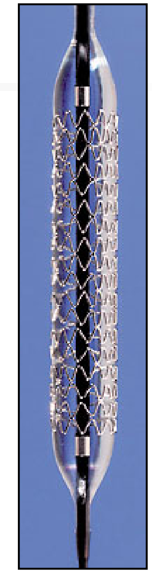
Stent-Delivery System



Engineers at a MN medical device company needed a high-resolution detailing on the effects of 10 factors* affecting the performance (burst, push and track) of an angioplastic stent. They were under great pressure.

	Name	Units	Type	Low	High
A [Numeric]	Balloon wall	in	Numeric	0.0011	0.0015
B [Numeric]	Waist length	mm	Numeric	2	3
C [Numeric]	Waist wall	in	Numeric	0.001	0.002
D [Categoric]	Wing fold	#	Categoric	3	5
E [Numeric]	Inner ID	in	Numeric	0.016	0.018
F [Numeric]	Inner wall	in	Numeric	0.002	0.003
G [Numeric]	Inner weld	cm	Numeric	3	9
H [Numeric]	Inner length	mm	Numeric	2	3
J [Numeric]	Tip length	mm	Numeric	2	4.2
K [Numeric]	Tip matl	durometer	Numeric	43	69

*Ones shown here are only for illustrative purposes.

Standard (Classical) Two-Level Designs

Combined
Mixture
Response Surface
Factorial

Randomized
- Regular Two-Level
- Min-Run Characterize
- Irregular Res V
- Min-Run Screen
- Definitive Screen
- Plackett-Burman
- Taguchi OA
- Multilevel Categoric
- Optimal (custom)

Split-Plot
- Regular Two-Level
- Multilevel Categoric
- Optimal (custom)

Simple Sample

Regular Two-Level Factorial Design

Design for 2 to 21 factors where each factor is set to 2 levels. Useful for estimating main effects and interactions. Fractional factorials can be used for screening many factors to find the significant few. The color coding represents the design resolution: Green (Characterization) = Res V or higher, Yellow (Screening)= Res IV, and Red (Ruggedness testing) = Res III.

Number of Factors

Runs	2	3	4	5	6	7	8	9	10	11	12
4	2^{2}	2^{3-1}_{III}									
8		2^{3}	2^{4-1}_{IV}	2^{5-2}_{III}	2^{6-3}_{III}	2^{7-4}_{III}					
16			2^{4}	2^{5-1}_{V}	2^{6-2}_{IV}	2^{7-3}_{IV}	2^{8-4}_{IV}	2^{9-5}_{III}	2^{10-6}_{III}	2^{11-7}_{III}	2^{12-8}_{III}
32				2^{5}	2^{6-1}_{VI}	2^{7-2}_{IV}	2^{8-3}_{IV}	2^{9-4}_{IV}	2^{10-5}_{IV}	2^{11-6}_{IV}	2^{12-7}_{IV}
64					2^{6}	2^{7-1}_{VII}	2^{8-2}_{V}	2^{9-3}_{IV}	2^{10-4}_{IV}	2^{11-5}_{IV}	2^{12-6}_{IV}
128						2^{7}	2^{8-1}_{VIII}	2^{9-2}_{VI}	2^{10-3}_{V}	2^{11-4}_{V}	2^{12-5}_{IV}
256							2^{8}	2^{9-1}_{IX}	2^{10-2}_{VI}	2^{11-3}_{VI}	2^{12-4}_{VI}
512								2^{9}	2^{10-1}_{X}	2^{11-2}_{VII}	2^{12-3}_{VI}

Replicates: 1 Blocks: 1 Center points per block: 0 Show Generators

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

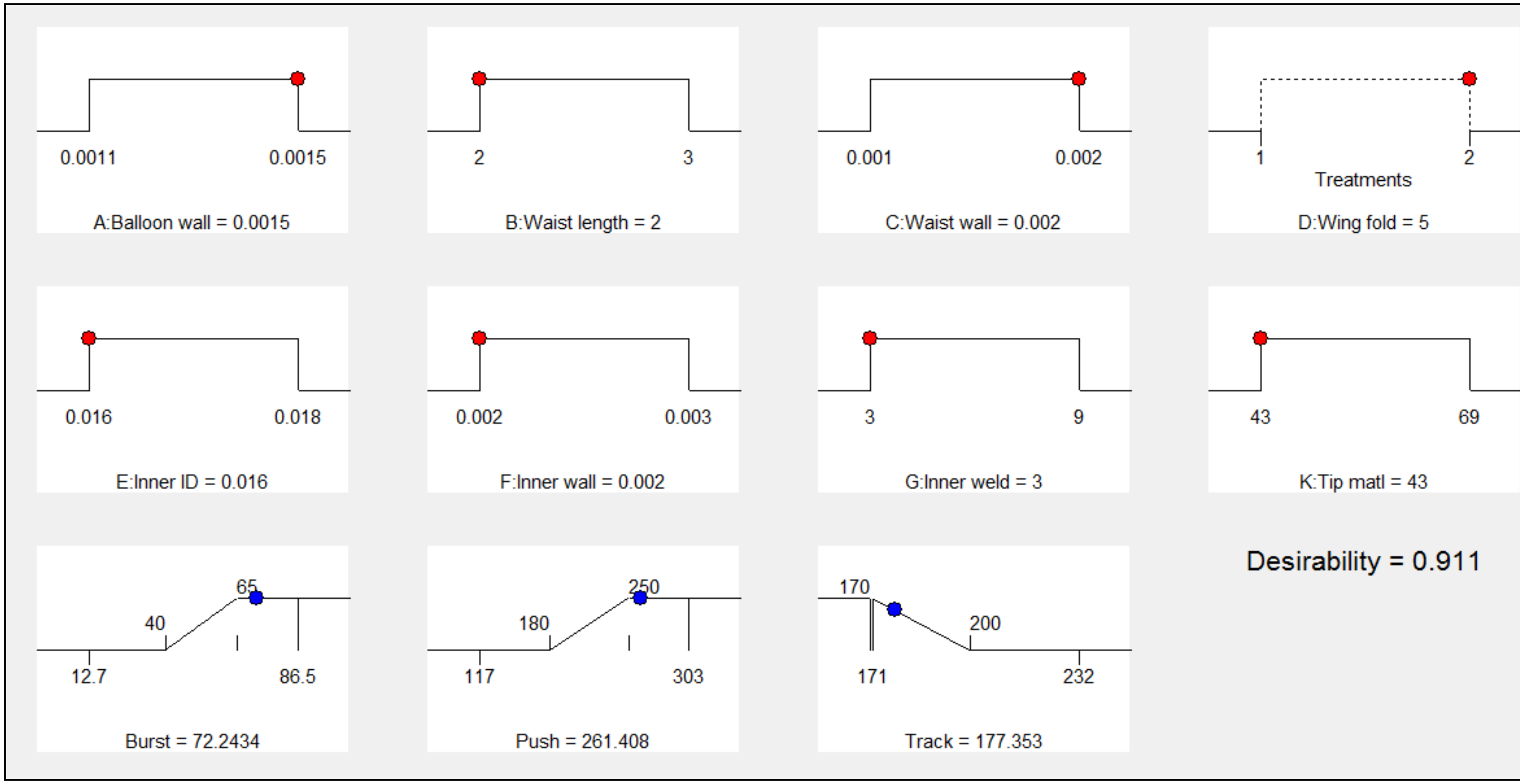
Screening

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

Success: A Desirable Setup Discovered!



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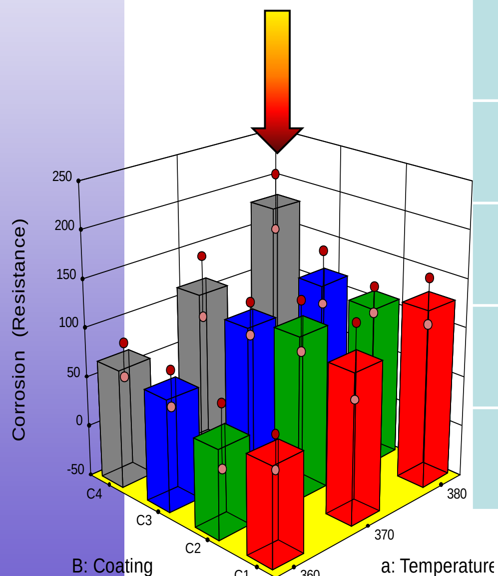
Factorial Split Plots

For hard-to-change (HTC) factors

DOE software now handles HTC factors such as oven temperature in this classic split plot by George Box—a general multilevel factorial on metal coatings for corrosion resistance.



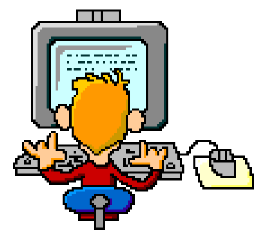
Group	Heats (Deg C) (Whole plots)	Positions (Subplots)			
1	360	C2 (73)	C3 (83)	C1 (67)	C4 (89)
2	370	C1 (65)	C3 (87)	C4 (86)	C2 (91)
3	380	C3 (147)	C1 (155)	C2 (127)	C4 (212)
4	380	C4 (153)	C3 (90)	C2 (100)	C1 (108)
5	370	C4 (150)	C1 (140)	C3 (121)	C2 (142)
6	360	C1 (33)	C4 (54)	C2 (8)	C3 (46)

Factorial Split Plots

Helicopter Experiment

SE engineers applied new split-plot tools in DX9 to paper helicopters—often deployed as an in-class exercise per DOE guru George Box. By restricting randomization of HTC design factors, they saved a lot of time in the building.*

*(See "Employing Power to 'Right-Size' Design of Experiments," *ITEA Journal* 2014; 35: 40-44.)



Conqueror trials-FT avg only

"Oftentimes, complete randomization is extremely inefficient, or even totally impractical. One or more of these parameters (e.g. altitude) can be altered a minimum number of times during testing by rearranging the test run order."

Alex Sewell, 53rd Test Management Group, 28th Test and Evaluation Squadron, Eglin AFB (Sewell et al, 2009)

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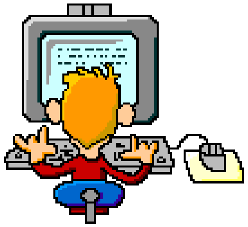
Definitive Screening Designs (DSD)*

- Near-minimal run (2K+1) with three (not just two!) levels
  - Thus factors must be continuous numeric*
    **(Can be combined with some categoric factors.)*
- Resolve main effects clear of any two-factor interactions and squared terms.
  - But beware of confounding of 2FIs with X^2s.

[A^2] = A^2...-0.75 * BC + 0.75 * BD + 0.75 * BE + 1.25 * CD + 0.75 * CE - 1.25 * DE

- Good alternative to MR4s if the region might be curvy.



DSD k5.dxpx

* Jones, Nachtsheim ,"A Class of Three-Level Designs for Definitive Screening in the Presence of Second-Order Effects," January 2011, Journal of *Quality Technology*

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Conclusion

- Trim out the OFAT!

By making use of multifactor design of experiments (DOE) starting with simple two-level factorials, split plots or new-fangled definitive screening designs, you will greatly accelerate quality initiatives aimed at process troubleshooting and improvement.

Educational Communications on DOE

- Bimonthly *DOE FAQ Alert* e-mail
  - Subscribe at: www.statease.com/doealertreg.html.

- Triannual *Stat-Teaser* newsletter
  - Link to digital posts provide via *DOE FAQ Alert*
  - Sign up to get them directly by email from homepage

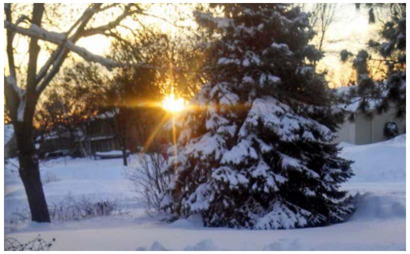
- StatsMadeEasy Blog at www.statsmadeeasy.net
  Enjoy periodic posts with *"A wry look at all things statistical and/or scientific with an engineering perspective."*

Statistics Made Easy®

Best of luck for your experimenting!

Thanks for listening!

-- Mark



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