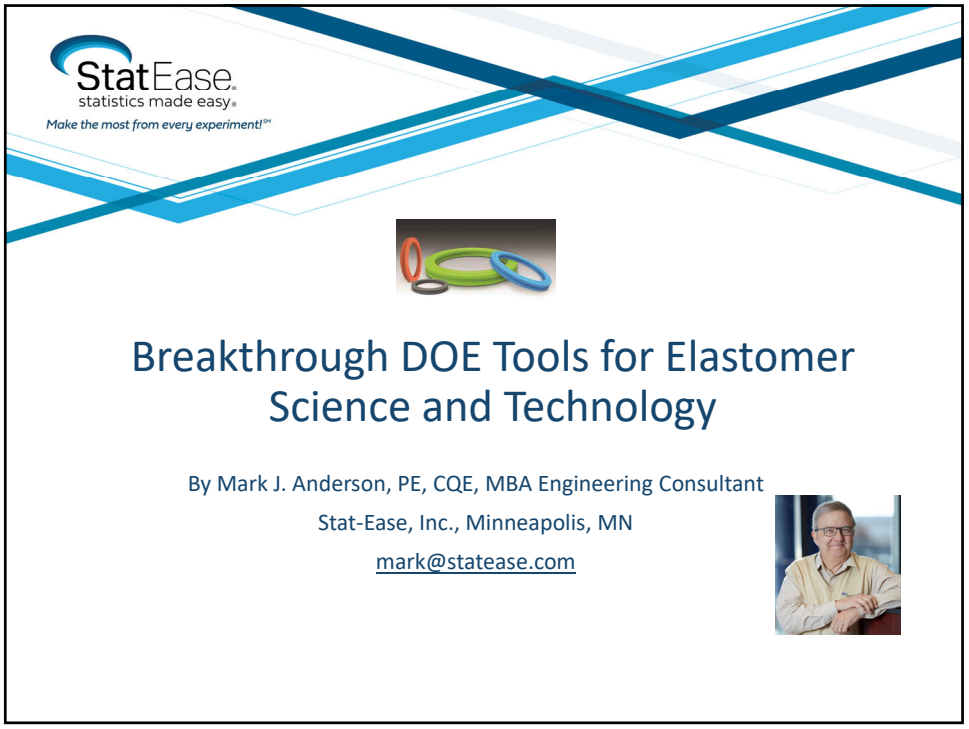
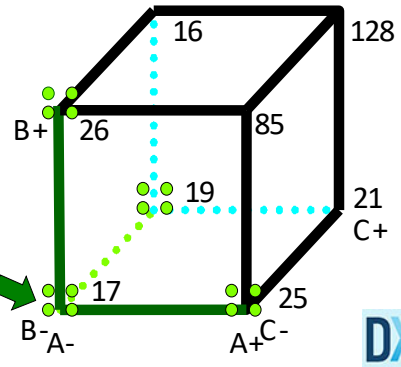


- Multiple versus one factor at a time testing
- Elastomer case studies by design type:
  - ✓ Factorial: Rubber-to-metal bonding Failure
  - ✓ Response surface: Vulcanization
  - ✓ Mixture: Play putty
  - ✓ Combined mixture & categorical: Composite material
- Conclusion

Multi-Factorial (vs OFAT)

Bearing life in hours from accelerated test



Start point for One Factor at a Time (OFAT). Goal: 40 hours.

Relative efficiency = 16/8

2 to 1!

DX

Bearings with elastomer cage Rebuld with d/s 40/15 & analyze. Do 2nd model w log transform.

DOE for Elastomer Science 4

*The rest of the story**
DOE Saves the Company

Swedish SKF, inventors of the rolling bearing (1919), nearly went of business in the 1970's due to Japanese competition. Led by Christer Hellstrand, they abandoned one factor at a time (OFAT) for multifactor DOE. As a result, SKF improved bearing life ten-fold from 41 million to 400 million revolutions at reduced cost.**

"Christer showed them how they could test two additional factors 'for free' – without increasing the number of runs and without reducing the accuracy of their estimate of the cage effect."

-George Box, *Improving Almost Anything: Ideas and Essays*

*("Breaking the Boundaries," *Design Engineering*, Feb 2000, pp 37-38.)
**(US Patent 4227754 www.freepatentsonline.com/4227754.pdf)

Factorial:
*Rubber-to-metal bonding failure**

Via a two-level factorial, engineers at a custom rubber molder uncovered a breakthrough combination of material and manufacturing settings that reduced scrap from 10% to zero. Over two days (blocked), they tested:

A. Vulcanizing temperature, 295 – 395 deg F
B. Bond material, B1 vs B2 (two types—kept confidential)
C. Bond thickness, 1 – 2 coats
D. Injection pressure, 1000 – 3000 psi
E. Bond settling time, 1 – 120 minutes

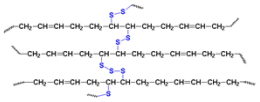
Investigating the effects on fraction defect due to:

1. Inadequate cure
2. Low bond (poor coverage rubber on metal)

RR factorial
Rebuild, showing impact of blocking
Skip diagnostics, note Cure outlier, flip Bond axes

*("Design of Experiments Reduces Rubber Scrap by 90%," *Rubber & Plastics News*, September 2008, Mark J. Anderson.)

Response Surface
*Vulcanization process**



Elastomer scientists aimed to produce a steel-reinforced elastomeric structural bearing operating beyond a customer's required compressive stiffness (CS) and the European standard for vertical deflection under maximum load (VDUML). These physical properties being related to the crosslinking of the rubber led to a Box-Behnken experiment on these factors in the vulcanization process:

A. Time, 140 – 160 min.
B. Temperature, 100 – 120 deg C
C. Pressure, 160 – 180 bar

Vulcanization RSM
Overall desirability & sweet spot

*("Optimisation of elastomeric bearings' vulcanisation process using response surface methodology and desirability function approach", *Journal of Rubber Research*, Boyaci & Bayna, 2019.)

DOE for Elastomer Science 7

Mixture design
*Play Putty**

In this fun and educational formulation, a chemical reaction occurs between a polymer (polyvinyl acetate in white glue) and a crosslinker (borax). Water participates as a solvent and modifies the physical properties (rebound and deformability) of the resulting delightfully dilatant (non-Newtonian) material. To practice what we preached, my fellow chemical engineer and colleague at Stat-Ease took over the office kitchen to experiment on this play putty—varying the components by weight as follows:

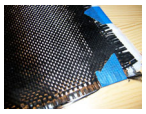
A. Borax, 1 – 3%
B. White glue, 40 – 59%
C. Water, 40 – 59%

Play putty mix (quad modeled)
Overall desirability & sweet spot

*("Mixture DOE uncovers formulations quicker," *Rubber & Plastics News*, October 21, 2002, Anderson & Whitcomb.)

DOE for Elastomer Science 8

Mixture & Categorical
*Composite Material**



Aerospace engineers aimed to maximize the impact and tensile strength of an epoxy-fiber composite by varying the materials as follows (a 4-component mixture combined with two categoric factors):

A. Elastomer, 5 – 20% (two types—Factor E)
B. Fiber, 54 – 62% (three types—Factor F)
C. Hardener, 0 – 100%
D. Epoxy resin, 0 – 100%

Subject to this multicomponent ratio constraint to achieve proper stoichiometry for the reaction:

C/D. Epoxy/hardener, 1.8 – 2.1

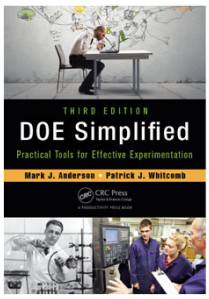
Composite
Rebuild to show ratio constraint & KCV
Max impact (100-140) & tensile (1200-1400)

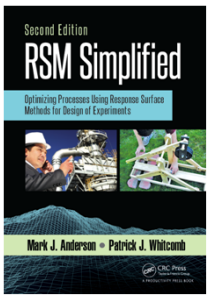
*(Mixture Design for Optimal Formulation workshop, Stat-Ease, 2021, Section 7.)

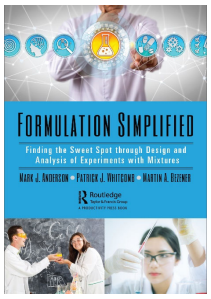
Conclusion

- Via a series of case studies, this webinar demonstrated multifactor testing tools for elastomer science and technology.
- Design-Expert empowers experimenters to quickly converge on the "sweet" spot—factor settings that meet all specifications.
- Engineers and scientists working with rubber and other elastomers will do well by applying :
  - Factorials for screening and characterization,
  - Response surface methods (RSM) for process optimization, &
  - Mixture design for optimal formulation.

References
*DOE/RSM/Formulation Simplified Series**







**Anderson, et al, Taylor & Francis, Productivity Press, New York, NY.*

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