

Custom measurement system design and qualification, a case study

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Learning objectives

- **How we addressed a seemingly impossible measurement challenge**
- **Our sequential, statistical approach**
- **Tricks of the DOE and MSA trade**

Presentation framework

- Risk, background
- DOE for fixture design*
- V-FMEA & MSA for test method*

**All data are simulated*

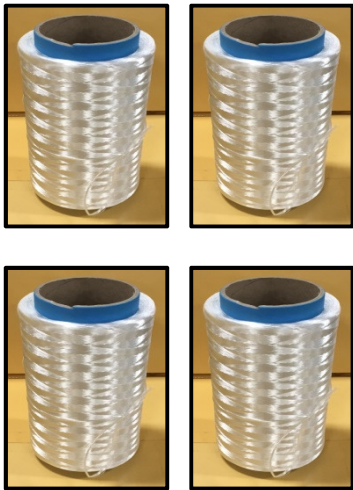
Risk, in context

***The ships
need to stay
attached...***

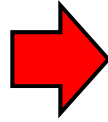


Risk guided our decisions

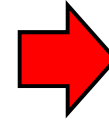
The process of interest



HMPE Fibers



Twister



Twisted yarn

And a few more steps to make rope...

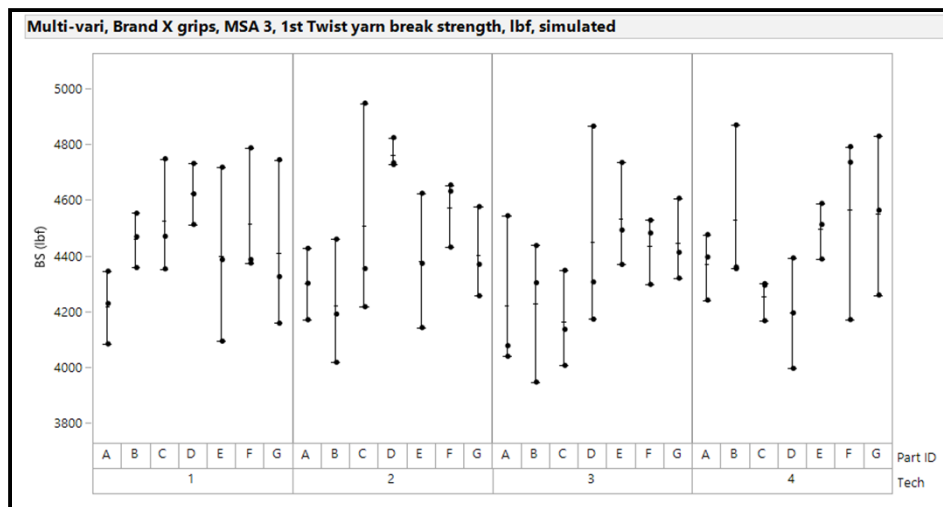
However...

- **HMPE is slippery**
- **Multi-ton break strength (!)**
- **Twisted in 2 directions (S, Z)**
- **Destructive test ☹️☹️☹️**



Now the real bad news...

**Off-the-shelf grips useful for PET
or small HMPE only**



So now what do we do???

Work sequence

Prepare	Collect the facts
Model cause & effect	Iterative DOE to optimize grips
Look for trouble	V-PFMEA and iterative MSA to optimize process

Where to start?

The wisdom of colleagues

- Lab Technicians
- Operators
- Maintenance staff
- Engineers



This step pays big dividends

Presentation framework

- Risk, background
- **DOE for fixture design***
- V-FMEA & MSA for test method*

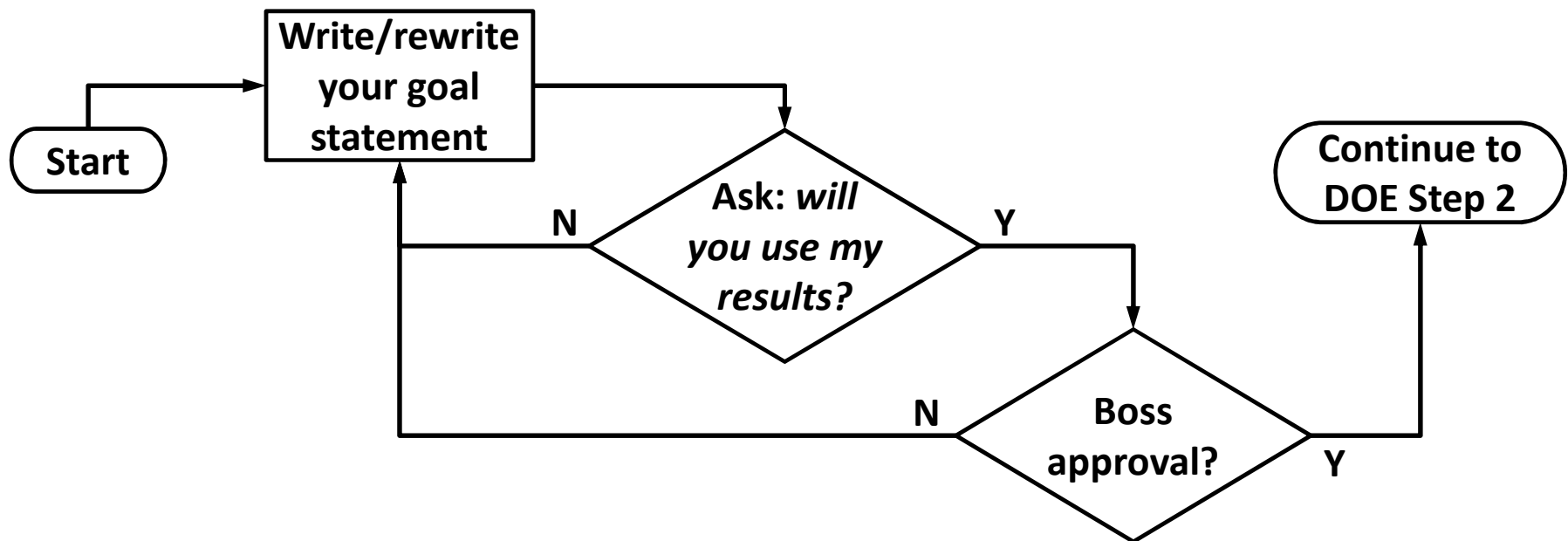
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DOE Step 1: Clear goal statement

Develop break strength measurement fixtures for twisted yarn type X, Y and Z, with a 90% chance to detect desired differences with sample sizes ≤ 5 when tested per SRT-100.

Begin with the end in mind

Trick-of-the-DOE-trade



DOE Step 2: Choose Strategy

Strategy	Essentials
Comprehensive (<i>I-optimal</i>)	Response Surface Model, but more work
Reserved (<i>Factorial</i>)	Conserves resources but main effects, interactions only
Screening (<i>DSD</i>)	Separates vital few from trivial many, ✓ but limitations for categorical & mixtures

DOE Step 2: Choose Strategy

**9 factors to study,
Definitive Screening needed**

Capstan diameter	X₆
Surface COF	X₇
X₃	X₈
X₄	X₉
X₅	



DOE Step 3A: Create a Plan

DOE - JMP [2]

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

Definitive Screening Design

Responses

Add Response Remove Number of Responses...

Response Name	Goal	Lower Limit	Upper Limit	Importance
BS, lbf	Maximize	.	.	.

optional item

Factors

Continuous Categorical Remove Add N Factors 1

Name	Role	Values
X1	Continuous	-1 1
X2	Continuous	-1 1
X3	Continuous	-1 1
X4	Continuous	-1 1
X5	Continuous	-1 1
X6	Continuous	-1 1
X7	Continuous	-1 1
X8	Continuous	-1 1
X9	Categorical	L1 L2

Specify Factors

Add a Continuous or Categorical factor by clicking its button. Double click on a factor name or level to edit it.

Continue

DOE - JMP

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

Definitive Screening Design

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X5	Continuous	-1 1
X6	Continuous	-1 1
X7	Continuous	-1 1
X8	Continuous	-1 1
X9	Categorical	L1 L2

Design Options

No Blocks Required

Add Blocks with Center Runs to Estimate Quadratic Effects

Add Blocks without Extra Center Runs

Number of Blocks 2

Number of Extra Runs 4

Make Design

DOE Step 3B: Check the plan

2019-09-18 DSD - JMP

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

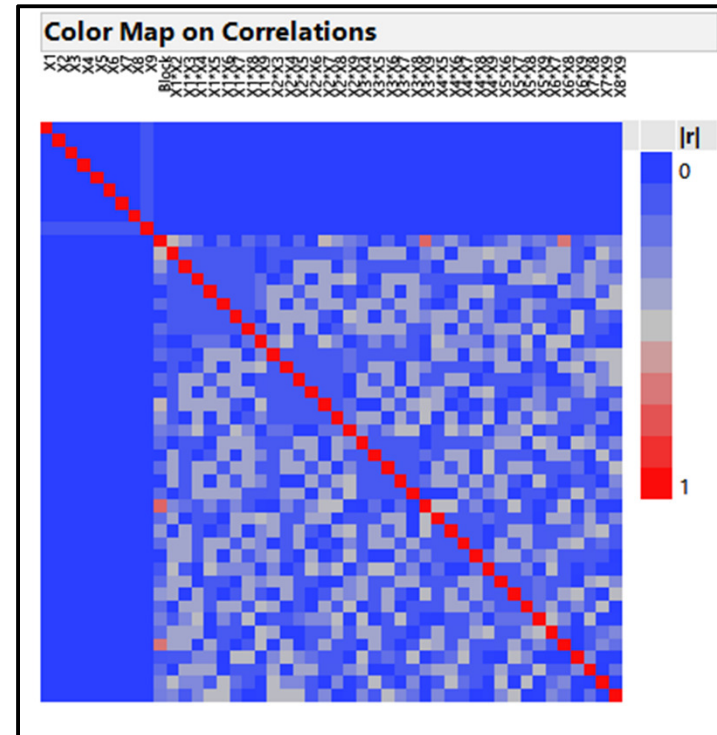
2019-09-18 DSD

- Design Definitive Screen
 - Fit Definit...creening
 - Evaluate Design
 - DOE Dialog
 - DOE Simulate
 - Fit Model
 - Fit ME model

	Block	X1	X2	X3	X4	X5	X6	X7	X8	X9	Column 11
1	1	1	-1	-1	-1	1	-1	0	1	L1	
2	1	-1	-1	-1	1	1	1	-1	1	L1	
3	1	1	1	-1	-1	-1	-1	1	-1	L2	
4	1	-1	1	-1	1	0	-1	1	-1	L1	
5	1	0	0	0	0	0	0	0	0	L1	
6	1	-1	1	0	-1	1	-1	-1	-1	L2	
7	1	1	-1	0	1	-1	1	1	1	L1	
8	1	-1	1	1	1	-1	1	0	-1	L2	
9	1	0	1	1	1	1	1	1	1	L2	
10	1	-1	1	-1	-1	-1	1	1	1	L1	
11	1	0	0	0	0	0	0	0	0	L2	
12	1	1	-1	1	1	1	-1	-1	-1	L2	
13	1	0	-1	-1	-1	-1	-1	-1	-1	L1	
14	1	1	-1	1	-1	0	1	-1	1	L2	
15	2	-1	1	1	-1	1	0	-1	1	L1	
16	2	-1	-1	-1	-1	1	1	1	-1	L2	
17	2	-1	-1	1	-1	-1	-1	1	1	L2	
18	2	1	-1	-1	1	-1	0	1	-1	L2	
19	2	1	1	-1	1	1	1	-1	-1	L1	
20	2	-1	-1	1	0	-1	1	-1	-1	L1	
21	2	1	1	-1	0	1	-1	1	1	L2	
22	2	1	1	1	1	-1	-1	-1	1	L1	
23	2	-1	0	-1	1	-1	-1	-1	1	L2	
24	2	-1	-1	1	1	1	-1	1	0	L1	
25	2	1	0	1	-1	1	1	1	-1	L1	
26	2	1	1	-1	-1	-1	1	-1	0	L2	

Columns (13/1)

- Block *
- X1 *
- X2 *
- X3 *
- X4 *
- X5 *
- X6 *
- X7 *
- X8 *
- X9 *
- Column 11
- BS, simulated
- BS, sim

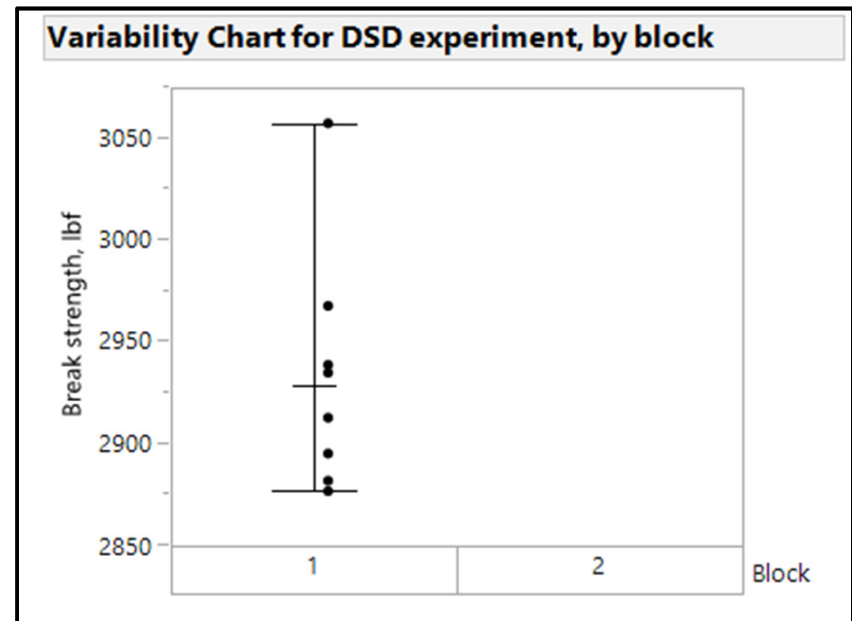


Tricks of the data collection trade

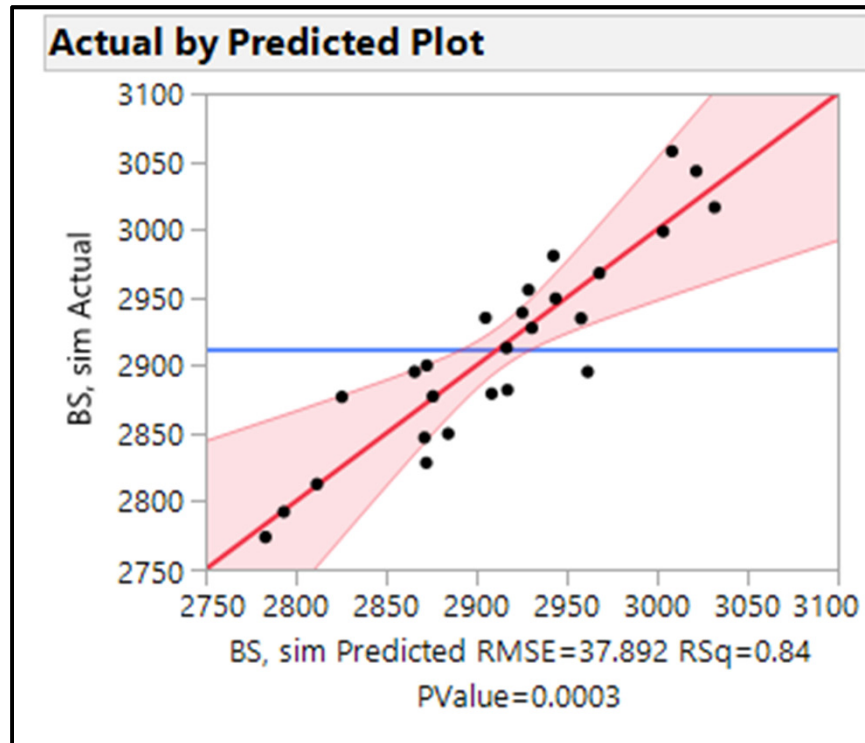
- **Do the work yourself, where practical**
- **Always do at least one practice run**

Tricks of the data collection trade

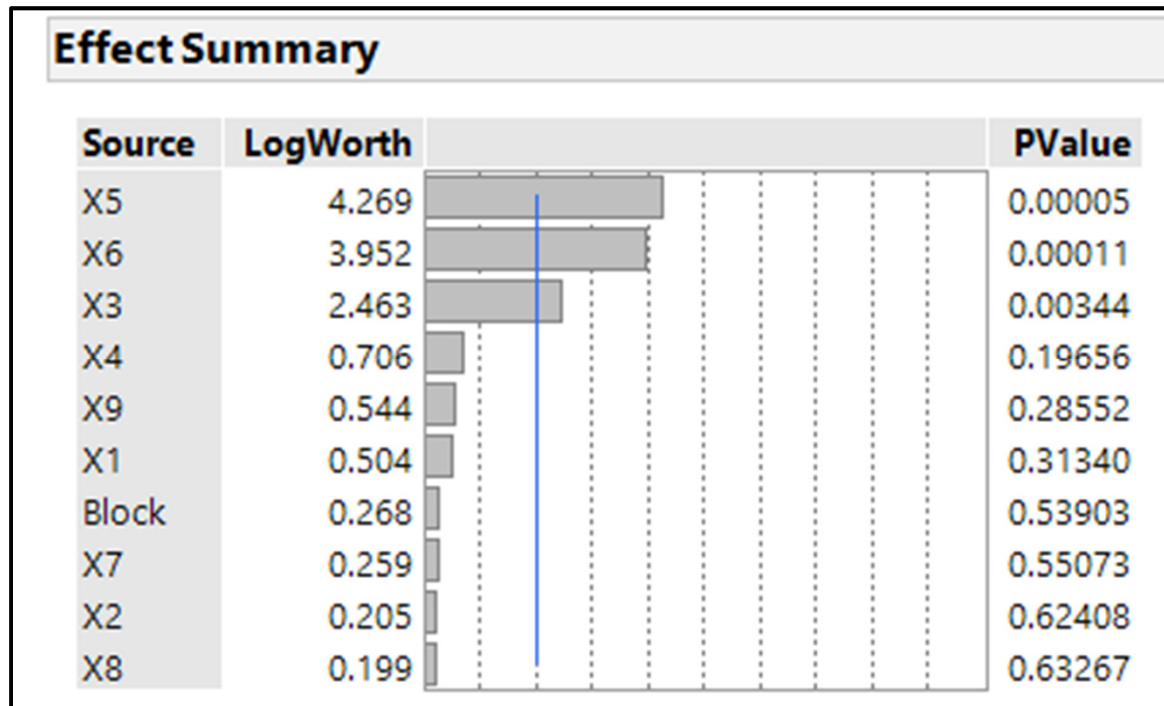
- **Beware arbitrary deadlines**
- ***Manage the Managers* with JMP graphics**



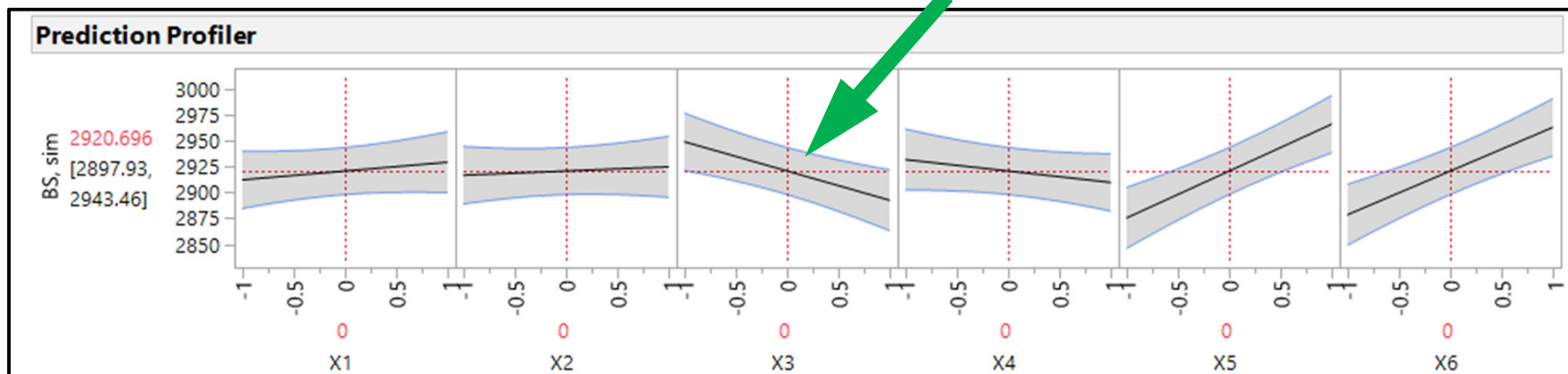
DOE Step 4A: Evaluate the results



DOE Step 4A: Evaluate the results

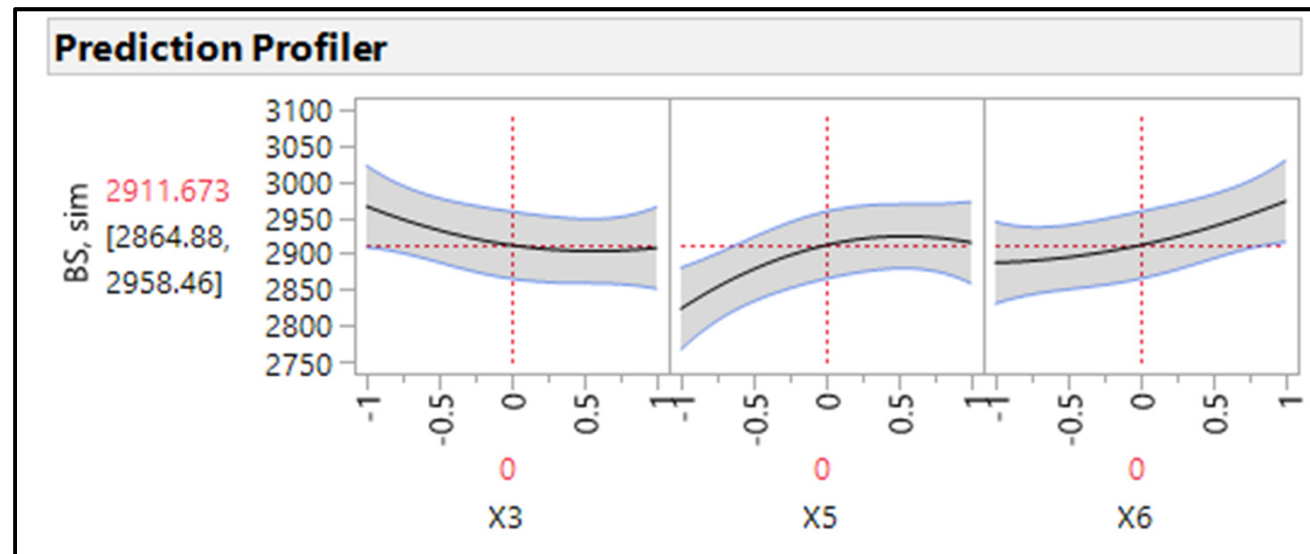


DOE Step 4A: a similar view



DOE Step 4B: augment & reduce

Grip
design
guidance

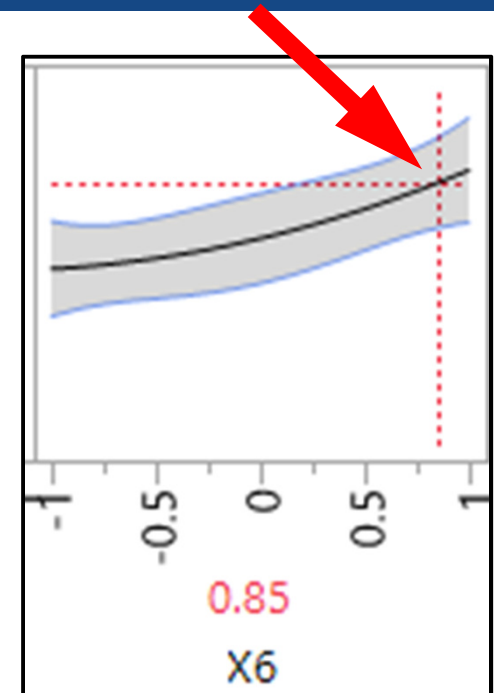


DOE Step 5: acknowledge others

- **Give a loud, clear shout-out to those that helped you along the way**
- **Skip this step at your own peril...**

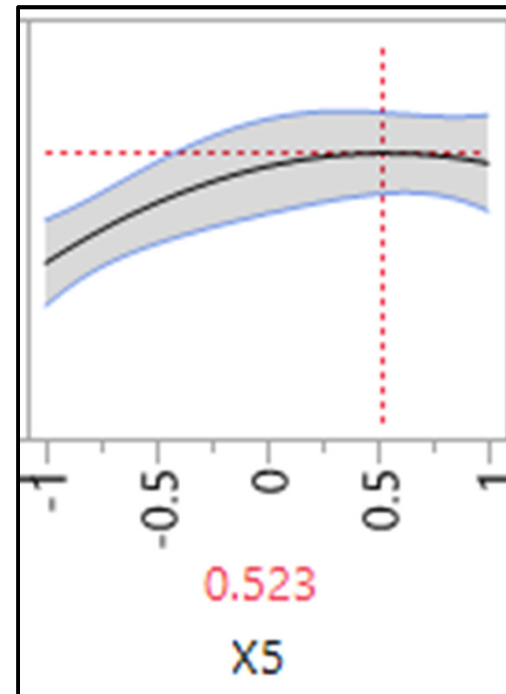
Trick of the DOE trade

- Be careful asking statware to optimize
- Instead, consider safety, practicality & cost and choose a “balanced sweet spot” away from the edge
- *Only the paranoid survive* (Andy Grove)



Trick of the DOE trade

Take full
advantage of
friendly response
curves...



DOE results

Because of the risk, we followed up the DSD with two I-optimal designs with X_3 , X_5 and X_6 and a new factor, X_{10} . Then, we had our grip design.

DOE results

**But, would the grips
give us good data
day in, day out?**

Presentation framework

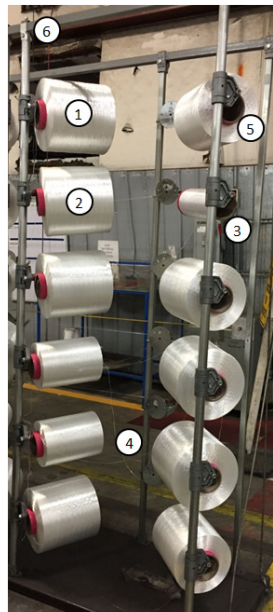
- Risk, background
- DOE for fixture design*
- **V-FMEA & MSA for test method***

**All data are simulated*

Visual FMEA

- What could go wrong?
- What can we do about it?

Visual-PFMEA-worksheet



Process-step	T-300-twisters
Process-sub-step	Creel-rack-payoff
Location	Multiple-machines-in-both-Lafayette-and-Ferndale
Date-of-issue	December-6,-2016
Written-by	Huynh,-Khong,-Czupryna

Present-state,-calculate-SOD-based-on-1-5-scale-from-Q-SOP-01

ID	POTENTIAL-FAILURE	POTENTIAL-EFFECT-&-CAUSE	SEV	OCC	DET	SOD
1	Bad-winding-from-supplier	Poor-payoff-leading-to-breakage	2	2	1	221
2	Wrong-fiber-selected-by-operator	Unacceptable-rope-performance-due-to-fiber-properties	4	2	3	423
3	Pin-hardware-loosens	Fiber-bobbin-falls-and-breaks-fiber	2	1	1	211
4	Piggyback-not-tied-together	Ply-quantity-reduced-by-1	3	3	2	332
5	Cardboard-tube-damaged	Bobbin-off-center	1	2	1	121
6	Frame-hardware-loosens	Fiber-bobbins-fall-and-break-fiber	3	1	1	311

Action-taken,-if-SOD>400,-new-SOD-score

ID	CURRENT-CONTROLS	ACTION-TAKEN	RISK-ABATEMENT	SEV	OCC	DET	SOD
2	Systematic-pallet-placement,-operator-knowledge-of-cardboard-tube-colors	Floors-marked-with-fiber-type-and-cardboard-tube-colors-documented	Operator-clarity	2	2	3	223

Trick-of-the-safety-trade

Use visual FMEA to review processes for safety hazards



MSA design

- **7 parts x 3 operators x 3 measurements = 63 datapoints**
- **EMP* analysis**
- **Assume it'll be iterative (it was)**

**Evaluating the Measurement Process (Donald J. Wheeler)*

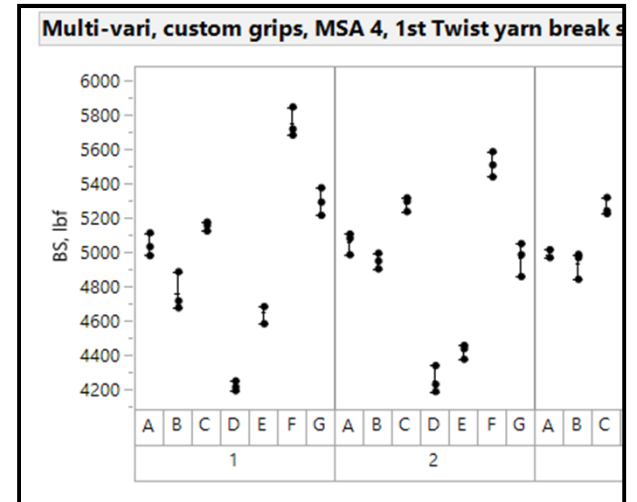
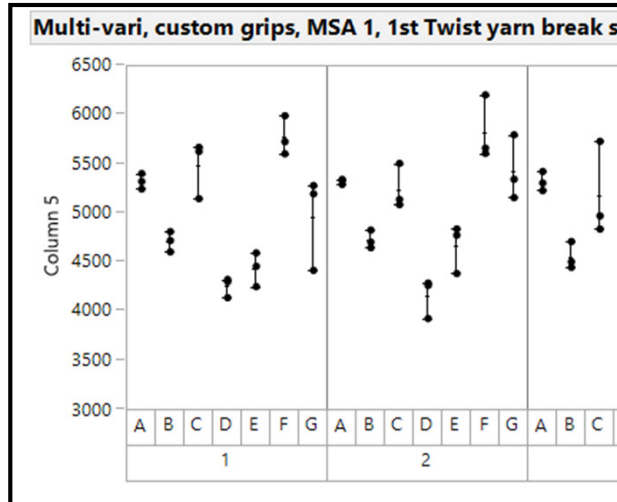
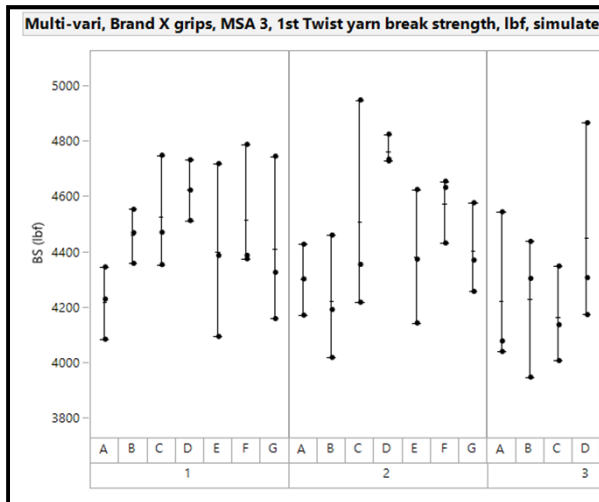
Persistence pays...

Off-the-shelf grips

MSA,
Rev 1

Iterations

MSA,
Rev 5



Optimize the system

Sweat the human elements

- *safety hazards: sonic, electrical, flying debris...*
- *left handed people*
- *vision-impaired*
- *height differences*

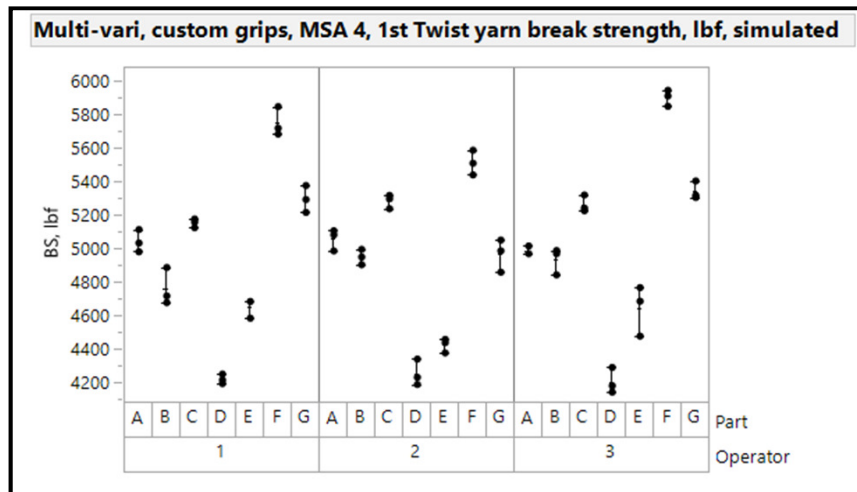
Optimize the system

Apply lean principles

- *Avoid chaos & clutter, use 5S*
- *Choose the right light (4200 °K)*
- *Avoid “Orwellian Bias”*

Tricks-of-the-MSA-trade

Use Variability Charts as an easy-to-understand visual MSA for some audiences.



-VS-

EMP Results

EMP Test	Results	Description
Test-Retest Error	74.66	Within Error
Degrees of Freedom	38.365	Amount of information used to estimate within error
Probable Error	50.358	Median error for a single measurement
Intraclass Correlation (no bias)	0.9804	Proportion of variation attributed to part variation without including bias factors
Intraclass Correlation (with bias)	0.9683	Proportion of variation attributed to part variation with bias factors
Bias Impact	0.0121	Amount by which the bias factors reduce the intraclass correlation

System	Classification
Current (with bias)	First Class
Potential (no bias)	First Class

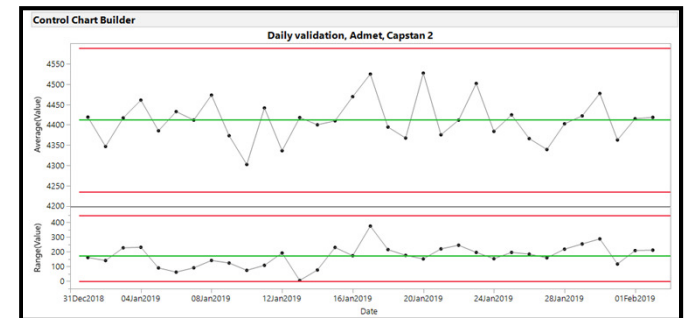
Monitor Classification Legend

Classification	Intraclass Correlation	Attenuation of Process Signal	Probability of Warning, Test 1 Only*	Probability of Warning, Tests 1-4*
First Class	0.80 - 1.00	Less than 11%	0.99 - 1.00	1.00
Second Class	0.50 - 0.80	11% - 29%	0.88 - 0.99	1.00
Third Class	0.20 - 0.50	29% - 55%	0.40 - 0.88	0.92 - 1.00
Fourth Class	0.00 - 0.20	More than 55%	0.03 - 0.40	0.08 - 0.92

* Probability of warning for a 3 standard error shift within 10 subgroups using Wheeler's tests, which correspond to Nelson's tests 1, 2, 5, and 6.

Continued success...

- Entropy is merciless
- We validate with a “standard yarn” every morning
- Control chart signals mean STOP immediately



Case study take-away list

- **Statistical thinking: not optional**
- **Iterative DOE for fixture design, DSD or I-optimal, depending on # of factors**

Case study take-away list

- **Iterative MSA and Lean Principles to tune test method**
- **Neither is a spectator sport, we must get our hands dirty (*but Mama, that's where the fun is...*)**

Last point

This approach is useful for other custom equipment designs, torque measurement fixtures, for example.

Questions? Comments?

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