DOE: From Hunch to Crunch

A Tremco Case Study

Richard Wiltse
Tremco Inc.
Master Black Belt

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Today's Program

- Welcome
- Introduction of MBB Webcast Series
  - Ellen Milnes, MoreSteam.com
- Presentation:
  - Richard Wiltse, MoreSteam.com
- Open Discussion and Questions

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Today's Presenter

Richard Wiltse

Tremco Commercial Sealants & Waterproofing

- Divisional Black Belt developing Lean Six Sigma teams and continuous improvement culture across organization
- Founded the AME Lean Consortia Cleveland chapter
- B.S. – Illinois State University, MBA – Shenandoah University, Master Black Belt – Ohio State/MoreSteam.com

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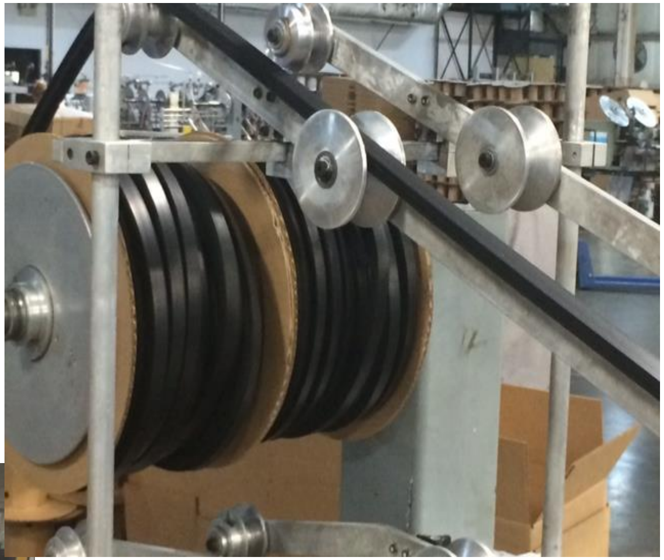
A Tremco Case Study: Silicone Viscosity

- DOE: Effect of processing and time on silicone viscosity



Background information

- Silicone rubber is produced in small, 175 lb batches that cycle approximately every 15 – 20 minutes
- “Small adds” of various raw’s are weighed and sent to a mixer for a 15 minute mix time
- The mixed material is then sent to a mill where it is milled for several minutes
- The milled material is sent to an extruder and extruded into strips, then placed in a tote for shipment
- Various Quality checks are performed on each batch, including viscosity
- Shelf life

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Tremco Case Study: DOE Silicone

Effect of processing and time on silicone viscosity: AGENDA

- Hunch and clues that a DOE may be needed
  - How to spot when a DOE may be the best approach
- What are we out to achieve?
  - Problem definition and supportive data, DMAIC
- Critical Success Factors (CSF's)
  - What can make or break your experiment! Culmination of experience
- Additional DOE Benefits
  - Getting the most from your experiment
- Analyze the Experiments!

Clues that a DOE may be needed

- There exists a quality issue that comes and goes….
- Everyone has a reason why the issue occurs….yet the quality problem persists
- There exists little or no supporting data…only opinions and perceived observations
- No one – including Engineers, Operators, and Front Line Personnel, can precisely define process specifications

Define: What are we out to achieve?

Project Charter

Project Name:	**Silicone variance reduction**	**Process Metrics: Cpk values**				
Project Sponsor:	Chris Kerr- primary Ken Recko - back-up	Capability Analysis	BL .50	Goal 1.33	B-I-C 2.0	
Project Originator:	Ryan Eichar	Start Date:			7/1/13	
Project Manager:	Richard Wiltse	**Duration (in months)**			6	
Project Level:	2.00	Strategic Imperative Aligned to:			**LEAN**	

Problem Statement:

Over the course of the last several years, Silicone 557 has been rejected 11 times for being sticky, gummy, brittle, and losing feed. These rejections were all attributed to changes in viscosity levels. There was no specification for viscosity.

Goal Statement:

1) Determine the proper viscosity specifications, 2)Determine critical process variables 3) Try to achieve Ppk 1.33 4) Determine outcome on manufacturing

CSF # 1: Agreed upon charter

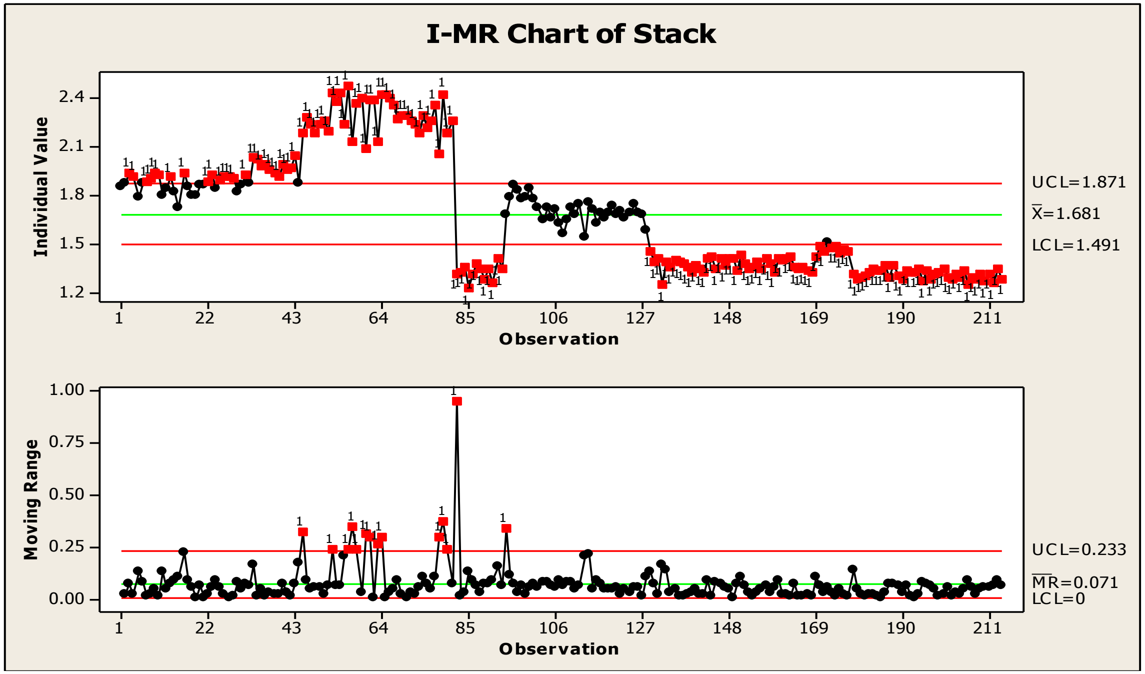
- Reduces scope expansion
- Eliminates confusion over problem severity
- Properly directs Team forward

Measure - Historical baseline

MEASURE

Gathered data from Supplier Certs

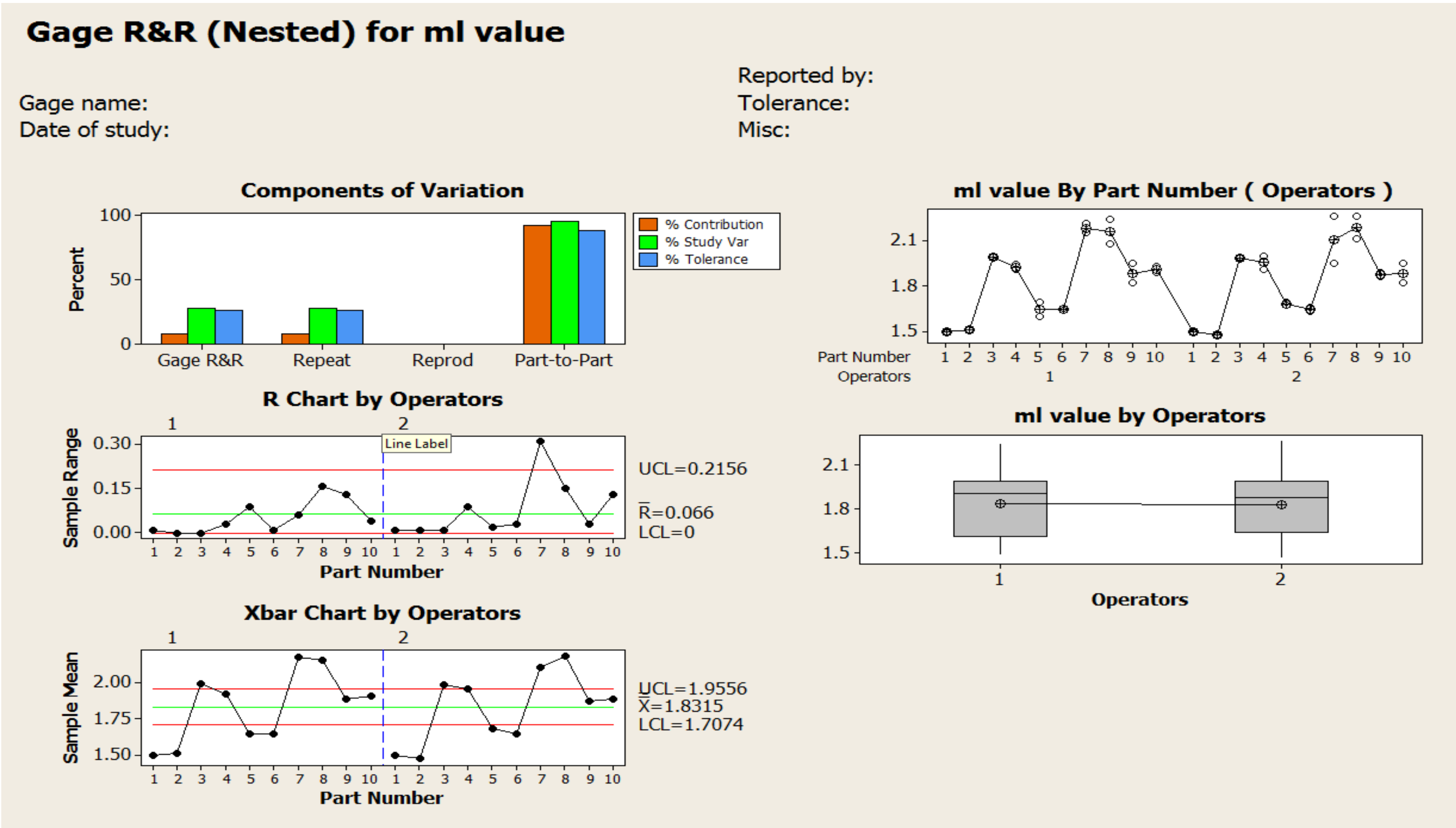
Evidence of both trending and stratification



CSF#2: Do your homework on baseline data

- Demonstrates a need
  - Our data clearly shows excess variability that is detrimental to manufacturing
- Allows the ability to quantify an improvement
  - "If you don't know where you are, how will you get to where you are going?"

Measure - Gage R&R



CSF#3: Insist on Measurement Standard Work

- Document, document, document
  - Procedural drift
- Will take several trials to ensure complete understanding

Analyze

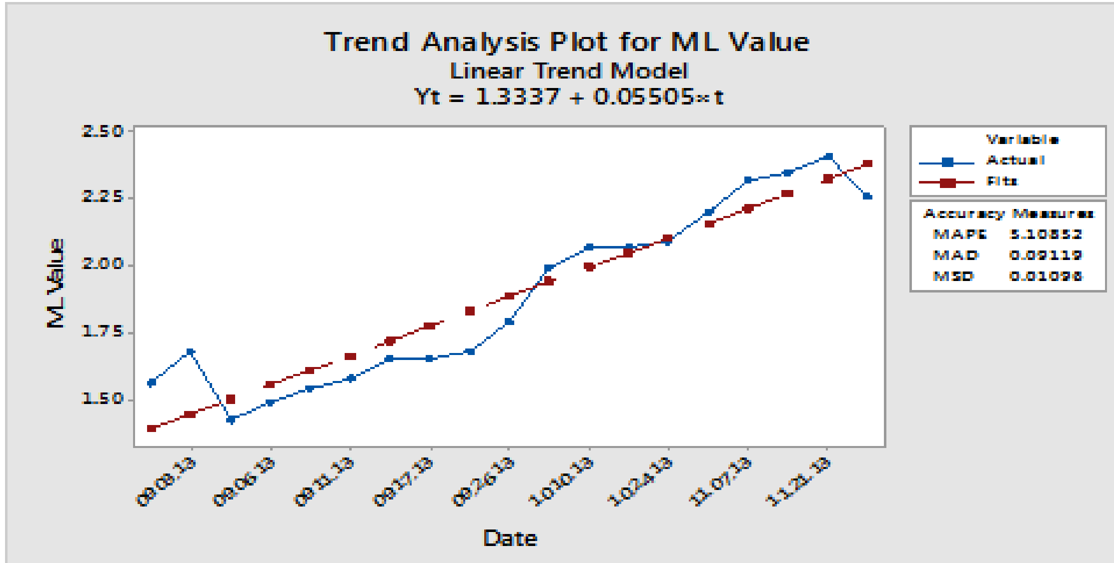
- What is the true shelf life of Silicone Rubber?
- What viscosity levels should we trial at (in extrusion) in order to start specification development?
- What are potential processing factors (at our supplier) that influence viscosity?

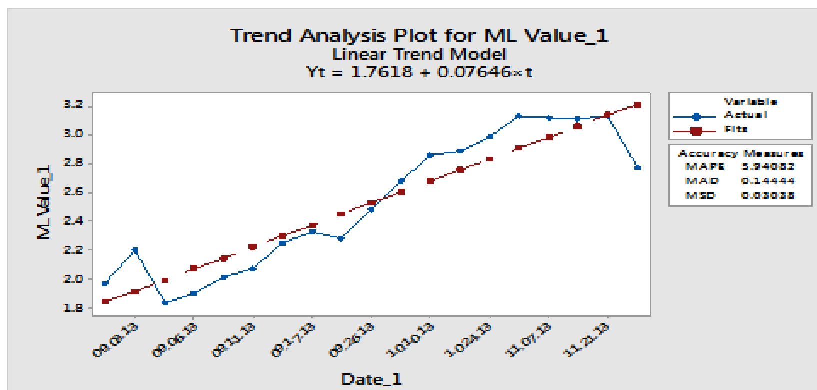
Analyze: Time Series Trend Analysis, 10 weeks

Silicone changes in viscosity over time. How much depends on starting point. Regression coefficients:

ML	Coefficient
1.5	.055
2.0	.076
2.5	.164

Extrusions ran well at the 2.0 + - .3 range





DOE benefit – specification analysis

- DOE's (Factorial or OFAT) provide samples that properly defines specifications
  - Data based specifications, as opposed to "Industry Standards"
  - Samples for both setting and confirming specs

Analyze: Factorial DOE - Brainstorming

**Please rank 1-5, with 5 having the most impact.

Possible Inputs for Variation:	Ken	Alan	Jim	Sara	Rick	Average Ranking	RANK	Notes from Dec meeting:
	Weight of Input to Output							
Raw Materials								
• Durometer of Base	4	5	3	5	5	4.40	**2**	
• Plasticity of Base	5	5	5	5	4	4.80	**1**	Co-variate - cannot change
• Age of Base	3	1	3	2	2	2.20		
• Age of Catalyst	3	1	3	3	2	2.40		
• Age of Other Ingredients	2	1	2	2	1	1.60		
• Particle Size of Powders	1	1	2	1	3	1.60		*Co-variate: Plasticity of Base*
• Color Variability	1	1	1	1	3	1.40		
Storage Condition of Raw Materials	2	1	2	2	2	1.80		
Weigh-up of Raw Materials	5	2	5	5	5	4.40	**2**	
Operators								
• Weigh-up Operator	5	2	5	5	4	4.20	**4**	Exclude - this is simulated by Weigh up of raw materials
• Mixer Operator	4	2	4	4	3	3.40	**9**	
• Mill Operator	3	1	3	3	4	2.80		
• Extruder Operator	5	1	3	3	3	3.00		
• Lab Technician	2	1	2	2	3	2.00		
Mixer								
• Dispersion	5	1	4	4	5	3.80	**5**	Exclude and use Mixer Time as a
• Heat / Temperature	4	1	5	4	5	3.80	**5**	
• Time	4	3	4	4	3	3.60	**7**	Out - does not vary
Mill								
• Temperature	3	1		3	5	3.00		
• Time	4	2	3	3	5	3.40	**9**	
• Thickness	3	2	2	2	3	2.40		
Number of Batches Mixed per Run	2	1	2	2	1	1.60		
Time Between Mixing and Extruding	2	1	3	4	4	2.80		

DOE factors:	L1	L2
Base Durometer	55 - 56	62 - 65
Catalyst	-5%	5%
Mixer Temperature	Co-variate - cannot change	
Mill Time	1 min	4 min

CSF#4: Facilitated Brainstorming

- Use a skilled facilitator that is neutral..i.e…no bias
- Involve the right people
- Use “Round Robin” to ensure everyone has an equal chance of contributing
- Multi vote potential factors

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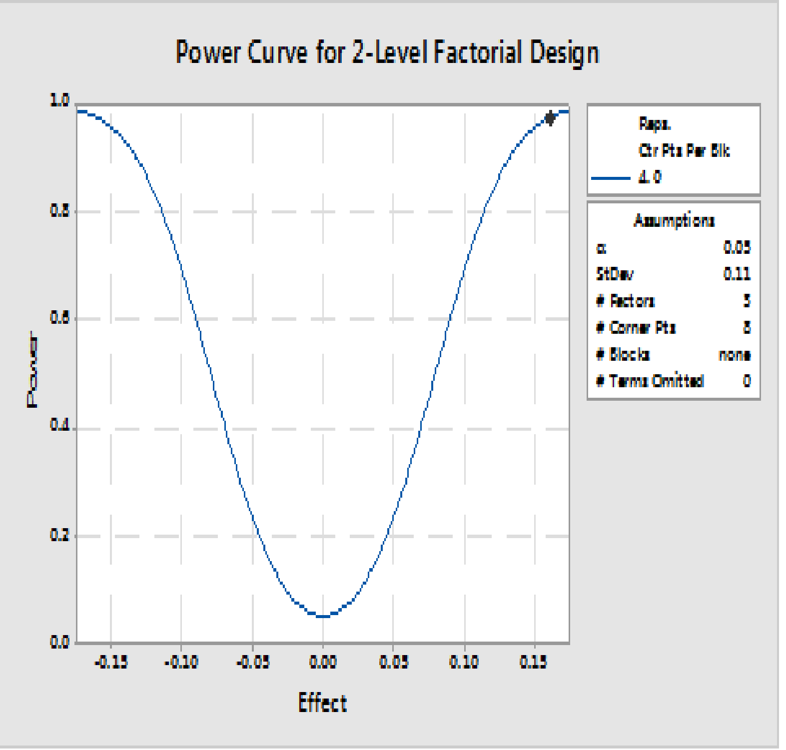
Improve: DOE

Factor	Low	High
A Base Durometer	55	63
B Catalyst	-0.05	0.05
C Mill time	1	4

Covariate: Temp of material

Response: ML viscosity Replicates: 4



CSF#6: Factor Level Settings

- Study what the historical factors ran at – review set up sheets
  - Many Operators have their own set up sheets

- For initial screening experiments like this, Level 1 and Level 2 should be set at the extremes of normal processing parameter values
  - Associates unfamiliar with DOE will tend to over inflate parameter values

CSF#7: Strive for adequate power through additional replicates

- Associates unfamiliar with DOE often do not see the need for replicates and randomization

  - Power: "the likelihood you will find a significant effect when one truly exists"
  - "You get what you pay for"
  - Committing resources, time, and material … jump in with both feet

Monitoring the DOE

- Recommend to have at least two people monitoring the experiment
    - Are factor levels correct?
    - Has the process levelled out since the last change?
    - Are we randomized?
    - Are measurements of the Quality Characteristic being performed correctly?
- Check and double check each other

CSF #7: Have a Plan for Monitoring

- There are a million ways your DOE can go wrong….
  - False signals
- There is only one way for the DOE to go right

Have a Plan !!!!!

- Review randomization and overall design
- Who will be monitors
- Sample identification
- Sample placement and measurement

Review

- DOE Critical Success Factors:
  - CSF #1 Proper charter
  - CSF #2: Good historical baseline
  - CSF #3: Adequate Gage R&R w/ Std Work
  - CSF #4: Facilitated Brainstorming
  - CSF #5: Correct Factor Levels
  - CSF #6: Adequate Power
  - CSF #7: Proper monitoring

- DOE Additional benefit(s)
  - Sample based specifications

ANOVA

- **Factorial Regression: Results versus Temp of mate, base duromet, Catalyst, ...**

- Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	0.587247	0.073406	10.43	0.000
Covariates	1	0.006659	0.006659	0.95	0.341
Temp of material	1	0.006659	0.006659	0.95	0.341
Linear	3	0.324007	0.108002	15.35	0.000
base durometer	1	0.319617	0.319617	45.42	0.000
Catalyst	1	0.002421	0.002421	0.34	0.563
mill time	1	0.004114	0.004114	0.58	0.452
2-Way Interactions	3	0.010969	0.003656	0.52	0.673
base durometer*Catalyst	1	0.009194	0.009194	1.31	0.265
base durometer*mill time	1	0.001265	0.001265	0.18	0.676
Catalyst*mill time	1	0.000822	0.000822	0.12	0.736
3-Way Interactions	1	0.001418	0.001418	0.20	0.658
base durometer*Catalyst*mill time	1	0.001418	0.001418	0.20	0.658
Error	23	0.161841	0.007037		
Lack-of-Fit	21	0.139741	0.006654	0.60	0.786
Pure Error	2	0.022100	0.011050		
Total	31	0.749088			

ANOVA – Reduced Model

- Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	3	0.572212	0.190737	30.19	0.000
Linear	2	0.557762	0.278881	44.15	0.000
base durometer	1	0.556512	0.556512	88.10	0.000
Catalyst	1	0.001250	0.001250	0.20	0.660
2-Way Interactions	1	0.014450	0.014450	2.29	0.142
base durometer*Catalyst	1	0.014450	0.014450	2.29	0.142
Error	28	0.176875	0.006317		
Lack-of-Fit	4	0.008375	0.002094	0.30	0.876
Pure Error	24	0.168500	0.007021		
Total	31	0.749088			

- Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0794793	76.39%	73.86%	69.16%

Analyze: DOE Results

Factorial Regression: Results versus base durometer, Catalyst

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	3	0.572212	0.190737	30.19	0.000
Linear	2	0.557762	0.278881	44.15	0.000
base durometer	1	0.556512	0.556512	88.10	0.000
Catalyst	1	0.001250	0.001250	0.20	0.660
2-Way Interactions	1	0.014450	0.014450	2.29	0.142
base durometer*Catalyst	1	0.014450	0.014450	2.29	0.142
Error	28	0.176875	0.006317		
Lack-of-Fit	4	0.008375	0.002094	0.30	0.876
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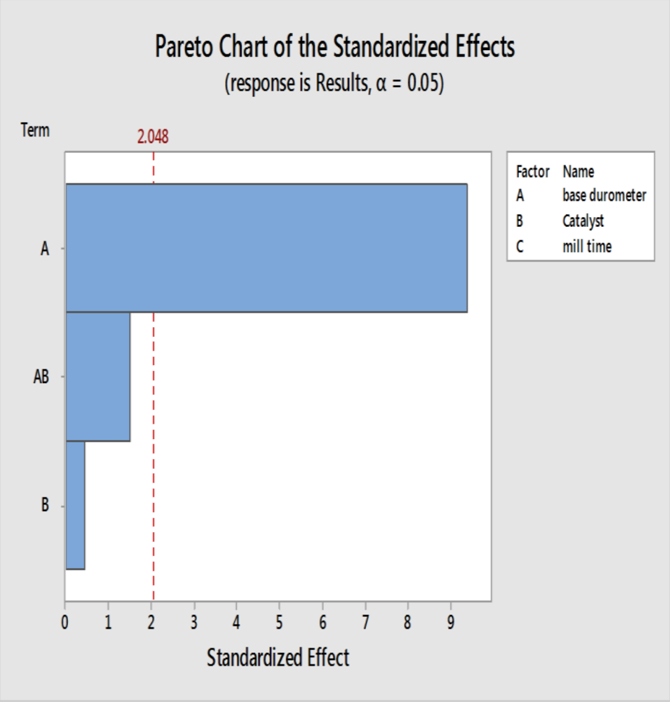
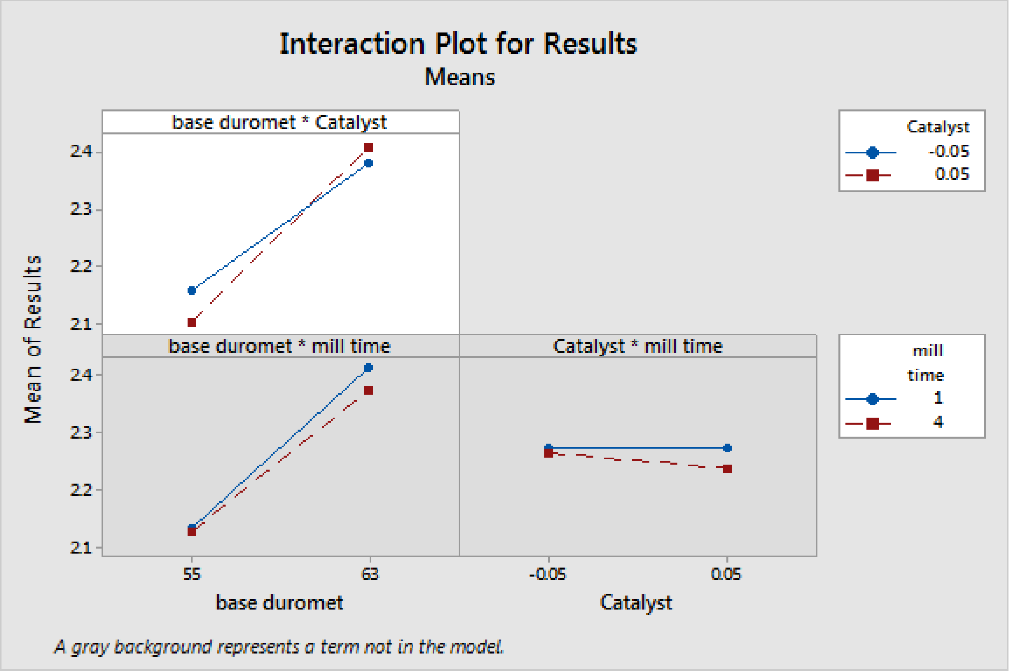
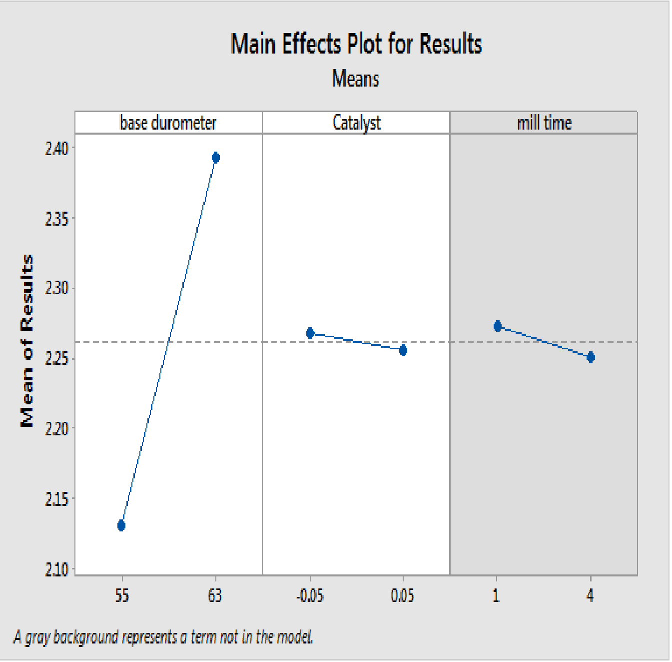
0.0794793	76.39%	73.86%	69.16%



Interaction / Main Effect

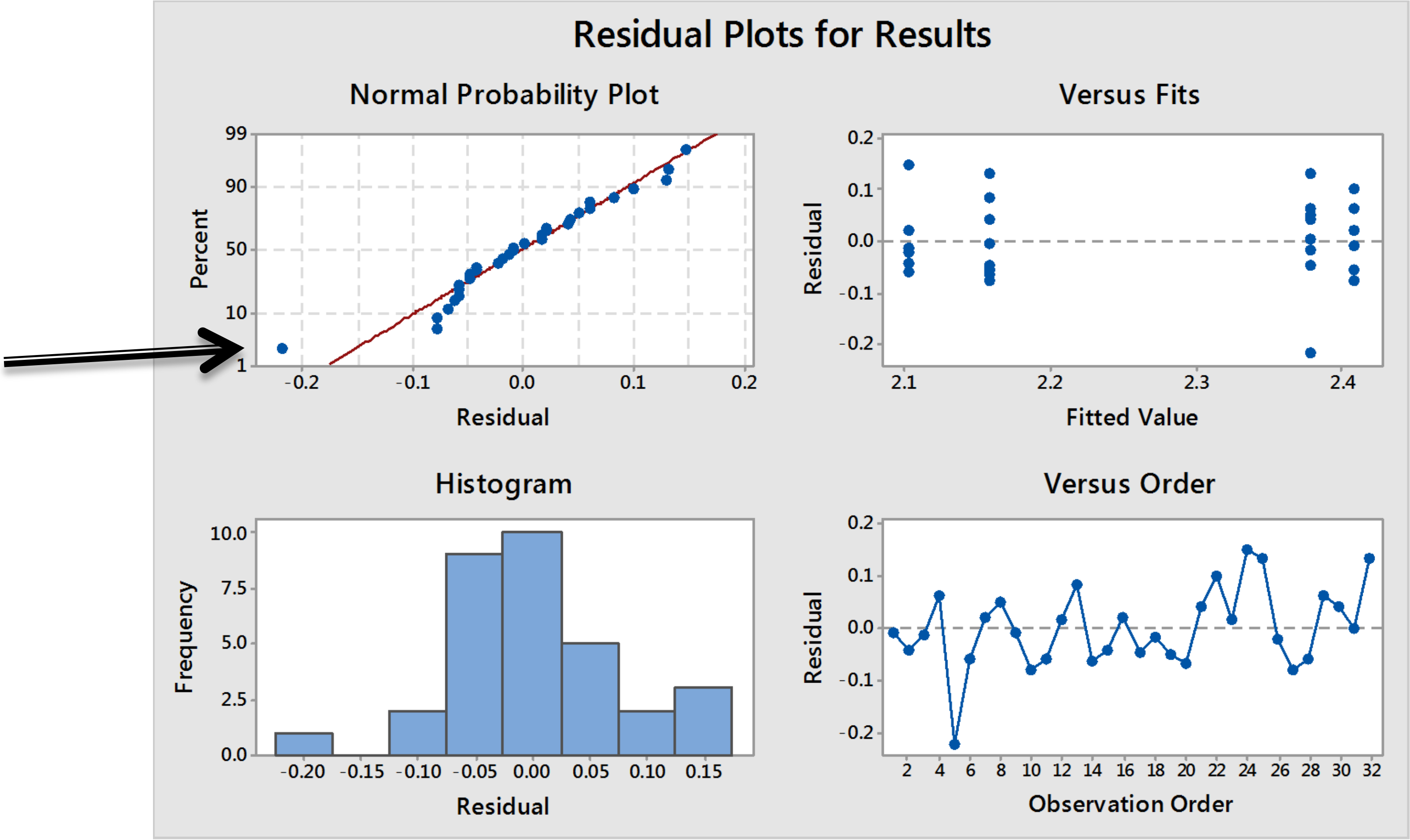




CSF #7: Look at the Data…..

StdOrder	Run Order	Center Pt	Blocks	base durometer	Catalyst	mill time	Temp of material	Results
16	1	1	1	63	0.05	4	142.34	2.4
17	20	1	1	55	-0.05	1	134.24	2.09
18	4	1	1	63	-0.05	1	144.5	2.44
19	14	1	1	55	0.05	1	139.1	2.04
20	11	1	1	63	0.05	1	139.28	2.35
21	10	1	1	55	-0.05	4	134.6	2.08
22	19	1	1	63	-0.05	4	143.06	2.33
23	2	1	1	55	0.05	4	139.1	2.06
24	28	1	1	63	0.05	4	139.1	2.35
25	17	1	1	55	-0.05	1	136.4	2.11
26	5	1	1	63	-0.05	1	143.42	2.16
27	24	1	1	55	0.05	1	135.5	2.25
28	22	1	1	63	0.05	1	140.18	2.51
29	9	1	1	55	-0.05	4	139.1	2.15
30	31	1	1	63	-0.05	4	144.86	2.38
31	3	1	1	55	0.05	4	135.32	2.09
32	27	1	1	63	0.05	4	142.88	2.33

....And review the Residuals

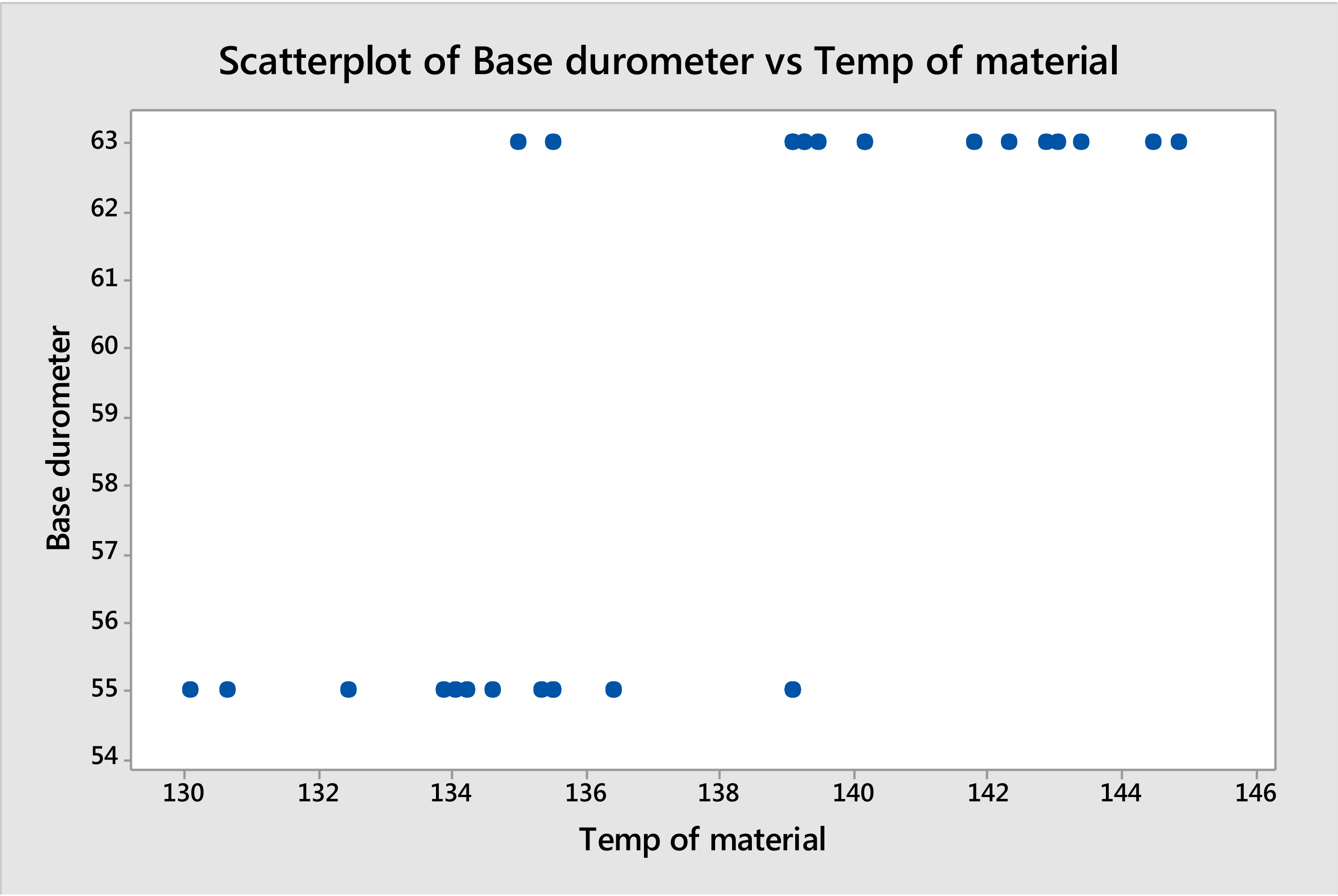


Variance Inflation Factor: Are predictors correlated?

- Model Summary

Term	VIF
Constant	
Temp of material	2.31
base durometer	2.18
Catalyst	1.03
mill time	1.00
base durometer*Catalyst	1.07
base durometer*mill time	1.01
Catalyst*mill time	1.02
base durometer*Catalyst*mill time	1.01

VIF



Scatterplot of Base durometer vs Temp of material
Base durometer
63
62
61
60
59
58
57
56
55
54
130
132
134
136
138
140
142
144
146
Temp of material

DOE: Analyze Variability

- Full factorial
- One replicate
- Used additional replicates as repeats

Base Durometer	Catalyst	mill time	R1	R2	R3	R4	Std dev	mean		
63	0.05	1	2.47	2.43	2.35	2.51	0.068313	2.44		
55	0.05	1	2.06	2.08	2.04	2.25	0.096393	2.1075		
55	0.05	4	2.12	2.12	2.06	2.09	0.028723	2.0975	L1	0.097629
63	-0.05	1	2.51	2.43	2.44	2.16	0.154164	2.385	L2	0.052821
55	-0.05	1	2.2	2.24	2.09	2.11	0.071647	2.16		
63	-0.05	4	2.42	2.36	2.33	2.38	0.037749	2.3725		
63	0.05	4	2.43	2.44	2.35	2.33	0.055603	2.3875		
55	-0.05	4	2.29	2.21	2.08	2.15	0.089209	2.1825		

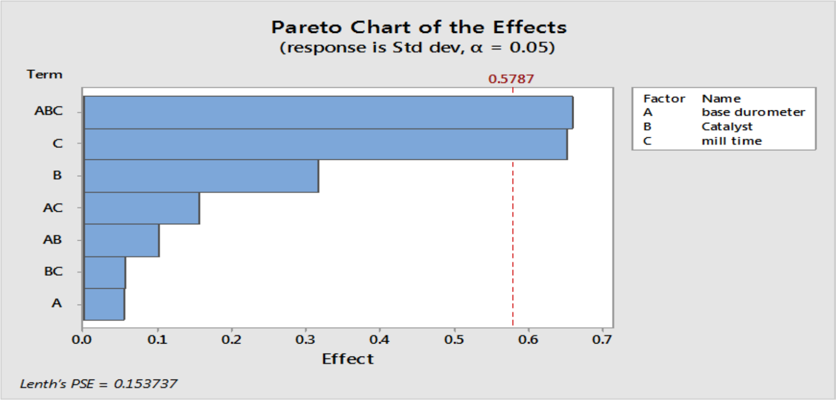
Replicates as Repeats ???

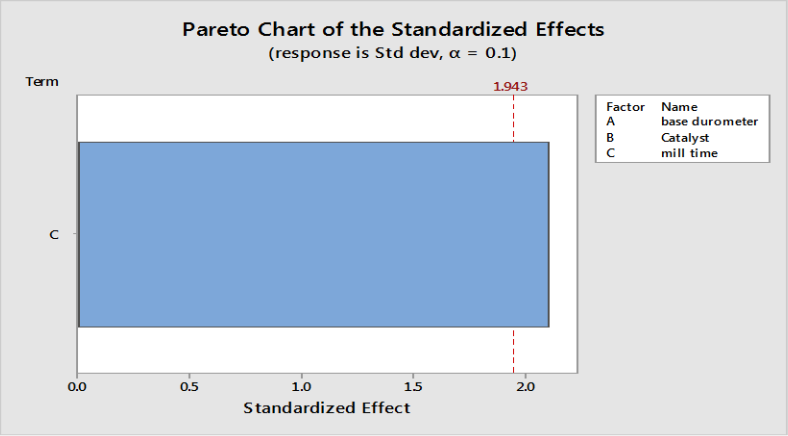
- Replicates “look like” repeats

- Very minimal set up
  - Added / deleted Mill Time with a timer
  - No tear down
  - Raws were all added the same
  - Mix was the same

Analyze: DOE Variability

- Mill time and the 3 way interaction appears to have influenced batch to batch variability
- Sparsity of Effects
- Mill time significant at .10 level



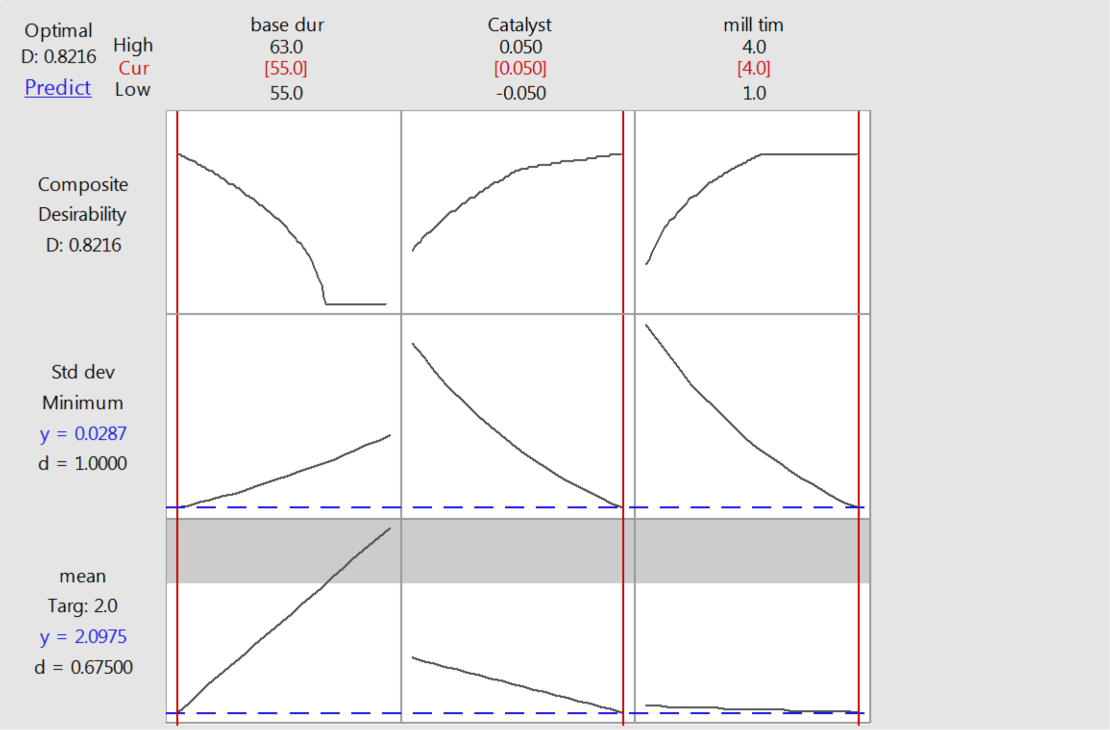


Improve: DOE optimal parameters

Optimal parameter settings occurred at:

Base Durometer 55
Catalyst .05
Mill Time 4 min

DOE samples were used to confirm specifications

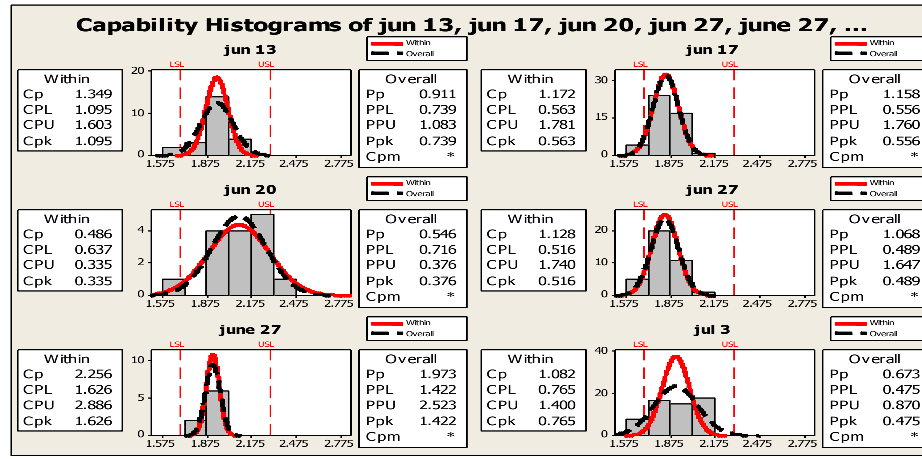


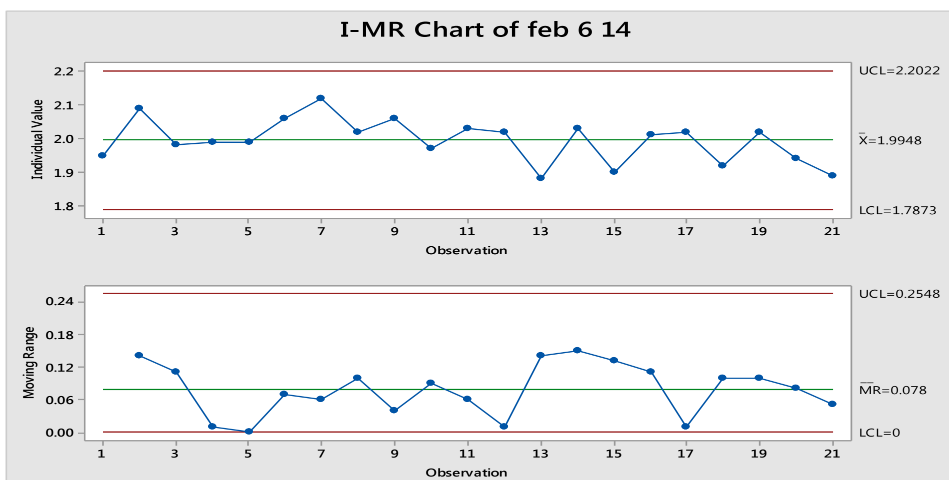
Improve: Supplier Commitments

- Run to specification 2.0 +- .3
- Mix Base durometers to achieve target value of 2.0 ML
- Increase Mill time to reduce within lot variance (more analysis forthcoming)
- Investigate larger mixer batch sizes to reduce both within batch and batch to batch variation

Control: Supplier SPC

- Cpk and Ppk values for each lot of material
- SPC Individual Moving Range Charts





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Lessons Learned

- Joint DOE efforts with Suppliers are achievable and can result in win-win

- Using replicates instead of repeats to analyze variability, along with only 4 readings, is risky and should only be used where minimal set ups are occurring. Confirm !!!

Questions

Richard Wiltse

Tremco Inc., MBB

How have you handled ….

Have you ever encountered ….

Would you explain more how you've approached ….

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Questions? Comments about today's program?

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