Improve Yields and Profitability through DMAIC

Cam Fowler

Unlocking the magic of nature

Contents of the Presentation

- Case for Improvement
- DMAIC – Framework for Improvement
  - Description of Steps
  - Value
- Currently Available Tools
- MSE - Measurement System Evaluation
  - Justifying Equipment Purchases and Upgrades
  - Adding Value to Data Collection
- Summary and Questions

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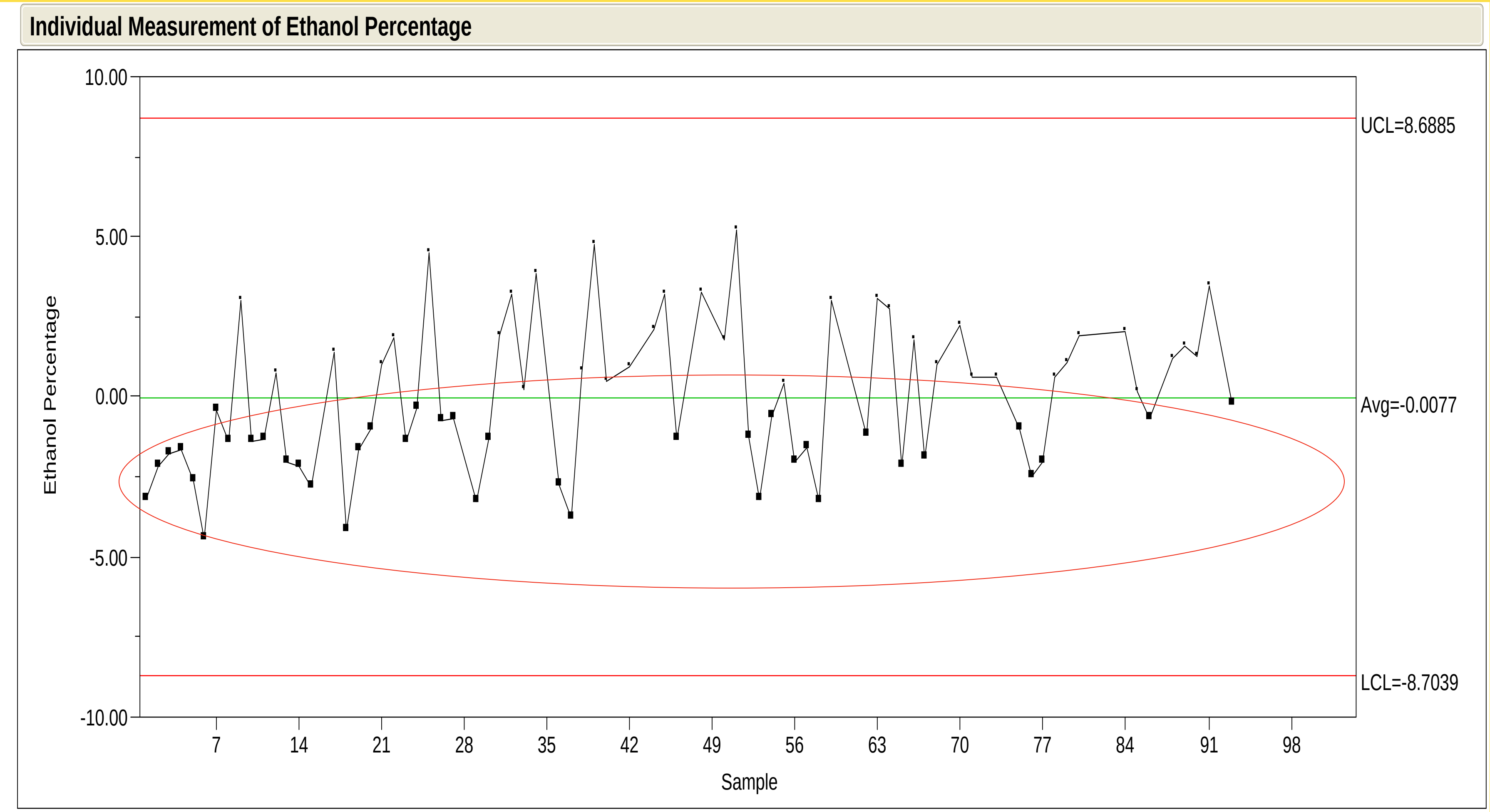
Case study or Why should a plant do this?

- If you define and understand the largest contributors to process variation you can manage your process more efficiently under a variety of circumstances.
- It allows you to allocate scarce or costly resources in the most effective manner.

Typical Ethanol Process Variation



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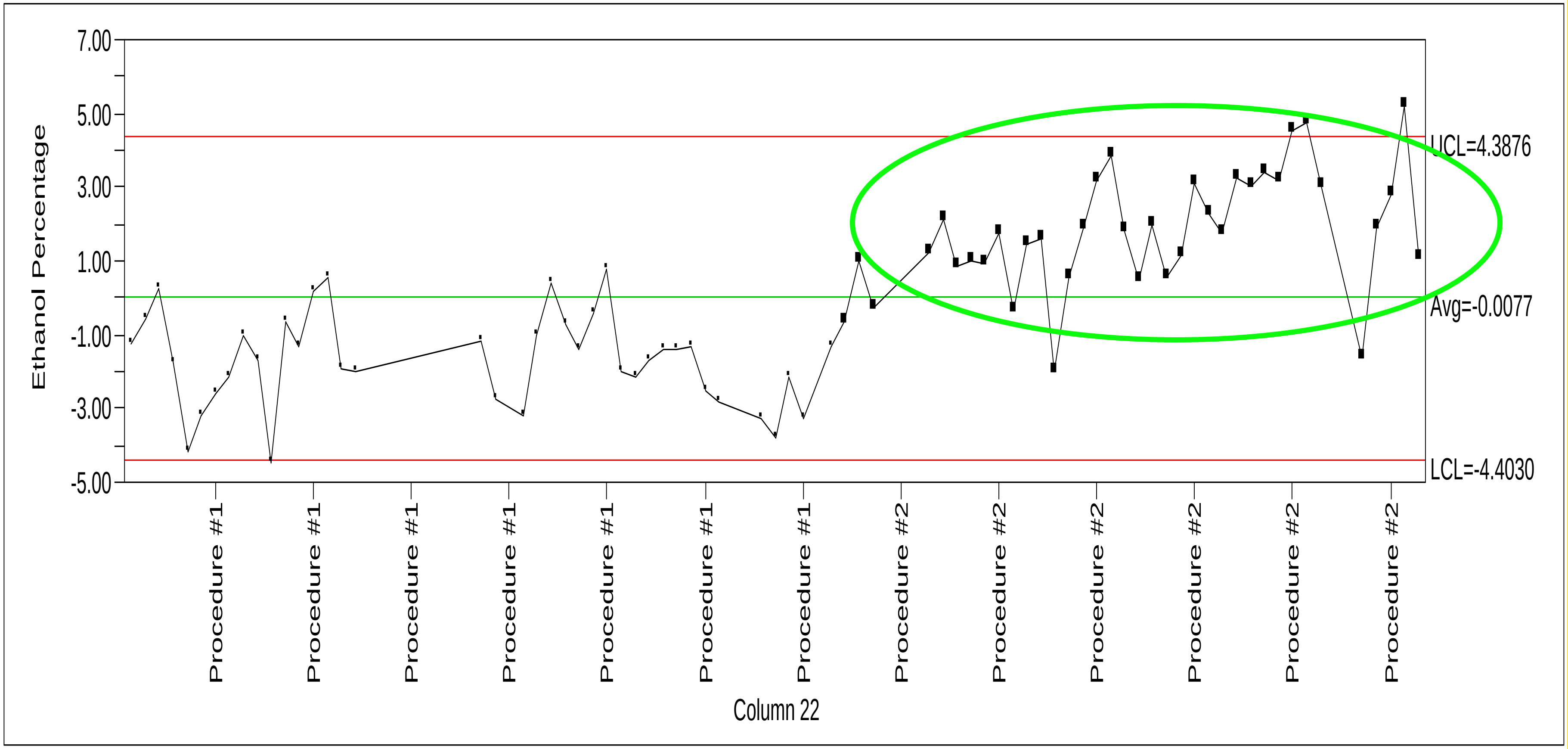
Improvement Process

- Define
  - Area of Interest or Scope
  - Process Map
  - Increase the End Level of Ethanol of Fermentation
- Measure
  - Perform Measurement System Evaluation
  - Measure Baseline
- Analyze
  - Happenstance Data Analysis
  - Regression Fitting to Determine Largest Variance Contributors
- Improve
  - Validate Model
  - Compare the Means (t-test)
- Control
  - Train Operations Staff
  - Change Documentation
  - Change Automation where Applicable
  - Audit on a Frequent Basis

Individual Measurement of Ethanol Percentage



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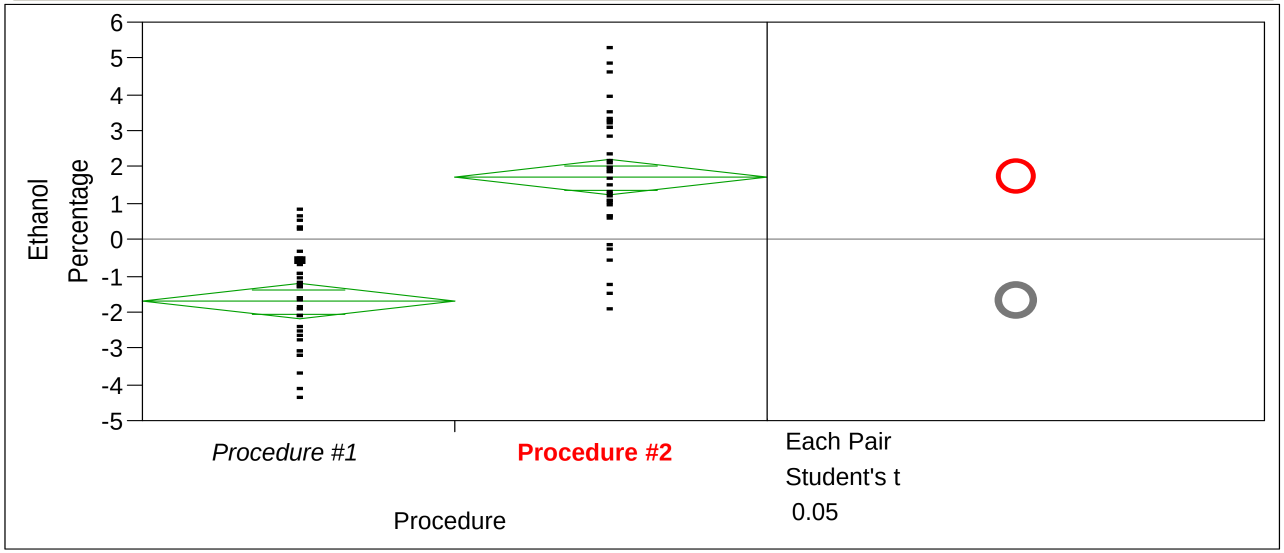
Oneway Analysis of Ethanol Percentage By Procedure



Excluded Rows 17

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Procedure #1	38	-1.7169	0.24430	-2.204	-1.230
Procedure #2	38	1.7015	0.24430	1.215	2.188

Std Error uses a pooled estimate of error variance

Means Comparisons

Results Discussion

- Significant improvement
  - No investment, other than data collection and analysis
  - Explains 56% of Current Variability
- Reduced impact on bottlenecks from steadier operation
- Increased Profit Based on $1.91 Gallon EtOH. Source CBOT 6/11/07

Plant Size MGal	New Increase	MUSD*
40	41.4	$2.67
50	51.7	$3.25
100	103.4	$6.49

DMAIC

Framework for Improvement

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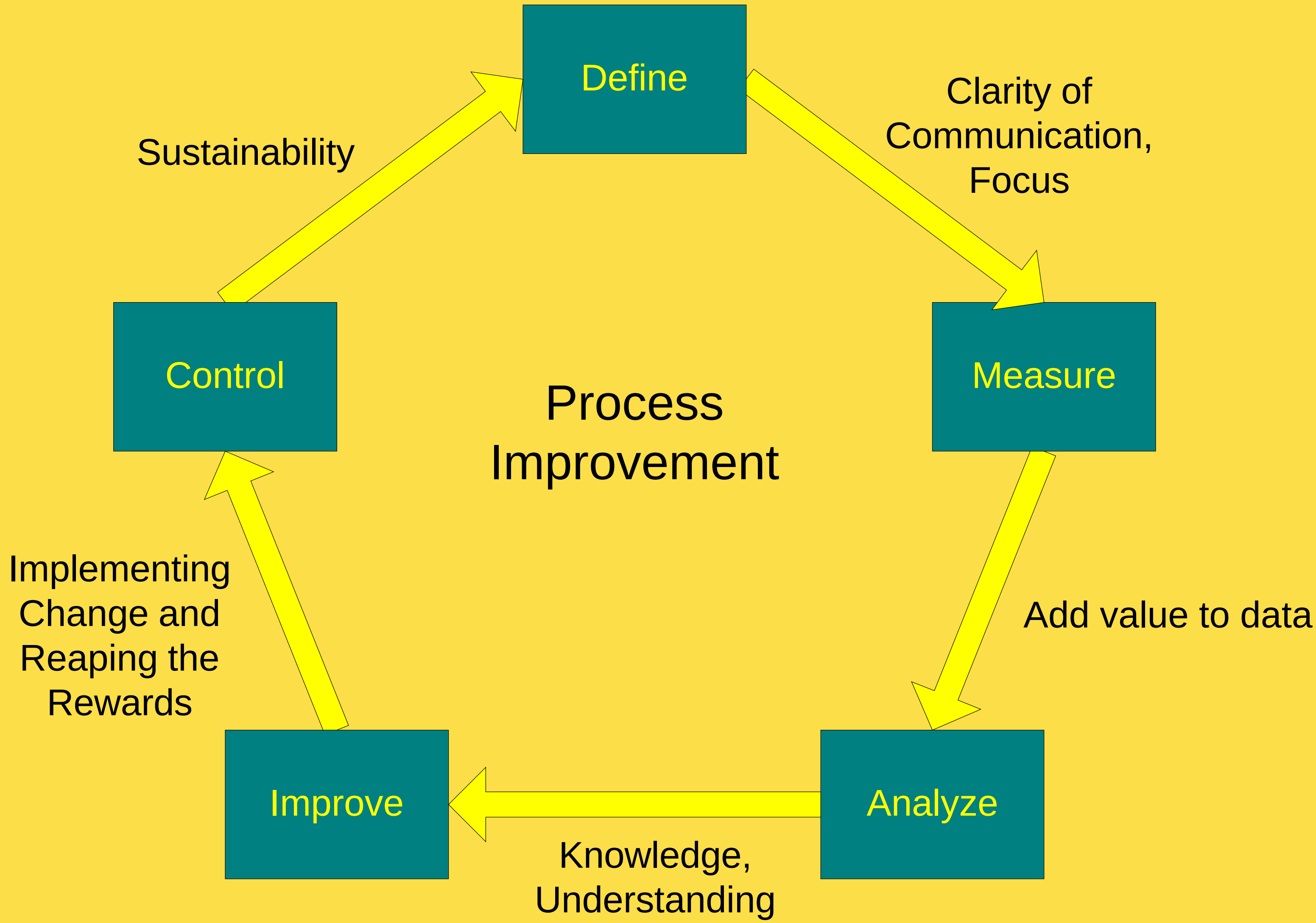
What is DMAIC?

- Organized process or framework for understanding any process
- Comes from the six sigma methodology
- Generalized
  - Works in most environments
    - Production
    - Transactional Process
    - Service Process
- Based on sound scientific and statistical principles

DMAIC Cycle of Improvement



Techniques and Tools for Improvement

- **Techniques**
- Define
  - Thought Maps
  - Process Maps
- Measure
  - Measurement System Evaluation (MSE)
  - Gage R&R
- Analyze
  - DOE
    - Screening Design
    - Full Factorial
    - Response Surface
- Improve
  - Gantt Chart
  - FMEA – Failure Mode Effect Analysis
- Control
  - SPC, Training, and Documentation

- **Tools**
- Define
  - MS Office, Project, Visio
- Measure, Analyze, Improve, Control (SPC)
  - SAS JMP, Minitab, Excel Plug-in (Sigma XL)
- Control
  - Organization Documentation and Training Systems
- Misc. Tools
  - Data Historian and Database
    - OSI PI
    - Oracle, MYSQL, etc.

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Measurement System Evaluation

a.k.a. Gage R&R

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Measurement System Evaluation

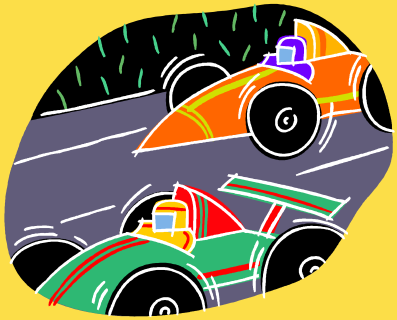
- Components of an Excellent Measurement System
  - Stable
    - Does not change drastically from one repeated measurement of the same sample over time. This is different from repeatability.
  - Repeatability
    - Goal - Same result time after time
    - By same operator, same machine
    - Retest Error
  - Reproducibility
    - Goal – Same result with different operators
  - Measurement variance must be small compared to process variance.

MSE Hypothetical Example

- You are the manager of an race car team.
- Your crew chief wants to make some changes to the car and see if there is an improvement in lap time.
- Crew Chief thinks he can shave .2 sec of the lap time
- Potential Set-up
  - Time the car for a few laps before changes are made.
  - Make the changes
  - Time the car for a few laps after changes
  - Compare the times
  - Let the crew chief know how he did.

Poor Measurement System

- You are given a sundial to time the race car with.
  - Poor Repeatability
  - Poor Reproducibility
- The sundial has high variability compared with lap times of the car.



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Marginal Measurement System

- You are given a wrist watch
  - This is better but still tough to see a .2 sec difference.
  - Average Laps?
    - How many laps are needed?
      - 3, 6, 10, more?
    - Need more runs to be successful
    - This isn't always possible and is certainly inconvenient
    - What if the improvement was only .05 sec / lap?

Good System

- State of the Art Electronic timing system
  - Measurement Variation is small by comparison to lap time variation
  - Small variation in lap time are now identifiable
  - Need fewer laps to make conclusions
  - Can ‘see’ smaller process changes that can add up over time.

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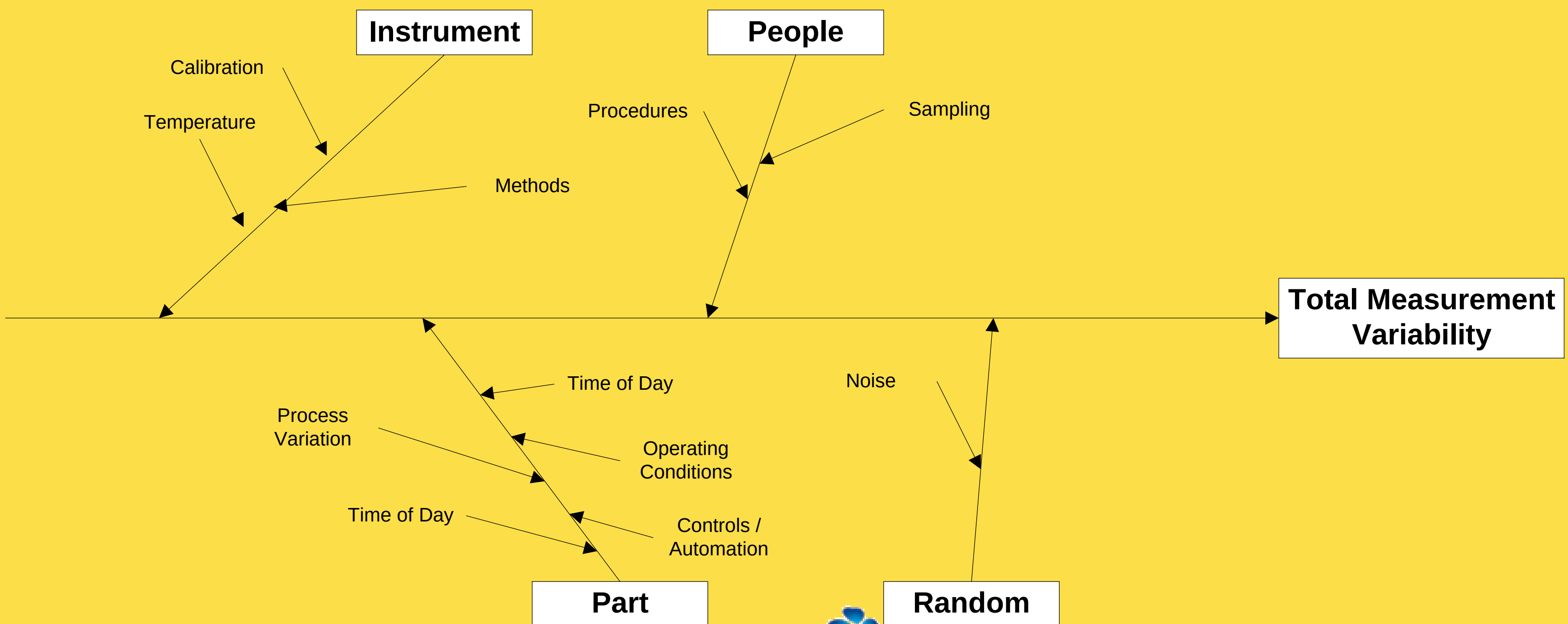
Sources of Measurement Variation



Measurement System Evaluation

$$\sigma^2_{Total} = \sigma^2_{Ai} + \sigma^2_{M} + \varepsilon$$

Where

σ^2_{Ai} = Area of interest or process

σ^2_{M} = Measurement

ε = Error

$$\sigma^2_{M} = \sigma^2_{O} + \sigma^2_{P} + \sigma^2_{G} + \varepsilon$$

Where

$\sigma^2_{M} = \textit{Measurement}$

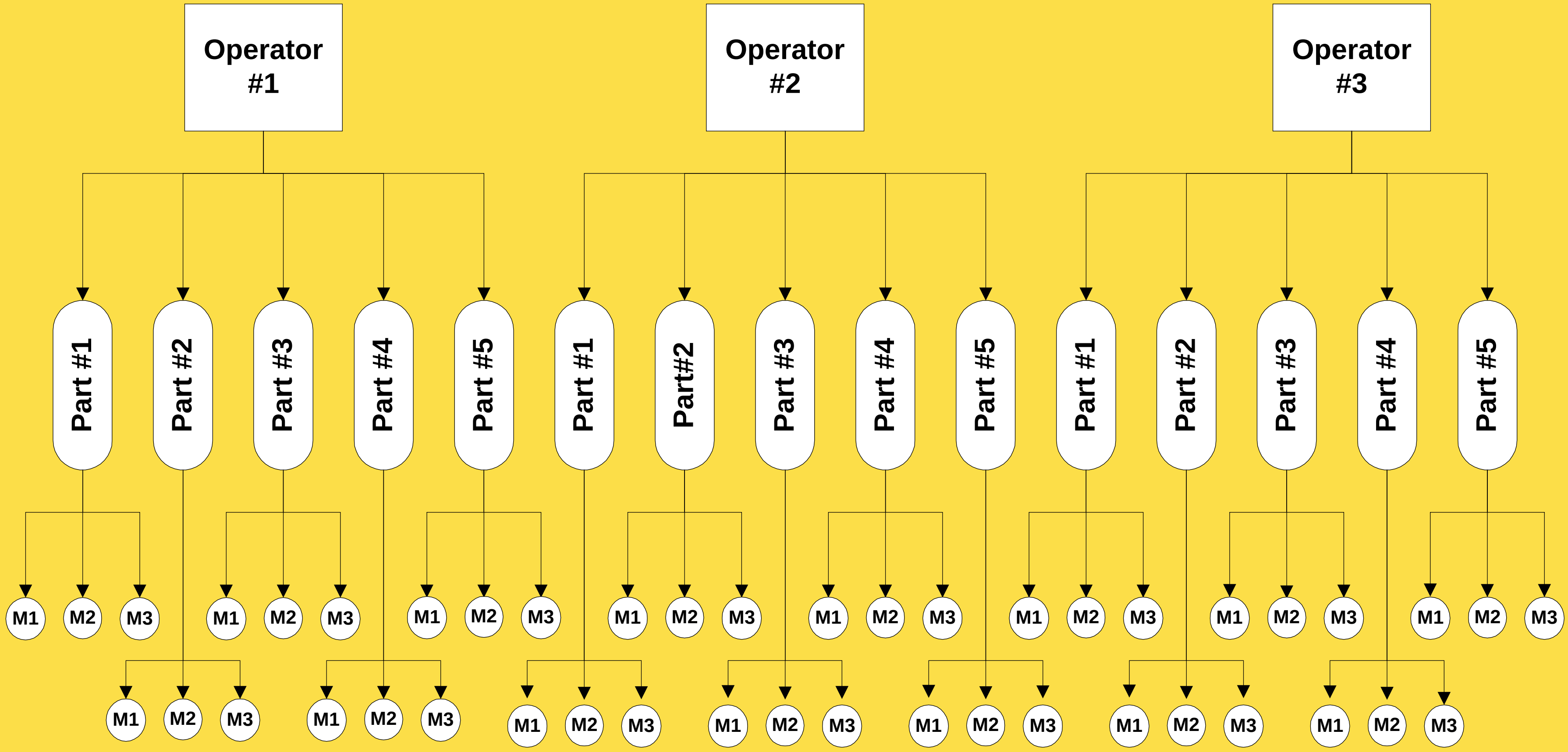
$\sigma^2_{O} = \textit{Operator}$

$\sigma^2_{P} = \text{Procedure} / \textit{Method}$

$\sigma^2_{G} = \textit{Gage} / \textit{Instrument}$

$\varepsilon = \textit{Error}$

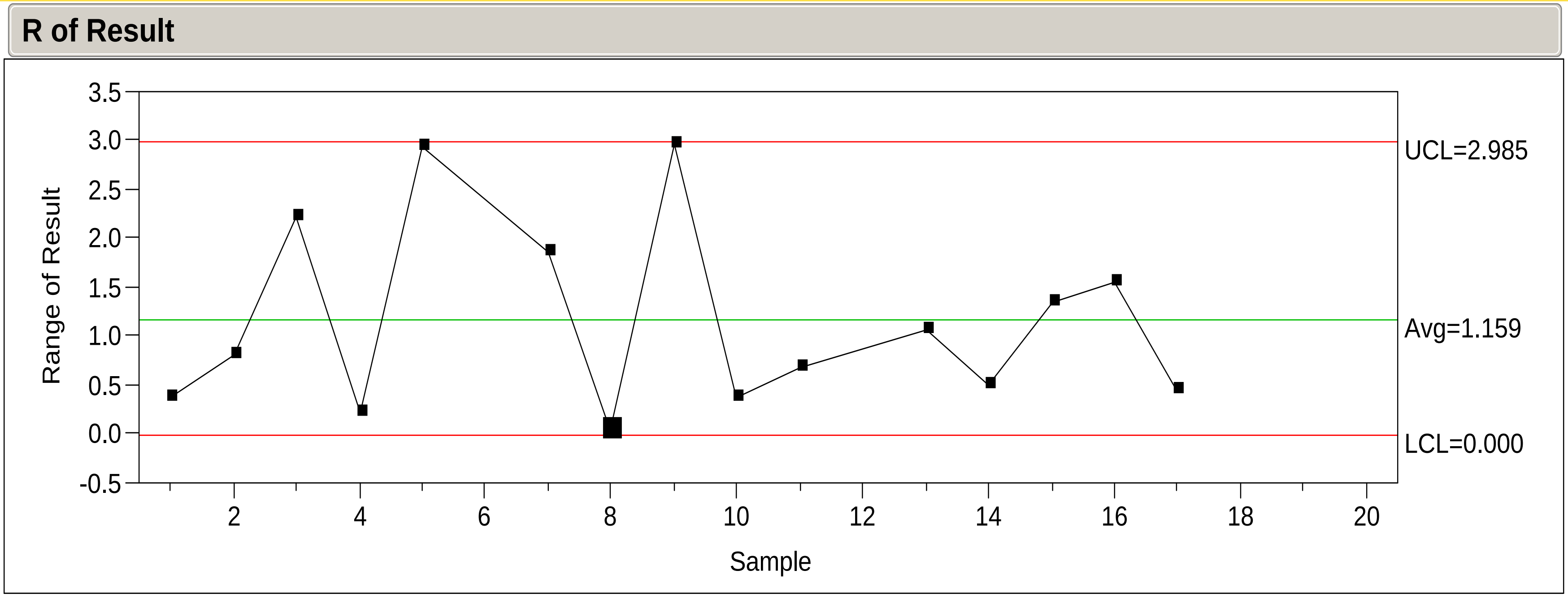
Classical MSE or Gage R&R Set-up



Measurement System Evaluation

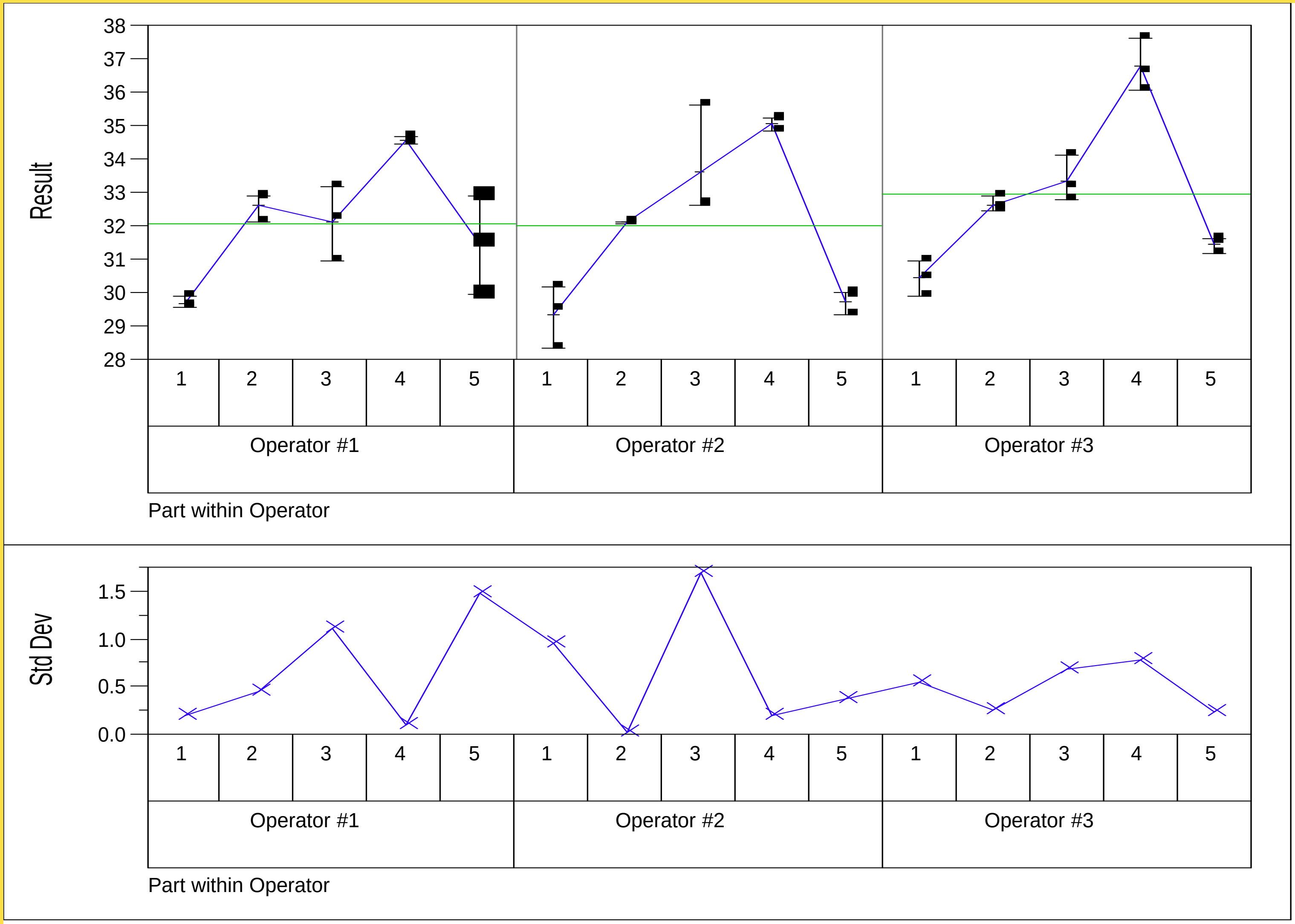
- A good measurement system
  - Stable
    - Variability of the instrument does not change with time
  - Repeatability
    - Goal - Same result time after time
    - By same operator, same machine
    - Retest Error
  - Reproducibility
    - Goal – Same result with different operators

Stability Evaluation – Range Chart



Note: 3 samples were excluded.

Variability Chart



Gage R&R Evaluation

Gage R&R

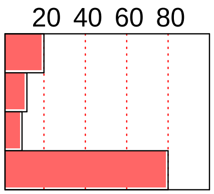
Measurement		Variation		which is k*sqrt of
Repeatability	(EV)	4.672387	Equipment Variation	V(Within)
Operator*Part	(IV)	3.289872	Interaction Variation	V(Operator*Part)
Reproducibility	(AV)	4.105538	Appraiser Variation	V(Operator)+V(Operator*Part)
Gage R&R	(RR)	6.219859	Measurement Variation	V(Within)+V(Operator)+V(Operator*Part)
Part Variation	(PV)	12.722404	Part Variation	V(Part)
Total Variation	(TV)	14.161434	Total Variation	V(Within)+V(Operator)+V(Operator*Part)+V(Part)

6	k
43.9211	% Gage R&R = 100*(RR/TV)
0.48889	Precision to Part Variation = RR/PV
2	Number of Distinct Categories = 1.41(PV/RR)

Using column 'Operator' for Operator, and column 'Part' for Part.

Variance Components for Gage R&R

Component	Var Component	% of Total
Gage R&R	1.0746289	19.29
Repeatability	0.6064222	10.89
Reproducibility	0.4682067	8.40
Part-to-Part	4.4960991	80.71



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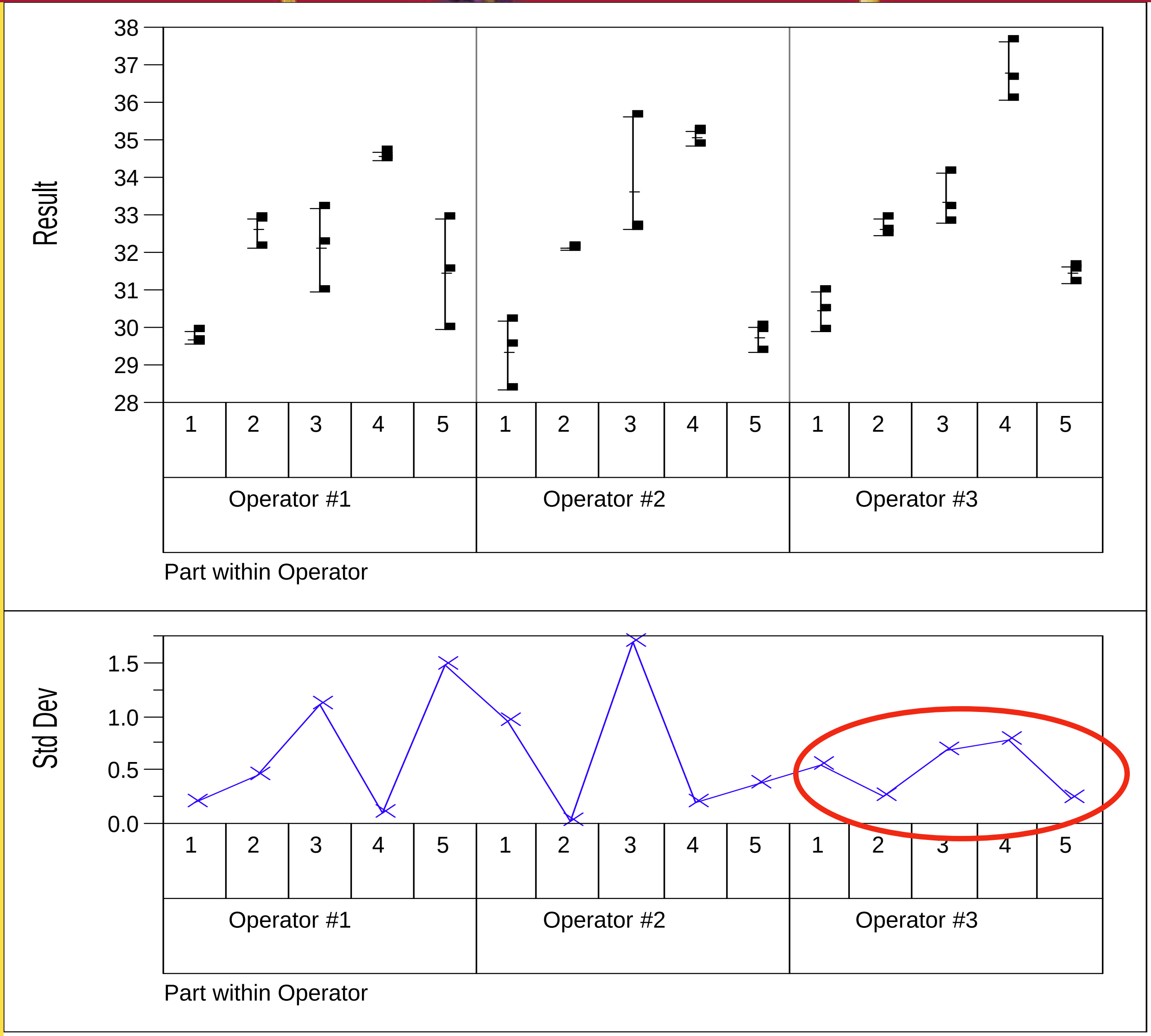
MSE Evaluation

- Gage R&R
  - Unacceptable >30
  - Poor 21 – 30
  - Adequate 11 – 20
  - Excellent < 10
- Our result was 19.29
  - Adequate, just barely
  - What can we do to improve?

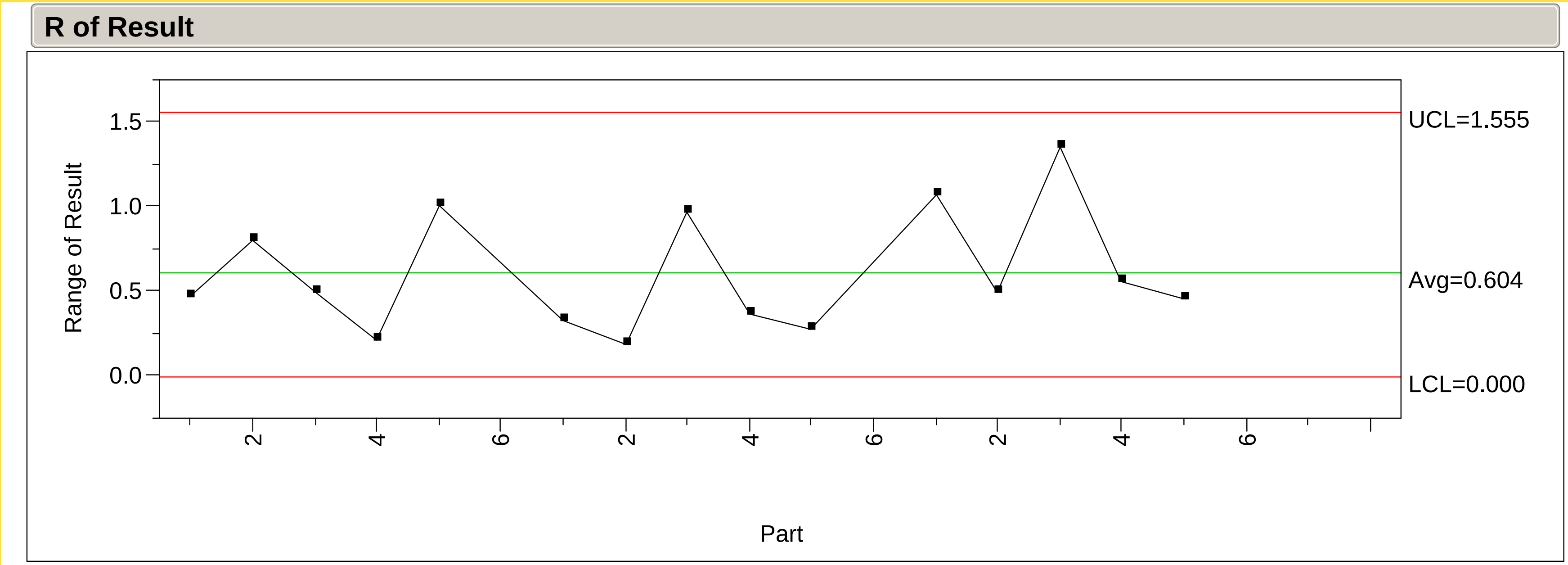
Variability Chart



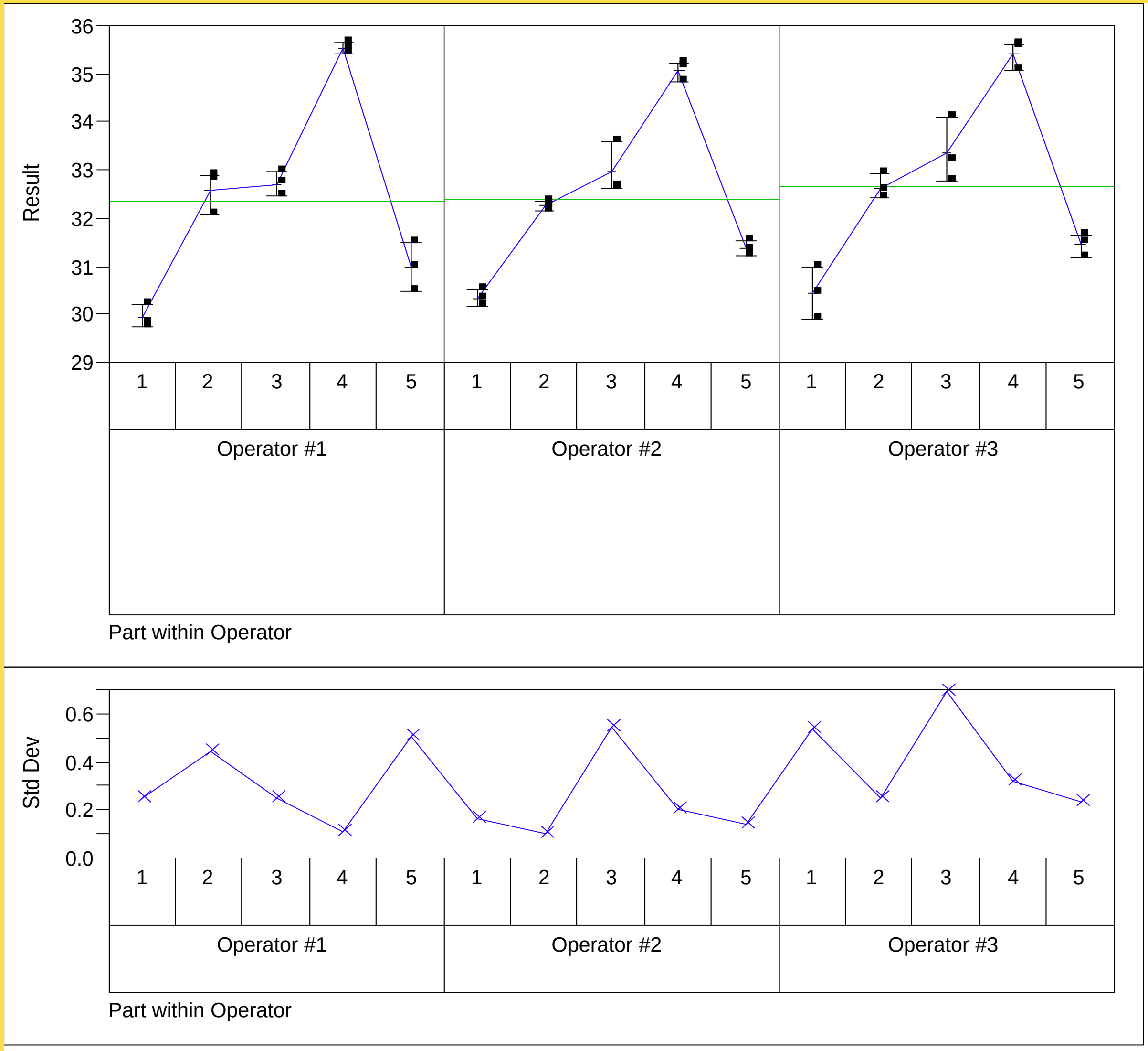
How can we improve the performance?

- We saw that operator #3 had the best performance.
- We watched the procedure used by everyone.
- Sample preparation was performed differently by operator #3.
- We changed the procedure and trained the other two operators and repeated the experiment.

New Range Chart - Stability



Note: 3 samples were excluded.



Result
36
35
34
33
32
31
30
29
1
2
3
4
5
Operator #1
Operator #2
Operator #3
Part within Operator
Std Dev
0.6
0.4
0.2
0.0
Operator #1
Operator #2
Operator #3
Part within Operator

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Improved Gage Analysis

Gage R&R

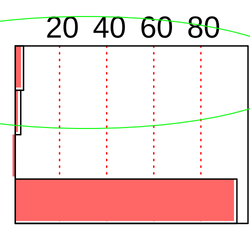
Measurement		Variation		which is k*sqrt of
Repeatability	(EV)	2.170077	Equipment Variation	V(Within)
Operator*Part	(IV)	0.516027	Interaction Variation	V(Operator*Part)
Reproducibility	(AV)	0.933552	Appraiser Variation	V(Operator)+V(Operator*Part)
Gage R&R	(RR)	2.362362	Measurement Variation	V(Within)+V(Operator)+V(Operator*Part)
Part Variation	(PV)	11.595252	Part Variation	V(Part)
Total Variation	(TV)	11.833453	Total Variation	V(Within)+V(Operator)+V(Operator*Part)+V(Part)

6	k
19.9634	% Gage R&R = 100*(RR/TV)
0.20374	Precision to Part Variation = RR/PV
6	Number of Distinct Categories = 1.41(PV/RR)

Using column 'Operator' for Operator, and column 'Part' for Part.

Variance Components for Gage R&R

Component	Var Component	% of Total
Gage R&R	0.1550210	3.99
Repeatability	0.1308121	3.36
Reproducibility	0.0242089	0.62
Part-to-Part	3.7347185	96.01



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Summary

- DMAIC – Provides a tested framework for improvement.
- Data analysis and planned experimentation can provide significant process improvement.
- MSE – Are a good start for improving the quality of data and decision making.

Suggested Sources for Further Information

- The Six Sigma Handbook: The Complete Guide for Greenbelts….Revised and Expanded Copyright 2003 The McGraw-Hill Companies ISBN-13: 978-0071410151
- Six Sigma and Minitab: A complete toolbox guide for all Six Sigma practitioners (2nd Ed.) QSB Consulting ISBN-13: 978-0954681326
- SAS JMP Statistics and Graphics Guide Software Documentation www.jmp.com