AESQ STRATEGY GROUP™
A Program of SAE ITC

WHAT MAKE A GOOD PROCESS CAPABILITY STUDY?

Tools & Tips Webinar sponsored by the AESQ Process Control Methods SMIG

Jan 26th, 2023

PROCESS CAPABILITY

Agenda – 60 minutes

Overview – P. Teti

Who is the PCM Subject Matter Interest Group – P. Teti

Why this webinar? Where can we find help?

PCM Community of Practice – Linked In

A Walk Through a Capability Analysis – S. Hampton

Case Studies – S. Hampton

Q&A – PCM SMIG Team

Summary and Close – P. Teti

Steve Hampton
Process Control Manager LPC-T
PCC Structurals

Pete Teti
Fellow, Quality Engineering
Pratt and Whitney

WEBINAR OVERVIEW

We are **recording** today's webinar and will distribute the video link following the close of the webinar. It will also be posted on the AESQ website for free viewing.

We will take **questions** during today's webinar using the **Chat** feature.

Please remain on Mute during the presentation to prevent background noise. We will also be muting all lines at the start of the session.

PROCESS CAPABILITY

Why this webinar?

Communicate how to conduct a robust Process Capability study that meets RM13006 guidelines

Show how to use statistical tools in conducting and analyzing a Process Capability Analysis

Promote the available free documents and tools that can be used by any AESQ supplier

Answer questions suppliers may have about process capability methods

PROCESS CONTROL METHODS PER RM13006

Purpose of this reference manual

RM13006 provides the user with an array of practical approaches to process control used to ensure consistent product quality.

The purpose of this reference manual is to raise the overall capability of the aerospace engine supply chain, standardize the process control requirements across AESQ suppliers, and build on the requirements for PFMEA and Control Plans (ref. RM13004).

RM13006 supports AS9145 - Requirements for Advanced Product Quality Planning and Production Part Approval Process, and AS9103 - Variation Management of Key Characteristics, supported by detailed guidance and case studies.

This reference manual was developed by a dedicated team from AESQ member companies with expert knowledge and experience in the areas of process control, process improvement, quality systems, and supplier engagement.


SAE INTERNATIONAL

AEROSPACE STANDARD

AS13100™

Issued 2021-03

AESQ Quality Management System Requirements for Aero Engine Design and Production Organizations

RATIONALE

This standard has been created by the SAE G-22 Aerospace Engine Supplier Quality (AESQ) Technical Committee to harmonize and simplify supplier quality requirements that are in addition to the requirements of 9100 Quality Management Systems - Requirements for Aviation, Space, and Defense Organizations and 9145 Advanced Product Quality Planning and Production Part Approval Process.

Previously the Aerospace Engine Manufacturers based their supplier quality requirements on 9100 but had differing supplemental requirements and guidance albeit with largely the same intent. These supplemental requirements originate from the need to meet Regulatory, Customer, Industry, and Business requirements that are not explicitly covered by 9100 and 9145.

This standard sets out to create a common set of supplemental requirements with common reference materials to improve understanding, efficiency, and performance. While significantly simplifying the businesses of suppliers with multiple customers, the primary intent of this new standard is to improve overall product quality by focusing on the key systems and processes currently delivering consistent aerospace engine product quality.

These common supplemental requirements aim to raise the bar for anticipated performance in these key areas, and therefore detailed guidance is provided to ensure clarity of expectations.

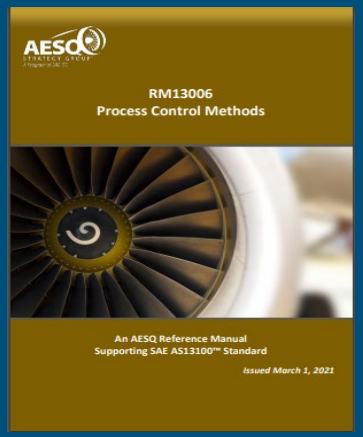
FOREWORD

To assure customer satisfaction, the aviation, space, and defense industry organizations have to produce and continually improve safe, reliable products that equal or exceed customer and regulatory authority requirements.

The globalization of the industry and the resulting diversity of regional/national requirements and expectations have complicated this objective. End-product organizations face the challenge of assuring the quality of end integration of product purchased from suppliers throughout the world and at all levels within the supply chain. Industry suppliers face the challenge of delivering product to multiple customers having varying quality expectations and requirements.

The SAE G-22 Aerospace Engine Supplier Quality (AESQ) Technical Committee was established under the SAE Aerospace Council to develop, specify, maintain, and promote quality standards relating to the aerospace engine supply chain. The principles defined within this standard may be applicable to other segments of the aviation, space, and defense industries.

The AESQ strategy is to promote defect prevention approaches across the supply chain including those associated with Advanced Product Quality Planning and Process Control to enable the supply chain to achieve Zero Defects.



PROCESS CONTROL METHODS SUPPORT

What is the Process Control Methods SMIG Group?

- The purpose of the PCM Subject Matter Interest Group is to promote the effective deployment of the process control methods across the AESQ Supply Chain.
- The Group is made up of Subject Matter Experts from the AESQ Member Companies.
- The Group is accountable for the AS13100 related Requirements and associated Reference Manual content, ensuring that it is up to date and reflects current knowledge and best practice.
- It shall promote the effective deployment of the Reference Manual using Communities of Practice (CoP). The CoP is open to any subject matter expert or individual experienced or trained in process control from the aero engine community.
- Activities may include webinars, best practice sharing, development of shared training materials, conferences and published papers.

NO.	FUTURE WEBINAR TOPICS	TARGET DATE/TIME
1	Process Control Methods - What is RM13006? Interaction with other AESQ Reference Manuals	12/6/2022 (11 AM US Eastern)
2	What makes a good Process Capability Study?	1/26/2023 (11 AM U.S. Eastern)
3	Process Capability Study for True Position (handling MMC)	2/8/2023 (11 AM U.S. Eastern)
4	The use of non-statistically based process control methods	3/8/2023 (11 AM U.S. Eastern)
5	The Power of Precontrol	4/11/2023 (11 AM U.S. Eastern)
6	The One-Hour Process Control Assessment	5/16/2023 (11 AM U.S. Eastern)
7	Why is statistical control a prerequisite for process capability?	Target 2nd Qtr (June)
8	Dealing with Non-Normal Data	Target 3rd Qtr (September)
9	Conducting capability studies for one-sided geometric tolerances	Target 4th Qtr (October)

https://aesq.sae-itc.com/interest-groups

SUBJECT MATTER INTEREST GROUPS

Who is the Process Control Methods SMIG Team?

Pete Teti
PWA
(Leader)

Andrew
Stout
PWC
(Co-Lead)

Nicklas
Gödebu
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Paul Gorg
PCC

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Karen
Scavotto
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Steve
Hampton
PCC

Douglas
Dush
Honeywell

Grant
Braun
PCC

Geoffrey
Carpentier
Safran

Marnie
Ham
GE

Shailesh
Shinde
RR

Curators for RM13006

Experts to answer process control related questions

Provider of process control related

PROCESS CONTROL METHODS CoP

Where to get help

AESQ Supplementary Materials webpage for a copy of RM13000 and supporting templates

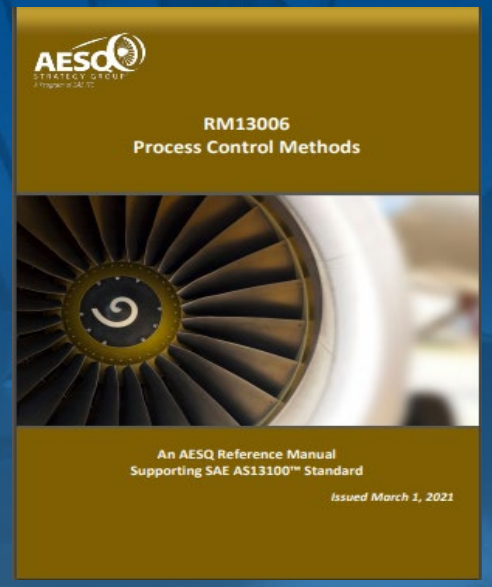
https://aesq.sae-itc.com/supplemental-material

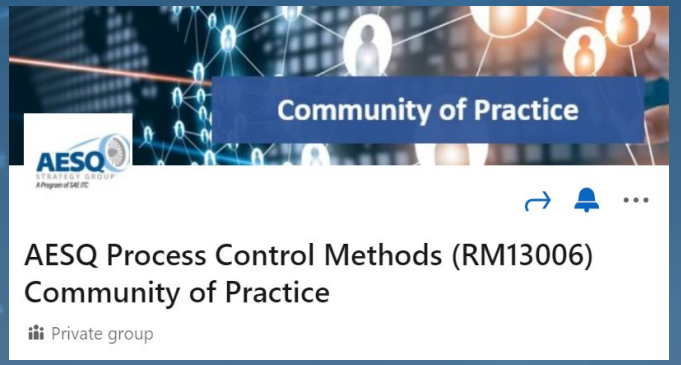
Subject Matter Interest Group – meets monthly – supports continuous improvement of RM13006 and supporting templates & tools

AESQ Process Control Methods Community of Practice (CoP) on Linked-In

Current membership is 200 – let's get some more!!

https://www.linkedin.com/groups/12647920/





A WALK THROUGH OF PROCESS CAPABILITY MATERIAL IN RM13006

SECTIONS INVOLVING PROCESS CAPABILITIES IN RM13006

- 2.1.1 IMPORTANCE OF PRODUCT CAPABILITY
- 3.3 CHOICE OF CAPABILITY METRIC
- 5.3 (PAGE22) PROCESS CAPABILITY FOR PROCESSES WITH INTENTIONAL SHIFTS
- 6.0 PROCESS CAPABILITY INDICES
  - 6.1 FUNDAMENTALS OF VARIABLE DATA
  - 6.2 PROCESS STABILITY IN PRACTICE
  - 6.3 PROCESS CAPABILITY FOR ATTRIBUTE DATA
- 7.0 GUIDANCE FOR NON-NORMAL DATA
  - 7.2 CAPABILITY ANALYSIS FOR NON-NORMAL DATA
- 9.1.2 (PAGE 57) PROCES CAPABILITY FOR MULTIPLE IDENTICAL FEATURES
- 11 (PAGE 67) DATA ANALYSIS ENABLERS
- 13 (TABLE 12) STATISTICAL FORMULAE FOR PROCESS CAPABILITY

WHAT MAKE A GOOD PROCESS CAPABILITY STUDY

Highlights

The importance of Process Capability

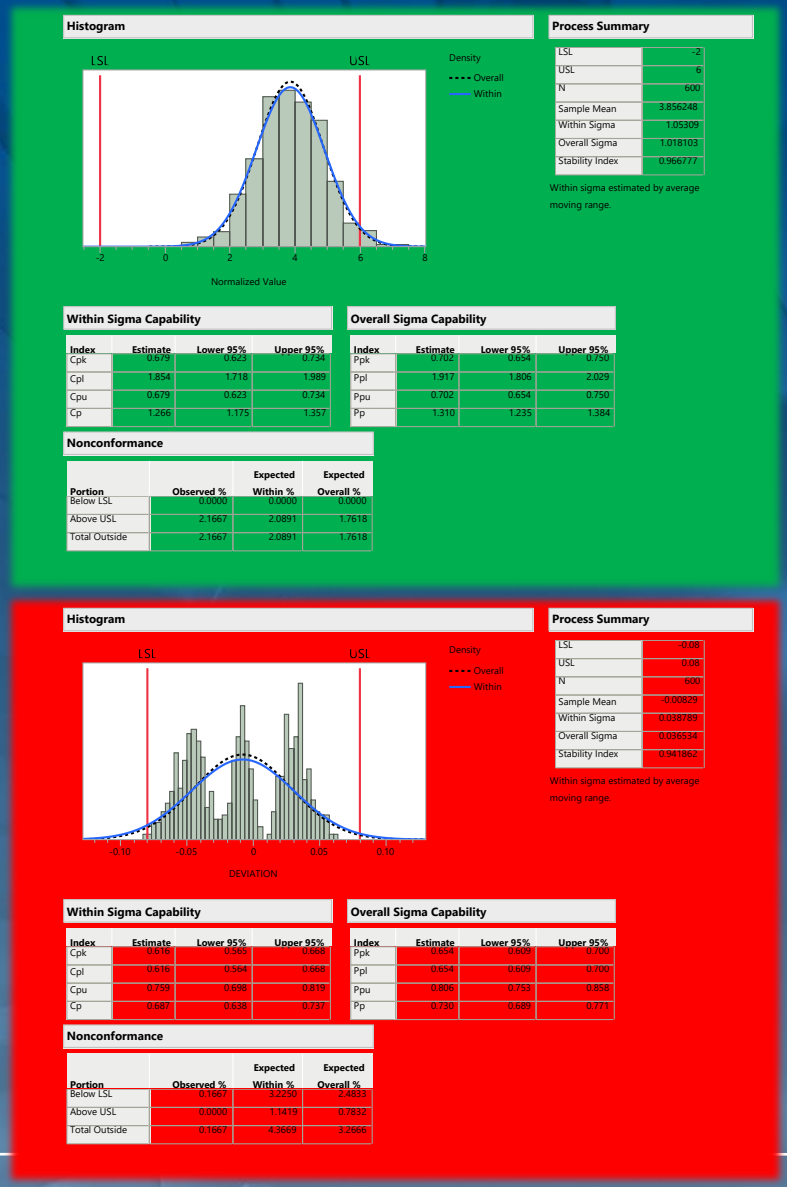
Key principles of Process Capability

Process Capability Indices

Guidance for Non-Normal Data

Case Studies

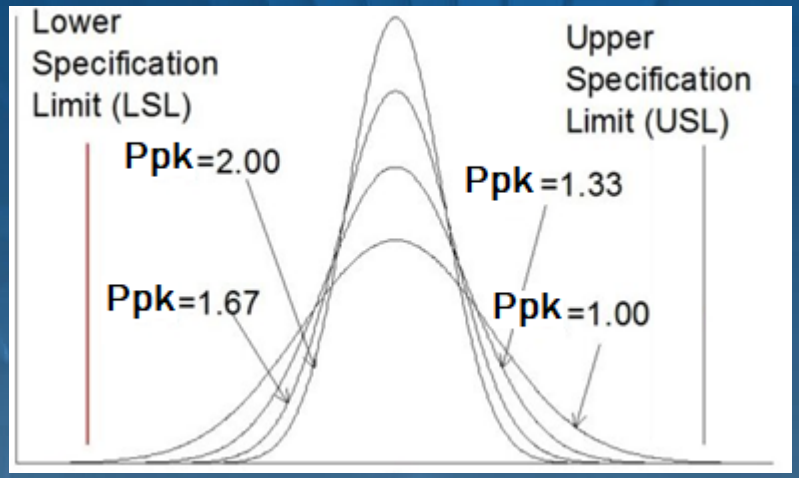
- Standard Capability Analysis
- Between within Capability Analysis
- Large scale Capability Analysis (e.g. CMM part inspection)



The importance of Process Capability

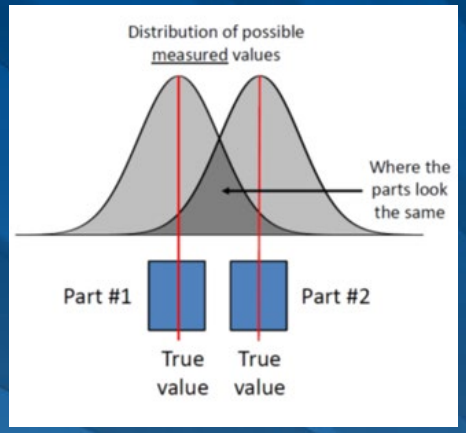
Why does Process Capability matter?

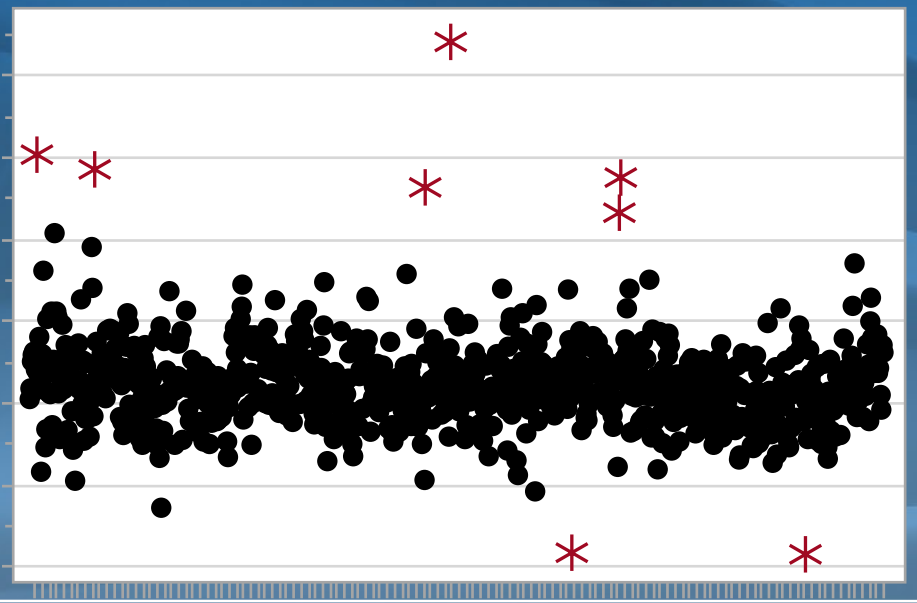
- It gives a voice to your process from the viewpoint of the customer
  - Will you be able to satisfy your customers?
- It gives you a number to evaluate your process
  - You can't understand what you can't measure
- It lets you know your potential
  - By comparing Ppk to Cpk to Cp you can see how much more improvement is possible
- It lets you know where to spend your resources and be proactive
  - Just because you have not rejected anything doesn't guarantee you are capable
  - Can Pareto process that are most at risk



Key Principles of Process Capability

- You trust your measurements.
  - Should have an MSA completed
- You can trust your data.
  - Visualize before you start!





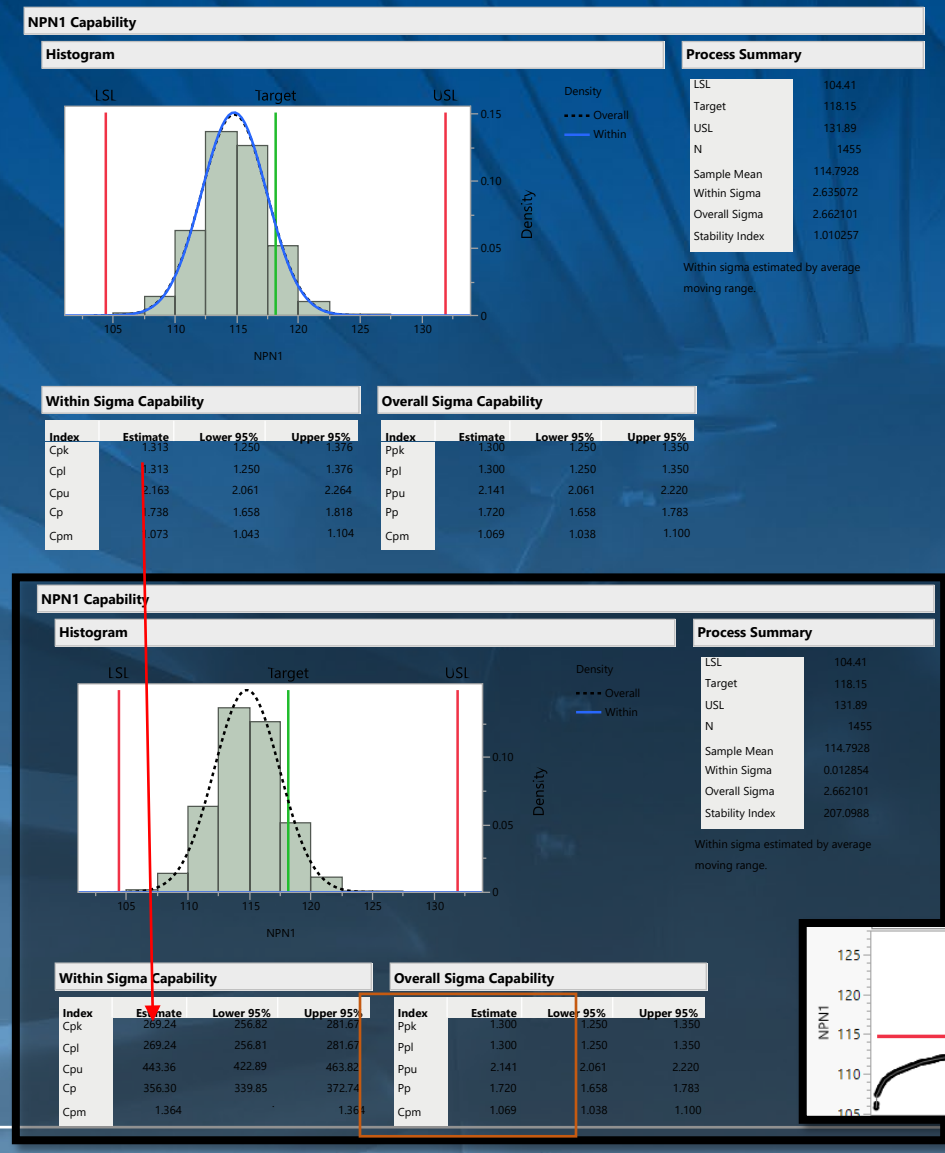
2. The Vasa warship

In 1628, crowds in Sweden watched in horror as a new warship, Vasa, sank less than a mile into her maiden voyage, with the death of 30 people on board. Armed with 64 bronze cannons, it was considered by some to be the most powerful warship in the world. Experts who have studied it since it was raised in 1961 say it is asymmetrical, being thicker on the port side than the starboard side. One reason for this could be that the **workmen were using different systems of measurement**. Archaeologists have found four rulers used by the workmen who built the ship. Two were calibrated in Swedish feet, which had 12 inches, while the other two measured Amsterdam feet, which had 11 inches.

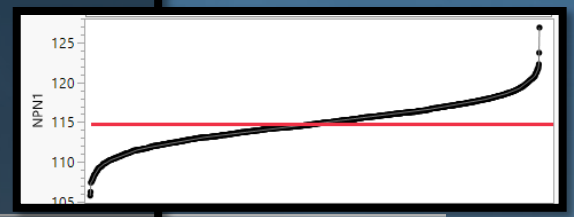
https://www.bbc.com/news/magazine-27509559

Key Principles of Process Capability

- You have enough GOOD data
  - You are capturing your process variations
  - Check with Confidence Intervals review
    - Are they small enough that the estimate is useful?
  - Data should be in time order
    - Super important for Cp/Cpk indices as well as correct control charting
  - Appropriate part family's have been identified if used
    - See RM 13006 section 9.2



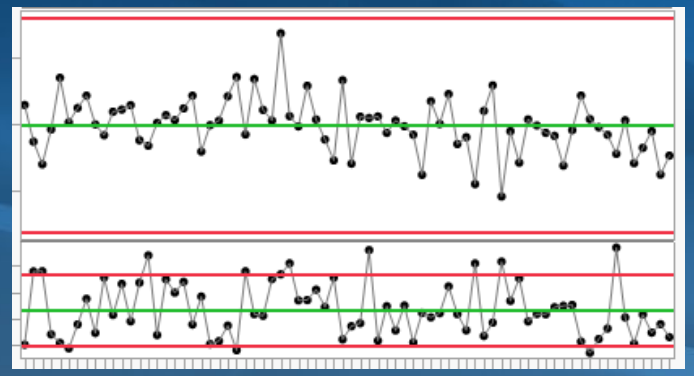
Data sorted by value



Key Principles of Process Capability

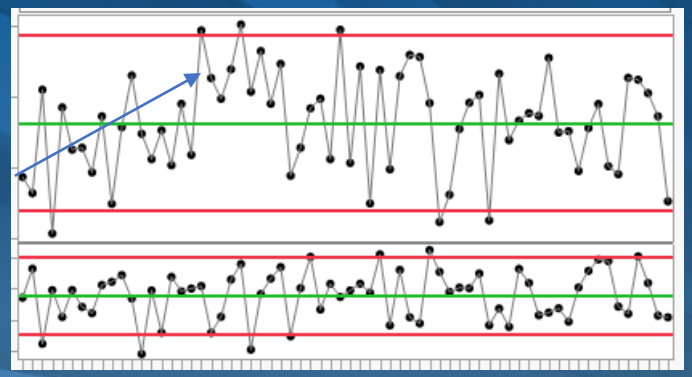
- Your process is in control
  - You have evaluated the control chart of your capability response BEFORE starting your Capability Analysis
  - You know that the factors driving the response are in control as well (or will at least be flagged)

I-MR



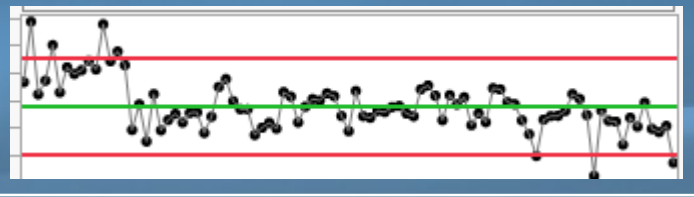
Looks good, Control limits may be slightly wider than they should be

I-MR



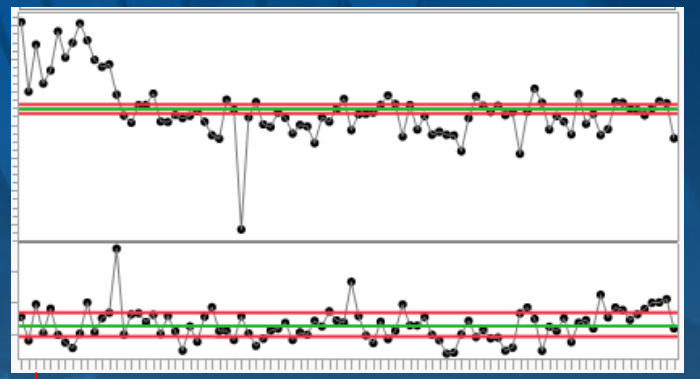
Looks good but there may be a trend at the start of the data. Should investigate prior to starting capability analysis.

X Bar

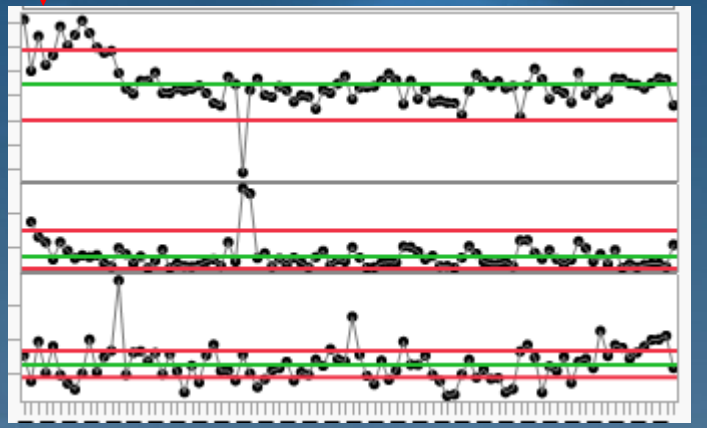


Red alert! Need to investigate shift before doing a capability analysis

X Bar-S



Between within (aka three way)



Issue is too many units in subgroup

WHAT IS A SUBGROUP

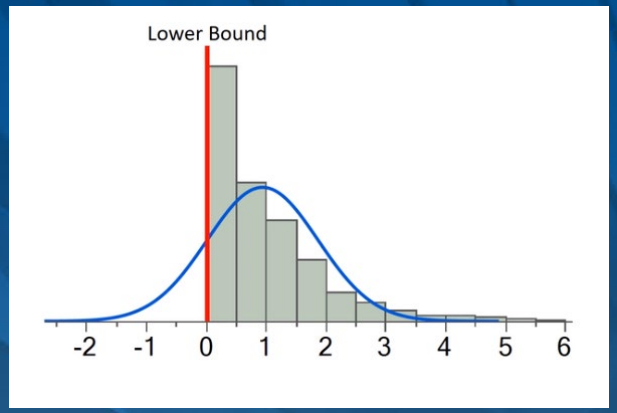
(AKA "A RATIONAL SUBGROUP")

A REPRESENTATIVE GROUPING OF PARTS THAT ARE PROCESSED CLOSE ENOUGH TOGETHER IN TIME AND/OR PROCESSING CONDITIONS THAT THEY HAVE A VERY LOW LIKLEYHOOD OF SPECIAL CAUSE VARAITION OCCURING WITHIN THE GROUP.

- This allows for sampling from this group to be effective
- This also give good within or short term variation estimates that can be used for X-Bar control limits and Cp/Cpk capability analysis
- Examples are:
  - Batches of parts between machine set ups or with different dies
  - Parts made over a shift or a day
  - Parts made on different machines
  - Parts made with different raw material batches
  - Multiple hits on a similar surface of a large part (with customer approval)

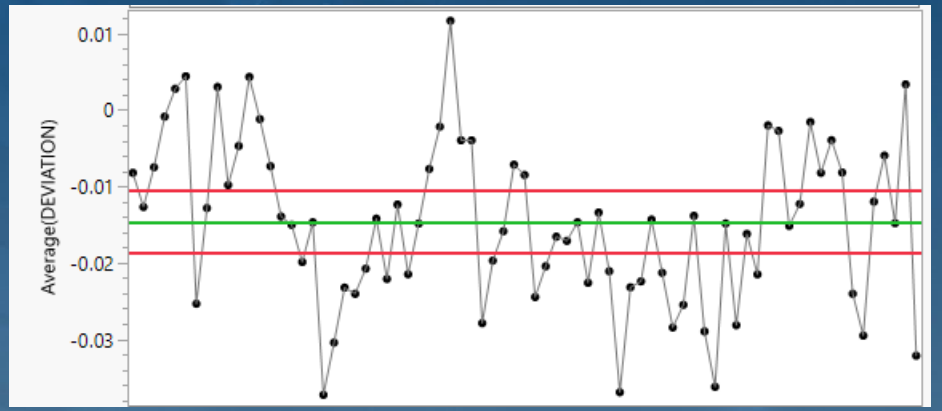
Key Principles of Process Capability

- You know what distribution to use
  - You confirmed the data is normal and fits well

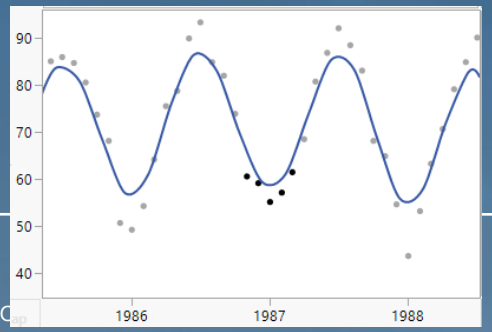


Example of normal distribution used on a naturally non-normal data set

- You know what indices to use
  - Ppk is your go to for communicating how your process will perform
  - All other indices require some improvement effort to get your Ppk to match

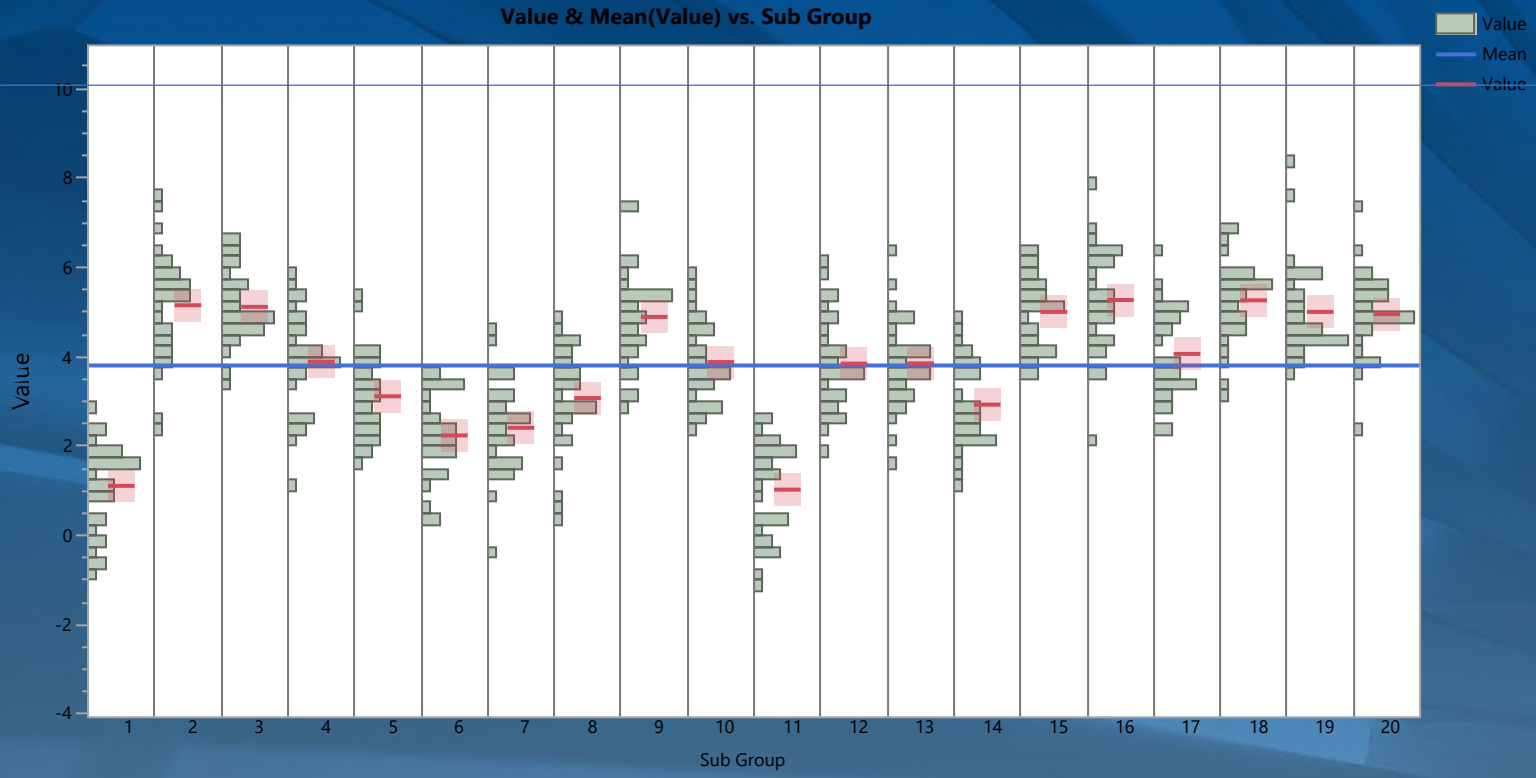


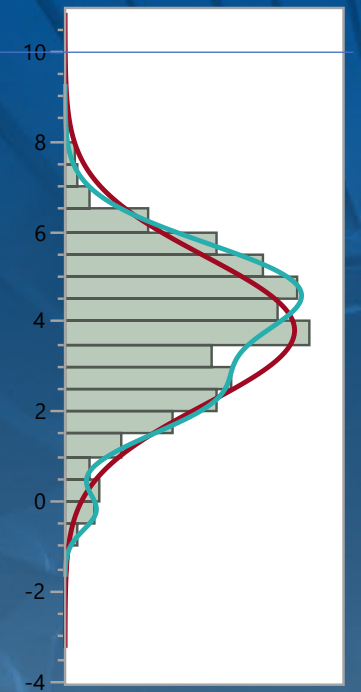
- You understand possible long term drifts or shifts
  - You take into account projected drifts if you haven't been able to capture in the data
  - A stand by unit started back up but Capability Analysis done on main unit
  - e.g. Seasonal issues but data only from summer



Process Capability Indices

- Cp vs Pp vs Cpk vs Ppk





Cp/Pp: how well does your process variation fit into your tolerance band?

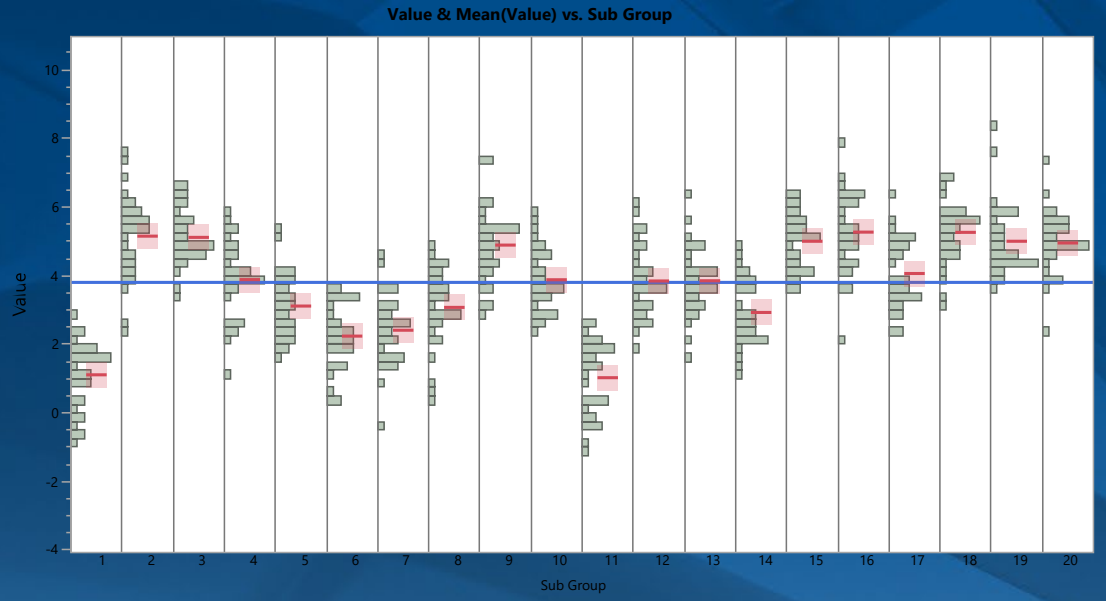
Cpk/Ppk: How well does your process variation combined with your process bias fit into your tolerance band?

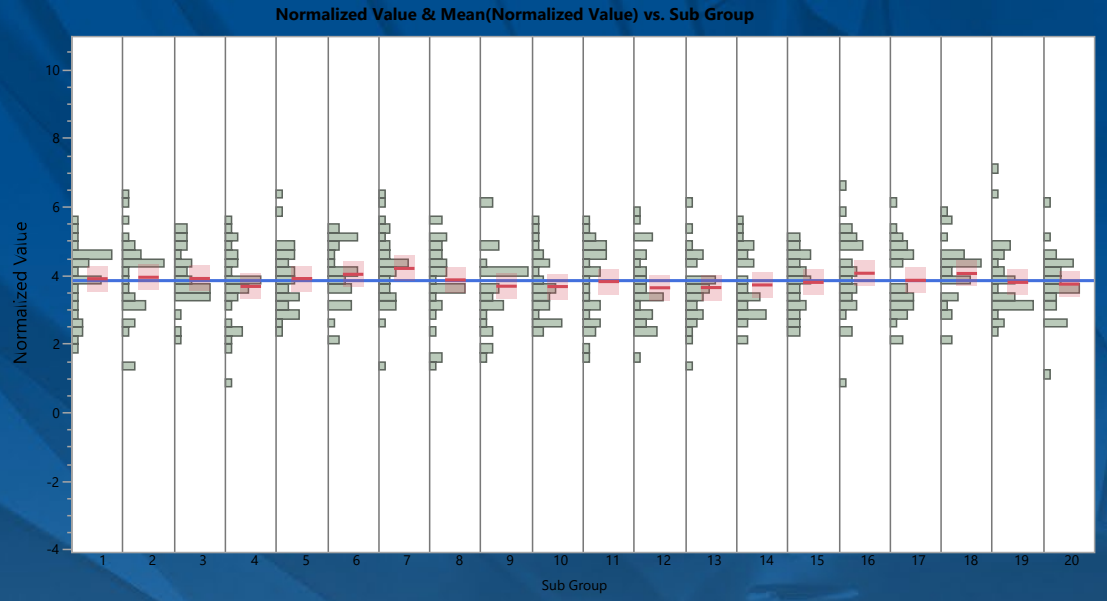
Cp/Cpk: within (aka short term) stdev used

Pp/Ppk: overall Stdev used

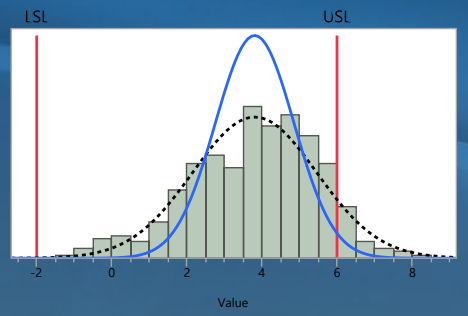
For this example using subgroups vs I-MR as it shows the difference more clearly:

- Each subgroup has a mean of zero,
- Each subgroup has a stdev of 1
- Each subgroups mean is randomly offset by an integer of 1 to 5).
  - This results in process mean of 3.8.





Histogram



Process Summary

LSL	-2
USL	6
N	600
Sample Mean	3.806248
Within Sigma	1.047801
Overall Sigma	1.65427
Stability Index	1.578802

Within sigma estimated by average moving range.

Within Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Cpk	0.698	0.641	0.755
Cpl	1.847	1.712	1.982
Cpu	0.698	0.641	0.755
Cp	1.273	1.181	1.364

Overall Sigma Capability

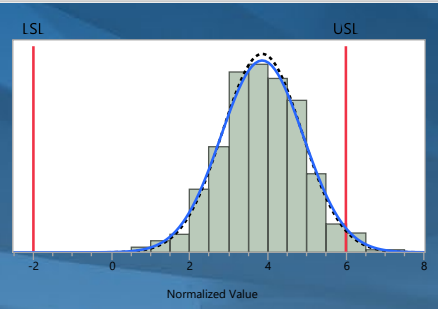
Index	Estimate	Lower 95%	Upper 95%
Ppk	0.442	0.405	0.479
Ppl	1.170	1.098	1.241
Ppu	0.442	0.405	0.479
Pp	0.806	0.760	0.852

Nonconformance

Portion	Observed %	Expected Within %	Expected Overall %
Below LSL	0.0000	0.0000	0.0224
Above USL	7.0000	1.8145	9.2401
Total Outside	7.0000	1.8145	9.2625

Normalized Value Capability

Histogram



Process Summary

LSL	-2
USL	6
N	600
Sample Mean	3.856248
Within Sigma	1.05309
Overall Sigma	1.018103
Stability Index	0.966777

Within sigma estimated by average moving range.

Within Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Cpk	0.679	0.623	0.734
Cpl	1.854	1.718	1.989
Cpu	0.679	0.623	0.734
Cp	1.266	1.175	1.357

Overall Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Ppk	0.702	0.654	0.750
Ppl	1.917	1.806	2.029
Ppu	0.702	0.654	0.750
Pp	1.310	1.235	1.384

Nonconformance

Portion	Observed %	Expected Within %	Expected Overall %
Below LSL	0.0000	0.0000	0.0000
Above USL	2.1667	2.0891	1.7618
Total Outside	2.1667	2.0891	1.7618

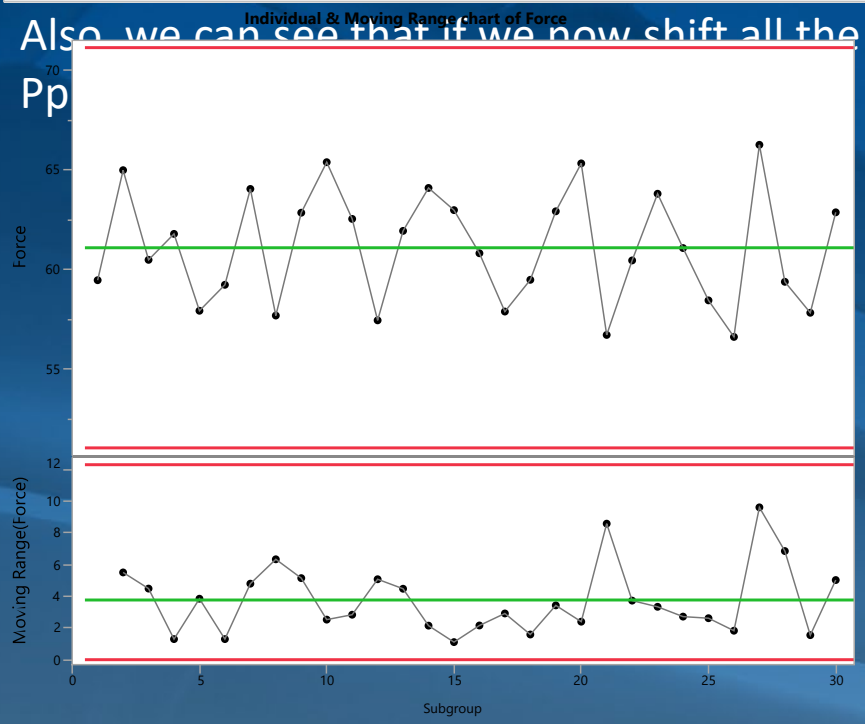
What we can see here is if we can reduce the overall variability from Overall Sigma to within Sigma, Ppk will become Cpk (red)

Also, we can see that if we now shift all the means to the target of 2 our Ppk will go to Cp (orange)

I-MR style data

Also, we can see that if we now shift all the [illegible] to the target of 2 [illegible] Pp

Control Chart Builder

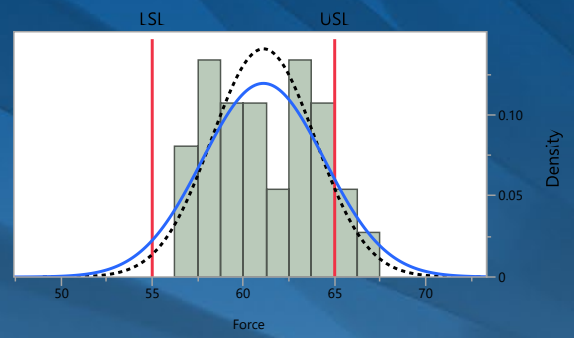


Force Limit Summaries

	Points plotted	LCL	Avg	UCL	Limits Sigma	Subgroup Size
Individual		51.07269	61.095	71.11731	Moving Range	1
Moving Range		0	3.769655	12.3137	Moving Range	1

Process Capability Analysis

Histogram



Process Summary

LSL	55
USL	65
N	30
Sample Mean	61.095
Within Sigma	3.34077
Overall Sigma	2.834988
Stability Index	0.848603

Within sigma estimated by average moving range.

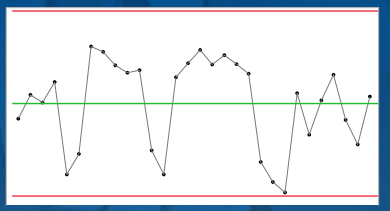
Within Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Cpk	0.390	0.215	0.564
Cpl	0.608	0.375	0.836
Cpu	0.390	0.213	0.561
Cp	0.499	0.337	0.660

Overall Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Ppk	0.459	0.291	0.627
Ppl	0.717	0.496	0.934
Ppu	0.459	0.290	0.625
Pp	0.588	0.437	0.738

What drives a difference between Cpk and Ppk will generally be shifts in the data



Within Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Cpk	0.781	0.499	1.062
Cpl	0.927	0.602	1.248
Cpu	0.781	0.499	1.058
Cp	0.854	0.577	1.130

Overall Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Ppk	0.539	0.356	0.722
Ppl	0.640	0.435	0.840
Ppu	0.539	0.354	0.719
Pp	0.589	0.438	0.740

Note: When using I-MR data, if Cpk is lower than Ppk, report both the Cpk and Ppk if asked for just the Cpk. The overall variation should always be equal to or greater than the within/short term variation so Cpk should always be equal to or larger than Ppk. However, since the within/short term variation is estimated by the moving range it may end up being a poor approximation and thus overstate the variation.

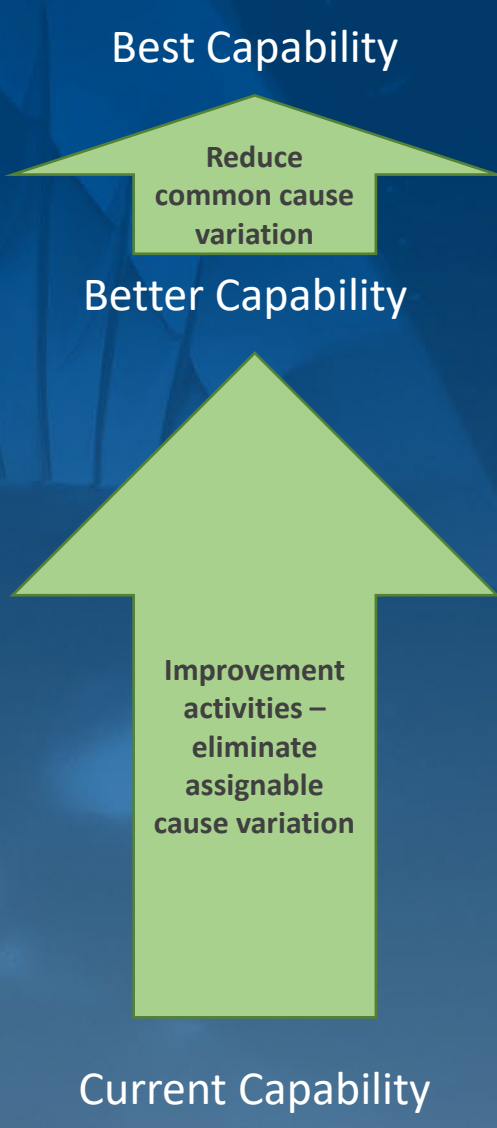
What does this show:

- Cp = uses the within subgroup variation and is the best your process can perform without diving into common cause variation. You can reach this capability by eliminating the between subgroup variation and shifting the process to the center of the spec band

- Cpk = uses the within subgroup variation and is the potential your process has if you can eliminate the between subgroup variation

- Pp=uses the overall variation and is the potential your process has if you can shifting the overall process to the center of the spec band

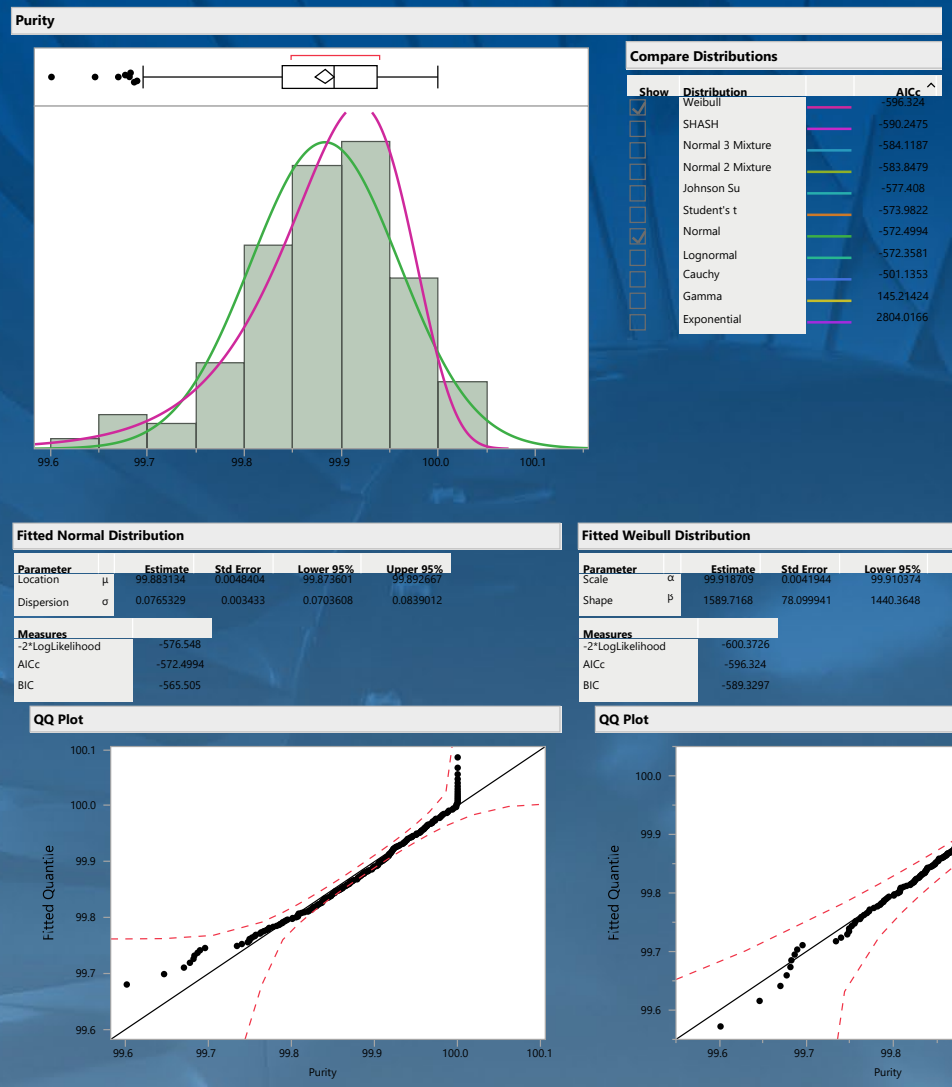
- Ppk = uses the overall variation and is the current capability of your process if you do nothing and it staying in control.



Guidance for Non-Normal Data

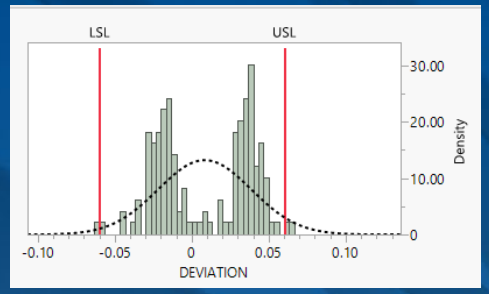
(it's more common than the name suggests)

- **Check your fit**
  - Too much data can make goodness of fit too sensitive
  - Use fat pencil test
- **Check your process**
  - Skewed or multi modal distributions may be from blended process
- **Check your data**
  - Being skewed may be from bad data entry or sensor issues
- **Find a non-normal distribution**
  - Weibull and Lognormal common ones to use
  - Note: Cpk will not be calculated for Non-normal data
- **Last resort: Transform with Box Cox or Johnson**
  - Can get you a Ppk number but much of the valuable information and "relatable representation" of the data is destroyed.

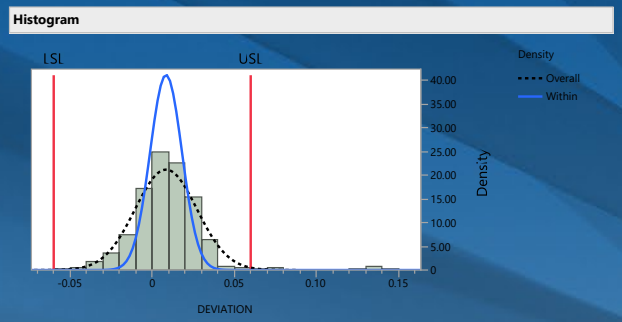


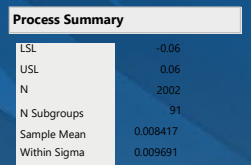
Live Case Studies

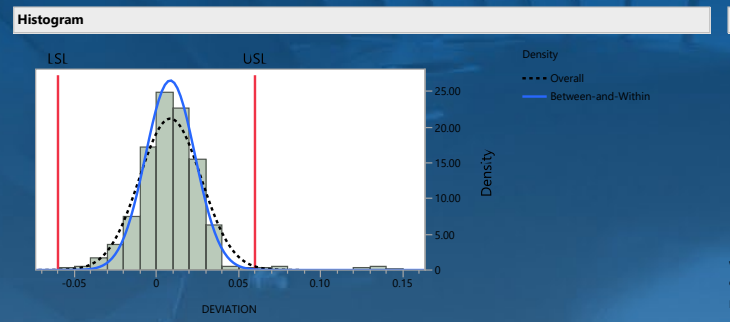
Standard Analysis (such a thing?)

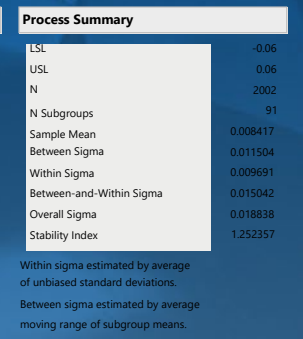


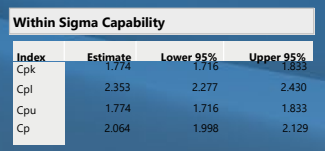
Between Within (such as multiple feature groups RM13006 Sect 9.1.2)

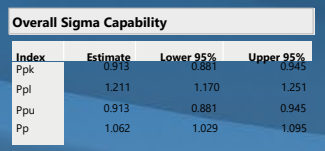


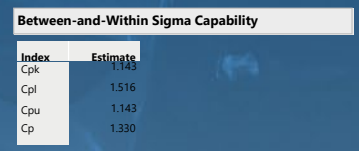


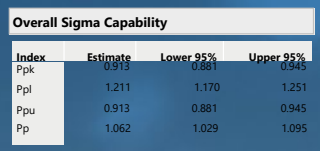




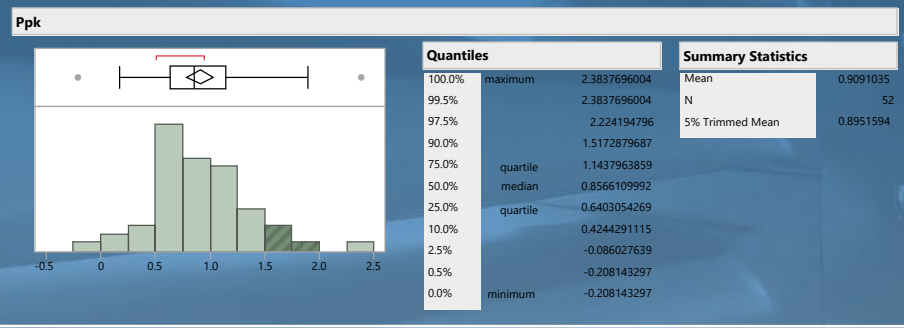








Large scale capability analysis (such as full CMM inspections)



52 Capability Analysis!

Summary

Have quality data you can trust (MSA and data clean up)

Have enough data that you have appropriately narrow confidence intervals and capture correct process variability

Choose the correct distribution

- Pre: use goodness of fit tests, quantile plots
- Post: expected vs observed outputs

Make sure your process is stable (Control Charts)

Choose the appropriate capability Indices to evaluate your process (Ppk should be the starting point, explains how your current process will perform overall)

Track and improve!

FUTURE WEBINARS

From the Process Control Methods SMIG Group

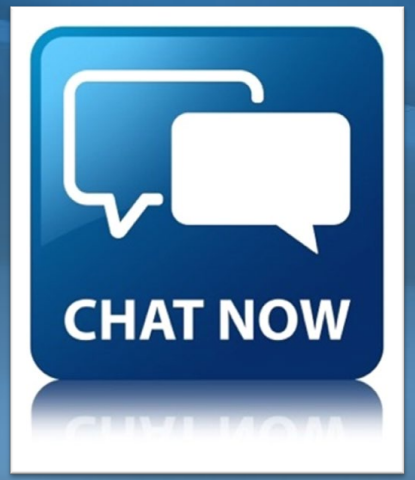
Look for these future topics in the "Upcoming Events" page on the AESQ website:

https://aesq.sae-itc.com/interest-groups

NO.	FUTURE WEBINAR TOPICS	TARGET DATE/TIME	WEBINAR LEAD	SUPPORTING SUB-TEAM	BRIEF DESCRIPTION
1	Process Control Methods - What is RM13006? Interaction with other AESQ Reference Manuals	12/6/2022 (11 AM US Eastern)	Pete Teti	Nicklas Godebu/Marnie Ham	Overview of RM13006 and how it interacts with other AS13100 reference manuals.
2	What makes a good Process Capability Study?	1/26/2023 (11 AM U.S. Eastern)	Steve Hampton	Marnie Ham/Karen Scavotto	Cpk values are only as good as what goes into the data used to calculate Cpk, such as the adequacy of the measurement system and achieving statistical control.
3	Process Capability Study for True Position (handling MMC)	2/8/2023 (11 AM U.S. Eastern)	Grant Braun	Karen Scavotto/Marnie Ham/Shailesh Shinde/Andrew Stout	How do we handle process capability for one-sided or unlateral tolerances such as true position where Maximum Material Condition modifiers may play a role?
4	The use of non-statistically based process control methods	3/8/2023 (11 AM U.S. Eastern)	Paul Gorg	Pete Teti/Earl Capozzi/Rudi Braunieder/Nicklas Godebu	Process controls need not only be statistically based. Here we explore non-statistical methods such as error-proofing devices, the PreControl method, and the use of run charts with non statistical limts.
5	The Power of Precontrol	4/11/2023 (11 AM U.S. Eastern)	Andrew Stout	Steve Hampton/Geoffrey Carpentier	PreControl is a powerpul non-statistical tool that is easy to get up and running with that can be used to qualify the set-up of a lot as well as a control for the production run.
6	The One-Hour Process Control Assessment	5/16/2023 (11 AM U.S. Eastern)	Pete Teti	Geoffrey Carpentier	If you were visiting a supplier and only had time to carve out one hour for a process control assessment, what questions would you ask and where whom would you ask those questions to?
7	Why is statistical control a prerequisite for process capability?	Target 2nd Qtr (June)	Marnie Ham	Andrew Stout/Geoffrey Carpentier/Douglas Dush	Process Capability indexes without the use of SPC Control Charts are invalid. Control Charts are the method to monitor and control a process and are a key prerequisite prior to calculating Cp & Cpk.
8	Dealing with Non-Normal Data	Target 3rd Qtr (September)	Karen Scavotto	Marnie Ham/Shailesh Shinde/Andrew Stout	What happens when the data coming from a process is non-normal? What can be done to accuratly assess process capability? We will show you!
9	Conducting capability studies for one-sided geometric tolerances	Target 4th Qtr (October)	Karen Scavotto	Marnie Ham/Shailesh Shinde/Andrew Stout	Aerospace component manufacturers the world over deal with geometric/one-sided features such as runout, flatness, etc. What rules have to change when assessing process capability?

Q & A SESSION

USE THE “CHAT” FUNCTION TO ASK A QUESTION…



SUMMARY

All resources will be available on the AESQ website within a few days.

An email will be sent to all registrants with a link.

AESQ
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THANK YOU FOR PARTICIPATING