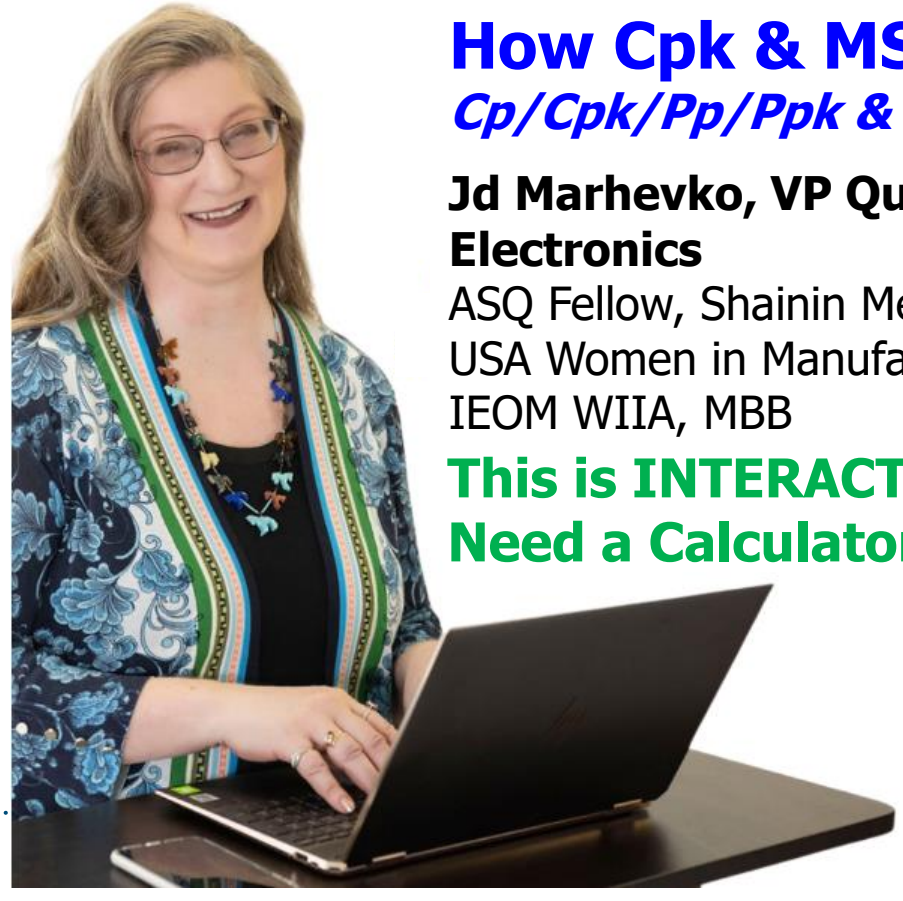


How Cpk & MSA Work Together

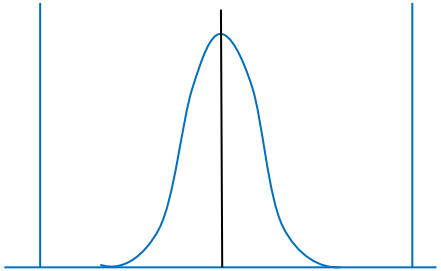
Cp/Cpk/Pp/Ppk & MSA…Whew!

Jd Marhevko, VP Quality, ZF Group, ADAS & Electronics
ASQ Fellow, Shainin Medalist, CMQ/OE, CSSBB, CQE
USA Women in Manufacturing Hall of Fame
IEOM WIIA, MBB

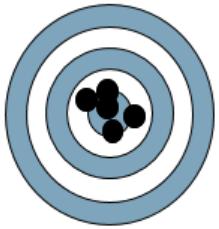
This is INTERACTIVE… You WILL Need a Calculator

Why are WE here?

- We will do a rapid, high-level overview of how cp/cpk/pp/ppk generally works
- Please have a calculator/paper handy, I will be asking you to do some work!
- From there, we will do a quick review of the variables portion of Measurement System Analysis (MSA) from the Gage Repeatability & Reproducibility (GRR) perspective
- We won't discuss on *how* to get the %GRR calculation (Range, ANOVA, etc)
- We will connect the two from the %Tolerance aspect and how an effective process capability is needed in tandem with an effective gage study



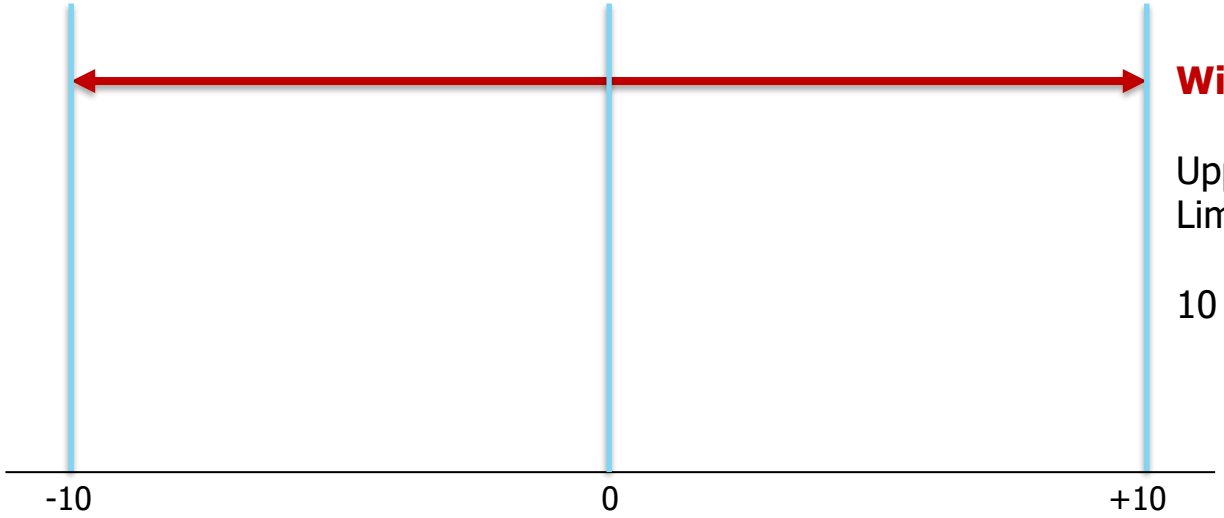
Process capability = 2.00



Accurate &
Precise

Cp/Pp. Process Capability (Ratio)

- A customer's quick "index" of identifying if a process is yielding all good parts or not
- It is a **RATIO** of the width of the process to the width of the Specification
- You first need the width of the specification



Width of SPECIFICATION =

Upper Spec Limit (USL) – Lower Spec Limit (LSL)

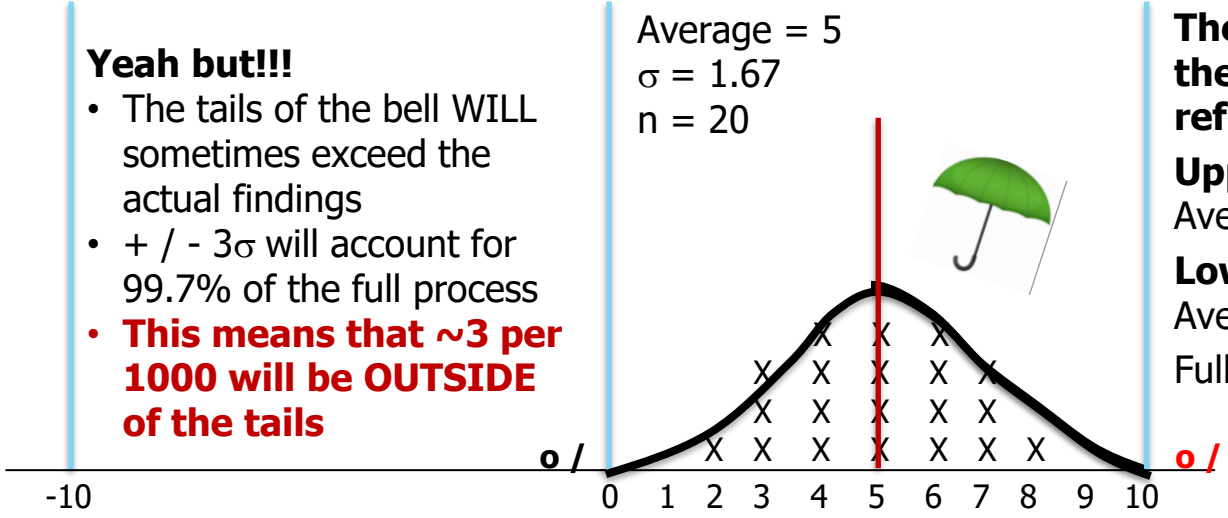
10 – (-10) = 20 units wide

Cp/Pp. Process Capability (Ratio)

- We now need the width of the process: This is the standard deviation (σ) multiplied by 6. "6σ"
  - BUT, there has to be enough samples (usually you need at least 25)
  - AND, the histogram has to look like a "normal" distribution (aka: Gauss, bell, normal)
  - The BELL (process tails) are calculated/drawn by adding 3σ and subtracting 3σ to the average
- If there are NOT enough samples AND/OR the histogram does not look "normal", the calculation may not be accurate (because the sigma will not calculate properly…there are ways to adjust this)

Yeah but!!!

- The tails of the bell WILL sometimes exceed the actual findings
- + / - 3σ will account for 99.7% of the full process
- **This means that ~3 per 1000 will be OUTSIDE of the tails**



There is a global agreement; the world uses 6 sigmas to reflect the full process width

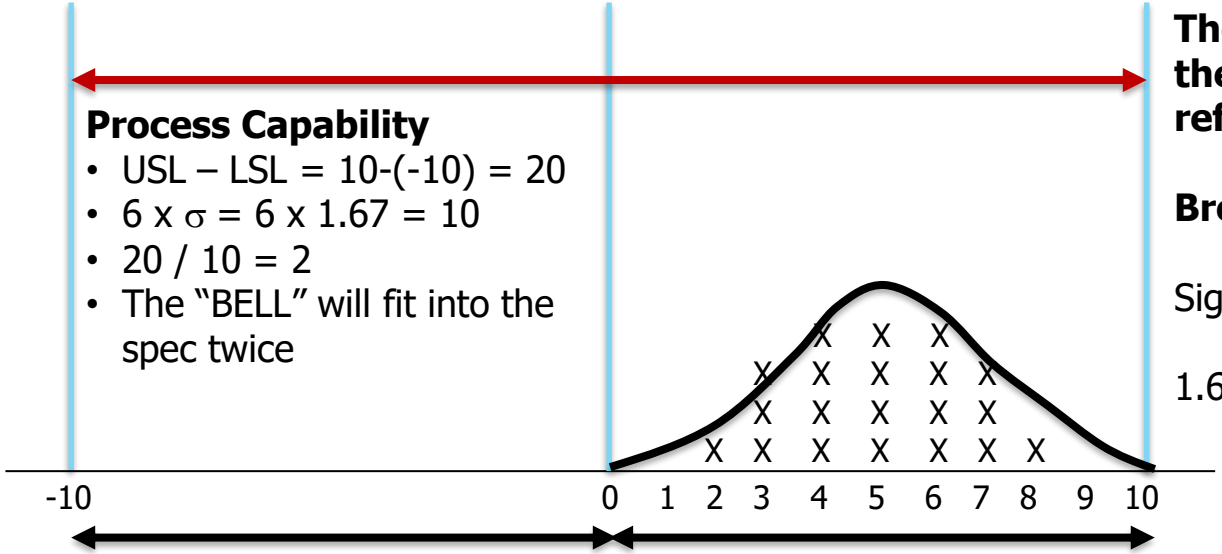
Upper tail of a PROCESS = Average + 3σ = 5 + (1.67 x 3) = 10

Lower tail of a PROCESS = Average - 3σ = 5 - (1.67 x 3) = 0

Full Process = 1.67 x 6 = 10

Cp/Pp. Process Capability (Ratio)

- IF the process is shaped like a BELL, and IF there are enough points to see normality, then the 2 distances can be compared:
- Process Capability = (USL – LSL) / (6 x sigma) = (10 – (-10)) / (6 x σ) = 20 / 10 = 2
- The "BELL" or the "PROCESS" fits into the breadth of the specification 2 times



There is a global agreement; the world uses 6 sigmas to reflect the breadth of a process

Breadth of PROCESS =

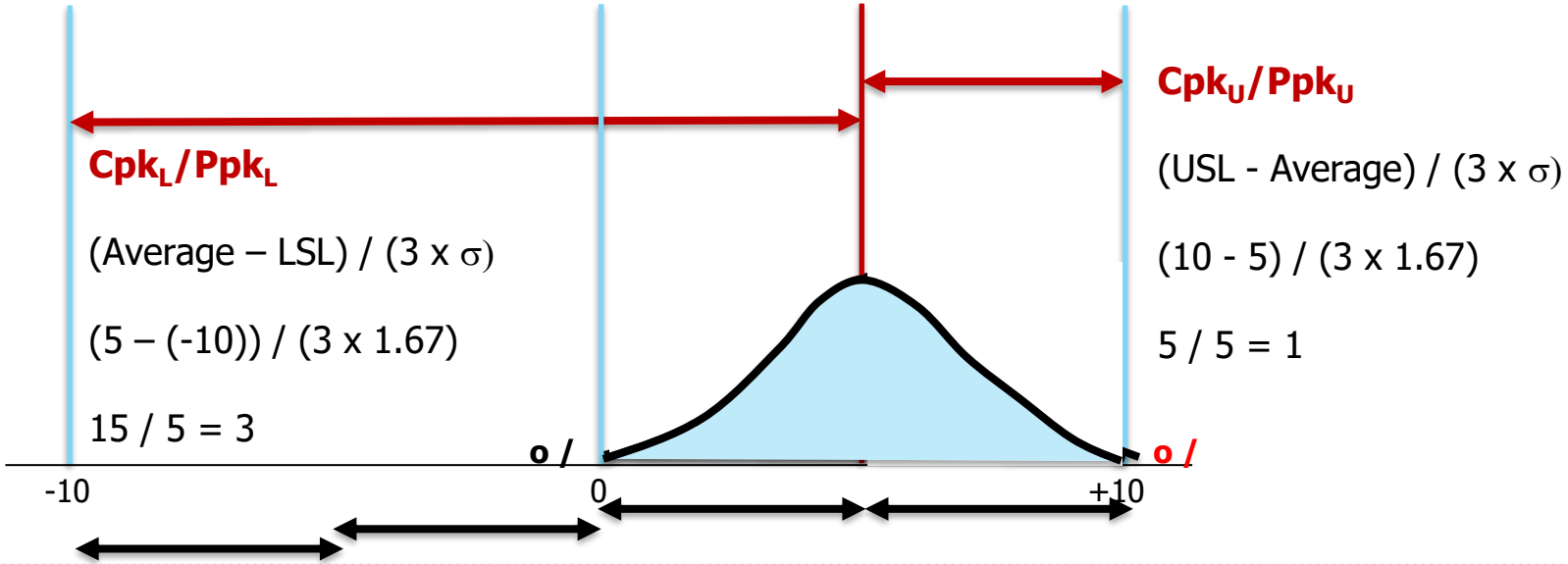
Sigma x 6 =

1.67 x 6 = 10

Cpk/Ppk. Process Capability (Ratio). Is the process centered?

- It is a **RATIO** of the width of DISTANCE from the AVERAGE to the nearest Specification
- To HALF of the full process (3 sigmas)
- There is an UPPER Cpk_U/Ppk_U for the upper spec and a LOWER Cpk_L/Ppk_L for the lower spec

If the average is NOT at the center of the specification, then these values will be different
Remember to properly enter negative numbers



The NORMAL (Gauss/Bell) Distribution

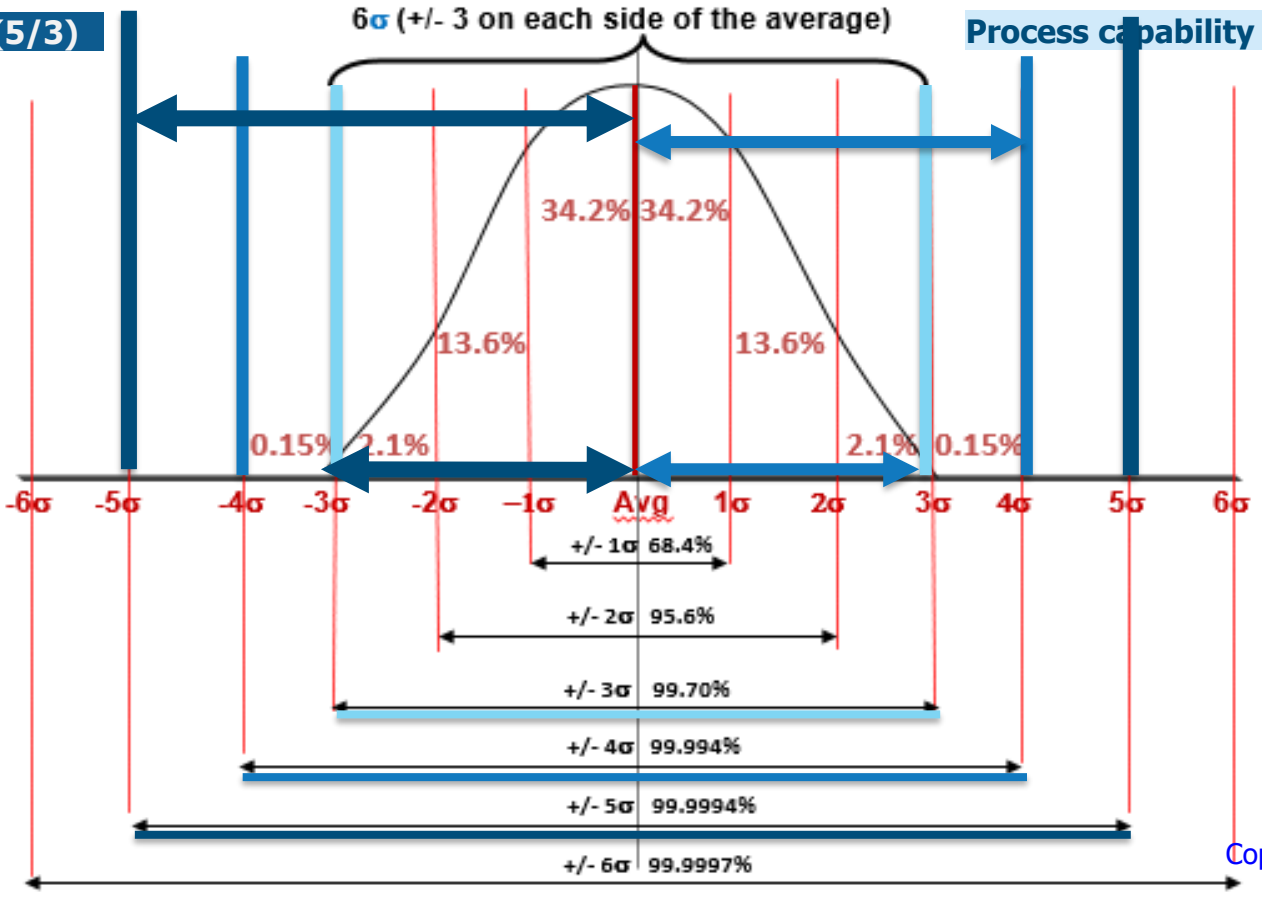
Percentage of process results that fall within "sigmas" of a normal distribution

Process capability = 1.67 (5/3)

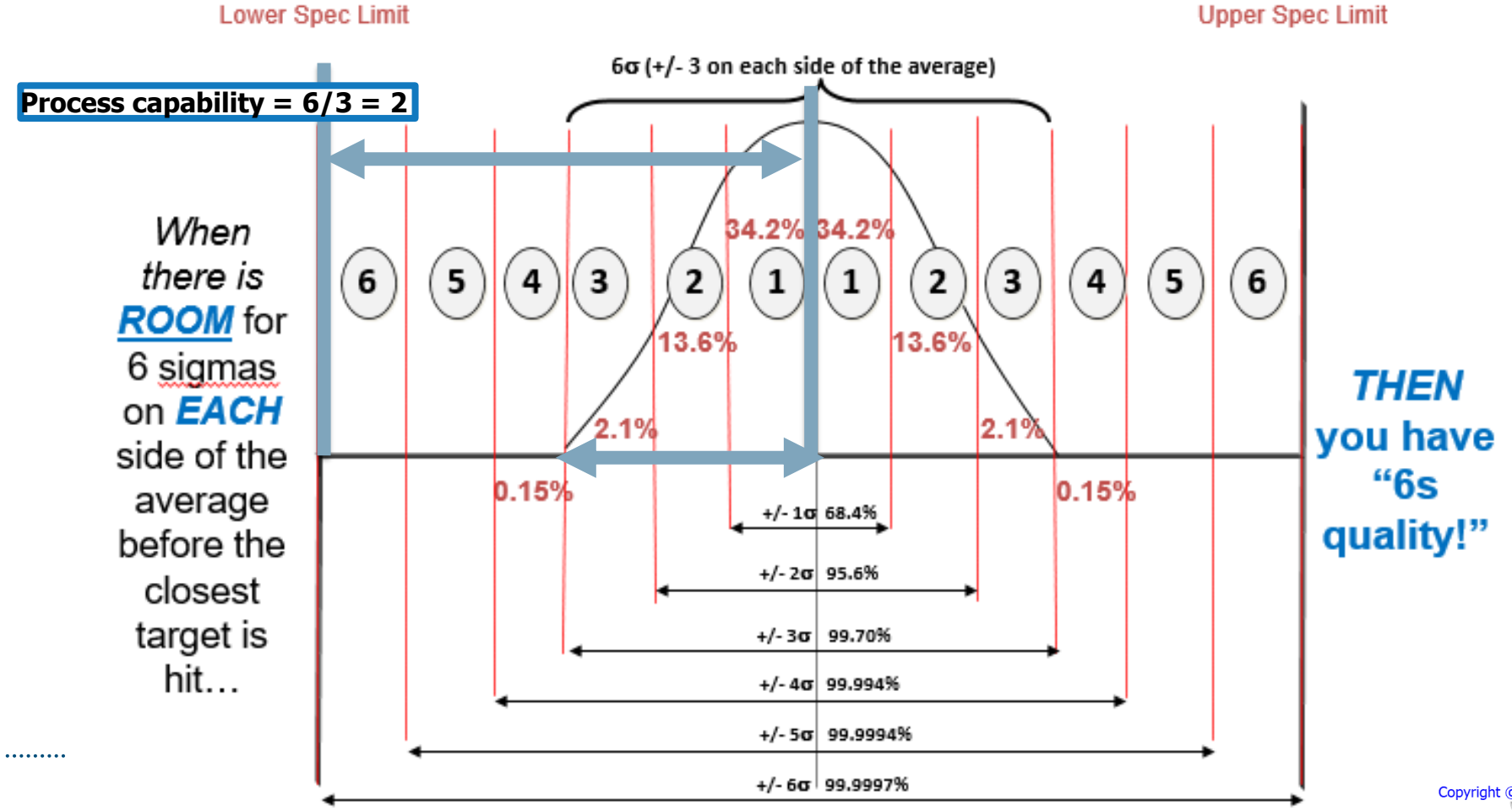
Process capability = 1.33

*Its **ALL** about **PREDICTING**!*

When we know where the tails hit, we can estimate how many of the results will be good or at risk



Six (6) Sigmas of "ROOM" (space)



.....

Which is which Cpk or Ppk? The World DISAGREES on TERMINOLOGY But AGREES on CONCEPT

- See the differences of terminology between the EU and the AMS/AP
- Some suppliers are savvy enough to take advantage of this terminology difference at contract review

Definition	USA (AIAG) AP Toyota	EU (VDA)	Notes
Initial Process Capability	Cp/Cpk (1.67-2.00)	Pp/Ppk (1.67-2.00)	First ~500 units…SOP. Limited shifts, Few set-ups, similar material lots, similar environmental conditions
Long Term Process Capability	Pp/Ppk (1.33-1.67)	Cp/Cpk (1.33-1.67)	>90 shifts, several quarters, multiple set-ups, tooling changes, operator changes

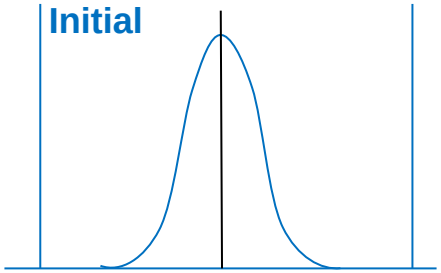
Initial Process Capability vs Long Term Process Capability

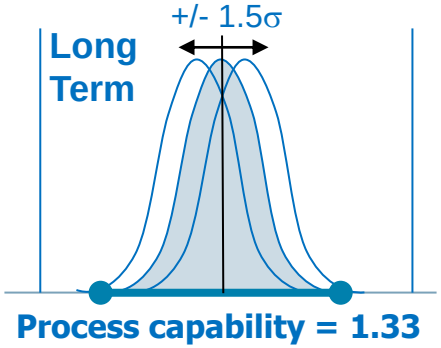
Shift Happens

Short term capability of 1.67-2.00 is desired for *initial* capability

1.33-1.67 is desired for *Long term* capability. This is the capability after the process experiences "life" via multiple material lot changes, set up and operator variation, seasonality, etc. Long term capability is usually calculated with "90 days" (or with a significant quantity) of process data. It is the type of product results that the *long term* process will represent

It is *hypothesized* that a process might "shift" by +/- 1.5σ in response to those changes. As such, if a process started with an initial capability of 2.00, then it is estimated that the long term capability would de-evolve to ~1.33 to accommodate the affects of further variation. Whatever the estimate, there is no way that the initial process capability will be sustained after launch and an increase in variance will be observed





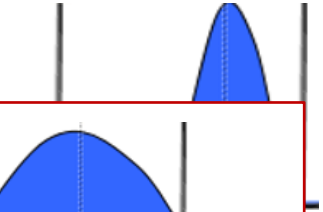
ONE SIDED Cpk/Ppk PPM tables. Divide by 10,000 for %

To calculate a percentage, divide by 10,000

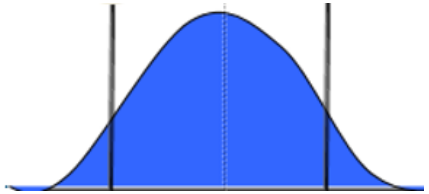
Cpk Fallout Table (ppm)

Cpk = a.bc	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	500,000	488,034	476,078	464,144	452,242	440,382	428,576	416,834	405,165	393,580
0.1	382,089	370,700	359,424	348,268	337,243	326,355	315,614	305,026	294,599	284,339
0.2	274,253	264,347	254,627	245,097	235,762	226,627	217,695	208,970	200,454	192,150
0.3	184,060	176,186	168,528	161,087	153,864	146,859	140,071	133,500	127,143	121,000
0.4	115,070									
0.5	66,807									
0.6	35,930									
0.7	17,864									
0.8	8,1									
0.9	3,4									
1.0	1,3									
1.1	4									
1.2	1									
1.3										
1.4										
1.5	3.3									
1.6	0.7									
1.7	0.170									
1.8	0.033									
1.9	0.006									
2.0	0.001									

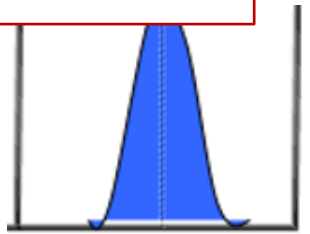
- If I have a process capability of 1.00(U) and 3.00(L)
- We look down the y-axis of the table to 1.0. There is no 3.0
- For 1.00, we look across the x-axis of the table to 0.00
- We see 1,350 PPM (for one side of the process)



- If I have a process capability of 0.67
- We look down the y-axis of the table to 0.6
- We look across the x-axis of the table to 0.07
- We see 22,216 PPM (for one side of the process)
- %Non-Conforming = 22,216 / 10,000 = 2.22%
- If the bell were centered, then there would be 2.22% on each side or 4.44% in total



- We look across the x-axis of the table to 0.00
- We see 0.001 PPM (for one side of the process)
- To get a %Non-Conforming, divide the 0.001 by 10,000 = 0.0000001%
- If the bell were centered, then there would be 0.0000002 in total...This is considered 6σ quality

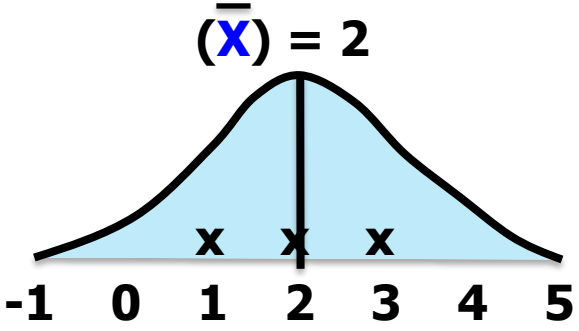


How to Calculate Sigma.

$$\sigma = \sqrt{\frac{\sum (\bar{X} - X)^2}{n - 1}}$$

3 Samples (x): 2, 1, 3 **n = 3** **Average ($\bar{X}$) = 2**

$$\sigma = \sqrt{\Sigma (\bar{X} - x)^2 \ / \ (n - 1)}$$



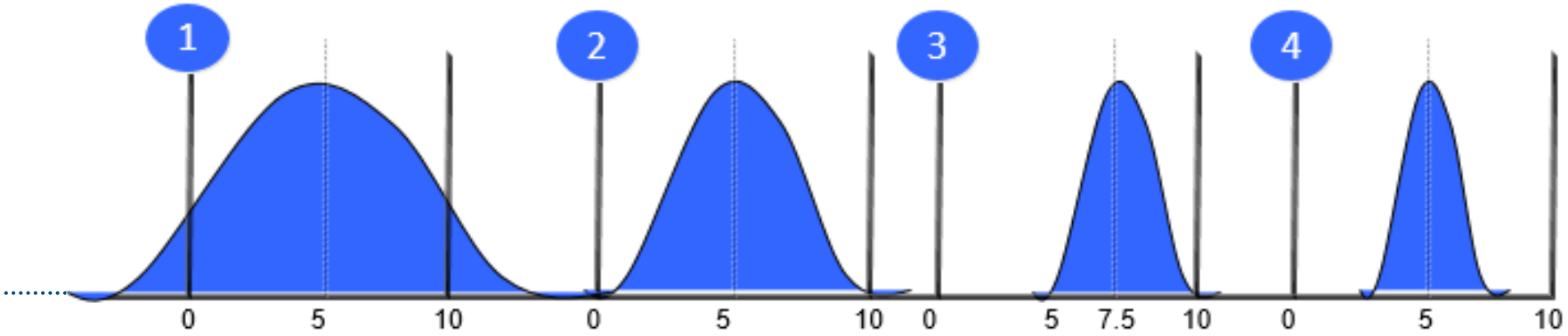
Process capability Worksheet.

Process Capability (Full)
(USL – LSL) / (6 x σ)

Process Capability (Upper)
(USL – Average) / (3 x σ)

Process Capability (Lower)
(Average - LSL) / (3 x σ)

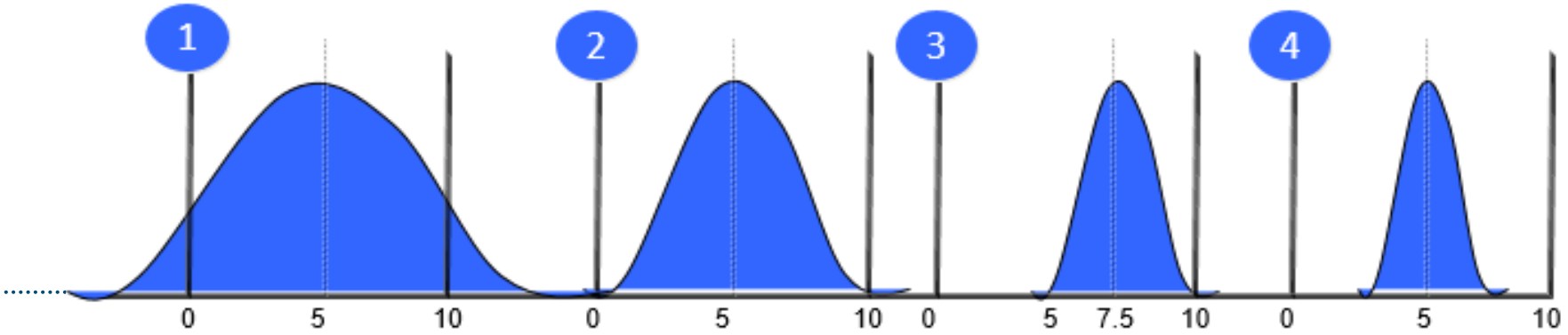
#	Avg	σ	Cp	Cpk_U	Cpk_L	%Non-Conf
1	5.0	2.50				Last name A - F
2	5.0	1.67				Last name G - L
3	7.5	0.83				Last name M - R
4	5.0	0.83				Last name S - Z



Process capability Worksheet. Sample 1

Process Capability (Full)
(USL – LSL) / (6 x σ)
(10 - 0) / (6x2.5) = 10 / 15 = 0.67
Process Capability (Upper)
(USL – Average) / (3 x σ)
(10 - 5) / (3x2.5) = 5 / 7.5 = 0.67
Process Capability (Lower)
(Average - LSL) / (3 x σ)
(5 - 0) / (3x2.5) = 5 / 7.5 = 0.67

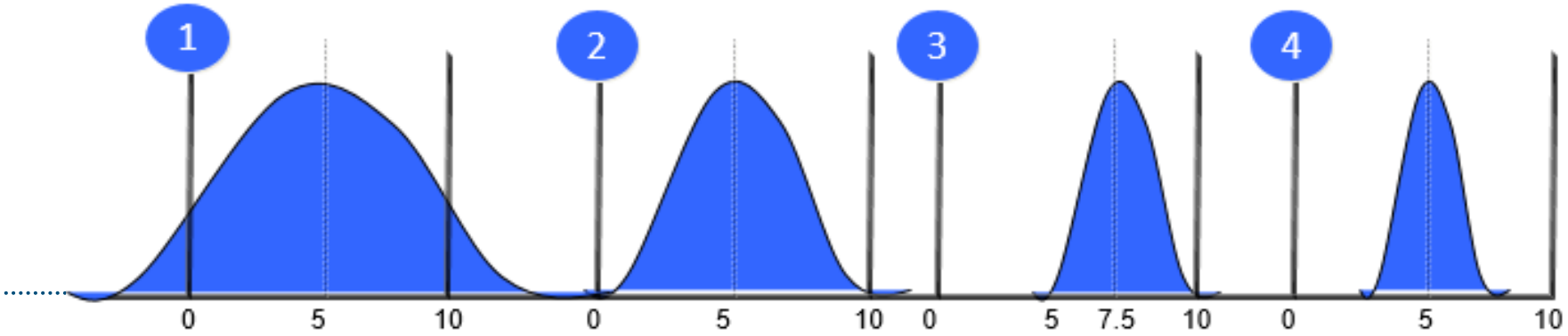
#	Avg	σ	Cp	Cpk_U	Cpk_L	%Non-Conf
1	5.0	2.50	0.67	0.67	0.67	4.44%
2	5.0	1.67				
3	7.5	0.83				
4	5.0	0.83				



Process capability Worksheet. Sample 2

Process Capability (Full)
(USL – LSL) / (6 x σ)
(10 - 0) / (6x1.67) = 10 / 10 = 1.00
Process Capability (Upper)
(USL – Average) / (3 x σ)
(10 - 5) / (3x1.67) = 5 / 5 = 1.00
Process Capability (Lower)
(Average - LSL) / (3 x σ)
(5 - 0) / (3x1.67) = 5 / 5 = 1.00

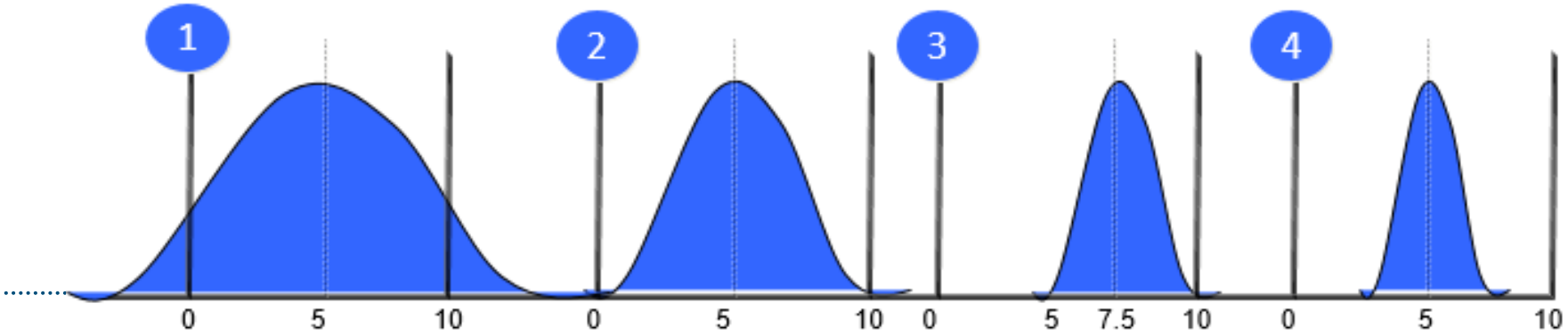
#	Avg	σ	Cp	Cpk_U	Cpk_L	%Non-Conf
1	5.0	2.50	0.67	0.67	0.67	4.44%
2	5.0	1.67	1.00	1.00	1.00	0.27%
3	7.5	0.83				
4	5.0	0.83				



Process capability Worksheet. Sample 3

Process Capability (Full)
(USL – LSL) / (6 x σ)
(10 - 0) / (6 x 0.83) = 10 / 5 = 2.00
Process Capability (Upper)
(USL – Average) / (3 x σ)
(10 – 7.5) / (3 x 0.83) = 2.5/2.5 = 1.00
Process Capability (Lower)
(Average - LSL) / (3 x σ)
(7.5 - 0) / (3 x 0.83) = 7.5 / 2.5 = 3.00

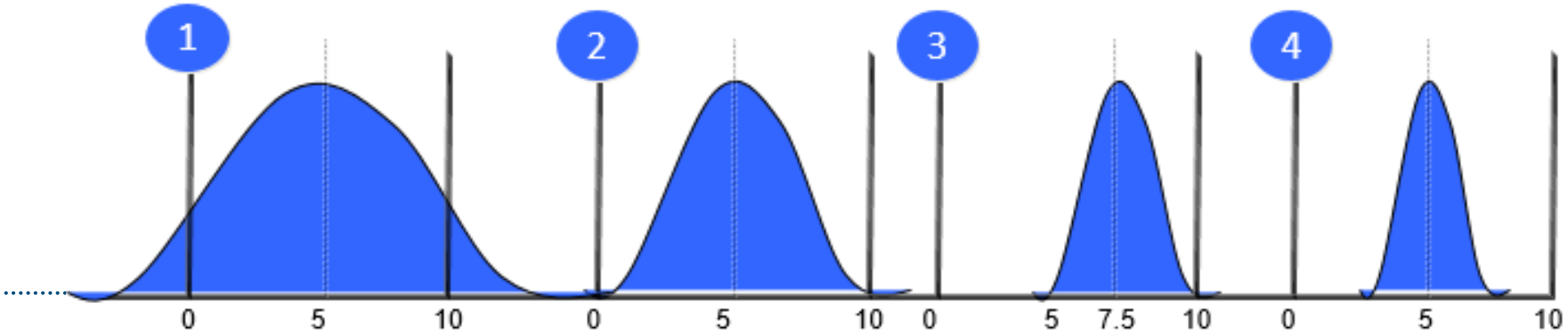
#	Avg	σ	Cp	Cpk_U	Cpk_L	%Non-Conf
1	5.0	2.50	0.67	0.67	0.67	4.44%
2	5.0	1.67	1.00	1.00	1.00	0.27%
3	7.5	0.83	2.00	1.00	3.00	0.135%
4	5.0	0.83				



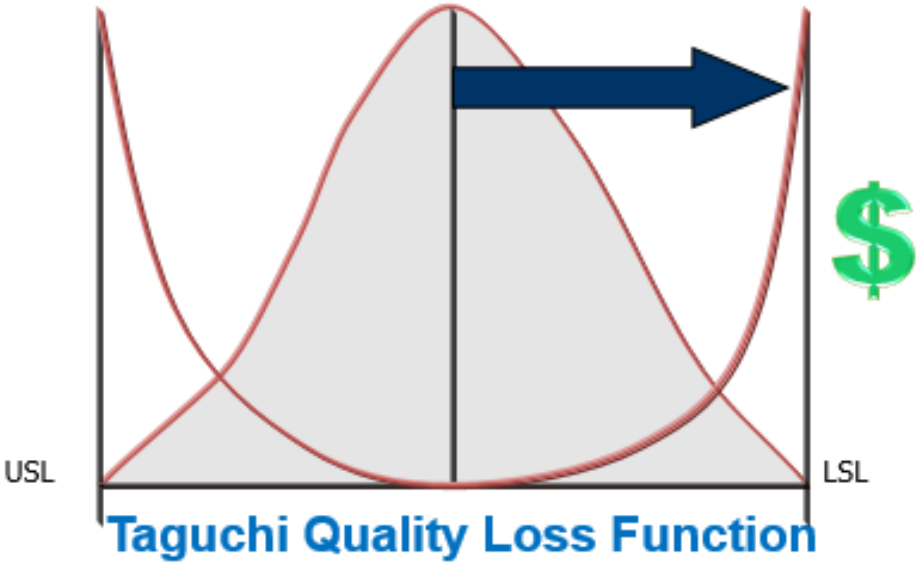
Process capability Worksheet. Sample 4

Process Capability (Full)
(USL – LSL) / (6 x σ)
(10 - 0) / (6 x 0.83) = 10 / 5 = 2.00
Process Capability (Upper)
(USL – Average) / (3 x σ)
(10 – 5) / (3 x 0.83) = 5/2.5 = 2.00
Process Capability (Lower)
(Average - LSL) / (3 x σ)
(5 - 0) / (3 x 0.83) = 5 / 2.5 = 2.00

#	Avg	σ	Cp	Cpk_U	Cpk_L	%Non-Conf
1	5.0	2.50	0.67	0.67	0.67	4.44%
2	5.0	1.67	1.00	1.00	1.00	0.27%
3	7.5	0.83	2.00	1.00	3.00	0.135%
4	5.0	0.83	2.00	2.00	2.00	0%



Taguchi Quality Loss Function



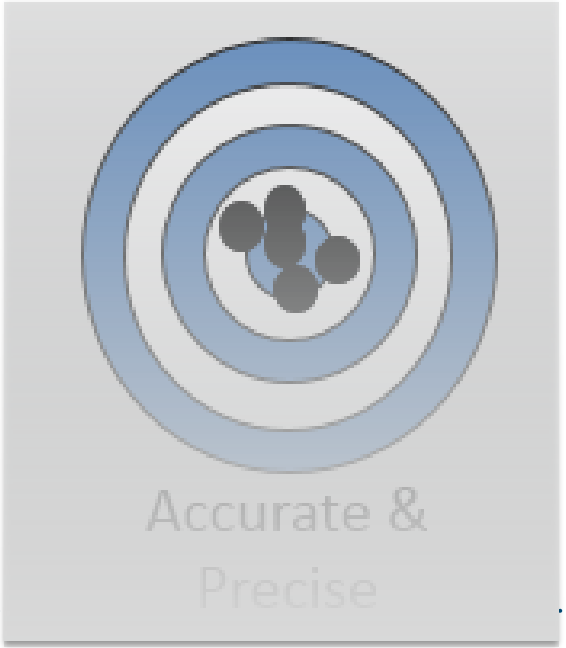
There are more dollars lost in margin and quality (form/fit/function) as the process and/or product moves away from the intended target

The difference between “in spec” and on-target

MSA

Measurement Systems Analysis

GRR & AAA



Measurement System Analysis (MSA)

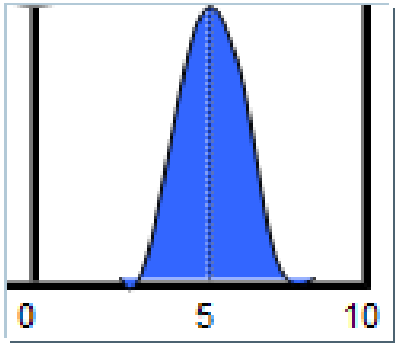
When we measure or make an assessment of the goodness of an item, we need to be sure that our result is correct. If it is not correct, we take two risks:

- **Alpha α Risk**: We may inadvertently discard or rework a good item (Aw, darn)
- **Beta β Risk**: We may inadvertently pass on a bad item (Boy, that was Bad)

Why Do We Need to Know?

We need to know how much error is in our measurement processes for several reasons:

- Prevent α and β errors
- Reduce scrap/rework/pass-through
- Understand what process capability we need our processes to have
- It is our **JOB** to ensure that our people are enabled to make the right pass/fail decision **EVERY** time



- And of course…it's required by IATF/VDA as a part of PPAP
- **NOTE**: *EVERY* item called out for measure or inspection on a control plan is **REQUIRED** to have an MSA analysis conducted

MSA: Variable (GRR) & Attribute (AAA)

As humans we usually believe what we see. We do not question the correctness of a value shown on an instrument. There are ***two typical types*** of ***MSA variables*** assessments to determine HOW much ERROR there is in our results:

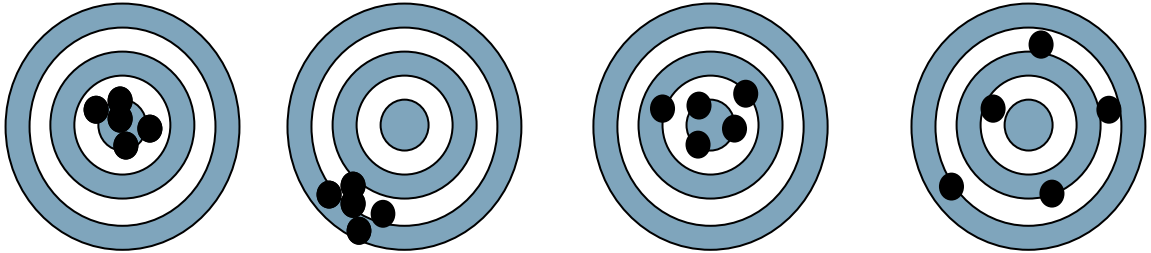
- **Crossed Gage R&R** (Repeatability & Reproducibility). Used with one instrument, multiple operators and multiple part samples
- **Nested GR&R**. Used to determine the amount of gage error in equipment for destructive testing

There is ***generally one type*** of Attribute MSA to determine HOW right or wrong we are in our results:

- **Attributes Agreement Analysis (AAA)** is used for items we assess visually for go/no go decisions

Is this window broken? It still opens. The wooden frame is in place

How Data Varies



Accurate & Precise

Inaccurate but Precise

Accurate but Imprecise

Inaccurate & Imprecise

Accuracy: Generally *managed by calibration* includes bias (how far off), linearity (across the breadth of the measured range) and stability (holding a measure over time)

Precision: Generally managed by Repeatability (gage) and Reproducibility (human) aka Gage R&R (GRR)

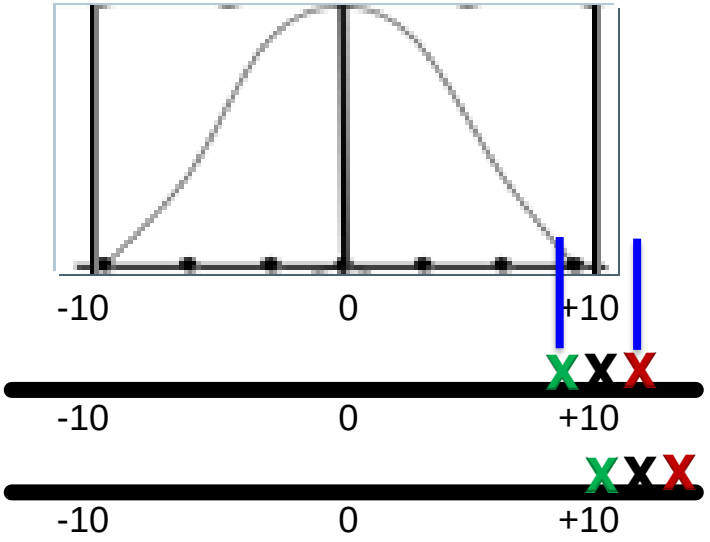
Other MSA Notes

For a variables Measurement System to work, three features are ***equally*** needed:

- **Resolution:** How well we can read the gage. Gage resolution is required to be at least 10% of the tolerance. Ex. A spec of 0 +/- 10 needs +/- 1 resolution (If not at 10% or better, additional actions are needed)
- **Calibration:** A check of bias, linearity and stability (performed on a regular basis). *Minitab has the ability to conduct a gage linearity and bias study*
- **R&R:** Amount of error in human and gage performance. GR&R needs <= 10% error. Included in PPAP, it insures that the gage system will work as intended **BEFORE** the process is started. After that, it is conducted on an as needed basis (1-2x/yr). GR&R is often used to objectively qualify personnel

Why %GRR is Critical to Process Capability

What does Resolution do for you?

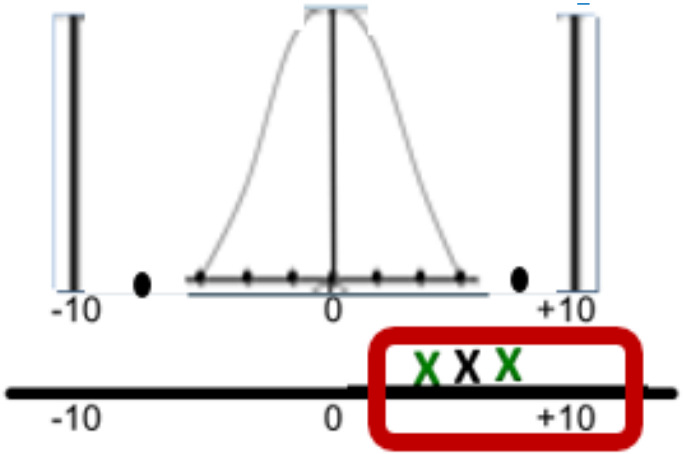


If I have a “10% gage”, I would accept a unit that read 10. But…it could be a 9 or an 11. We are at risk 1/3 of the time for a β error…**IF the capability is 1**

I would also reject an 11, (it could be a 10 or 12). I could have an α error 1/3 of the time...Again, IF the capability is 1

This is one reason why a process capability of 1 isn’t good enough for safety features

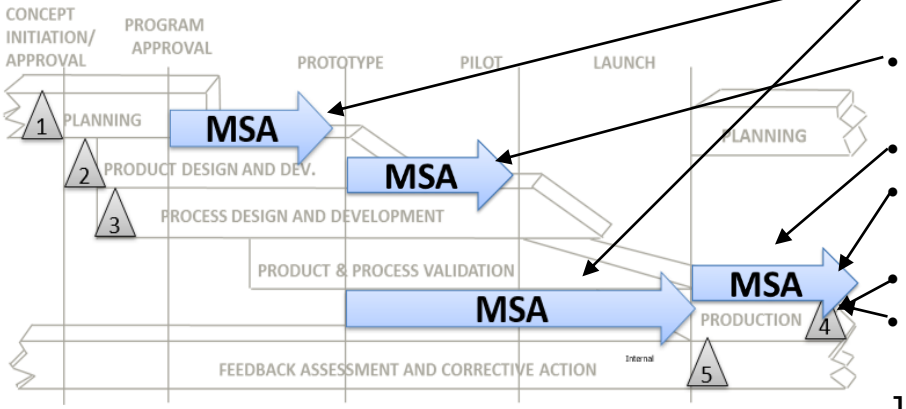
Why %GRR is Critical to Process Capability



With a more capable process, if I still have a "10% gage", the process is not likely to generate any units measuring a "10". As such, if I read a 6, it could still be a 5 or 7. However, there is now minimal risk for either an α or β error. In this case, the **Cp/Cpk is 1.67**

This is one reason of why a minimum process capability of 1.67 is required for safety features

GRR is Needed Everywhere Measurement Matters



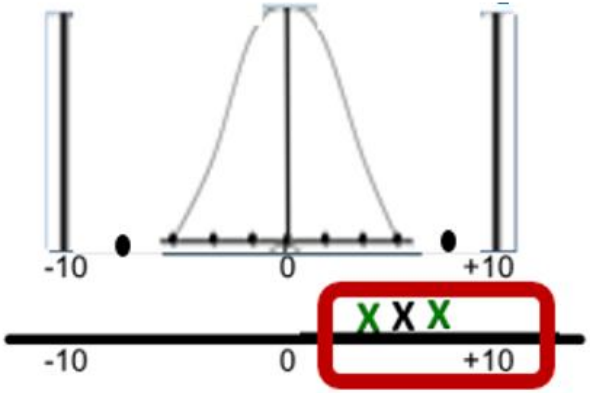
- Engineering Test Equipment (labs)
- Quality Testing Equipment (labs)
- Supplier Testing Equipment
- Maintenance Gaging Equipment
- Production Test Equipment
- Product Gaging

GRR is needed across the full product development process

Just because you SHOULD address gaging in all of these areas, **This does NOT mean they should all go on a control plan**

What we DID?

- We had a rapid, high-level overview of how cp/cpk/pp/ppk generally work
- We practiced!
- We connected process capability to the GRR %Tolerance aspect to understand how both are needed in tandem with an effective gage study to prevent **ALPHA** and **BETA** errors
- Use your new ***superpower*** to make a difference to your business and customers with your knowledge!



Cp/Cpk/Pp/Ppk & MSA…Whew

Jd Marhevko, VP Quality, ZF Group, ADAS & Electronics
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USA Women in Manufacturing Hall of Fame
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THANKS for joining in!
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