Capability Cp, Cpk

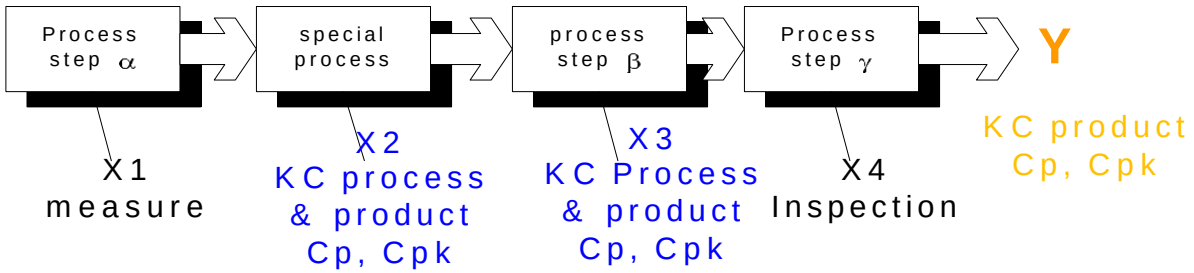
Process Capability Improvement

Process Capability Ratio Cp, Cpk

- **Process Capability Ratio Cp, Cpk definition:**

  - Process capability analysis is a statistical technique applied throughout the product cycle (including development activities prior to manufacturing) to :
    - quantify process variability,
    - analyze the variability relative to product requirements or specifications
    - assist development and manufacturing in eliminating or greatly reducing the variability

  - Process capability refers to the uniformity of the process by measuring the variability of Critical-To-Quality characteristics (e.g. KC) in the process.
  - A simple, quantitative way to express process capability is through the **process capability Ratio Cp, Cpk.** Cp, Cpk can be implement on all type of KC process or KC product:



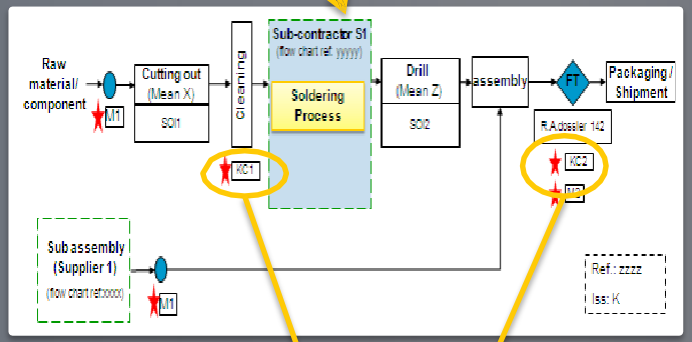
Process Capability Ratio Cp, Cpk

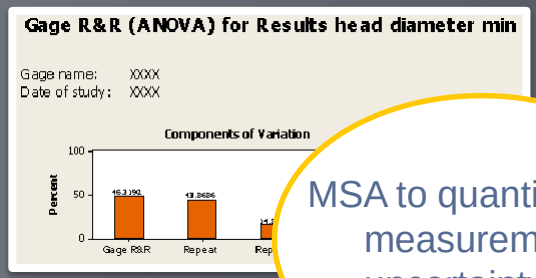
- **Why this requirement?**

  - To measure the process capability to manufacture the product in compliance with Customer expectations.
  - To compare the capability of several processes, each with different units of measurement and different specifications.
  - To estimate the percentage of internal defects or non-conforming product
  - To identify the process most in need of improvement, to manage process robustness.
  - To track drifts or relative improvement of an individual process over time.
  - To set an acceptance criteria for transferring a process/equipment from a development area to a manufacturing line

Process Capability Ratio Cp, Cpk

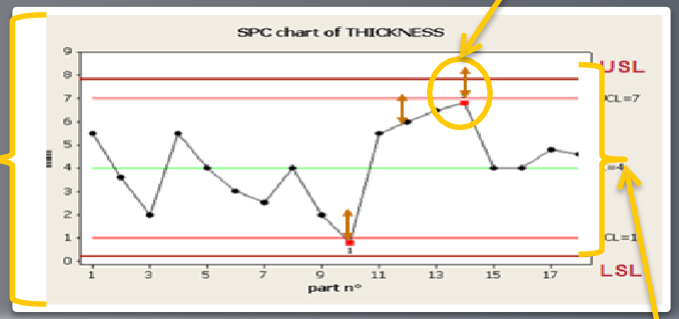
Manufacturing Flow chart lists which and where Key characteristics are monitored





MSA to quantify measurement uncertainty

To monitor KC through SPC Control Chart



Specification

Cp, Cpk calculation to estimate how KC is meeting customer specifications

Process Capability Ratio Cp, Cpk

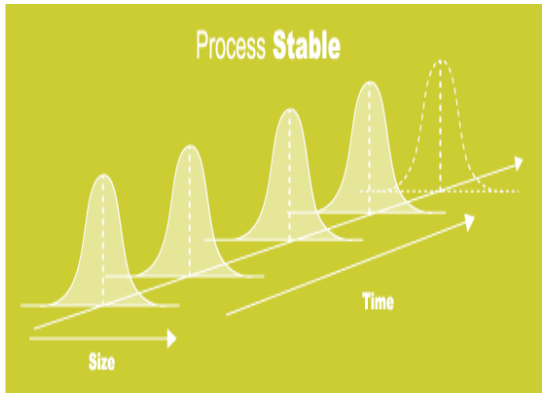
- **How to meet this requirement ?**

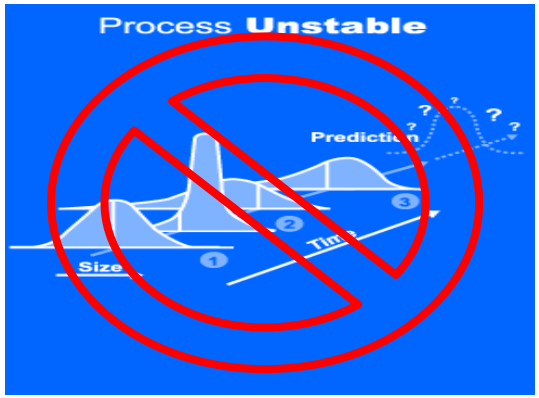
  - A process capability analysis (for continuous data) generally consists of five steps:

    - ***Step 1.*** Verify the **capability of the measurement system** by performing a MSA study (refers to Measurement System Analysis)
    - ***Step 2.*** Verify the **process stability**
    - ***Step 3.*** Determine if the **data distribution is normal**
    - ***Step 4.*** **Calculate the Process Capability Ratio Cp & Cpk** , determine
      Sigma Quality Level
    - ***Step 5.*** **Implement** a process improvement.

Verify the process stability (Step 2)

- Stability or statistical control of the process is essential to the correct interpretation of any Process capability Ratio.
- If the process is not in control state, then its parameters are unstable, and the value of these parameters in the future is uncertain. Thus the predictive aspect of Cp,Cpk regarding process performances are lost.

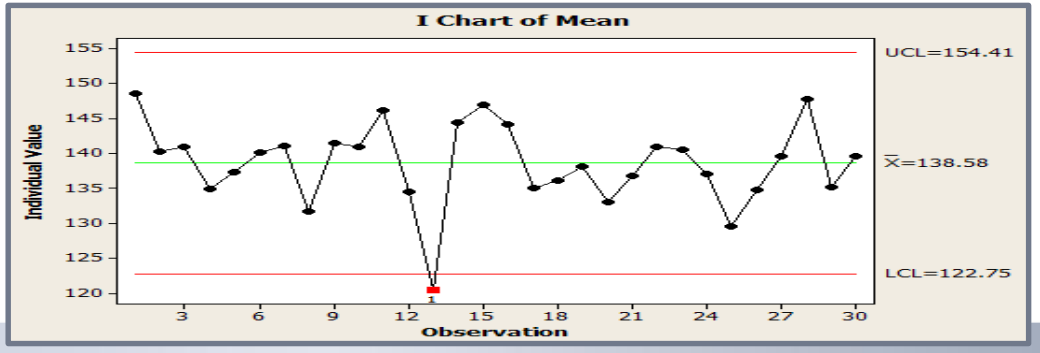




CHECK for COMMON CAUSES

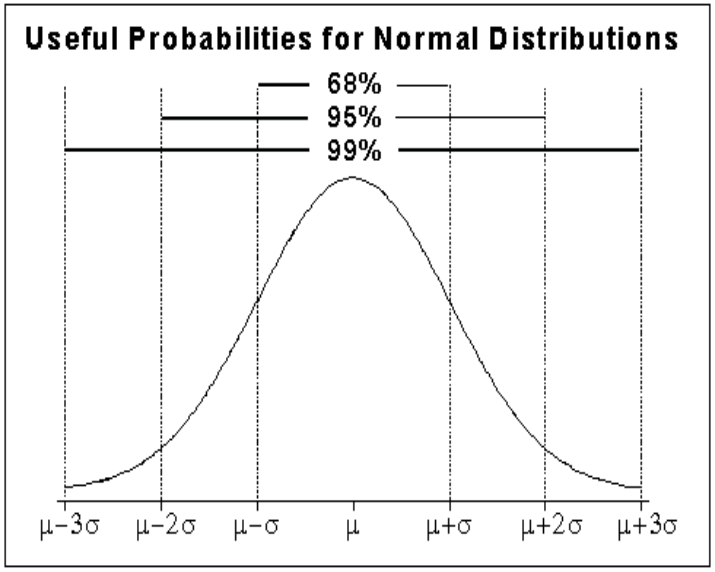
Make sure the process step is Standardized with standard operating instructions SOI

- Control Charts are the best way to assess process stability (time slides, Historical data). There should be no obvious visual trends and very few out-of-control points:

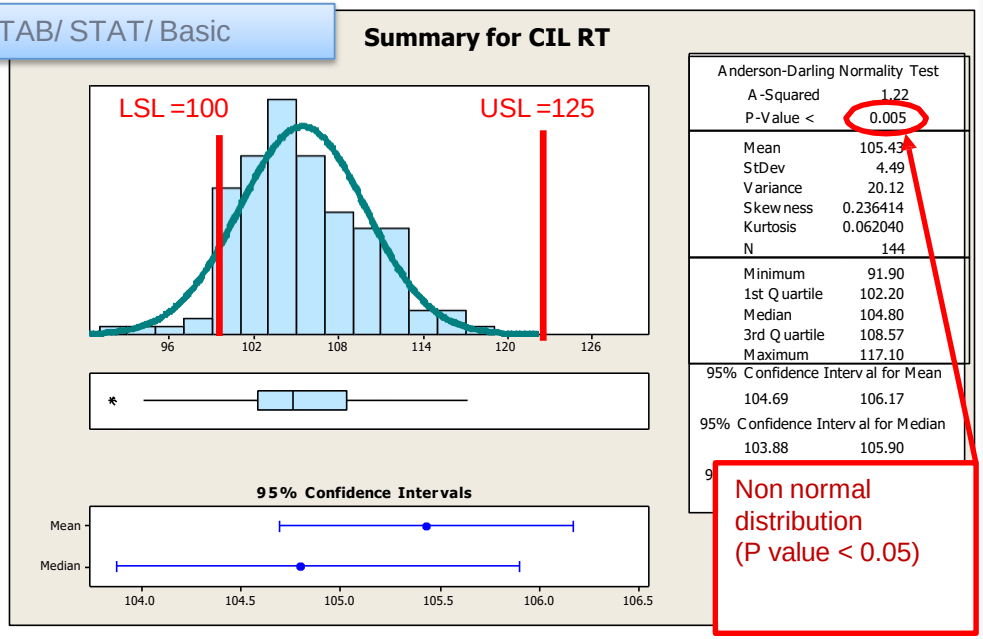


Determine if the data distribution is normal (Step 3)?

- In process capability studies, the correct interpretation of the Process Capability Ratio requires that the underlying measurements have approximately a normal distribution. If the distribution is non-normal, the Cp, Cpk calculation is erroneous.
- Perform with a statistical software a Normality analysis



MINITAB/ STAT/ Basic



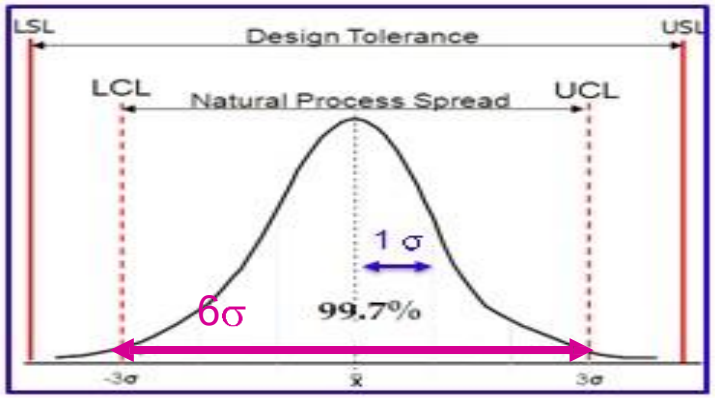
- If the distribution is non-normal, try to understand the root cause of the non normality and/or applied statistical transformation to recover it.

Cp Calculation and interpretation (Step 4)

- Cp is the capability index to measure process spread compare to the spread of the Tolerance (i.e. customer specification)

$$Cp = \frac{USL - LSL}{6\sigma}$$

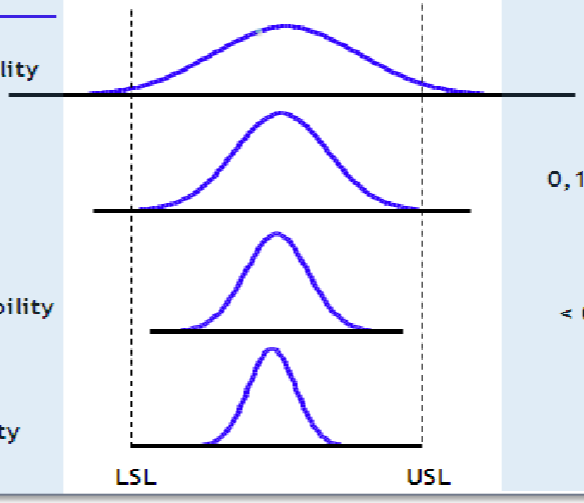
Note: refer to Capability formula



- The recommended minimum sample size to calculate Cp is 30 parts

Correlation between Cp and % defect quantity :

Cp	Interpretation	Defect Qty
< 1.0	Poor Capability	> 6%
1.0 - 1.5	Marginal Capability	0,1%< Defect Qty < 6%
> 1.5	Good Capability	< 0,1% (1000ppm)
> 2.0	6 σ Capability	< 3,4 ppm

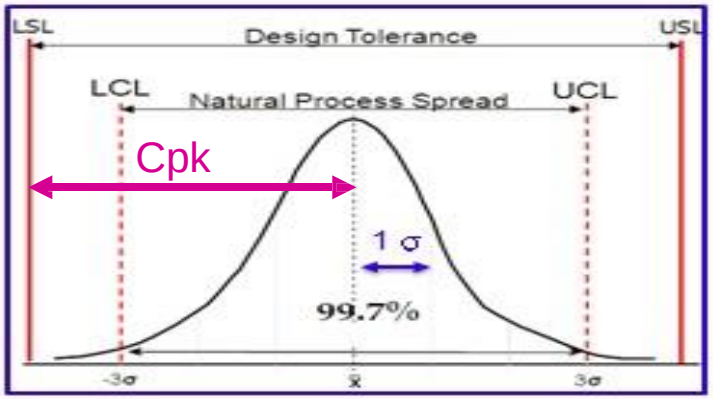


Cp Calculation and interpretation (Step 4)

- As Cp does not take into account the closeness of the mean of the sample to the specification limits, Cpk need to be evaluated to describe the capability of a process to conform to the specifications.
- Cpk represent where the mean of the sample is, process centering, relative to the specification limits.

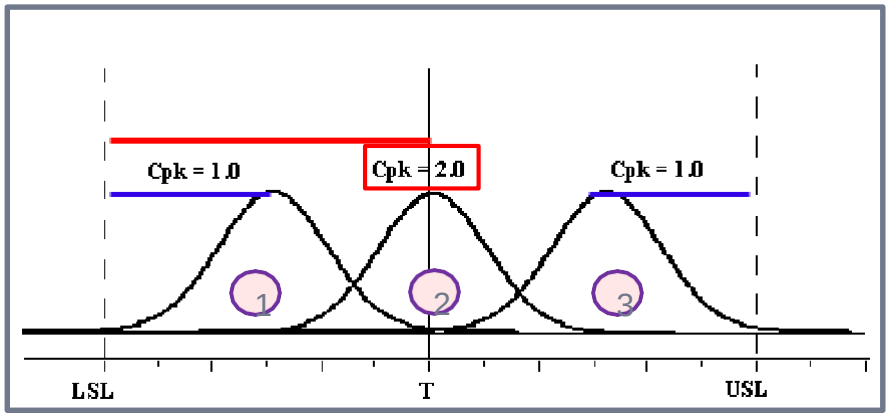
$$Cpk = \min\left[\frac{USL - \overline{X}}{3\sigma}, \frac{\overline{X} - LSL}{3\sigma}\right]$$

Note: Cpk is the minimum value between Cpk calculated against USL and calculated against LSL; refer to Capability formula



- For example, three processes with Cp = 2.0, but different Cpk :

Note: IAQG EN9103 recommended level : Cpk > 1.33.



Capability formula (Step 4)

- There are several statistics that can be used to measure the capability of a process: Cp, Cpk, Pp and Ppk.
- Cp and Cpk are based on short-term variability
- Pp and Ppk are based on total variability

$$Pp = \frac{USL - LSL}{6s}$$

$$Ppk = \min\left[\frac{USL - \bar{\bar{X}}}{3s}, \frac{\bar{\bar{X}} - LSL}{3s}\right]$$

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \qquad \bar{\bar{X}} = \frac{\sum_{i=1}^{n} x_i}{n}$$

$$Cp = \frac{USL - LSL}{6\hat{\sigma}}$$

$$Cpk = \min\left[\frac{USL - \bar{\bar{X}}}{3\hat{\sigma}}, \frac{\bar{\bar{X}} - LSL}{3\hat{\sigma}}\right]$$

$$\hat{\sigma} = \frac{\bar{R}}{d2} \text{ or } \frac{\bar{S}}{C4}$$

$\bar{R}, \bar{S}$

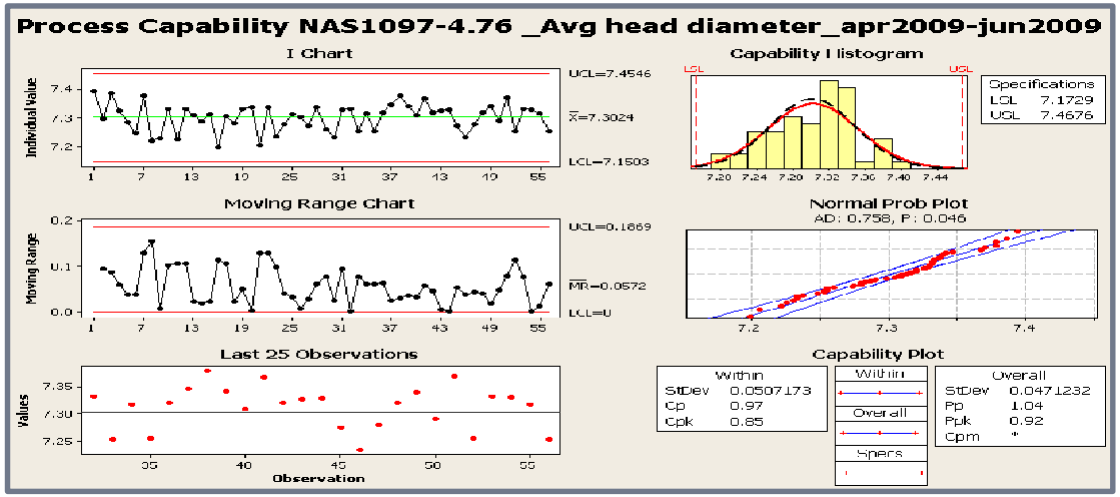
Find d2 & C4 in ISO 8258 (2001)

Range and standard deviation average

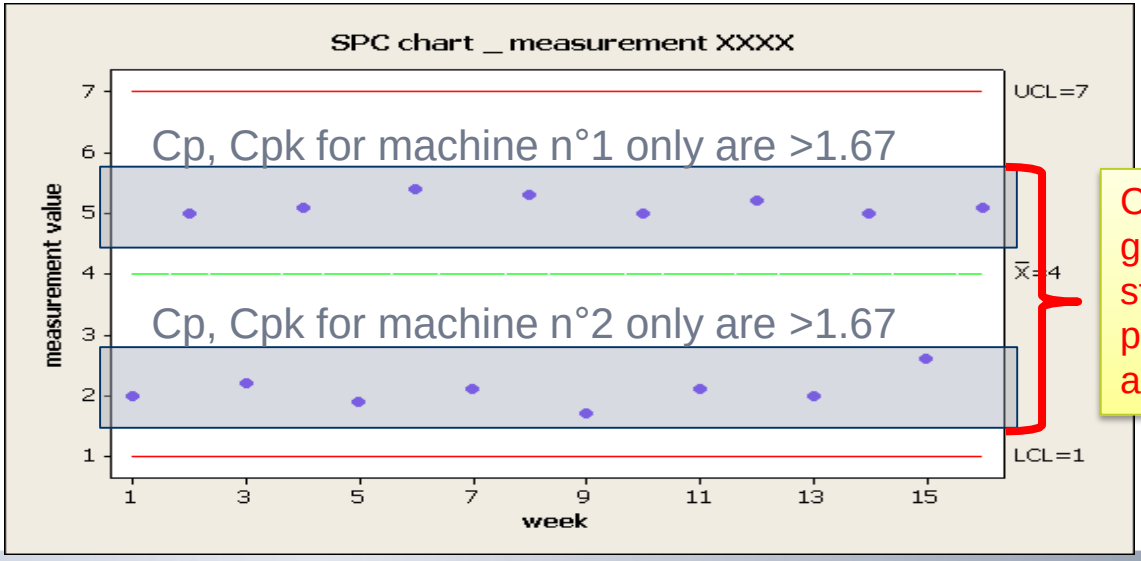
- USL : Upper Specification Limit (requested by the customer)
- LSL : Lower Specification Limit (requested by the customer)

Cp, Cpk Measurement (Step 4)

- The Cp, Cpk calculation should be performed on a regular basis, and take only into account measurements performed since previous calculation
- The new sample size shall be at least 30 parts, so the calculation period shall be establish accordingly.



Take into account for the Cp, Cpk calculation all measurements coming from all machines qualified to perform the process step



Cp, Cpk for the global process step (customer point of view) are < 1.33 !!

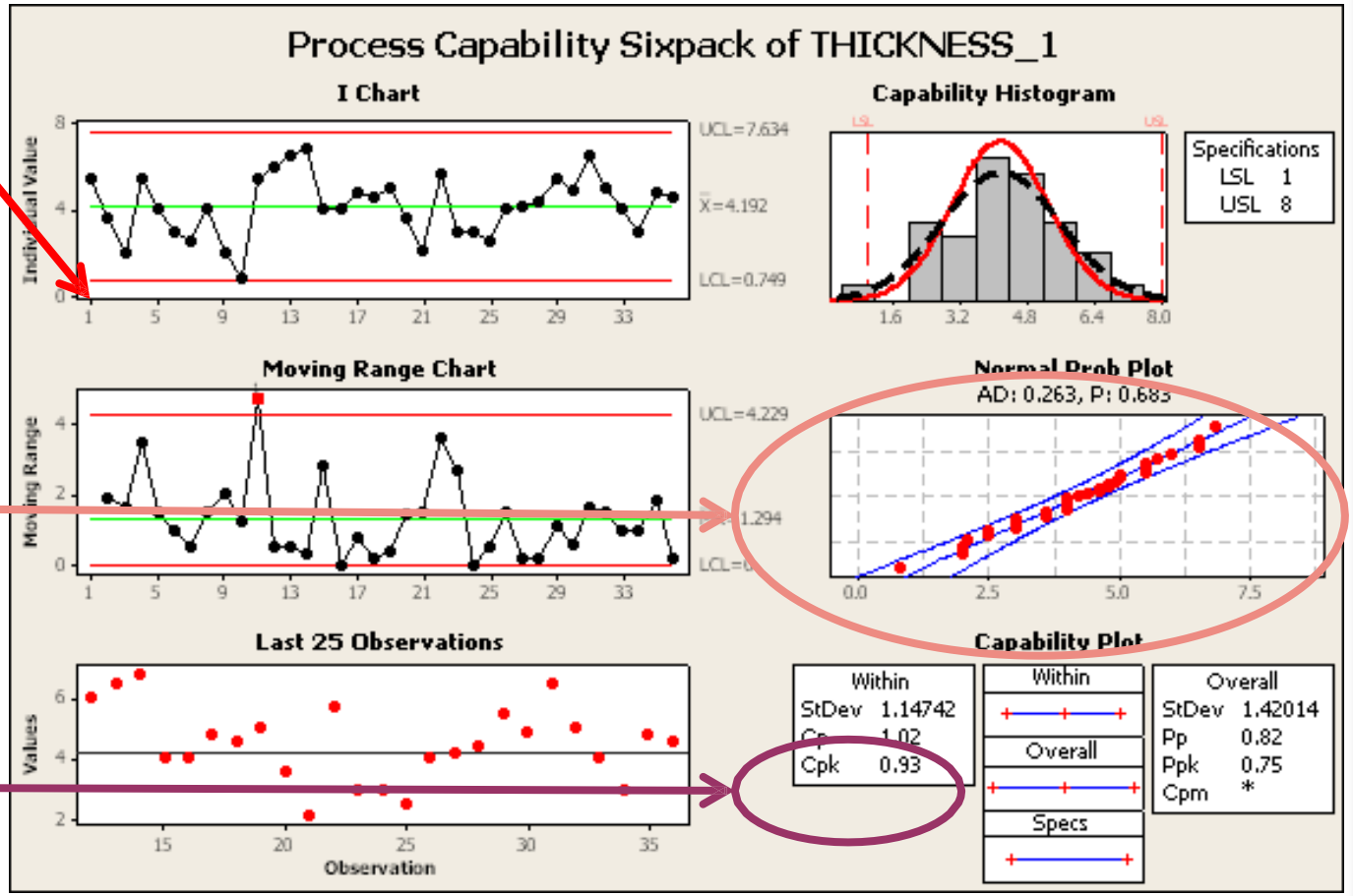
Cp, Cpk: Example (Step 4)

- Example of a Process Capability Analysis through a Statistical Software (Minitab):

UCL & LCL calculation (3σ)

Normality analysis

Cp and Cpk calculation



Analyse the opportunities for improvement (Step 5)

- If the Cp and Cpk are below the target level (1.33), the process shall be improved; understand reasons for variation and identify potential root causes

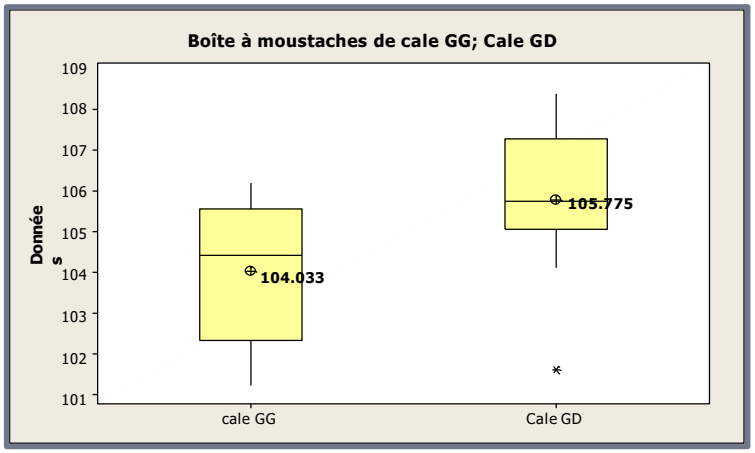
- Improve capability Cp, Cpk 1st results / Identify major Sources Of Variations:
  - Remove common causes and make sure that standard operating instruction are defined and applied at workstation.
  - Perform Root causes Analysis (Ishikawa, Kaizen, Is/Is Not/comparative analysis, SPC out of control, ...) to understand reasons for variations.
  - Use Design Of Experiment to determine key characteristics, main effects, interactions and best process set-up.
  - Use Hypothesis testing to validate any change by comparing statistically the old process to the new one, etc ... Hypothesis testing shall be use to qualify any new process or equipment by statistical comparison (refer to hypothesis Testing)

- Improve MSA & Gage R&R:
  - To improve reproducibility make sure that standard measuring instruction are defined and applied at workstation.
  - To improve repeatability work on measurement equipment itself.

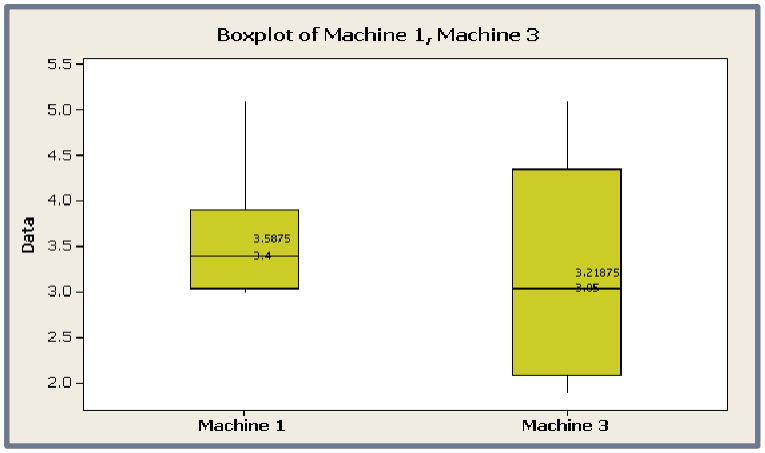
Hypothesis Testing: Compare 2 populations of data (Step 5)

- Hypothesis testing is the use of P-values to dichotomize significant or non-significant results

Does this process gives different results or Not ?



Are this equipments different or Not ?



Mann-Whitney Test and CI : cale GG; Cale GD

	N	Median
cale GG	12	104,40
Cale GD	12	105,75

Point estimate for ETA1-ETA2 is -1,65
The percentage Ci (95,4) for ETA1-ETA2 is (-3,50 ; -0,30)
W = 111,0
Test of ETA1 = ETA2 vs ETA1 different to ETA2 is significant at 0,0262

YES!
P value < 0.05 statistically significant

YES this 2 process are different

NO!
P value > 0.05 statistically non significant

Machine 1 = Machine 3

Mann-Whitney Test and CI: Machine 1, Machine 3

	N	Median
Machine 1	32	3.4000
Machine 3	32	3.0500

Point estimate for ETA1-ETA2 is 0.5000
95.1 Percent CI for ETA1-ETA2 is (0.0000,1.0002)
W = 1162.0
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.1028

Corrective actions (Step 5)

- Search & Implement correctives actions (solutions).
- Improve the process by permanently eliminating the defects/variation.
- Deliverables :
  - Develop & quantify potential correctives actions (Weight Matrix) and select the final solution
  - Implement in production the final solution by applying the qualification plan (in accordance with the customer). Keep a record of all tests & trials & pre-production in a Change Action Board (collect all data related to the change, lots number affected, etc ...).
  - Gain approval for final solution before full implementation in production . Make statistical comparison between the new and old process for each qualification phase (e.g. Systematic Hypothesis testing on test, trials, pre-production results).
- Improvement TOOLS :
  - POKA YOKE
  - 5S
  - Advanced Process Control systems (automation to replace manual activities)
  - TPM
  - ...

Change Management (Step 5)

Corrective action plan:

4. Immediate actions – contain the problem						
n°	Task	Owner	Target Date	Actual Date	Deliverable	Status
1	100% quality inspection	Charles Checkit	Today (put the date)			
2	100% inspection of Work in process and finished parts everywhere	Charles Checkit	put the due date	Check point date	*WIP analysis *Finished parts inside analysis *Finished parts outside analysis	% of achievement for each deliverable, support needed, etc...
3	Overtime – to allow increased production to compensate for increased rejection rate and OTD	Oliver Bossmann	put the due date			
4	Inform the customer that we are taking action using the 8D process.	Peter seller	put the due date			
5	Create KPI or data collection to go deeper in the analysis	Mark Maker	put the due date		Describe all the KPI and data collection you need	

Change Action board:

- Any corrective action is considered as a change, establish a qualification plan and certification plan for any change:
  - Define number of trials, tests phase, pre-production phase, additional inspections , additional measurements ,customer tests & acceptance.
- keep a record of all change dates/ tests results/ data .... e.g.:
  - Week xx/20xx : pre-production on one tool dedicated to the new process and record all incidents related to this new process
  - Week xx/20xx : Compare, after 3months production, the 2 populations (old and new process) by hypothesis testing to quantify statistically the gain (efficiency measurement).

Control (Step 5)

- Control the improved process's performances to ensure sustainable results
- Deliverables:
  - Sustain: guarantee improvements are maintained (e.g., train operators, audits...)
  - Standardize : update standard procedures and operating instruction (SOP, SOI) and copy concept on other industrial activities
  - Ensure new problems quickly identified (e.g. SPC, KPI regular follow-up,...)
  - Keep and disseminate Lessons learned
  - Update FMEA
  - Update control plan
- Tools examples :
  - Process control system : KC, KPI, SPC, Cp, Cpk, …
  - Standards & procedures, standard operating instructions, ….
  - Visual Management
  - Training / assessments / Team evaluation
  - ...

The Feedback Loop process flow