Lean Six Sigma Green Belt Certification Course

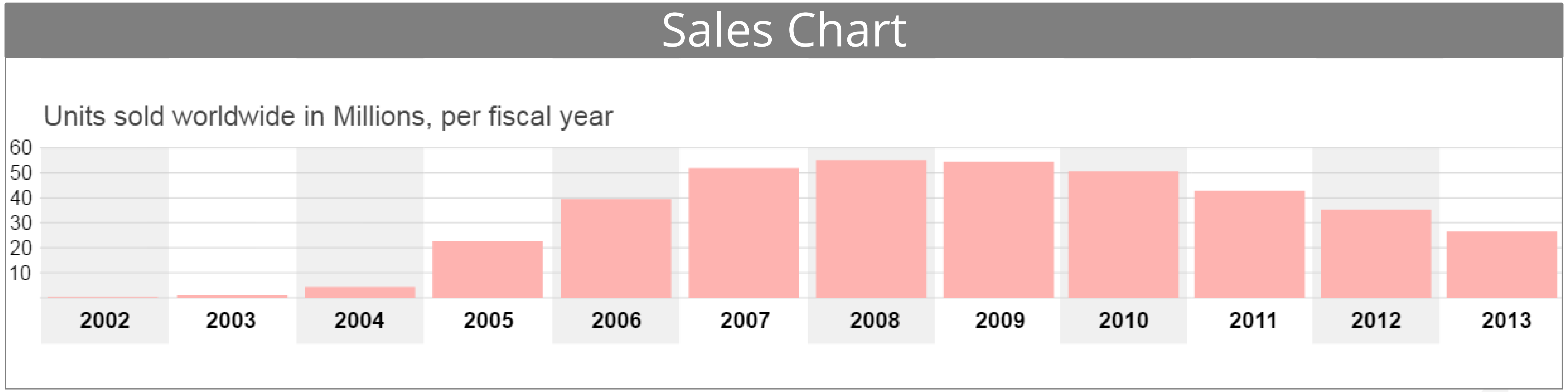
Process and Performance Capability

Learning Objectives

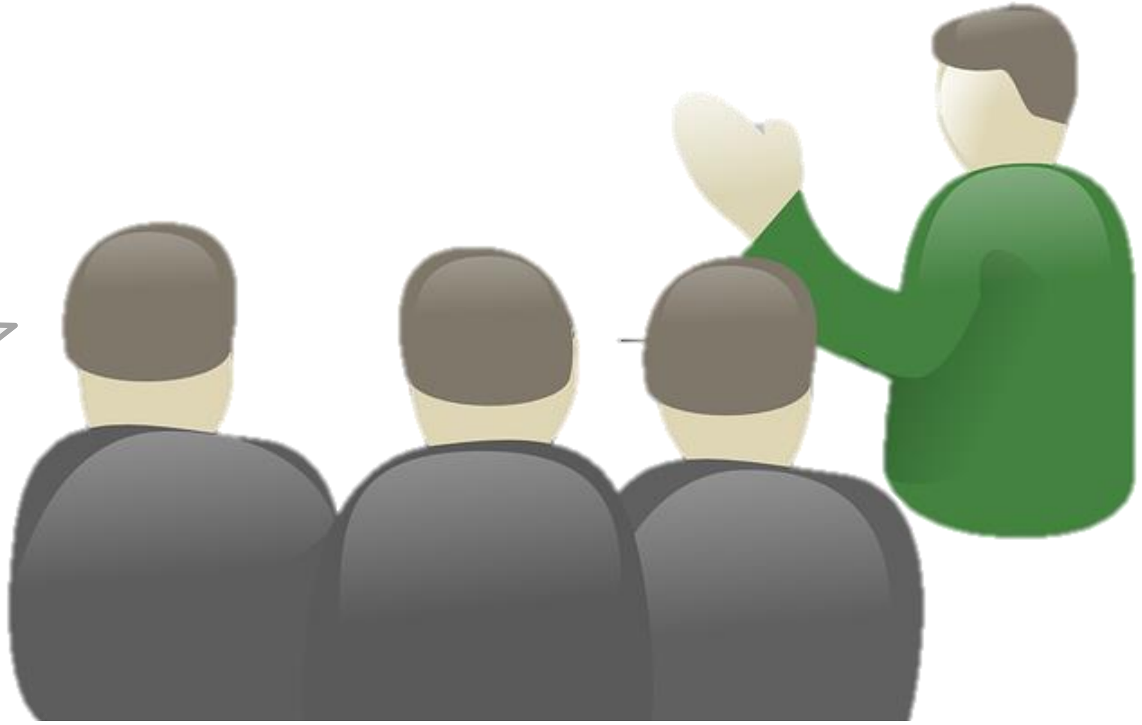
By the end of this lesson, you will be able to:

- Identify a stable or unstable process
- Verify process stability and normality in a process
- Interpret the results of a graph on natural process limits and specification limits
- Calculate the C_{pk} and C_p and C_{pm} and P_{pm} of a process
- Interpret capability indices

Introduction



How can we summarize the current performance of our process to determine if the product output is meeting customers' needs?



We need **capability analysis** to determine this. Then, we can decide what **steps** to take next.

DIGITAL OPERATIONS

Process and Performance Capability

Activities in the Measure Phase

- MSA
- Collection of data
- Statistical calculations
- Check for accuracy and validity

Determine if the process is stable or not

Test for stability

- Changes should not be made to an unstable process

Activities in the Measure Phase

?

Why does a process become unstable?

!

A process becomes unstable due to special cause of variation.

Multiple special causes of variation lead to instability.

A single special cause leads to an out-of-control condition.

Process Stability Studies

Variation can be due to two types of causes:

Common Cause Variation (CCV)

Special Cause Variation (SCV)

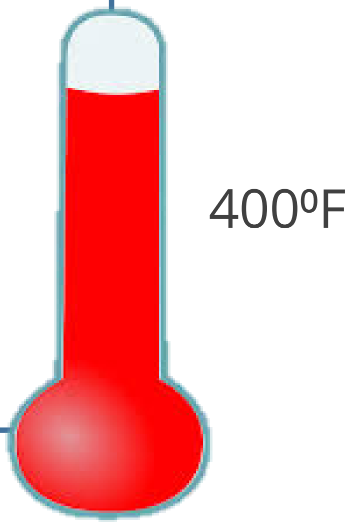
Process Stability Studies

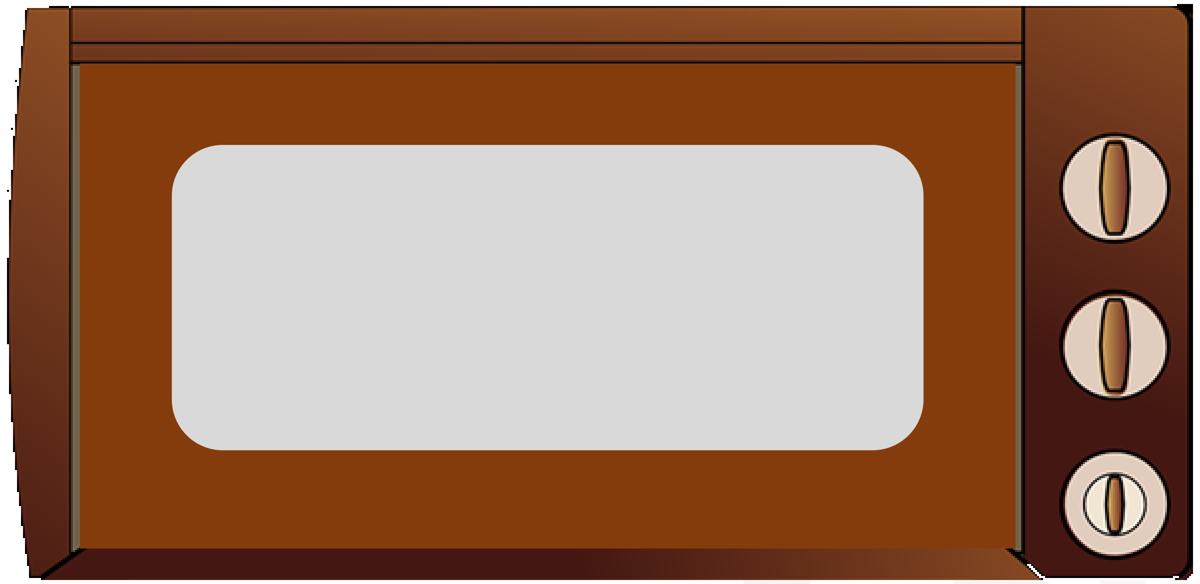
Common Cause Variation (CCV)	Special Cause Variation (SCV)
• Include many sources of variation within a process or inherent to it • Have a stable and repeatable distribution over time • Contribute to a state of statistical control where the output is predictable within a range	• Include factors external to and not always acting on the process • Sporadic in nature • Contribute to instability to a process output, which makes the output unpredictable • May result in defects and have to be eliminated • If identified, they point to the need for root cause analysis

CCV and SCV

Example of CCV

Difference in temperature inside the oven due to oven design

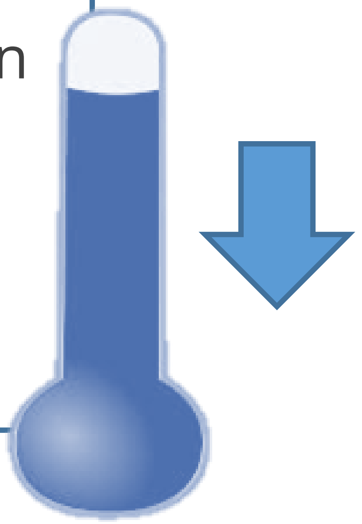


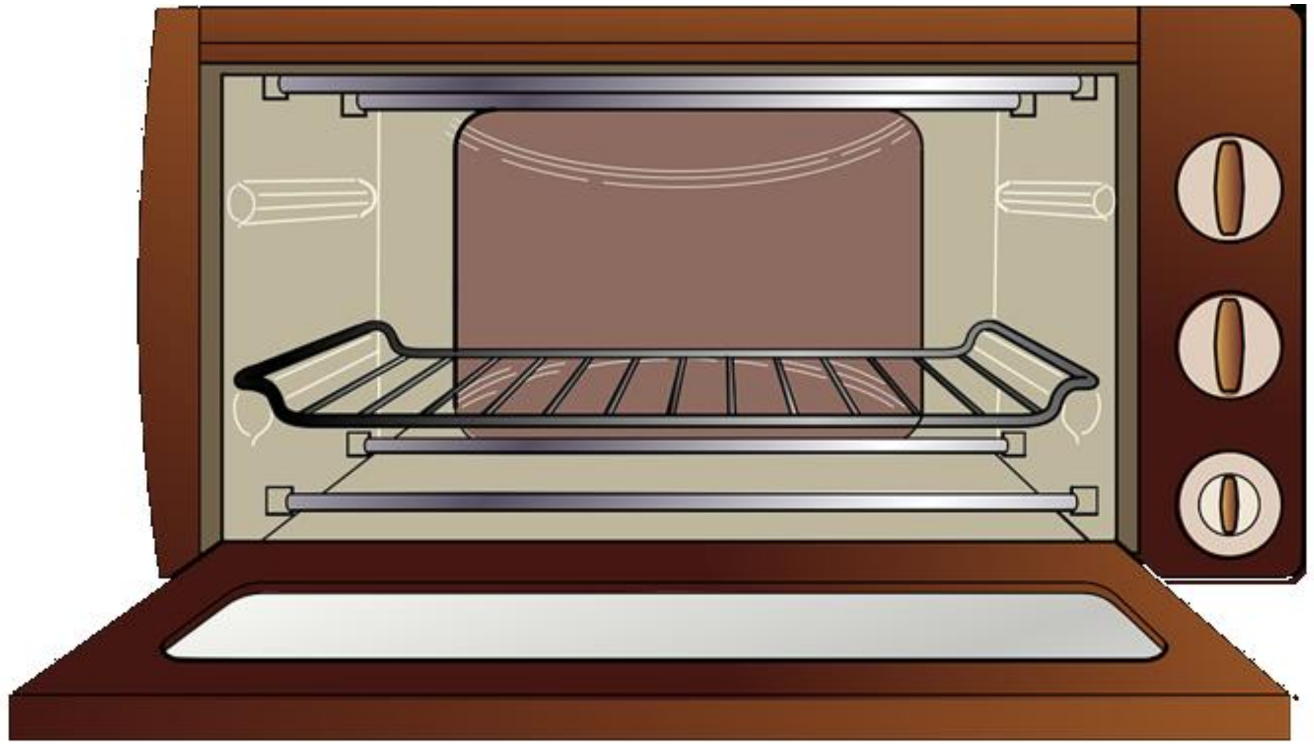


CCV and SCV

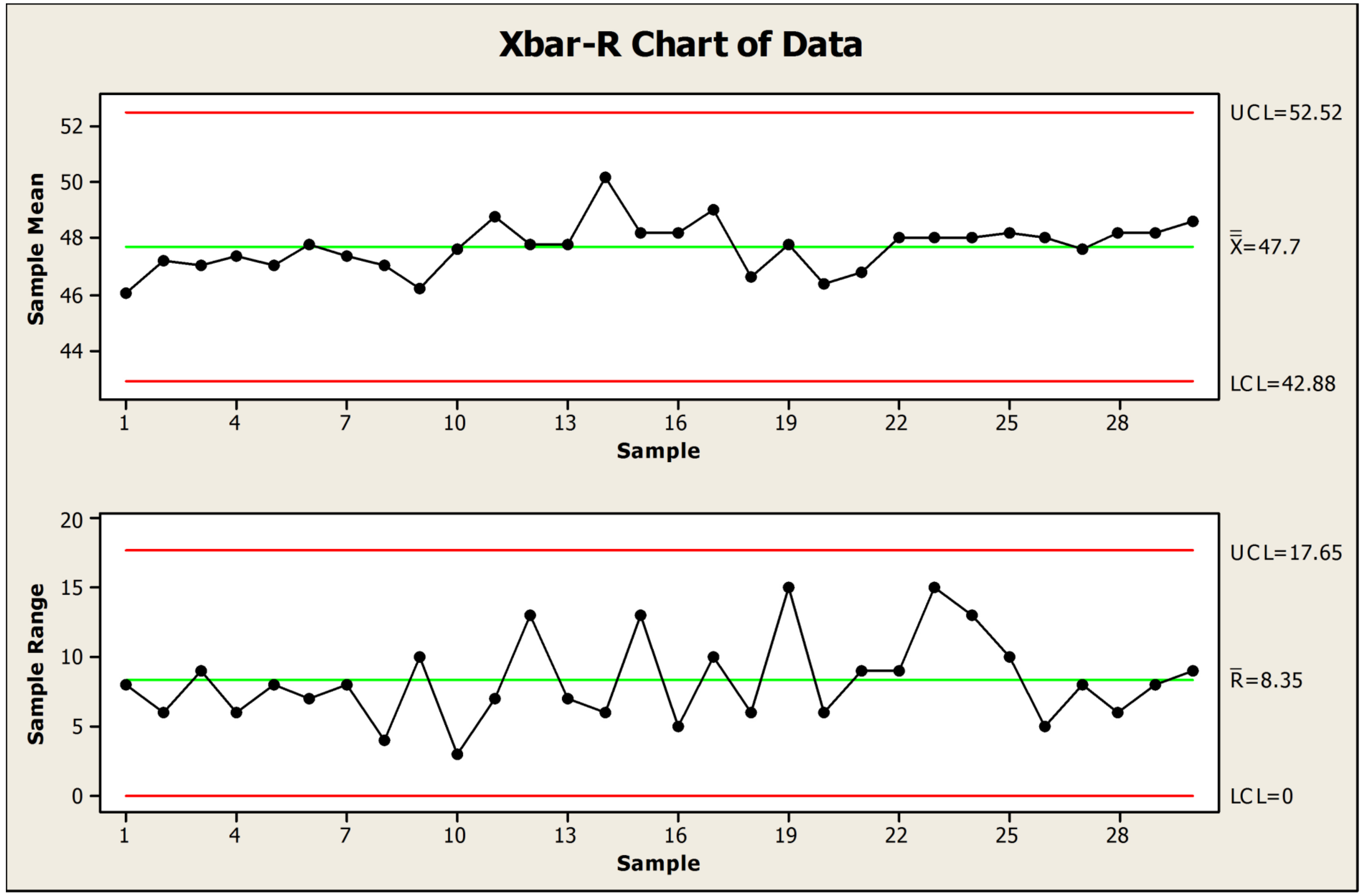
Example of SCV

Difference in temperature inside the oven due to external factors





Control Charts



If all the data points are within the UCL and LCL (red lines), the process could be stable.

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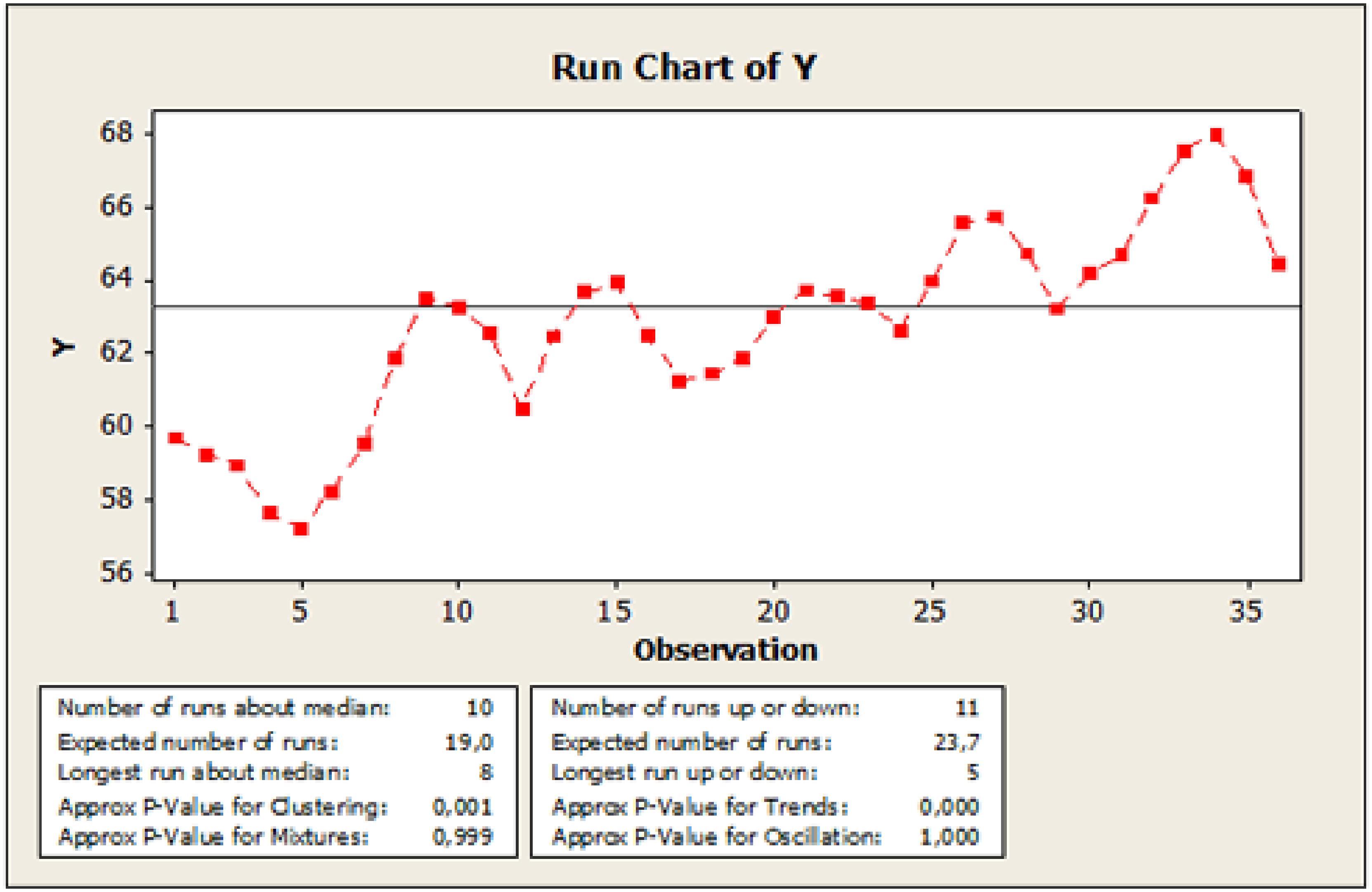
Run Charts



If p-values for any of the last 4 values provided in the chart are less than 0.05, the process has special causes of variation, and the chances of the process being unstable are high.

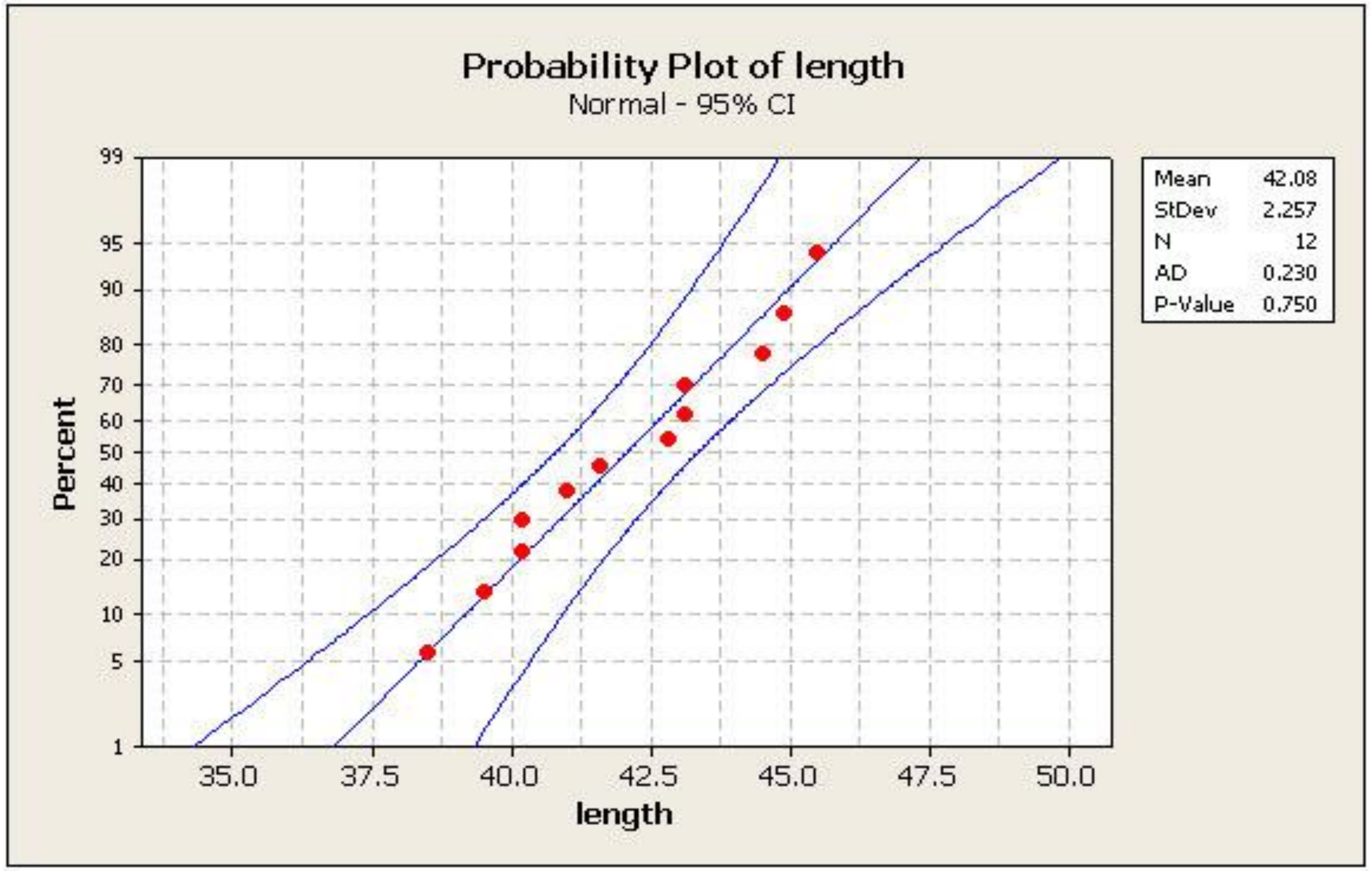
Verifying Process Stability and Normality

SCV present → Output unstable → Process not under control

CCV present → Output stable → Process under control

Normality

Normality is the condition of a process that follows a normal distribution.



If the P value is greater than 0.05, the data set could be described as normally distributed.

Process Capability Analysis

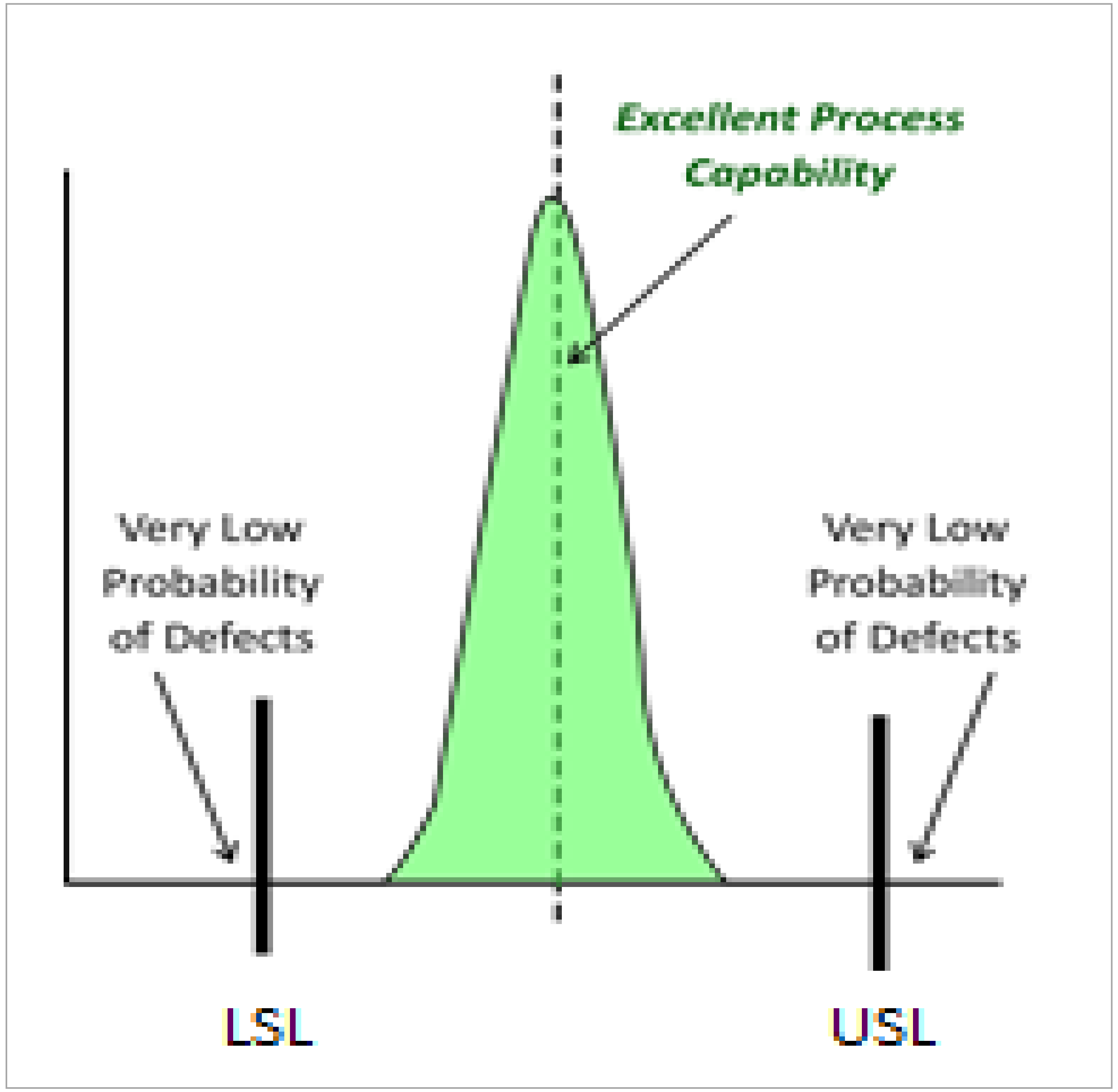
Process

Customer needs and expectations

Process capability is how well the process is meeting customer needs and expectations.

It is a metric that reflects only the common cause of variation.

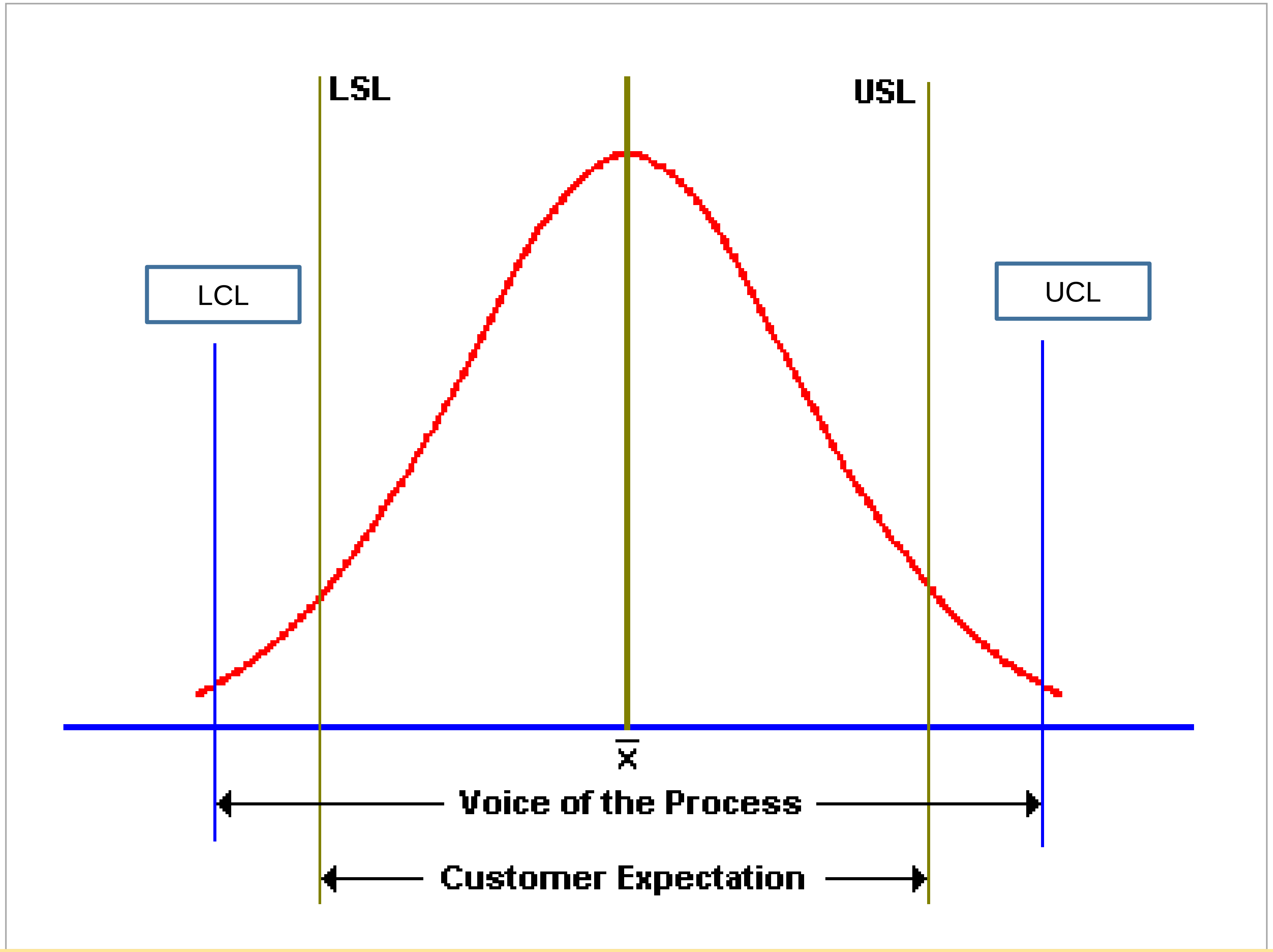
Interpretation of Data



Natural Process Limits vs. Specification Limits

Natural Process Limits	Specification Limits
Indicators of process variation	Targets set for the process
Voice of the process	Voice of the customer
Based on past performance	Based on customer requirements
Real-time values	Intended result
Derived from process data	Defined by the customer
Consists of Upper Control Limit (UCL) and Lower Control Limit (LCL)	Consist of Upper Specification Limit (USL) and Lower Specification Limit (LSL)

Natural Process Limits and Specification Limits



If the control limits lie within the specification limits, the process could be considered capable. Conversely, if the specification limits lie within the control limits, the process will not meet customer requirements.

Actions after Comparing Natural Limits and Spec Limits

Compare natural process limits with specification limits

Condition	Action
Process limits fall within specification limits	No action required
Process spread and specification spread are approximately the same	Adjust the process centering to bring the batch within specification limits
Process limits fall outside specification limits	Reduce variability by partitioning and targeting the largest offender

Process Capability Studies

Process capability is the actual variation in the process specification.

Plan for data collection → Collect data → Plot and analyze the results

The same data used for stability and normality analysis can also be used for capability.

Process Capability Index

Measures performance

Is the inherent variability of a characteristic of a process or a product

Is the indicator of the capability of a process

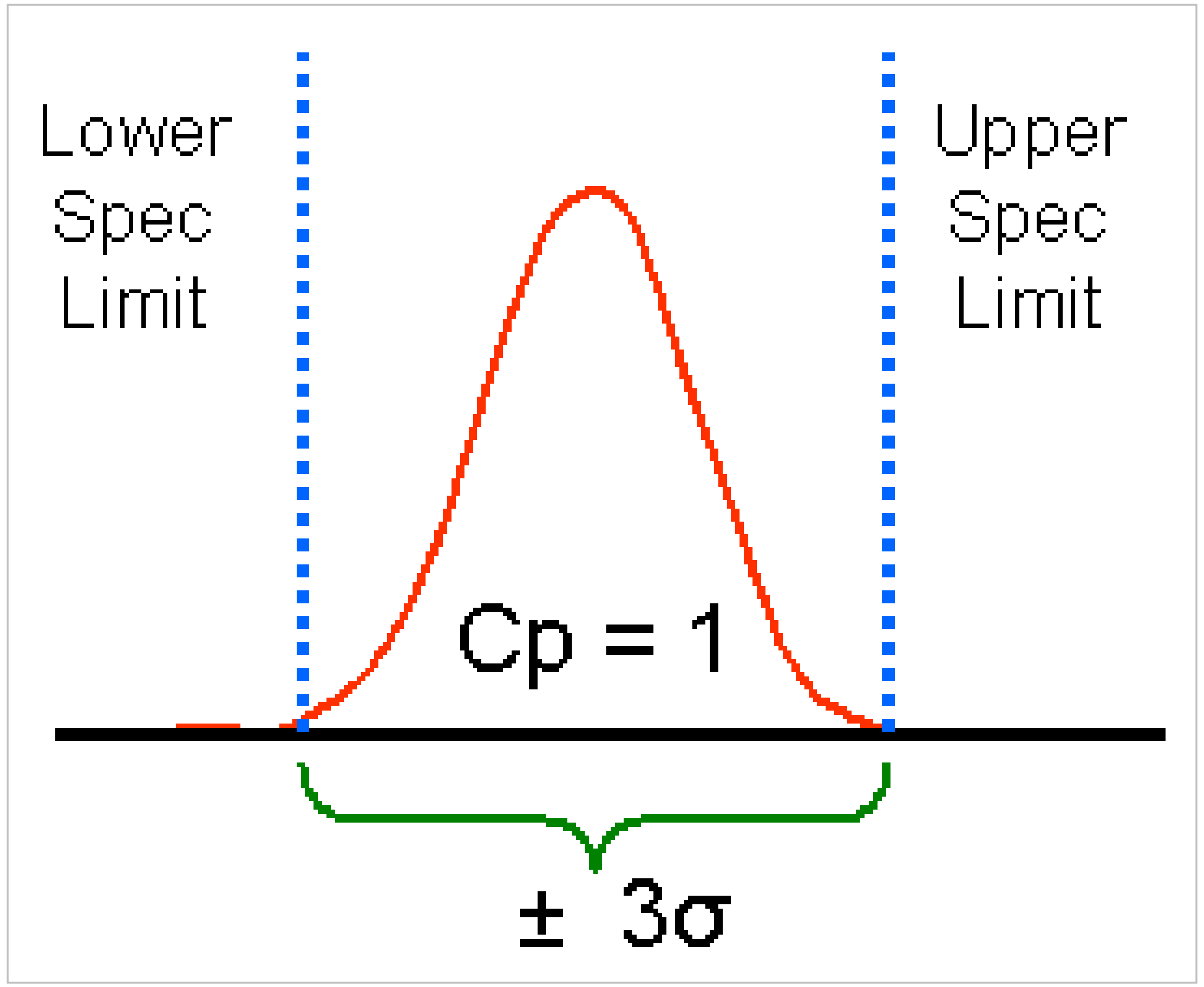
Process Capability Index

$$\text{Process capability (CP)} = \frac{\text{Upper specification limit} - \text{Lower specification limit}}{6\sigma}$$

OR

$$\text{Process capability CP} = \frac{\text{USL} - \text{LSL}}{6\sigma}$$

Process Capability Index



The formula assumes the process is perfectly centered between the upper and lower specification limits. It does not reflect how the process is actually performing in relation to the specification limits.

Process Capability Index

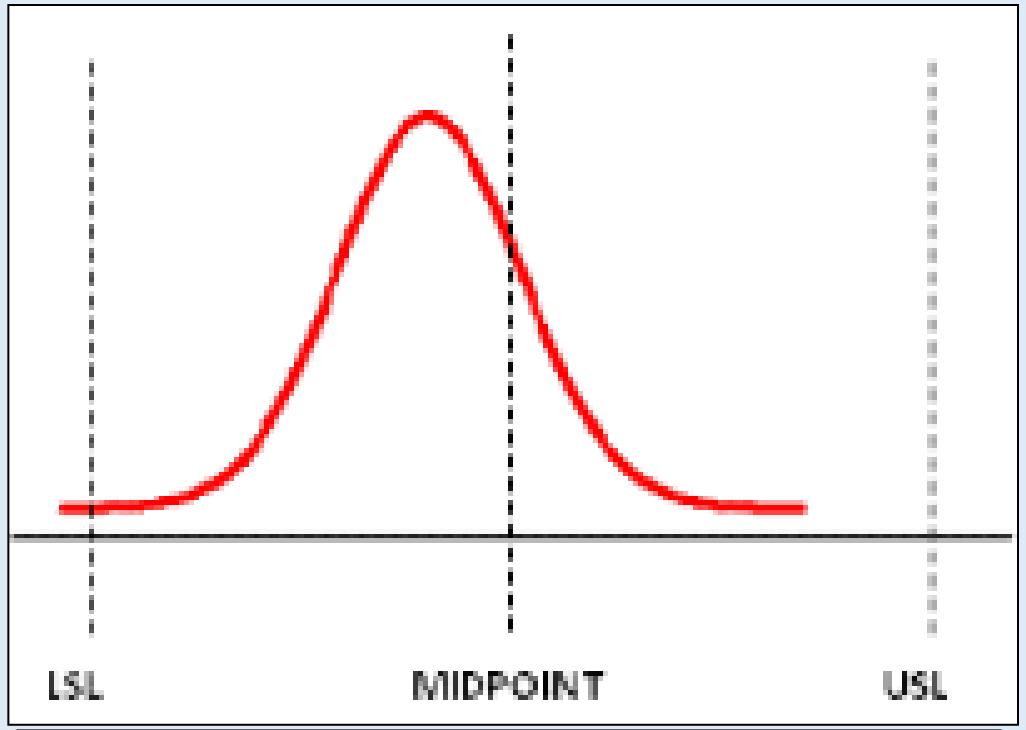
Process Capability (Cpk) was developed to objectively measure the degree to which a process meets or does not meet customer requirements.

$$C_{pk} = MIN(C_{pkl}, C_{pku})$$

$$C_{pl} = \frac{\bar{X} - \mathrm{LSL}}{3\sigma}$$

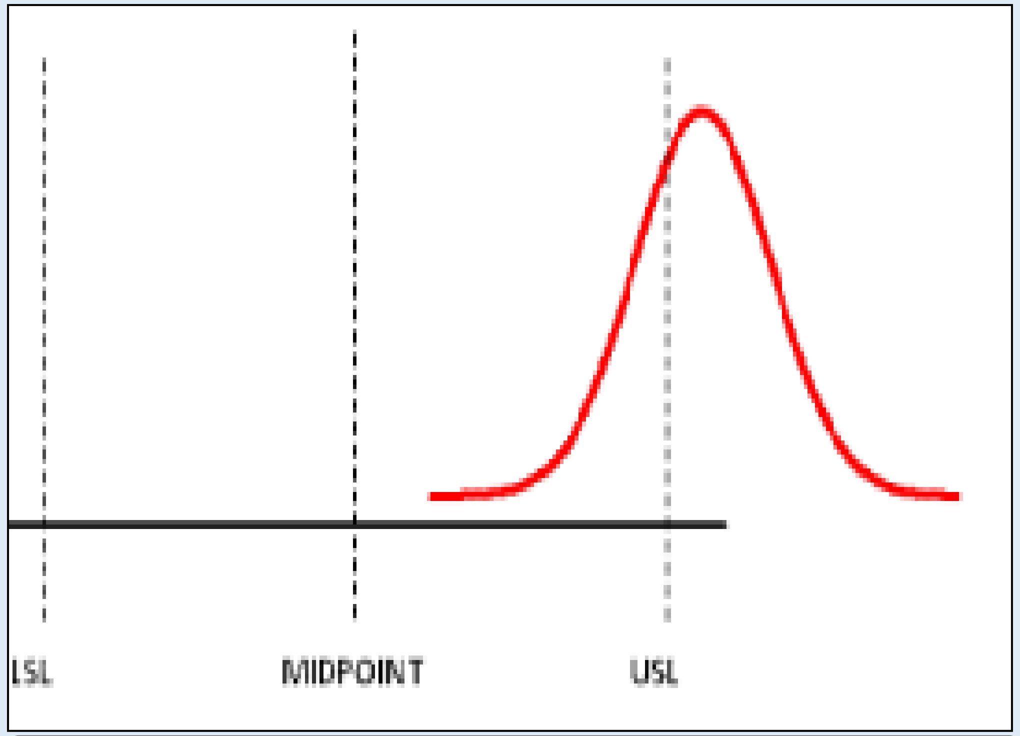
$$C_{pu} = \frac{\mathrm{USL} - \bar{X}}{3\sigma}$$

Comparison of Process Capability Indices



$C_{pk} < C_p$

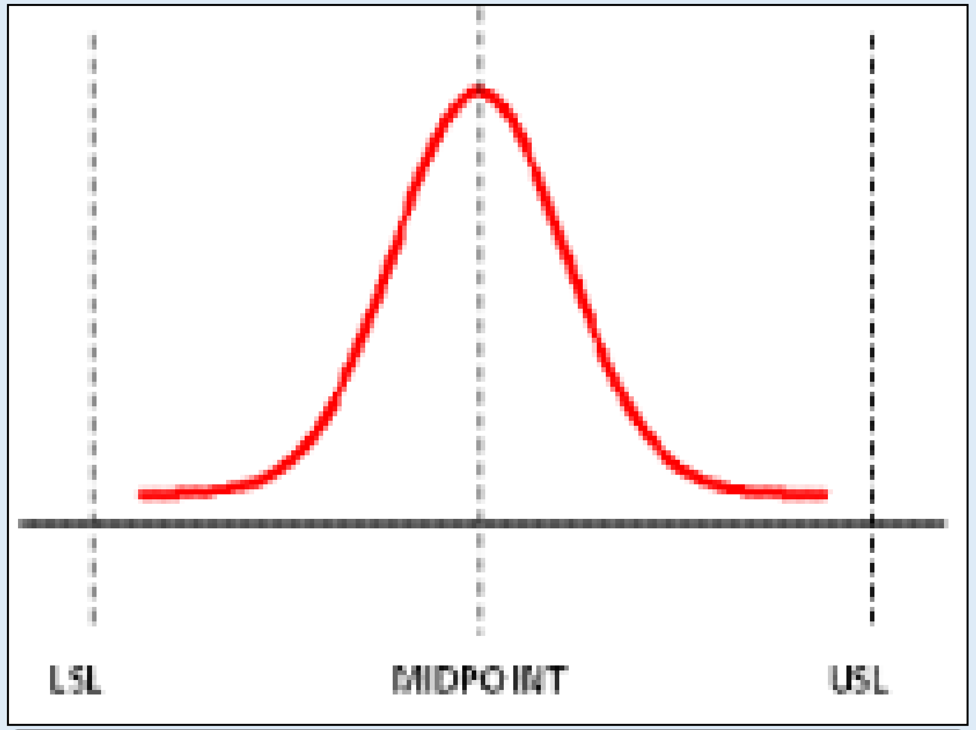
Mean is not centered between specification limits



$C_{pk} < C_p$

C_{pk} is negative

Mean exceeds specification limits



$C_{pk} = C_p$

Mean is centered between specification limits

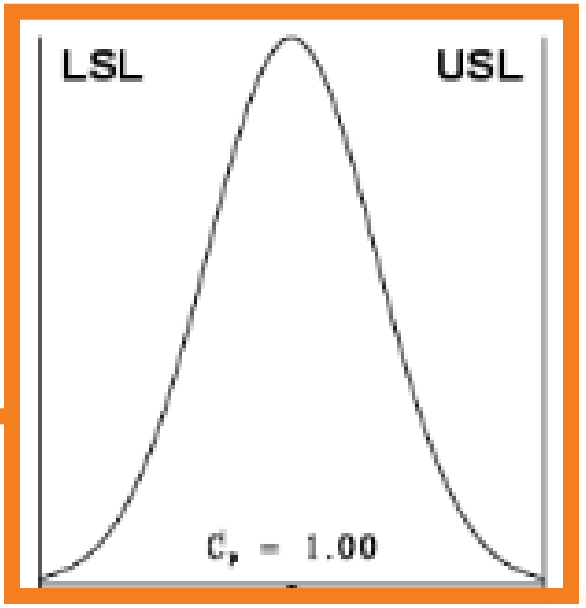
Cpk cannot be larger than Cp because Cp represents the maximum capability with the current process variation.

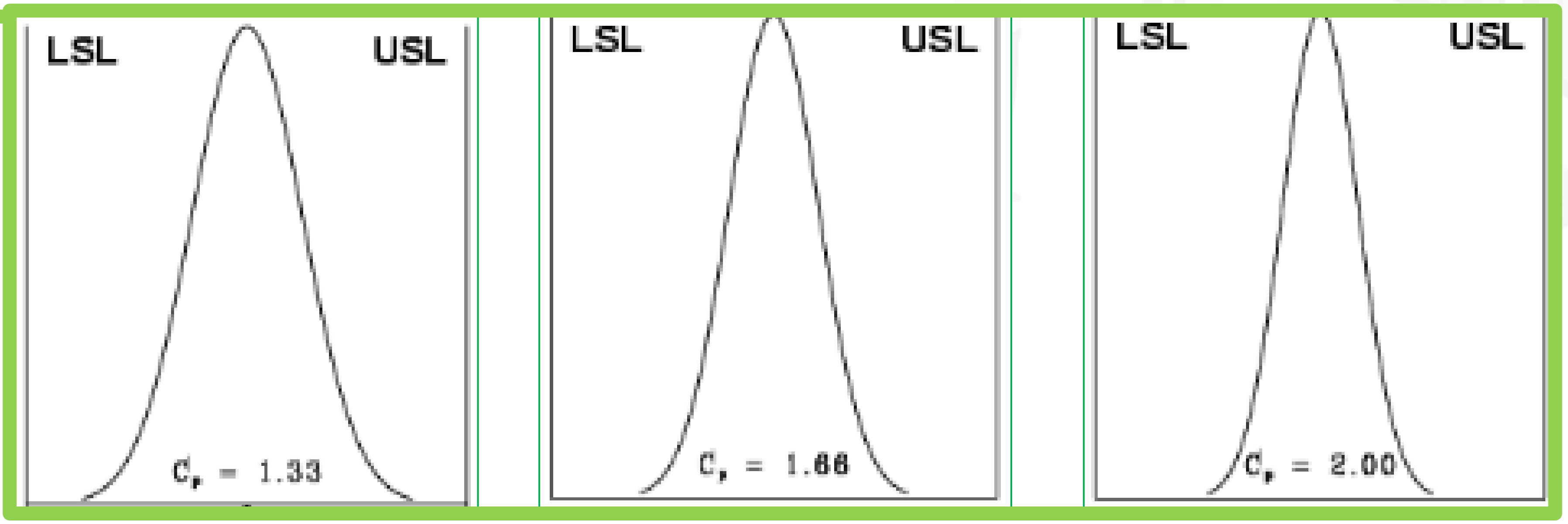
Interpretation of Process Capability Indices

	Sigma Level	Process Capability
Not capable	2	0.67
Marginally capable	3	1.00
Capable	4	1.33
	5	1.67
	6	2.00

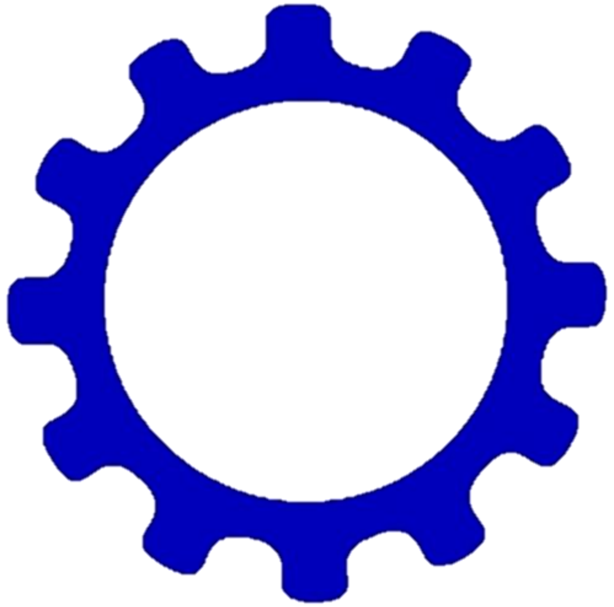
Interpretation of Process Capability Indices

Sigma Level	Process Capability
2	0.67
3	1.00
4	1.33
5	1.66
6	2.00





Process Capability: Example



- Mean diameter = 3.02 centimeters
- Standard deviation = 0.02 centimeters
- Lower engineering specification limits = 2.95 inches
- Upper engineering specification limits = 3.05 inches
- Process is stable
- Diameters are normally distributed

Determine the Cp and Cpk

Process Capability: Example

$$C_P = \frac{USL - LSL}{6\sigma} = \frac{3.05 - 2.95}{6(0.02)} = \frac{0.10}{0.12} = 0.833$$

$$C_{pkl} = \frac{\bar{X} - \mathrm{LSL}}{3\sigma} = \frac{3.02 - 2.95}{3(0.02)} = \frac{0.7}{0.06} = 1.17$$

$$C_{pku} = \frac{\mathrm{USL} - \bar{X}}{3\sigma} = \frac{3.05 - 3.02}{3(0.02)} = \frac{0.03}{0.06} = 0.5$$

$$C_{pk} = MIN(C_{pkl}, C_{pku}) = \mathbf{0.5}$$

Interpretation of the Example

The process is not capable in regards to true performance

Cpk = 0.5

Cp =0.833

The process is not be capable even if mean was centered

The process is not centered between the lower and upper specification limits

Cp (0.833) > Cpk (0.5)

Remedial steps

The team must focus on reducing variation and work with operations to center the average output.

Interpretation of the Example

The process is not capable in regards to true performance

Cpk = 0.5

Cp =0.833

The process is not be capable even if mean was centered

The process is not centered between the lower and upper specification limits

Cp (0.833) > Cpk (0.5)

If the Cp index shows process is capable but Cpk indicates a lack a capability, then it would mean that the process variation is small enough to allow for a capable process.

Identifying Characteristics

Criteria for a characteristic for a process capability study:

- ✓ Should indicate a key factor in the quality of the product or process
- ✓ Should influence the value of the characteristic through process adjustments
- ✓ Operating conditions that affect the characteristic should be defined and controlled
- ✓ Determined by customer requirements or industry standards

For a Six Sigma project, the characteristic is typically the "Y" or output variable defined in the charter.

Identifying Specifications or Tolerances

Process specification or tolerances are defined by:

Industry standards based on the customer requirements

OR

Organization in consultation with the customer

Process Performance Indices

Process Performance Index verifies if the sample generated from the process is capable of meeting the customer requirements.

It is only used when process control cannot be evaluated.

Process Performance Indices

Process Performance (P_p)

Process Performance Index (P_{pk})

Process Capability Index (P_{pm}/C_{pm})

Process Performance Indices vs. Process Capability

Process Performance Indices	Process Capability
Applies to a specific batch of output	Applies to all batches of output
Based on sample standard deviation	Based on population standard deviation
Long-term capability	Short-term capability

Process Performance Indices (P_p)

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

Where,

USL = upper specification limit

LSL = lower specification limit

s = natural process variation

Process Performance Indices (P_p)

$$P_{pk} = Min(P_{pu}, P_{pL})$$

Where,

P_{pu} (upper process capability index) = $\frac{USL-x}{3s}$

P_{pL} (lower process capability index) = $\frac{x-LSL}{3s}$

Where,

x = process average ($\bar{x}$)

s = sample standard deviation

Cpm and Ppm

$$C_{pm} = \frac{USL - LSL}{6 * \sqrt{\sigma^2 + (\mu - T)^2}}$$

$$P_{pm} = \frac{USL - LSL}{6 * \sqrt{s^2 + (\bar{X} - T)^2}}$$

Where,

USL = upper specification limit

LSL = lower specification limit

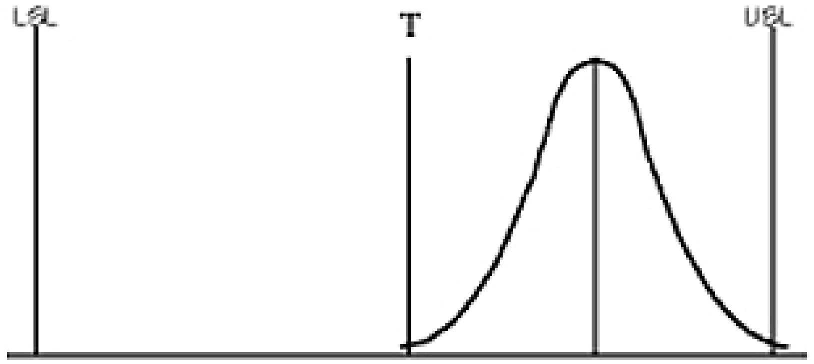
μ = process average

σ = process standard deviation

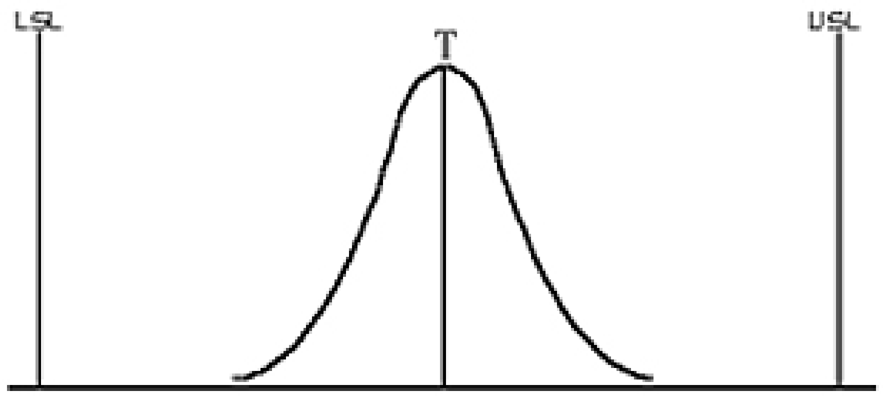
T = target value (typically, the center of tolerance)

$\bar{X}$= sample average

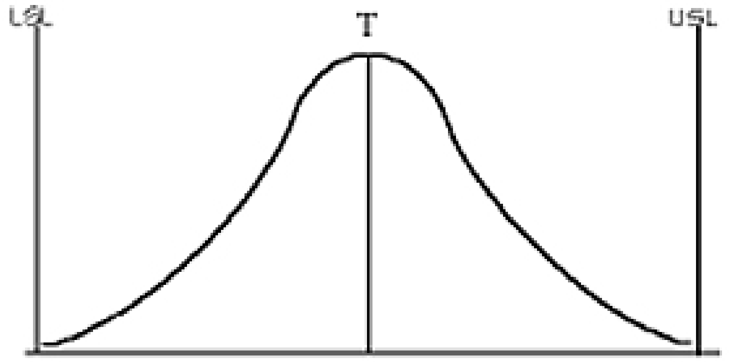
Cpm and Ppm: Interpretation



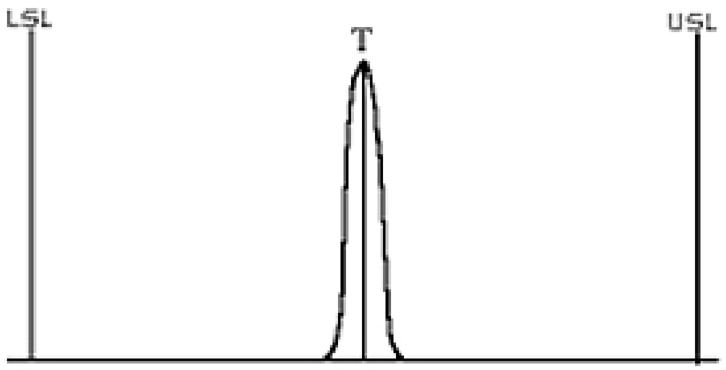
Improved position



Improved Cpm or Ppm



Improved variation



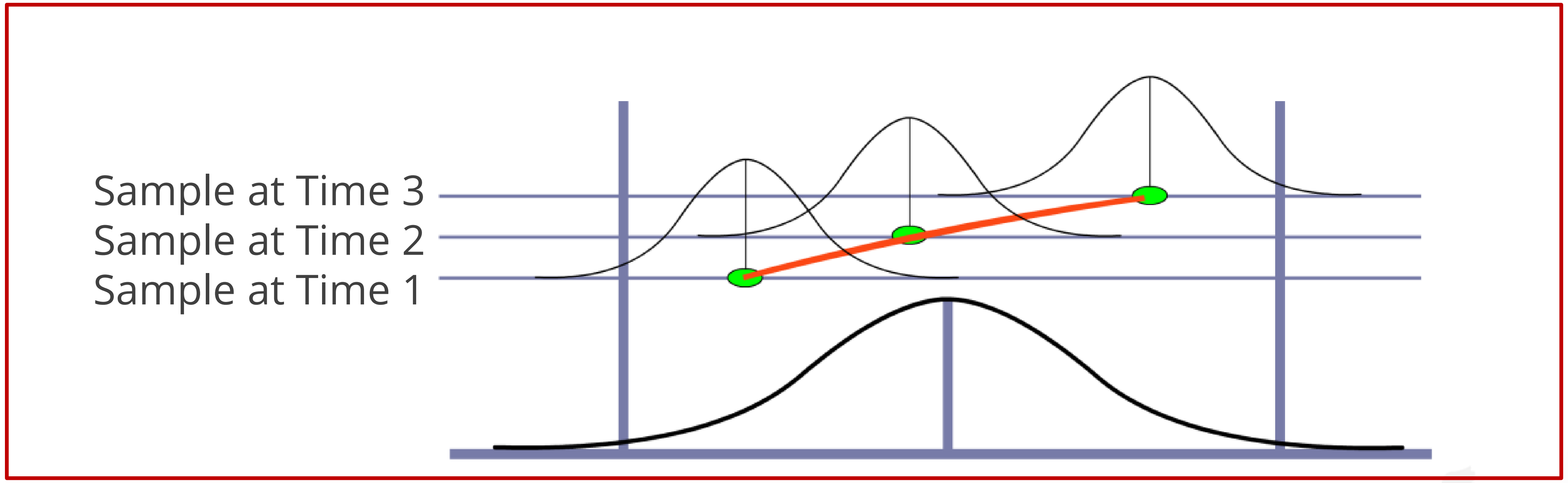
Improved Cpm or Ppm

- As the process variation reduces and/or as the process average reaches the target value, the Cpm or Ppm index improves or becomes larger.
- The ideal value is 1.33 or greater.

Process Mean Shift

Process shift ($Z_{ST} - Z_{LT}$)	• Reflects how well a process is controlled • Usually a factor of 1.5
Short-term capability (Z_{ST})	• Capability or the potential performance of the process in control at any point of time • Based on the sample collected in the short term
Long-term performance (Z_{LT})	• Actual performance of the process over time

Process Mean Shift: Example



Observations

- A typical process will shift by approximately 1.5 standard deviations.
- Long-term variation is more than the short-term variation.
- The difference between the short and long-term shifts is the Sigma Shift.
- A shift may be due to different people, raw material, wear and tear, time, and so on.

Process Mean Shift: Implications

Sigma Multiple	No Mean Shift	Mean Shift ±1σ	Mean Shift ±1.5σ
±3σ	2700 DPMO 99.73% Good	22800 DPMO 97.72% Good	66810 DPMO 93.32% Good
±4σ	63 DPM) 99.9937% Good	1350 DPMO 99.865% Good	6210 DPMO 99.379% Good
±5σ	0.57 DPMO 99.999943% Good	32 DPMO 99.9968% Good	223 DPMO 99.9767% Good
±6σ	0.002 DPMO 99.9999998% Good	0.29 DPMO 99.999971% Good	3.4 DPMO 99.99966% Good
Summary of the defect levels at different Sigma multiple values and mean shifts			

Observation

The effects of a mean shift become more negligible as the process capability increases. A Six Sigma process level of defects is not affected much by long-term variation.

Conversion From Long-term to Short-term Capability

			TO KNOW	
			Short-term Capability	Long-term Capability
With data collected	Zst	Short-term data	P	Subtract 1.5
	Zlt	Long-term data	Add 1.5	P

Process Variations

Short-term Variation	Long-term Variation
Attributed to common cause variation	Attributed to both common and special cause variations
Variance inherent in the process	Shows variation within and between sub-groups
Shows variation within subgroups	Increases due to special causes
Small number of samples collected at short intervals	Special causes have to be identified and corrected for improvement
Captures common cause variation	
Common causes are difficult to identify and correct and may require process redesign	

Long-term vs. Short-term Process Variation

Complaint Resolution Time (Hours)		
Week 1	Week 2	Week 3
48	50	49
49	48	48
48	36	39
53	50	49
58	50	34
50	62	33
46	45	57
50	47	48
49	51	47
47	44	39

Subgroup size = n_{week} = 10

Long-term vs. Short-term Process Variation

1. Average of each week = Total complaints resolved per week/subgroup size
2. Grand average = Sum of per week average/3
3. Variation within subgroups for a week = Σ(Week average – x)^2, where x is each reading in the week
4. Variation between subgroups for a week = (Grand average – week average)^2 $* \ n_{week}$
5. Total variation between subgroups = Σ(variation between subgroups for each week)
6. Total variation between subgroups = Σ(variation between subgroups for each week)
7. Overall variation = Total variation within subgroups + Total variation between subgroups
8. St. Dev. Short Term = S_{ST} =

$$\sqrt{\frac{Total\ variation\ within\ subgroups}{(Total\ sample\ size - number\ of\ subgroups)}}$$

9. St. Dev. Long Term = S_{LT} =

$$\sqrt{\frac{Overall\ Variation}{(Total\ sample\ size - 1)}}$$

Long-term vs. Short-term Process Variation

Measure	Value
Grand average	47.5
Total variation within subgroups	1023.8
Total variation between subgroups	161.67
Overall variation	1185.5
Standard Deviation short term	6.2
Standard Deviation long term	6.4

Process Performance

Guideline summary of process performance

Process	Less CCV, No SCV	Less CCV, SCV present	High CCV, No SCV	High CCV, SCV present
Variations	Only CCV	CCV and SCV	CCV	CCV and SCV
Variability	Less	High	Moderate to High	Very High
Capability	High	Less	Very Less	Poor
Possibility of defects	Less	High	Very High	Defective Process
Process Condition	**In Control, Capable**	**Out of Control, Incapable**	**Incapable, In Control**	**Incapable, Out of Control**

Attribute Data and Capability

DPU	DPMO
$\text{DPU} = \dfrac{\text{Defects}}{\text{Total no.of units}}$	DPMO = Defects per opportunity * 1,000,000

Process Performance: Example

The Quality Control department checks the quality of finished goods by sampling a batch of 10 items from the produced lot every hour.

It collects the following data over 24 hours.

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Defectives	2	1	0	0	2	3	1	4	5	1	2	0	0	1	2	1	1	1	4	0	0	0	1	2

Process Performance: Example

$\bar{p}$ or DPU is used to calculate process capability.

Total no. of defectives = 34

Subgroup size = 10

Total no. of units = 10 $*$ 24 = 240

DPU = $\frac{34}{240}$ = 0.0142

DPMO = DPU $*$ 1,000,000 = 141666.66

Observation

The process is currently working at 2.6 σ, which is 86.4% yield.

Process Capability for Attribute Data

Defectives	Defects
$\sigma = \sqrt{\bar{p}\,(1-\bar{p})/n}$	$\sigma = \sqrt{\frac{\bar{u}}{a}};\ \sqrt{\bar{c}}$
• $\bar{p}$ is used to check process capability for constant and variable sample sizes.	• $\bar{c}$ is used when the sample size is constant. • $\bar{u}$ is used when the sample size is variable.

Key Takeaways

- Variations can be due to Common Cause Variation (CCV) and Special Cause Variation (SCV).
- Process normality is verified using a normal probability plot.
- Process capability refers to how well the process meets customer needs and expectations.
- Process shift reflects how well a process is controlled. It is the difference between short-term and long-term performance.
- For attribute data, process capability is determined by the mean rate of non-conformity.

Knowledge Check

Knowledge Check

1

In the Measure Phase, which of these options should be determined first?

A. Process Capability

B. Process Stability

C. Normality

D. Sigma Shift

Knowledge Check
1

In the Measure Phase, which of these options should be determined first?

A. Process Capability

B. Process Stability

C. Normality

D. Sigma Shift

The correct answer is **B**

Ensuring that the process only has common cause variation or is stable is the first activity in the Measure Phase.

Knowledge Check

2

If Cpk = 1.1 and Cp = 1.33, what can we conclude about the process ?

A. Process is neither capable nor centered.

B. Process is capable but is not centered.

C. Process is capable and centered.

D. Process is not capable but is centered.

Knowledge Check

2

If Cpk = 1.1 and Cp = 1.33, what can we conclude about the process ?

A. Process is neither capable nor centered.

B. Process is capable but is not centered.

C. Process is capable and centered.

D. Process is not capable but is centered.

The correct answer is **B**

Since Cp and Cpk are greater than 1, we can say the process is currently marginally capable and because Cpk is not equal to Cp the process is not centered.

Knowledge Check

3

If Cpk = 0.7 and Cp = 1.33, what actions should be taken?

A. Process needs to be centered.

B. Variation needs to be reduced.

C. Stability needs to be rechecked.

D. Process performance index needs to be calculated.

Knowledge Check 3

If Cpk = 0.7 and Cp = 1.33, what actions should be taken?

A. Process needs to be centered.

B. Variation needs to be reduced.

C. Stability needs to be rechecked.

D. Process performance index needs to be calculated.

The correct answer is **A**

The process needs to be centered since a Cp value of 1.33 indicates good capability and with Cpk value less than 1 indicates centering is the issue.

Knowledge Check 4

If short-term variation is calculated at 3.5σ, what is the expected long-term variation?

A. 3.5σ

B. 2.0σ

C. 5.0σ

D. 1.0σ

Knowledge Check 4

If short-term variation is calculated at 3.5σ, what is the expected long-term variation?

A. 3.5σ

B. 2.0σ

C. 5.0σ

D. 1.0σ

The correct answer is **B**

The question requires the use of the 1.5 Sigma shift. Moving short-term to long- term Sigma will mean subtracting 1.5 from 3.5, which is 2.0.

Lean Six Sigma Activities and Tools: Measure

Activities

Define

- Review Project Charter
- Validate High-Level Value Stream Map and Scope
- Validate Voice of the Customer and Voice of the Business
- Validate Problem Statement and Goals
- Validate Financial Benefits
- Create Communication Plan
- Select and Launch Team
- Develop Project Schedule
- Complete Define Tollgate

Measure

- Process Map Flow
- Identify Key Input, Process and Output Metrics
- Develop Data Collection Plan
- Validate Measurement System
- Collect Baseline Data
- Determine Process Capability
- Complete Measure Tollgate

Analyze

- Identify Root Causes
- Reduce List of Potential Root Causes
- Confirm Root Cause to Output Relationship
- Estimate Impact of Root Causes on Key Outputs
- Prioritize Root Causes
- Statistical Analysis
- Complete Analyze Tollgate

Improve

- Develop Potential Solutions
- Evaluate, Select, and Optimize Best Solutions
- Develop 'To-Be' Process Maps
- Develop and Implement Pilot Solution
- Implement 5s Program
- Develop Full Scale Implementation Plan
- Cost/Benefit Analysis
- Complete Improve Tollgate

Control

- Develop SOP's, Training Plan and Process Controls
- Implement Solution and Ongoing Process Measurements
- Confirm Attainment of Project Goals
- Identify Project Replication Opportunities
- Training
- Complete Control Tollgate
- Transition Project to Process Owner

Tools

Define

- Project Charter
- Voice of the Customer
- SIPOC Map
- Project Valuation (ROI)
- Stakeholder Analysis
- Communication Plan
- Effective Meeting Tools
- Timelines, Milestones, and Gantt Charting
- Pareto Analysis

Measure

- Process Mapping
- Data Collection Plan
- Statistical Sampling
- Measurement System Analysis (MSA)
- Gage R&R
- Control Charts
- Histograms
- Normality Test
- Process Capability Analysis

Analyze

- Cause & Effect Matrix
- FMEA
- Hypothesis Tests
- Simple & Multiple Regression
- ANOVA
- Components of Variation

Improve

- Process Flow Improvement
- Design of Experiments (DOE)
- Solution Selection Matrix
- Piloting
- Pugh Matrix
- Pull System

Control

- Mistake-Proofing
- Standard Operating Procedures (SOP's)
- Process Control Plans
- Visual Process Control Tools
- Statistical Process Controls (SPC)
- Visual Workplace
- Total Productive Maintenance
- Metrics
- Team Feedback Session

Measure Tollgate Questions

- ✓ Has a more detailed Process Map been completed to better understand the process and problem, and where in the process the root causes might reside?
- ✓ Has the team conducted a process analysis, identifying areas where time and resources are devoted to tasks not critical to the customer?
- ✓ Has the team identified the specific input (x), process (x), and output (y) measures needing to be collected for both effectiveness and efficiency categories (i.e. Quality, Speed, and Cost measures)?
- ✓ Has an appropriate sample size and sampling frequency been established to ensure valid representation of the process we're measuring?
- ✓ Has the measurement system been checked for repeatability and reproducibility, potentially including training of data collectors?
- ✓ Has the team developed and tested data collection forms or check sheets which are easy to use and provide consistent, complete data?
- ✓ Has baseline performance and process capability been established? How large is the gap between current performance and the customer (or project) requirements?
- ✓ Have key learning(s) to-date required any modification of the Project Charter? If so, have these changes been approved by the Project Sponsor and the Key Stakeholders?
- ✓ Have any new risks to project success been identified, added to the Risk Mitigation Plan, and a mitigation strategy put in place?

Note: With answers to these questions you are now ready to move to the Measure Phase.