Universität Zürich[UZH]

Department of Business Administration

# Services & Operations Management

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# Module Overview

1. Operations strategy
2. Process analytics
3. **Quality management: SPC**
4. Platform management
5. Sport management

# Learning Goals (1/2)

After this lecture you should

- understand the importance of reliable quality
- know how reliable quality can be produced
- be familiar with the methods of Statistical Process Control (SPC)
- be able to calculate upper and lower control limits
- know whether a process is under control or not
- be able to bring an out-of-control process under control

# Learning Goals (2/2)

- be able to apply SPC in real time
- understand the cost effects of quality management decisions
- understand the differences between control, performance and specification limits
- be able to calculate process capability indices for symmetric and asymmetric processes

# Quality: Consumer vs. Producer

**Consumer:**

- Fulfilling/exceeding expectations
- Usability
- Serviceability
- Fulfilling/exceeding product-/service standards

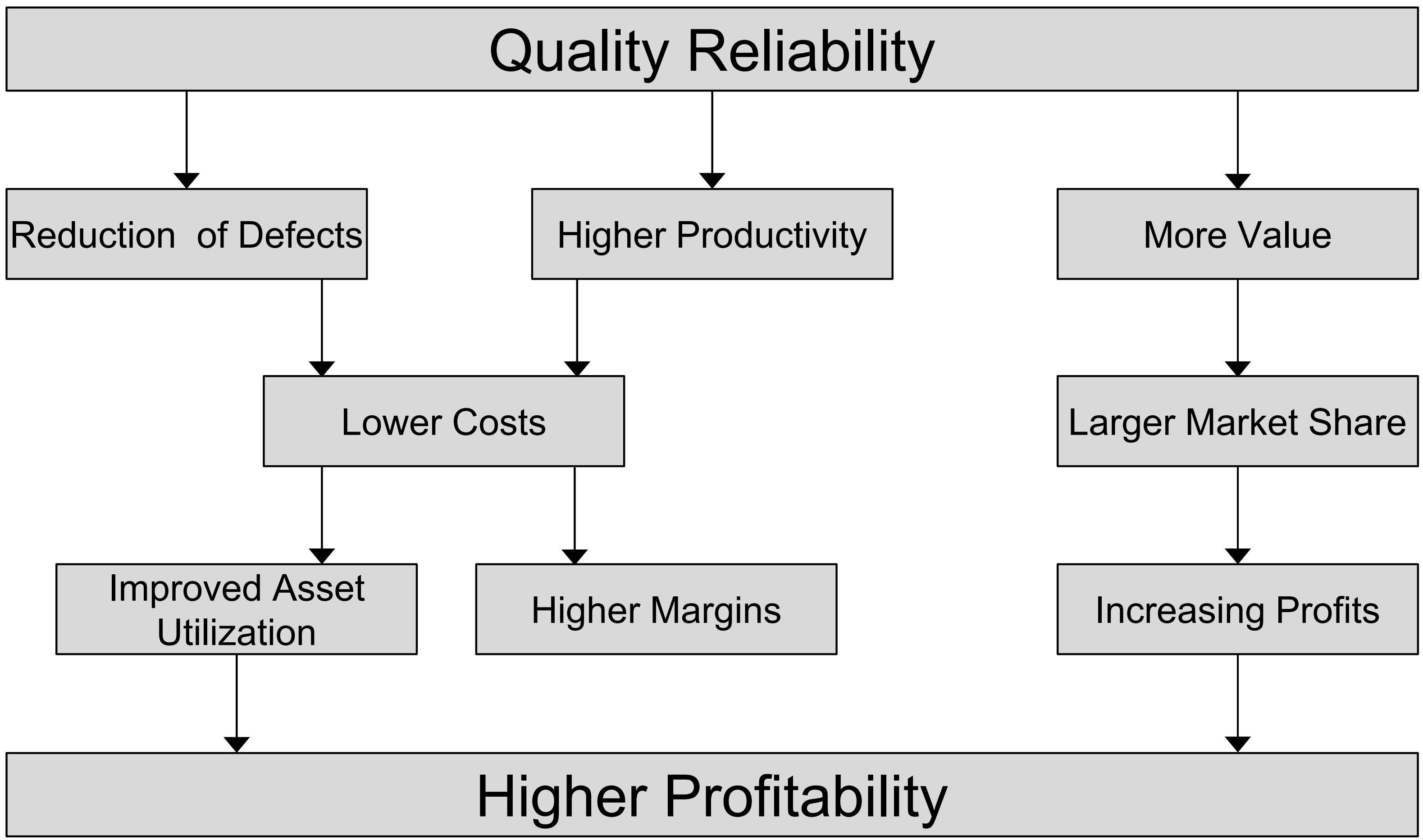
**Producer:**

- Adherence to product-/service specifications

# How is Quality Realized?

- Translate customer needs into product/service characteristics
  - Example (Product): gas mileage demanded by customers
  - Example (Service): medical results demanded by patients
- Translate product/service characteristics into product/service specifications
  - Example (Product): weight, wind resistance, etc.
  - Example (Service): 1-, 3-, 10-year survival rates, side effects, etc.
- Design a production system that realizes these product/service specifications

# Quality and Profitability



# Why is Quality Reliability so Important?

**Internal Costs**

- Correction of defects
- Inventory cost
- Capacity consumption
- Disruption of production

**External Costs**

- Loss of reputation and brand-name
- Liability costs (manufacturer liability, legal costs, sanctions, penalties)
- Warrantee costs
- Price reductions

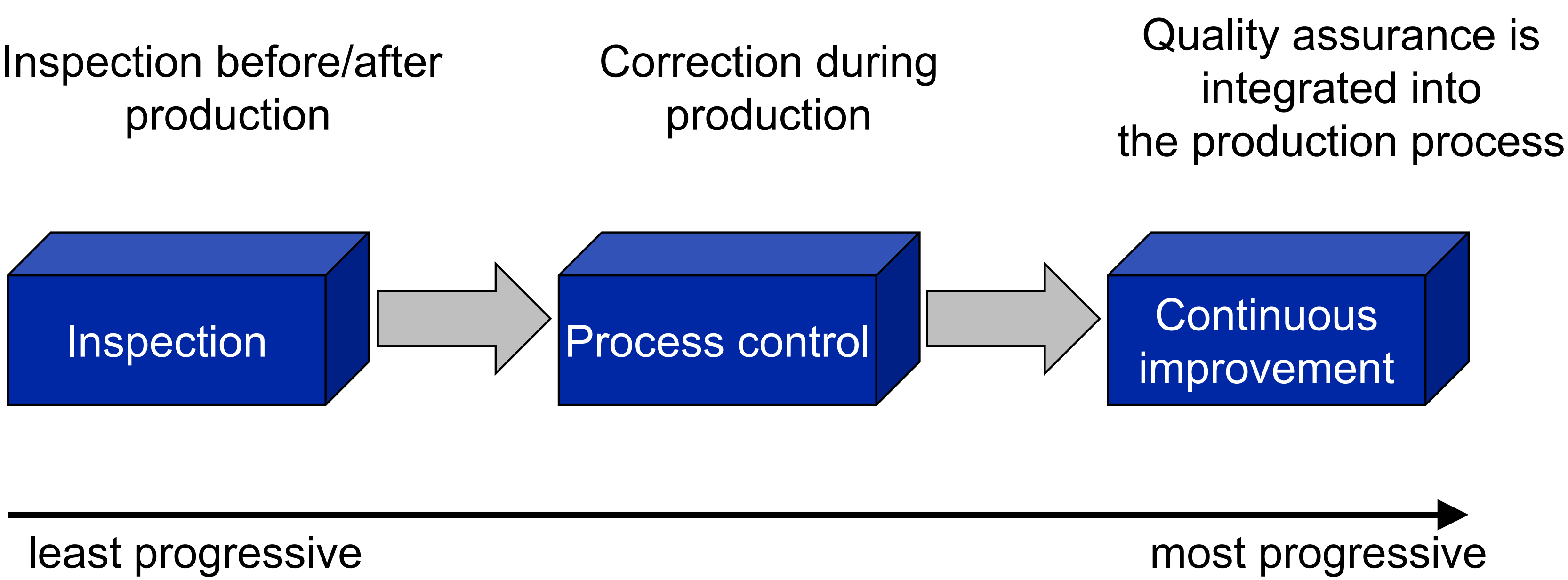
**Prevention and Detection Costs**

- Monitoring costs
- Inspection costs
- Error diagnosis/fault tracking

**Competitive advantages**

- Cost reduction for customers
- Profiting form customers' risk aversion (e.g. Disney)
- Brand loyalty/franchising

# Quality Assurance

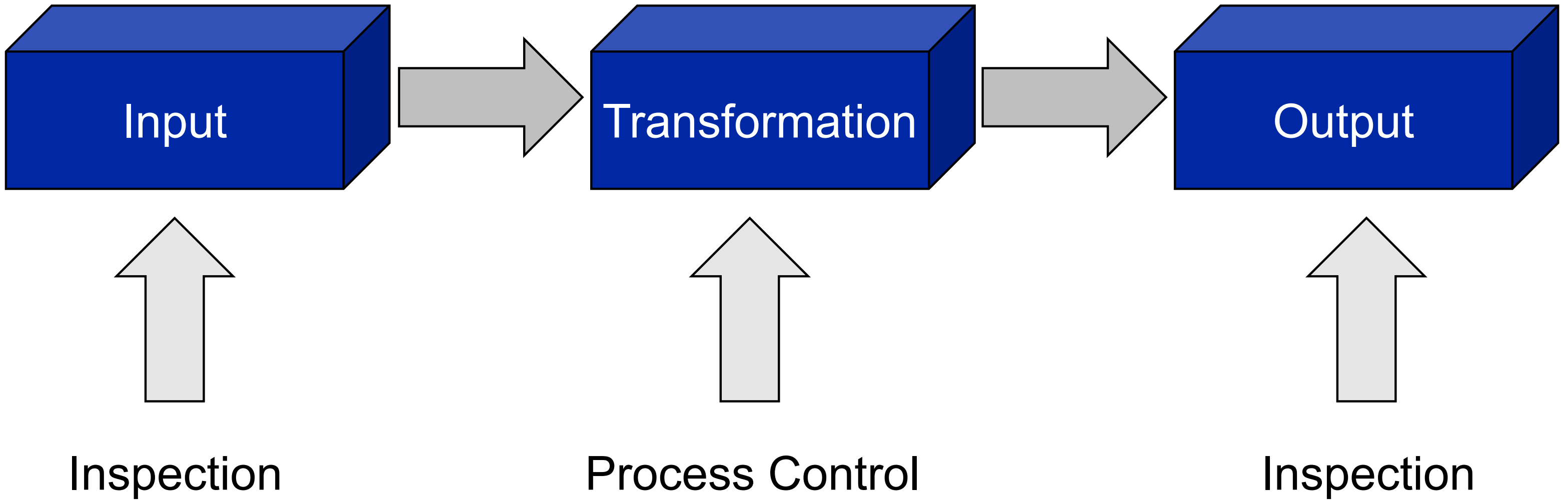


# Quality Management Objectives

- Production of reliable quality
- Identification and solution of quality problems
- Minimizing costs

**How do we achieve these objectives?**

# Inspection vs. Process Control



# Option 1: Inspection

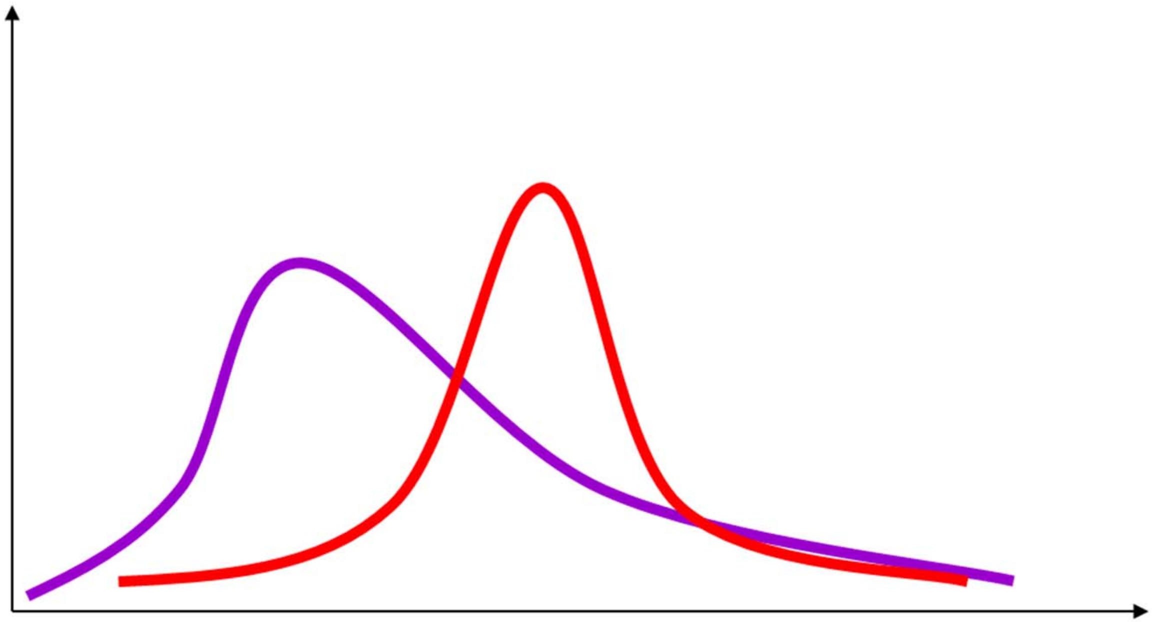
**Idea:** Eliminate wrong quality *before* it reaches the customer

Inspection can be very expansive

- Inspection costs
  - Direct: Inspection personnel, equipment
  - Indirect: Scrap, lost capacity
- Not suitable for industries with
  - Low margins
  - integral product architecture
  - high opportunity costs of production capacity

# Central Limit Theorem

The Central Limit Theorem states that the sampling distribution of the sampling means approaches a normal distribution as the sample size gets larger — no matter what the shape of the population distribution.



# Samples Inspection: Why?

- In most cases full (100%) inspection is too expansive (large production volumes)
- Often full (100%) inspection is impossible, e.g., if inspection consumes or destroys the product or service (for example: taster in restaurants, bomb testing)
- Often, inspection by the producer is cheaper than by the customer due to economies of scale (fixed costs of inspection)

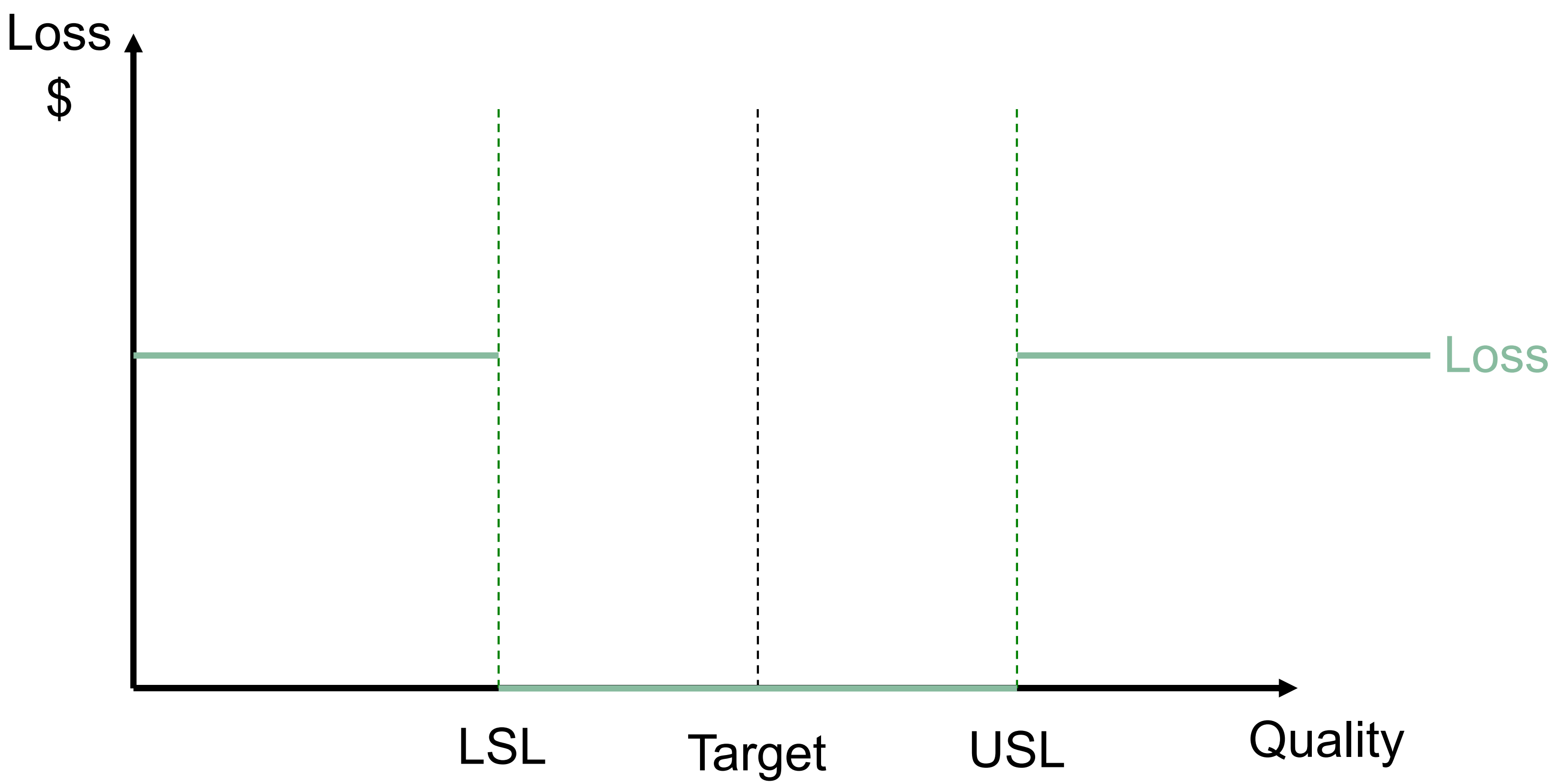
# Option 2: Process Control

**Basic Idea:** Control the process which produces quality

- SPC (Statistical Process Control)
- Control of quality dimensions (not only „good“ vs. „bad“ output)
  - How do values change over time?
  - If a product or service is of bad quality how far are the values from the desired quality level?

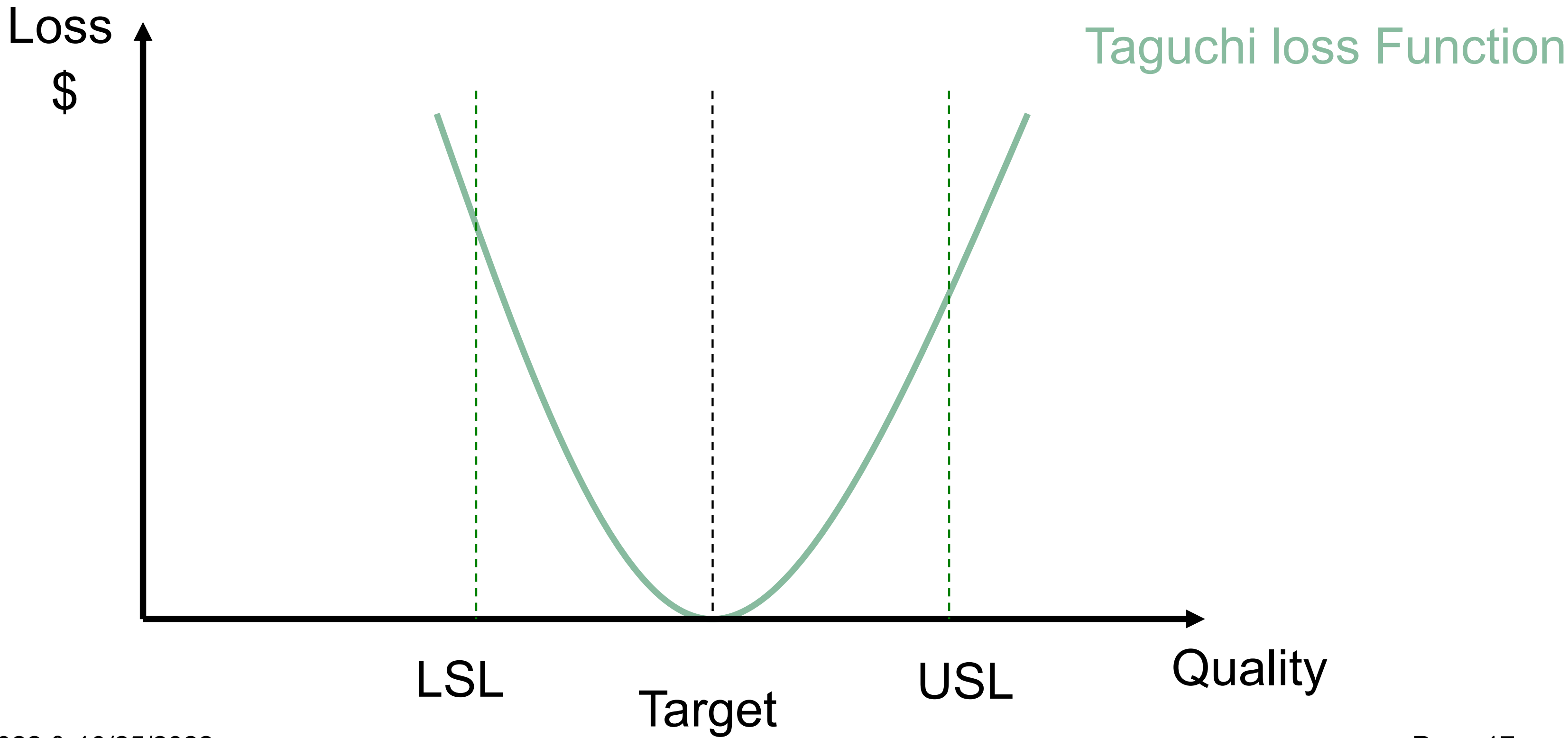
# “Goal Post” Philosophy

There is no quality problem as long as the quality stays within the lower (LSL) and upper specification limit (USL). If quality is outside the specification limits the product/service is defect/scrap



# Taguchi Loss Function

The customer experiences a loss of quality the moment quality deviates from its target value. This loss L is depicted by a quality loss function and it follows a parabolic curve mathematically given by $L = k(y-m)^2$, where m is the theoretical target value, y is the actual quality and k is a parameter

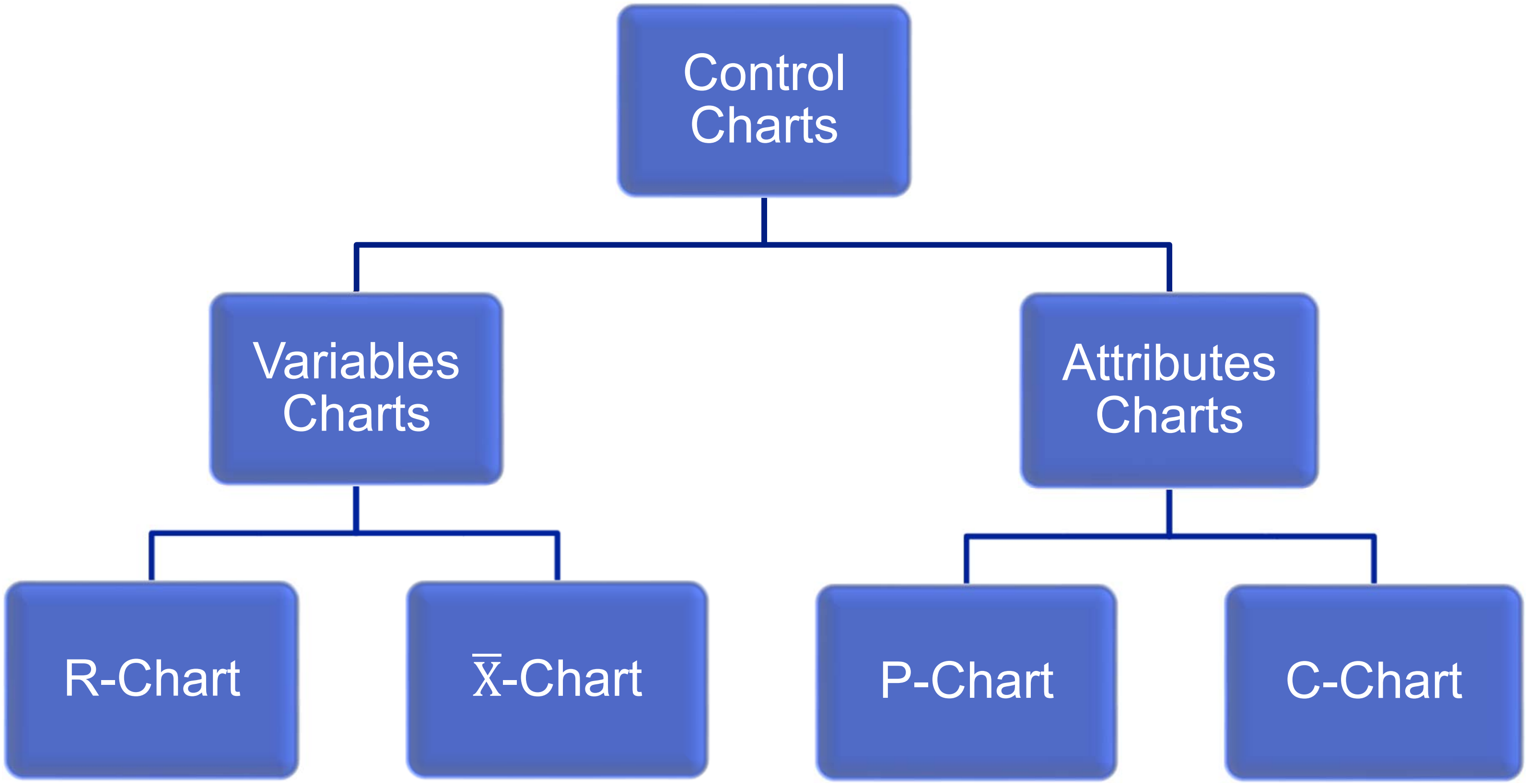


# Statistical Process Control (SPC)

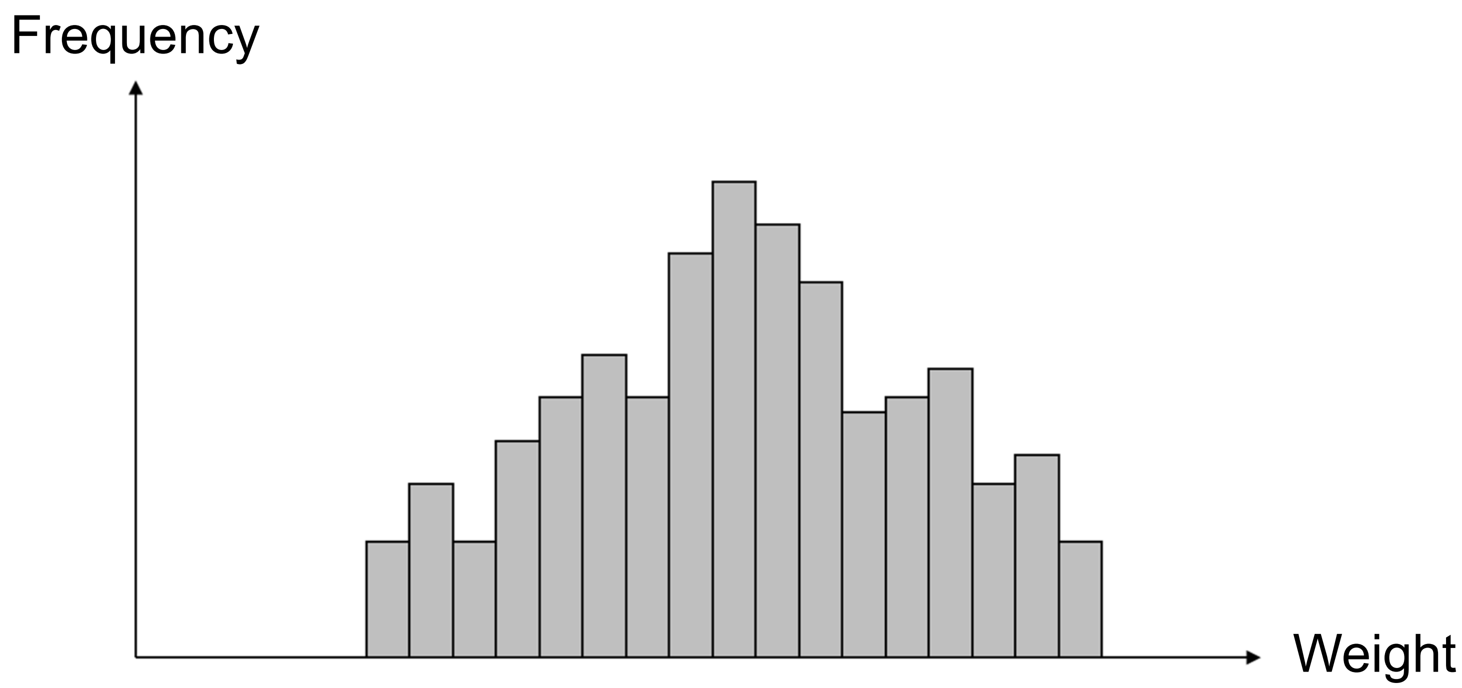
- SPC identifies the causes for process variations
  - General causes (lead to random variations)
    - affect the entire output
    - are process-immanent
    - avoidance requires new process design
  - Special causes (lead to systematic variations)
    - affect only part of the output
    - are based on avoidable errors (e.g., human failure)
    - avoidance does not require a new process design

- SPC determines process capability
  - Which quality level can be reliably achieved by the process?

# Control Charts

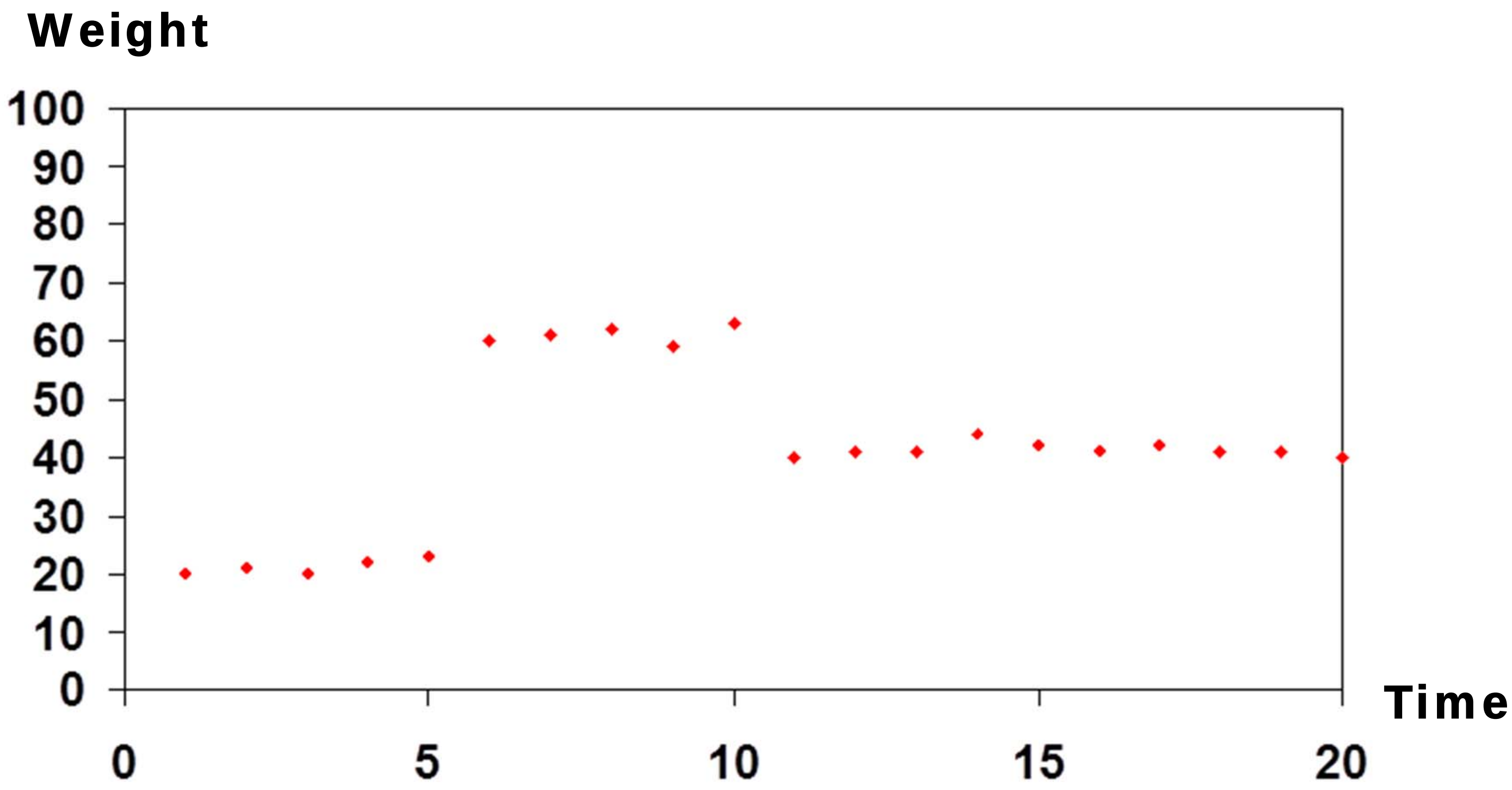


# Why Histograms are Problematic



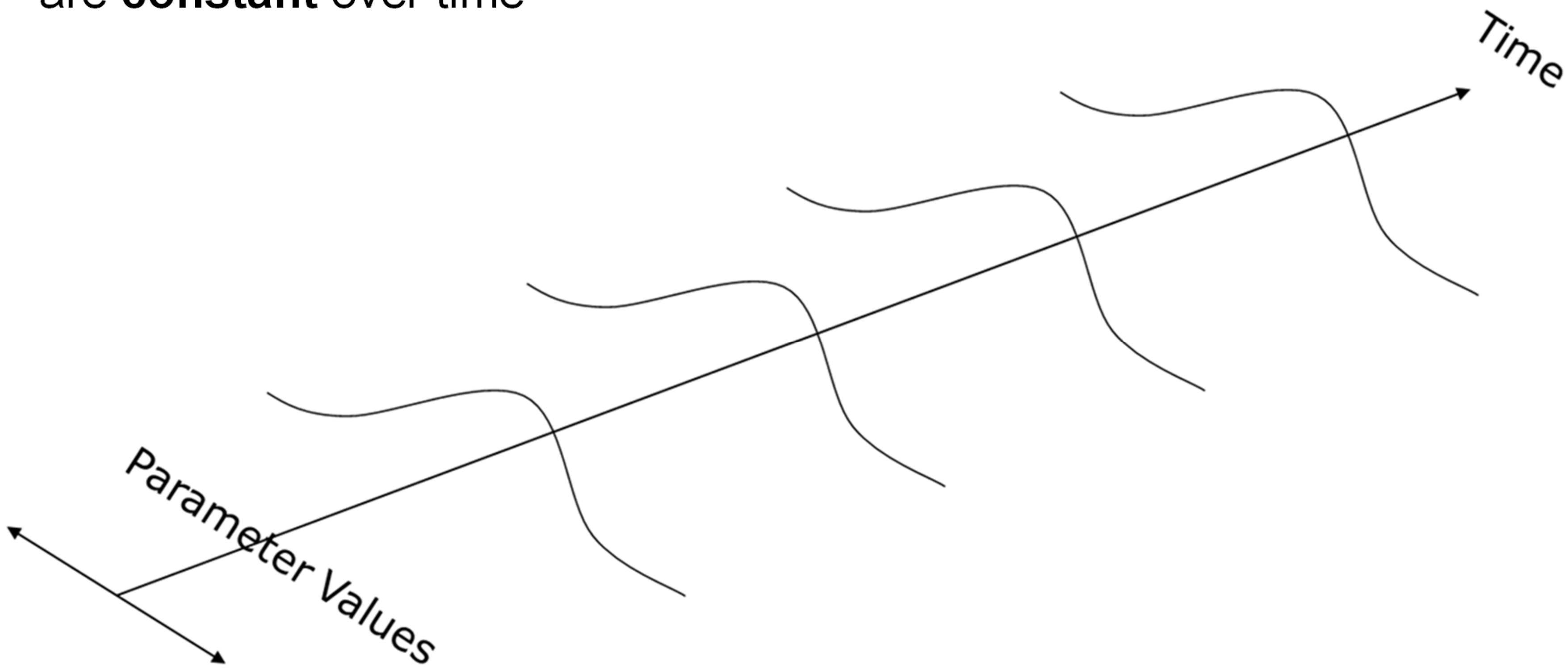

Problem: Histograms do not report variations over time

# SPC Analyzes Quality Variations over Time



# The Concept of SPC (1/2)

This process is statistically under control because its parameter values are **constant** over time



# The Concept of SPC (2/2)

This process is statistically **not** under control because its parameter values vary over time

# Control Charts: Tasks

Control Charts determine whether a process is statistically under control

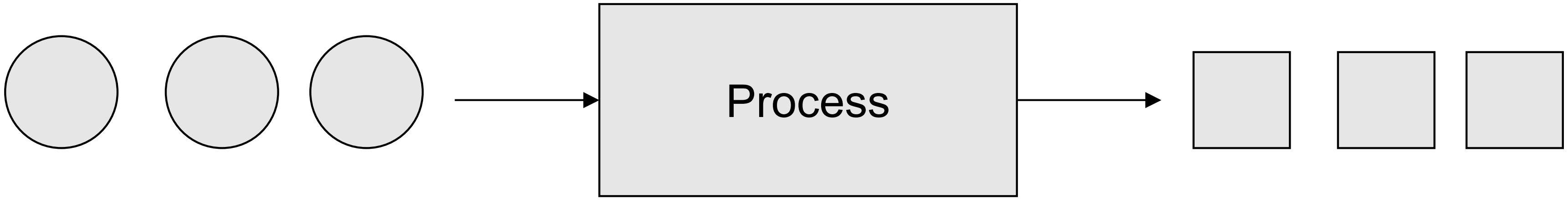
*and*

identify the causes of quality variations

*and*

monitor the production process

# Data Collection for Control Charts




**How to construct samples**

- **Goal:**
  - Minimize quality variation within each sample
  - Maximize quality variation across samples
- **Criteria:**
  - Constant environmental conditions within a sample
  - Constant materials within a sample
  - Constant personnel (e.g. one shift) within a sample

***Idea:*** *If quality variations have special causes, each sample is affected differently*

# Control Charts: Symbols

$n$ = Sample size

$\mu$ = Mean

$\sigma$ = Standard deviation

$\overline{X}$ = Sample mean

$\overline{\overline{X}}$ = Average mean (mean of sample means)

$R$ = Sample range

$\overline{R}$ = Average range (mean of sample ranges)

# Control Charts: $\overline{X}$ – Chart and R – Chart

## $\overline{X}$ – Chart

Shows whether a process is under control with respect to its means

- Control limits if parameters are known: $\overline{\overline{X}} \pm 3\frac{\sigma}{\sqrt{n}}$
- Control limits if parameters are unknown: $\overline{\overline{X}} \pm A_2\overline{R}$

## R – Chart

Shows whether a process is under control with respect to its variations

- Upper control limit (UCL): $D_4\overline{R}$
- Lower control limit (LCL): $D_3\overline{R}$

| n | $A_2$ | $D_3$ | $D_4$ |
|---|---|---|---|
| 2 | 1.88 | 0 | 3.27 |
| 3 | 1.02 | 0 | 2.57 |
| 4 | 0.73 | 0 | 2.28 |
| 5 | 0.58 | 0 | 2.11 |
| 6 | 0.48 | 0 | 2.00 |
| 7 | 0.42 | 0.08 | 1.92 |
| 8 | 0.37 | 0.14 | 1.86 |
| 9 | 0.34 | 0.18 | 1.82 |
| 10 | 0.31 | 0.22 | 1.78 |

Source: Grant E.L. (1988): Statistical Quality Control, 6. Aufl.

| n | $A_2$ | $D_3$ | $D_4$ |
|---|---|---|---|
| 11 | 0.29 | 0.26 | 1.74 |
| 12 | 0.27 | 0.28 | 1.72 |
| 13 | 0.25 | 0.31 | 1.69 |
| 14 | 0.24 | 0.33 | 1.67 |
| 15 | 0.22 | 0.35 | 1.65 |
| 16 | 0.21 | 0.36 | 1.64 |
| 17 | 0.20 | 0.38 | 1.62 |
| 18 | 0.19 | 0.39 | 1.61 |
| 19 | 0.19 | 0.40 | 1.60 |
| 20 | 0.18 | 0.41 | 1.59 |

# Example 1: Diameter

- Diameter, standard deviation = 0.09 nm
- Table shows results of 5 samples (sample size = 4)
- Is process under control?

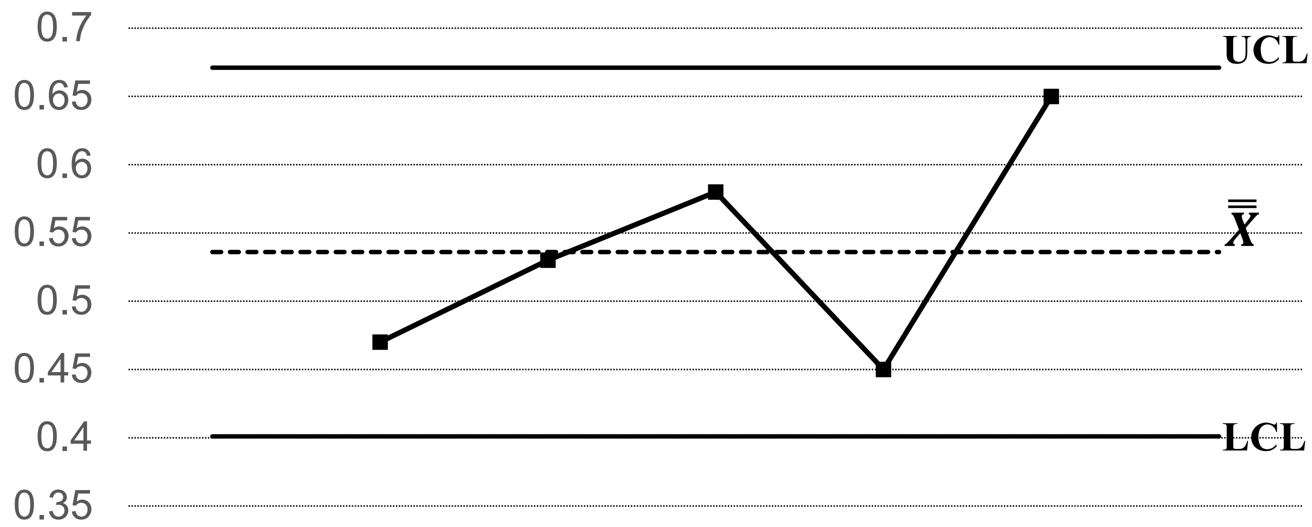
| Sample | Observations | | | | Mean | Range |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | | |
| 1 | 0.51 | 0.63 | 0.39 | 0.35 | 0.47 | 0.28 |
| 2 | 0.50 | 0.56 | 0.42 | 0.64 | 0.53 | 0.22 |
| 3 | 0.68 | 0.49 | 0.53 | 0.62 | 0.58 | 0.19 |
| 4 | 0.45 | 0.33 | 0.47 | 0.55 | 0.45 | 0.22 |
| 5 | 0.70 | 0.58 | 0.64 | 0.68 | 0.65 | 0.12 |

# Example 1: $\overline{X}$ – Chart

**$\overline{\text{X}}$ – Chart**

- $\overline{\overline{\text{X}}} = \frac{0.47+0.53+0.58+0.45+0.65}{5} = 0.536$
- UCL = $0.536 + 3 * \left(\frac{0.09}{\sqrt{4}}\right) = 0.536 + 0.135 = 0.671$
- LCL = $0.536 - 0.135 = 0.401$

→ Process is under control with respect to its means

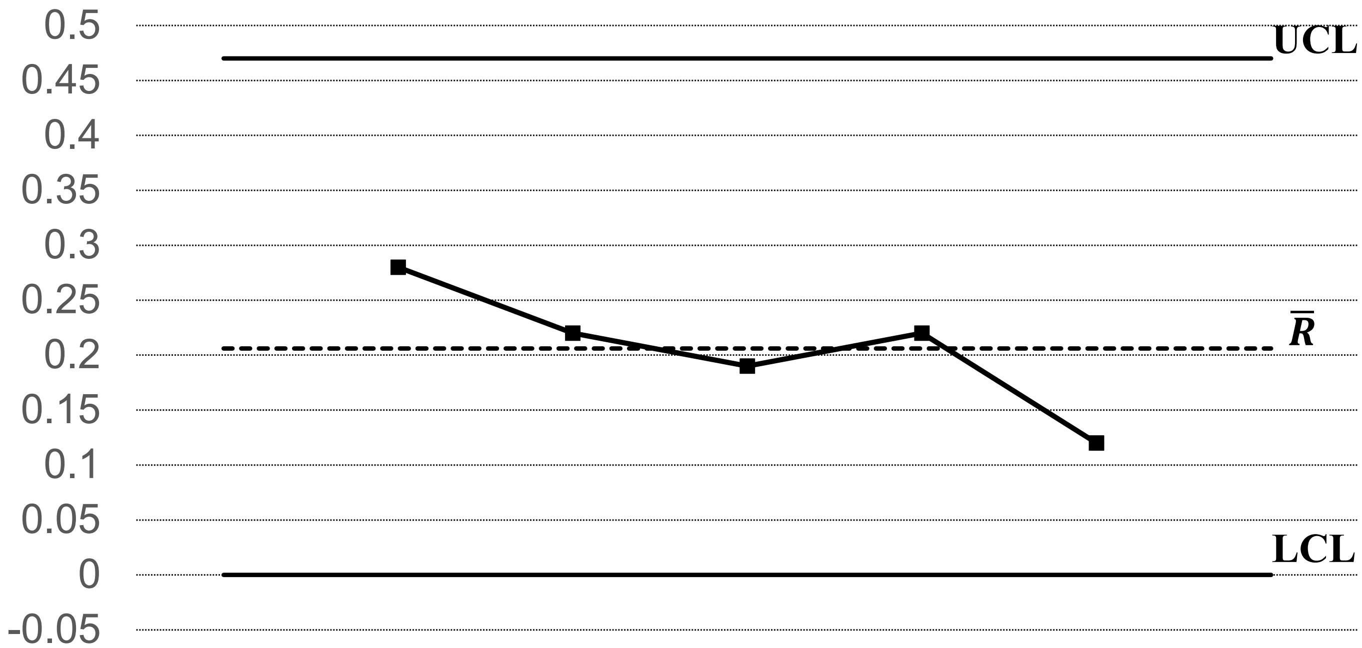


# Example 1: R-Chart

## R – Chart

- $\overline{R} = \frac{0.28+0.22+0.19+0.22+0.12}{5} = 0.206$
- UCL = $2.28 * 0.206 = 0.47$
- LCL = $0 * 0.206 = 0$

→ Process is under control with respect to its range



# Example 2: Abrasion

- Tire abrasion in nm, standard deviation unknown
- 20 samples à 10 tires (see Table)
- Is the process under control?

| Sample | Average | Range | Sample | Average | Range |
|---|---|---|---|---|---|
| 1 | 95.72 | 1.0 | 11 | 95.80 | 0.6 |
| 2 | 95.24 | 0.9 | 12 | 95.22 | 0.2 |
| 3 | 95.18 | 0.8 | 13 | 95.56 | 1.3 |
| 4 | 95.44 | 0.4 | 14 | 95.22 | 0.5 |
| 5 | 95.46 | 0.5 | 15 | 95.04 | 0.8 |
| 6 | 95.32 | 1.1 | 16 | 95.72 | 1.1 |
| 7 | 95.40 | 0.9 | 17 | 94.82 | 0.6 |
| 8 | 95.44 | 0.3 | 18 | 95.46 | 0.5 |
| 9 | 95.08 | 0.2 | 19 | 95.60 | 0.4 |
| 10 | 95.50 | 0.6 | 20 | 95.74 | 0.6 |

# Example 2: Control Limits

- $\overline{\overline{\mathrm{X}}} = 95.398$
- $\overline{\mathrm{R}} = 0.665$
- UCL ($\overline{\mathrm{X}}$ – Chart) = $95.398 + 0.31 * 0.665 = 95.60$
- LCL ($\overline{\mathrm{X}}$ – Chart) = $95.398 - 0.31 * 0.665 = 95.19$
- UCL (R – Chart) = $1.78 * 0.665 = 1.18$
- LCL (R – Chart) = $0.22 * 0.665 = 0.15$

# Example 2: Sample Mean

| Sample | Average | Range | Sample | Average | Range |
|---|---|---|---|---|---|
| 1 | 95.72 | 1.0 | 11 | 95.80 | 0.6 |
| 2 | 95.24 | 0.9 | 12 | 95.22 | 0.2 |
| 3 | 95.18 | 0.8 | 13 | 95.56 | 1.3 |
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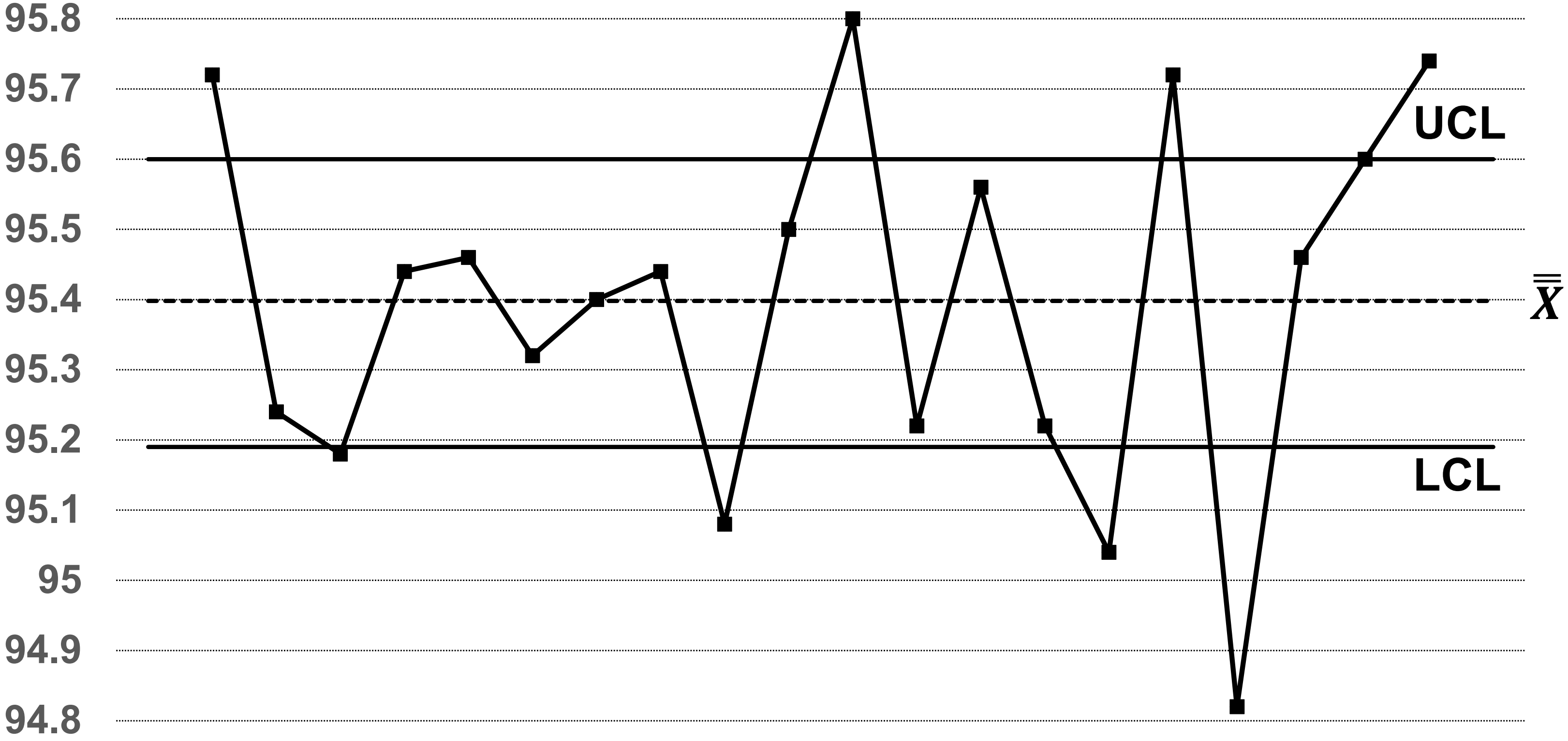
| 9 | 95.08 | 0.2 | 19 | 95.60 | 0.4 |
| 10 | 95.50 | 0.6 | 20 | 95.74 | 0.6 |

→ Process is not under control with respect to its mean

# Example 2: $\overline{X}$-Chart



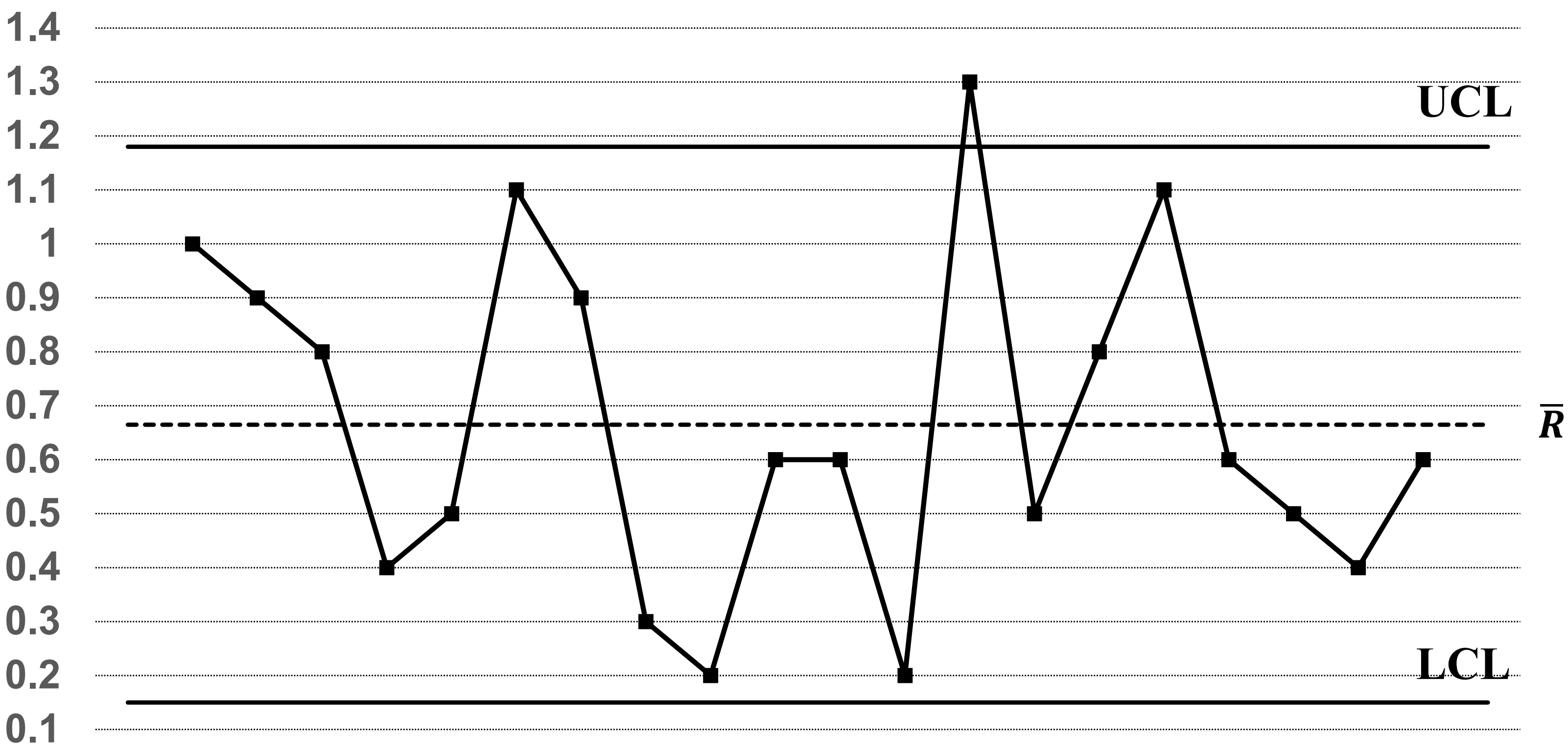

→ Process is not under control with respect to its mean

# Example 2: Sample Range

| Sample | Average | Range | Sample | Average | Range |
|---|---|---|---|---|---|
| 1 | 95.72 | 1.0 | 11 | 95.80 | 0.6 |
| 2 | 95.24 | 0.9 | 12 | 95.22 | 0.2 |
| 3 | 95.18 | 0.8 | 13 | 95.56 | 1.3 ← |
| 4 | 95.44 | 0.4 | 14 | 95.22 | 0.5 |
| 5 | 95.46 | 0.5 | 15 | 95.04 | 0.8 |
| 6 | 95.32 | 1.1 | 16 | 95.72 | 1.1 |
| 7 | 95.40 | 0.9 | 17 | 94.82 | 0.6 |
| 8 | 95.44 | 0.3 | 18 | 95.46 | 0.5 |
| 9 | 95.08 | 0.2 | 19 | 95.60 | 0.4 |
| 10 | 95.50 | 0.6 | 20 | 95.74 | 0.6 |

→ Process is not under control with respect to its range

# Example 2: R-Chart



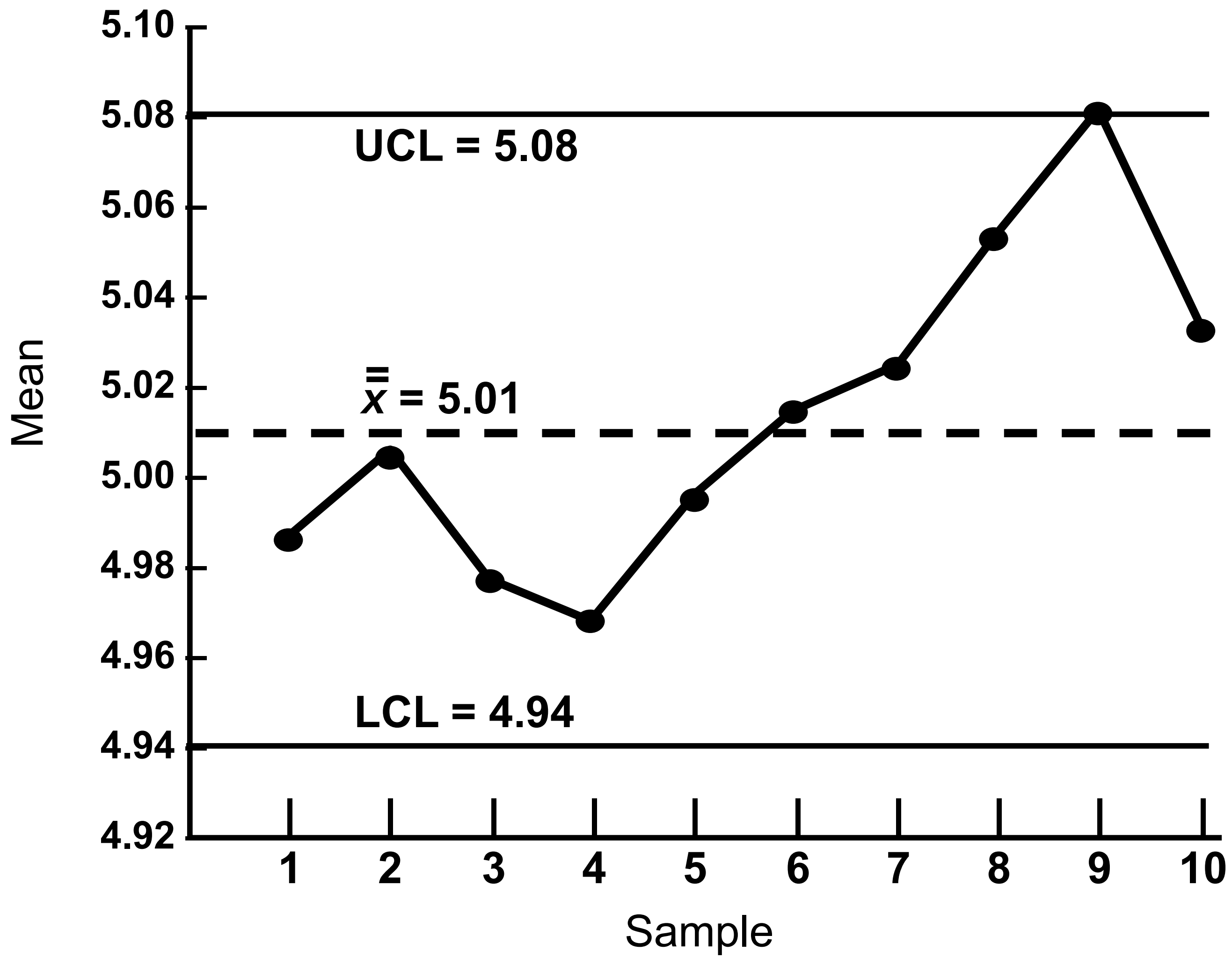

→ Process is not under control with respect to its range

# Example 3: Pod Weight Samples

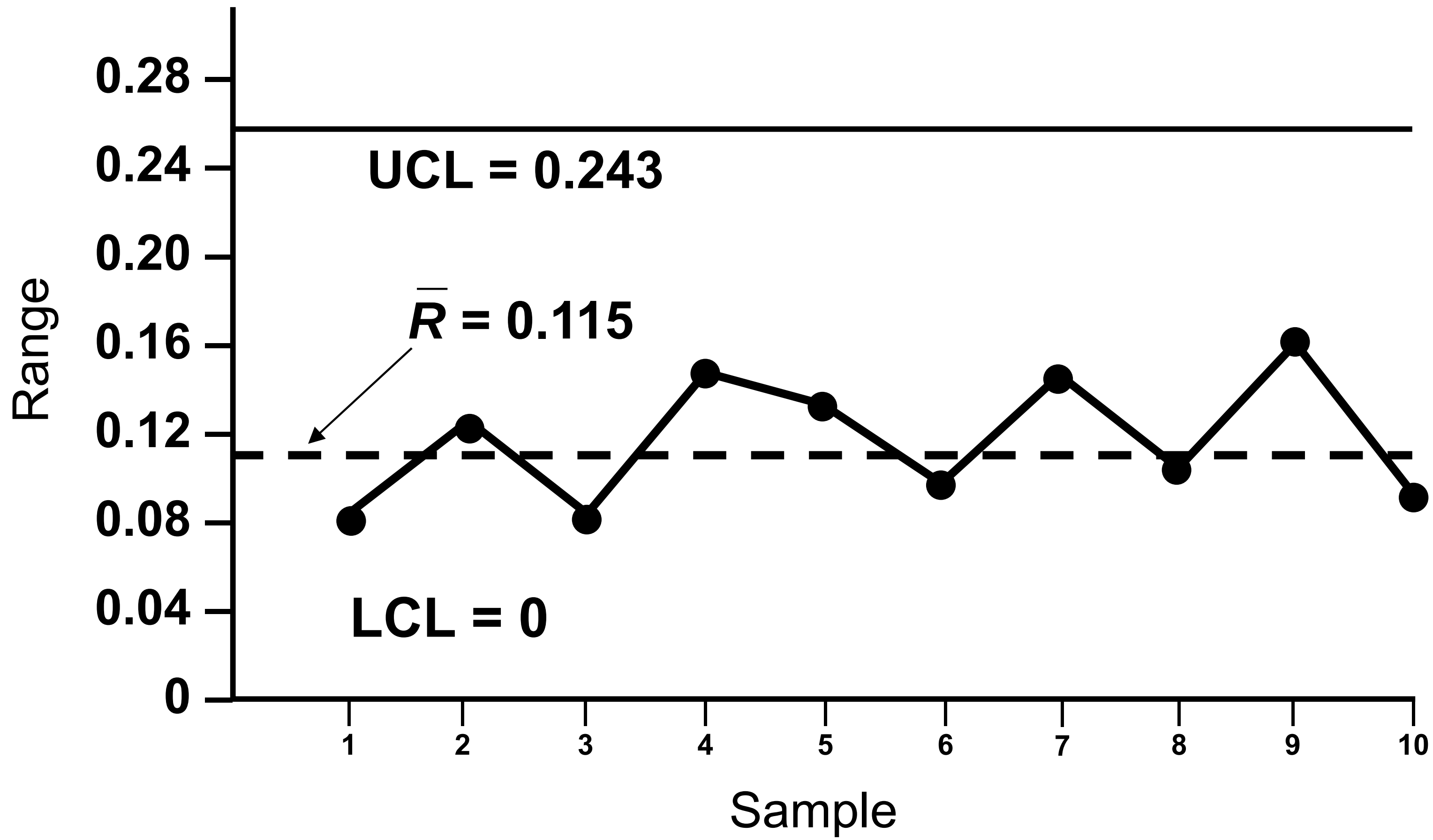
**Observations (weight in ng)**

| Sample k | 1 | 2 | 3 | 4 | 5 | $\bar{X}$ | R |
|---|---|---|---|---|---|---|---|
| 1 | 5.02 | 5.01 | 4.94 | 4.99 | 4.96 | 4.98 | 0.08 |
| 2 | 5.01 | 5.03 | 5.07 | 4.95 | 4.96 | 5.00 | 0.12 |
| 3 | 4.99 | 5.00 | 4.93 | 4.92 | 4.99 | 4.97 | 0.08 |
| 4 | 5.03 | 4.91 | 5.01 | 4.98 | 4.89 | 4.96 | 0.14 |
| 5 | 4.95 | 4.92 | 5.03 | 5.05 | 5.01 | 4.99 | 0.13 |
| 6 | 4.97 | 5.06 | 5.06 | 4.96 | 5.03 | 5.01 | 0.10 |
| 7 | 5.05 | 5.01 | 5.10 | 4.96 | 4.99 | 5.02 | 0.14 |
| 8 | 5.09 | 5.10 | 5.00 | 4.99 | 5.08 | 5.05 | 0.11 |
| 9 | 5.14 | 5.10 | 4.99 | 5.08 | 5.09 | 5.08 | 0.15 |
| 10 | 5.01 | 4.98 | 5.08 | 5.07 | 4.99 | 5.03 | 0.10 |
| | | | | | | 50.09 | 1.15 |

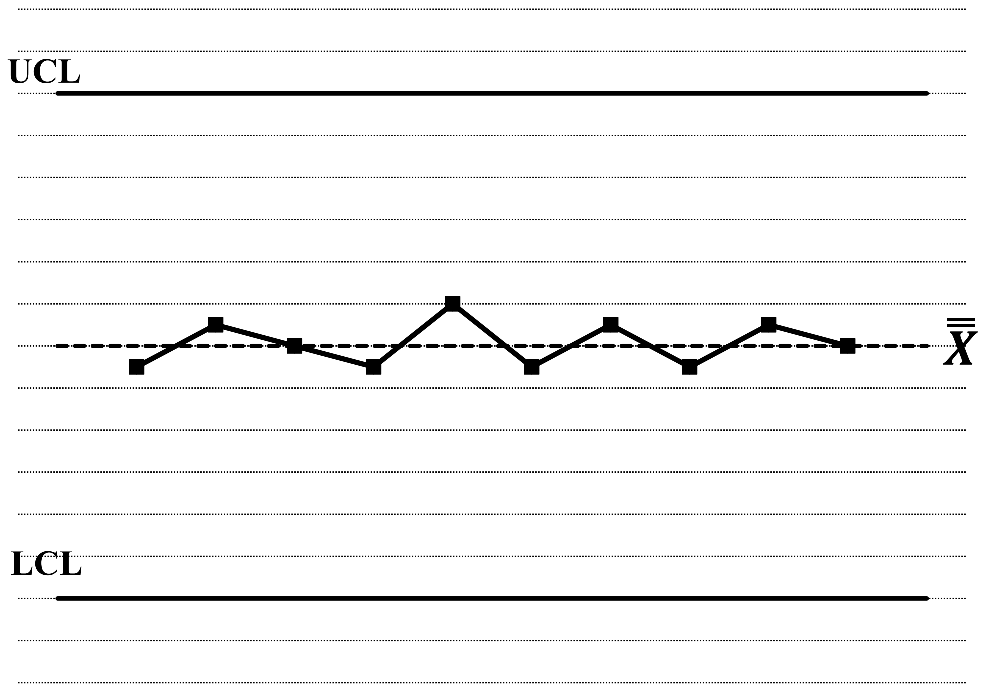
# Example 3: $\bar{X}$-Chart



# Example: R-Chart

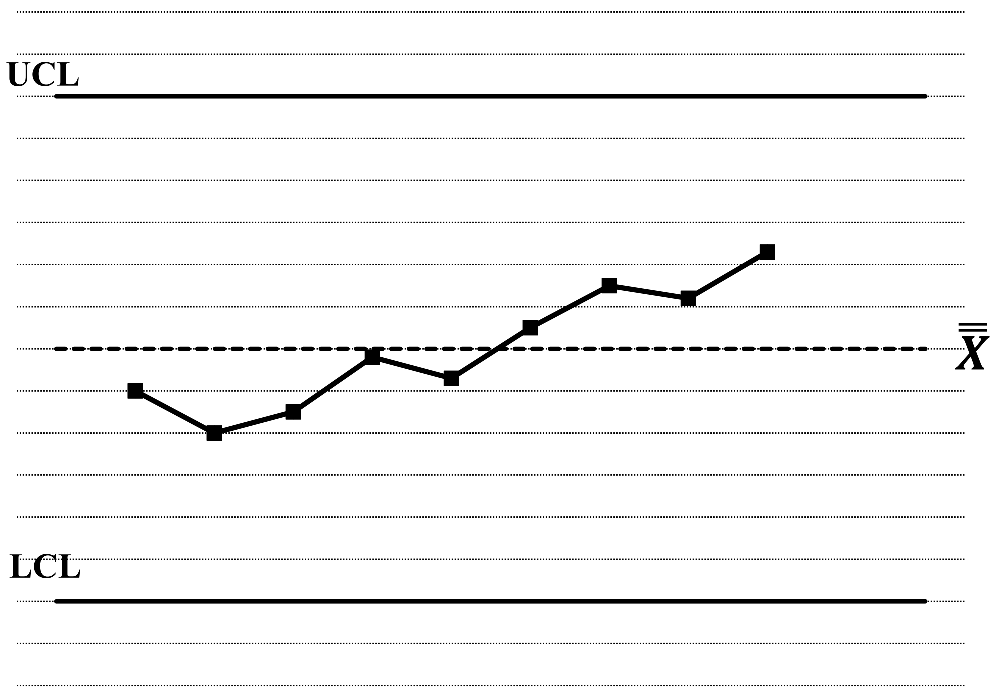


# Analyzing Control Charts: Process 1



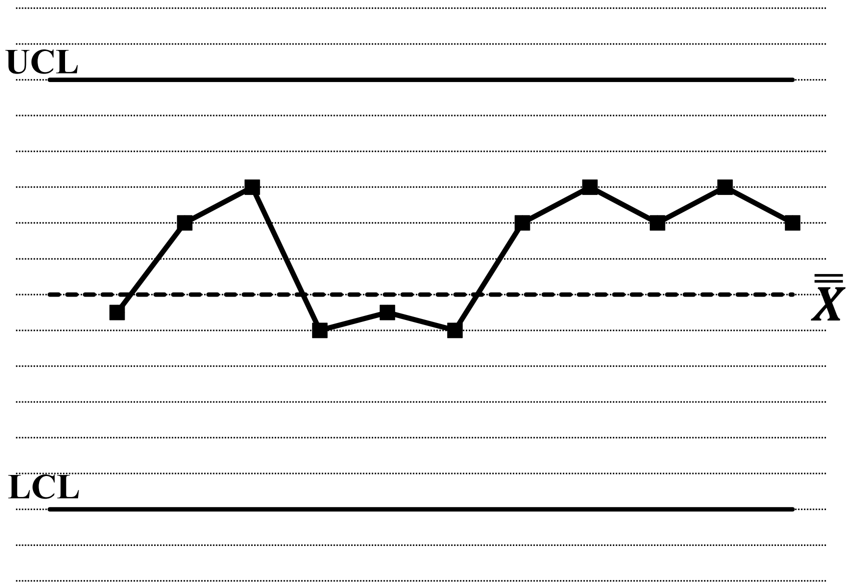

Process 1 is an ideal process

# Analyzing Control Charts: Process 2



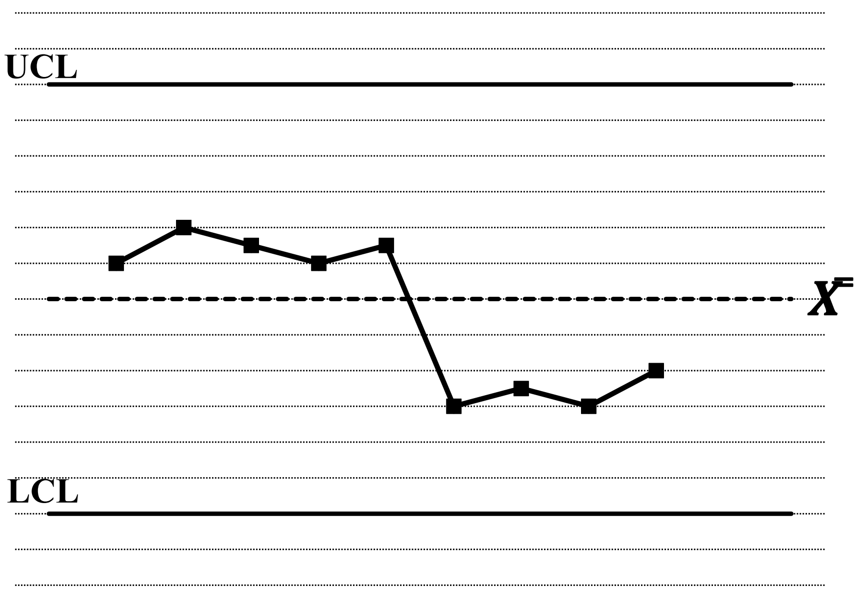

Process 2 is under control, but problematic because of an (upward) trend

# Analyzing Control Charts: Process 3



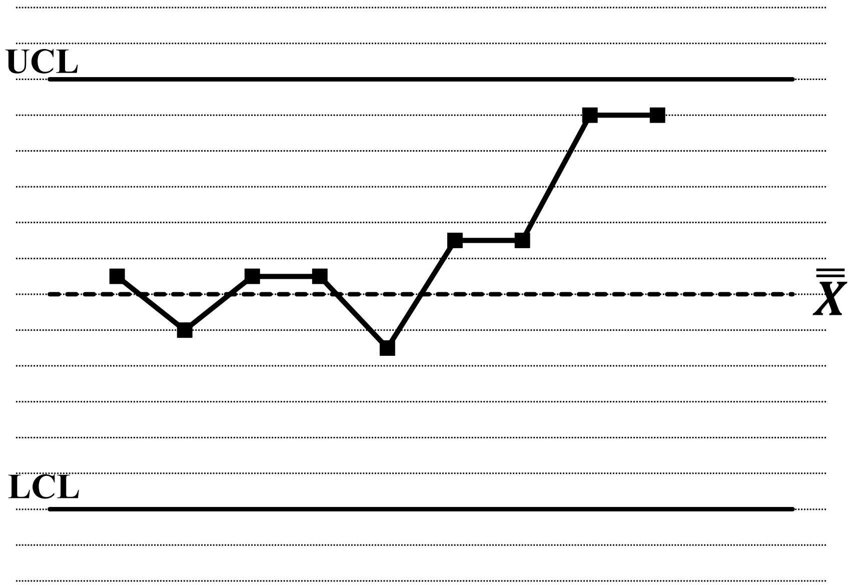

Process 3 is under control, but problematic because of 5 subsequent observations above $\bar{\bar{X}}$

# Analyzing Control Charts: Process 4



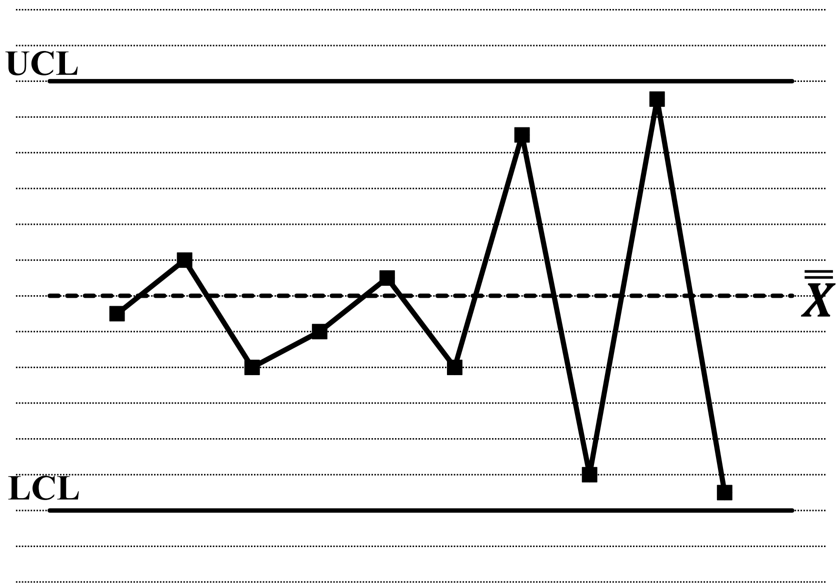

Process 4 is under control, but problematic because of a sudden shift

# Analyzing Control Charts: Process 5




Process 5 is under control, but problematic because the values are approaching the UCL

# Analyzing Control Charts: Process 6




Process 6 is under control, but problematic because
of increasing process variance

# Control Charts for Attributes

- Used to monitor the proportion of nonconforming units (defects, faults) in a sample
- Example: number of guests with complaints in a five-star hotel
- p-Chart:

$$\bar{p} = \frac{Number\ of\ Guests\ with\ Complaints}{Total\ Number\ of\ Guests}$$

$$n_j = size\ of\ sample\ j$$

$$UCL_j = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n_j}}$$

$$LCL_j = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n_j}}$$

# Example 4: Five-Star Hotel

| j | Sample | $n_j$ | # Guests with Complaints | Ratio |
|---|---|---|---|---|
| 1 | January | 100 | 8 | 0.08 |
| 2 | February | 50 | 4 | 0.08 |
| 3 | March | 100 | 10 | 0.1 |
| 4 | April | 100 | 8 | 0.08 |
| 5 | May | 75 | 6 | 0.08 |
| 6 | June | 100 | 10 | 0.1 |
| 7 | July | 150 | 15 | 0.1 |
| 8 | August | 100 | 12 | 0.12 |
| 9 | September | 50 | 8 | 0.16 |
| 10 | October | 100 | 10 | 0.1 |

# Example 4: Calculations

Calculation of $\bar{p}$: $$\frac{\sum_j Number\ of\ Guests\ with\ Complaints}{\sum_j n_j} = \frac{91}{925} = 0.1$$

Calculation of upper and lower control limits:

$n_j$=150: UCL$= 0.1 + 3\sqrt{\frac{(0.1)(1-0.1)}{150}} = 0.17$ LCL$= 0.1 - 3\sqrt{\frac{(0.1)(1-0.1)}{150}} = 0.03$

$n_j$=100: UCL$= 0.1 + 3\sqrt{\frac{(0.1)(1-0.1)}{100}} = 0.19$ LCL$= 0.1 - 3\sqrt{\frac{(0.1)(1-0.1)}{100}} = 0.01$

$n_j$=75: UCL$= 0.1 + 3\sqrt{\frac{(0.1)(1-0.1)}{75}} = 0.20$ LCL$= 0.1 - 3\sqrt{\frac{(0.1)(1-0.1)}{75}} = 0.00$

$n_j$=50: UCL$= 0.1 + 3\sqrt{\frac{(0.1)(1-0.1)}{50}} = 0.23$ LCL$= 0.1 - 3\sqrt{\frac{(0.1)(1-0.1)}{50}} = -0.03$

=> LCL = 0!

# Example 4: Control Limits

| Sample | $n_j$ | # Guests with Complaints | Ratio | LCL | UCL |
|---|---|---|---|---|---|
| 1 | 100 | 8 | 0.08 | 0.01 | 0.19 |
| 2 | 50 | 4 | 0.08 | 0.00 | 0.23 |
| 3 | 100 | 10 | 0.10 | 0.01 | 0.19 |
| 4 | 100 | 8 | 0.08 | 0.01 | 0.19 |
| 5 | 75 | 6 | 0.08 | 0.00 | 0.20 |
| 6 | 100 | 10 | 0.10 | 0.01 | 0.19 |
| 7 | 150 | 15 | 0.10 | 0.03 | 0.17 |
| 8 | 100 | 12 | 0.12 | 0.01 | 0.19 |
| 9 | 50 | 8 | 0.16 | 0.00 | 0.23 |
| 10 | 100 | 10 | 0.10 | 0.01 | 0.19 |
| Sum | 925 | 91 | **$\overline{p}$ = 91/925 = 0.1** | | |

# Example 4: Improvement?

- In October, the hotel personnel received special training
- In November and December samples of 150 observations each were analyzed
- The ratio of guests with complaints was 0.02 in November and 0.01 in December
- Were the measures successful?

# Performance Limits

## Control limits

- are based on actual output data
- help to distinguish special from general (process immanent) causes of quality variations

## Performance limits

- predict future process performance
- are calculated for processes which are under control
- make no sense for processes which are not under control

# Process Capability

**Specification limits**

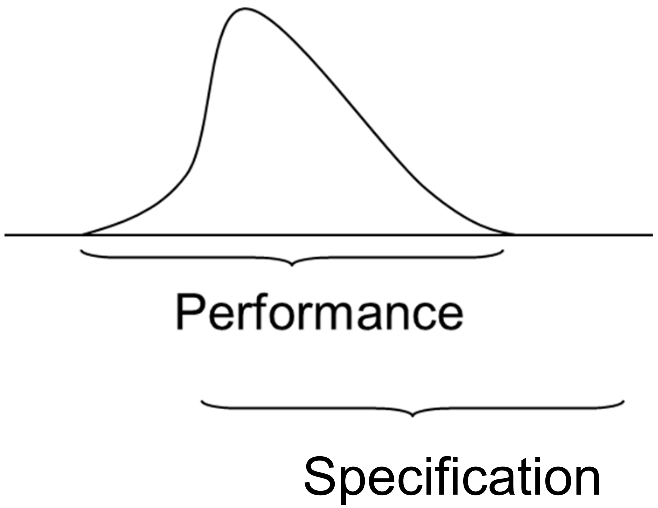
- describe desirable tolerance limits
- represent customer expectations

**Process capability**

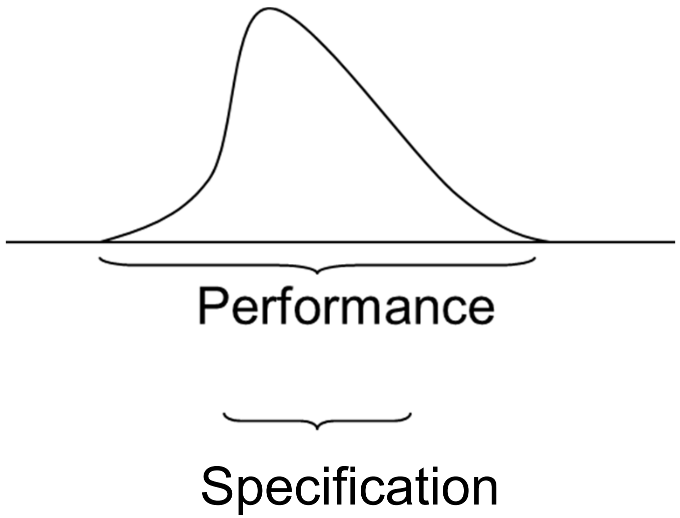
- can only be determined for processes which are under control
- If a process is under control, it is capable of producing within its performance limits
- **But:** even processes which are under control may produce undesirable products/services (i.e., quality which is outside the specification limits)

# Performance Limits versus Specification Limits (1/2)

**Undesirable situation:**

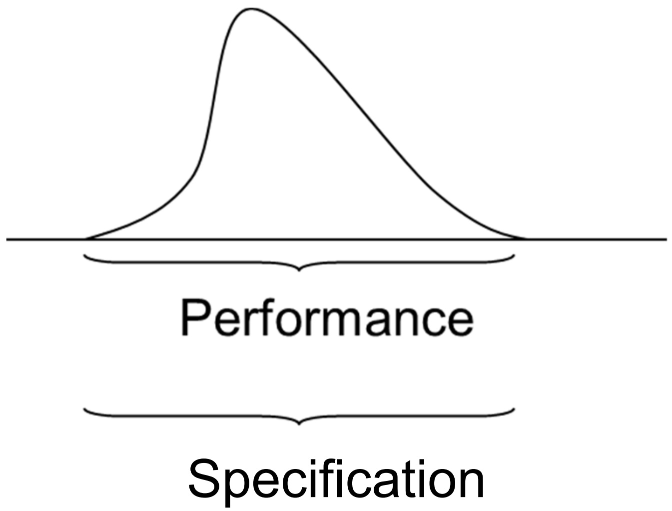



**Extremely undesirable situation:**

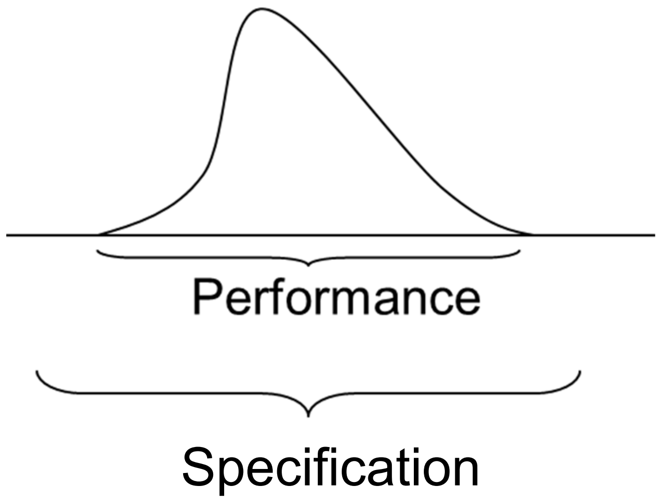


# Performance Limits versus Specification Limits (2/2)

**Vulnerable situation:**




**Highly desirable situation:**



# Capability Index (for symmetric processes)

Assumption: Process mean is centered between specification limits

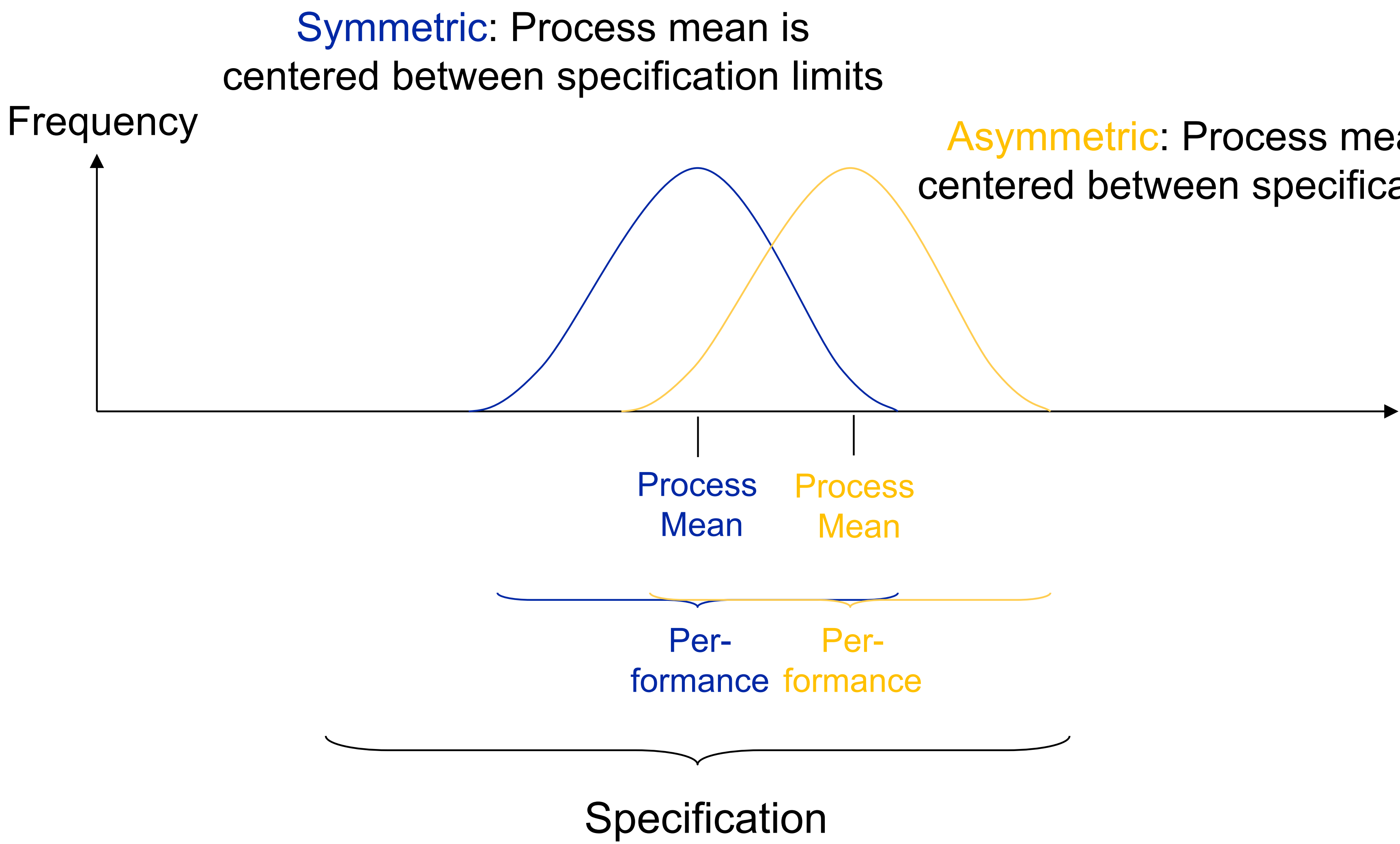
$$C_P = \frac{Upper\ Specification\ Limit\ (USL) - Lower\ Specification\ Limit\ (LSL)}{6 * \sigma}$$

Process is capable if $C_P \geq 1$

Recommended minimum $C_P = 1.33$

Six Sigma Quality process: $C_p$ = 2

# Symmetric vs. Asymmetric Processes



# Special Case: Capability Index for Asymmetric Processes

If process mean is not centered between specification limits:

$$C_{pk} = \min\left[\frac{USL-\mu}{3\sigma};\frac{\mu-LSL}{3\sigma}\right]$$

$C_{pk}$ Capability Index for asymmetric Processes

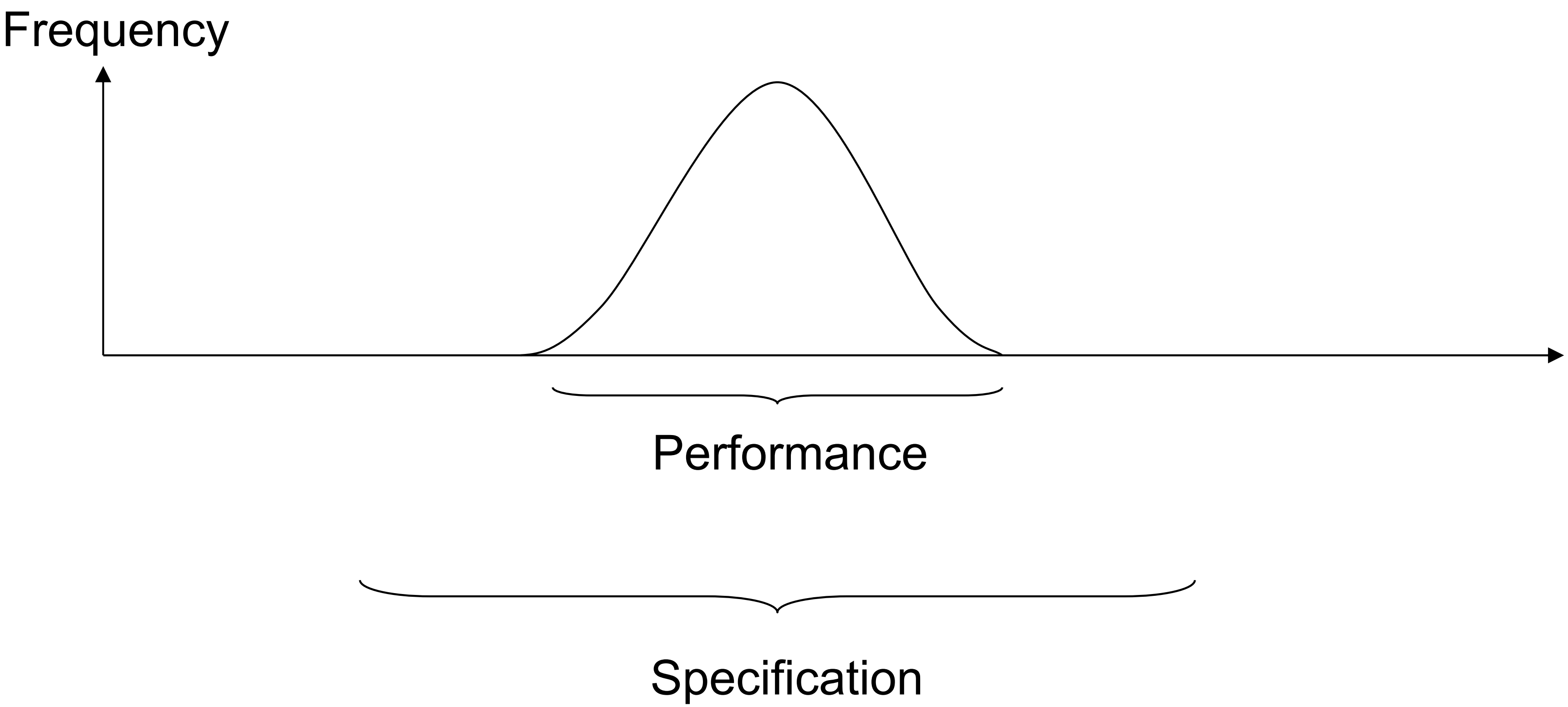
$USL$ upper specification limit

$LSL$ lower specification limit

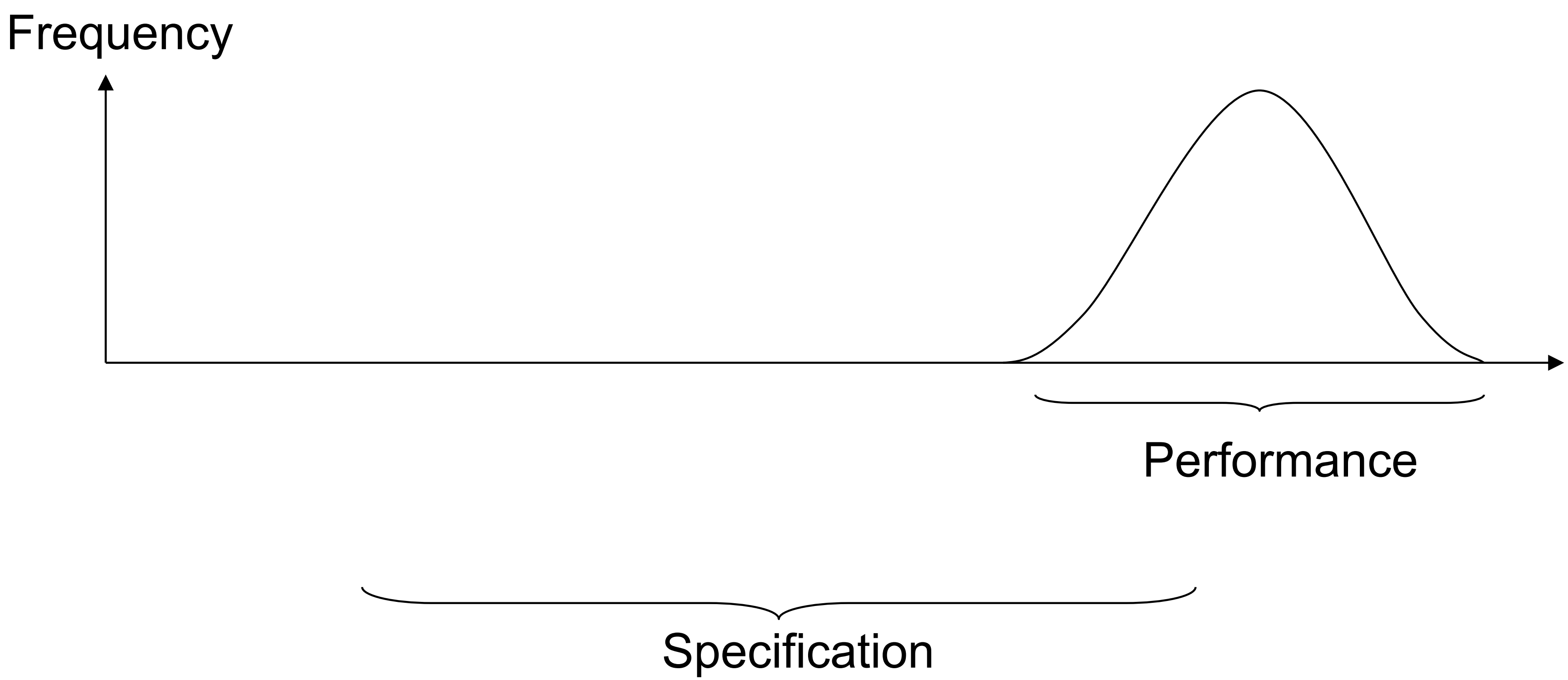
$\mu$ mean of the process (center between *UCL* and *LCL*)

$\sigma$ standard deviation of the process

# Ideal Situation: CP>1



# Bad, But Solvable: CP>1



# Not Solvable: CP<<1