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
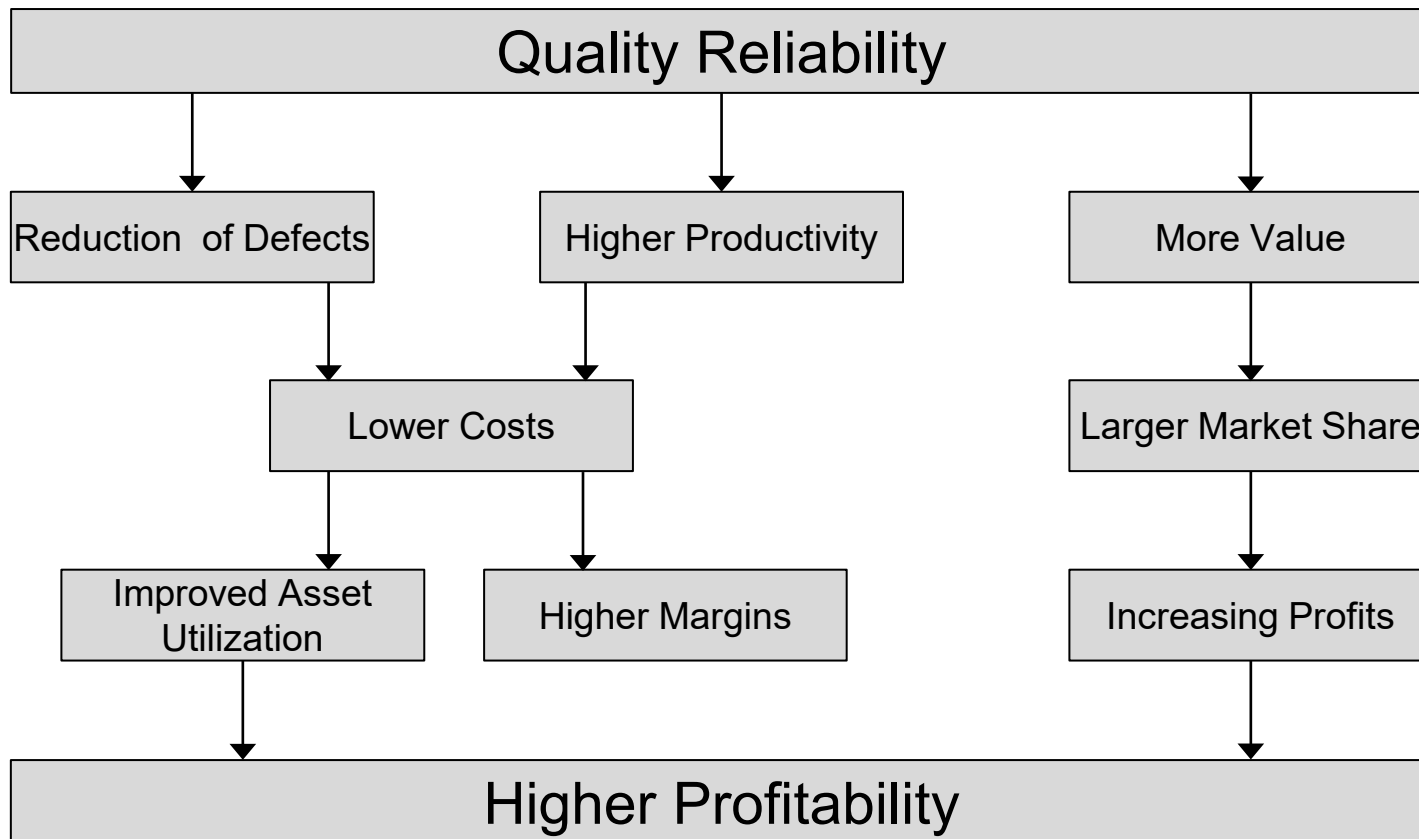
Why is Quality Reliability so Important?

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
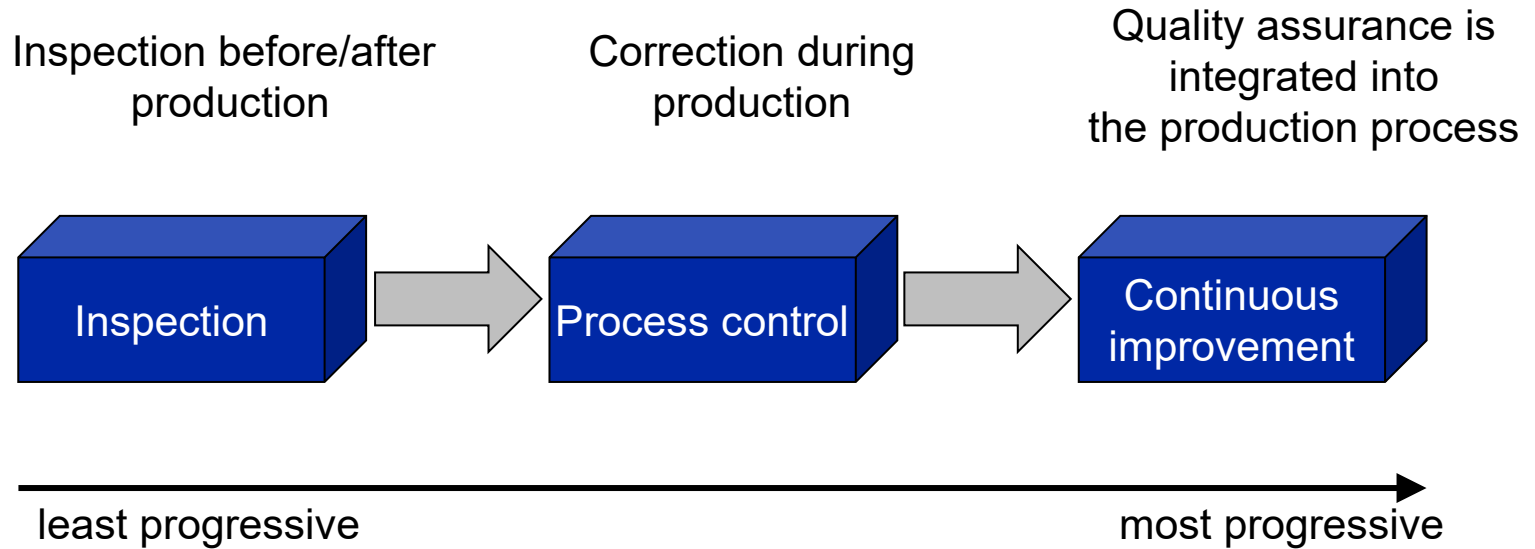
Prevention and Detection Costs

- 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

Inspection before/after production

Correction during production

Quality assurance is integrated into the production process

Inspection → Process control → Continuous improvement
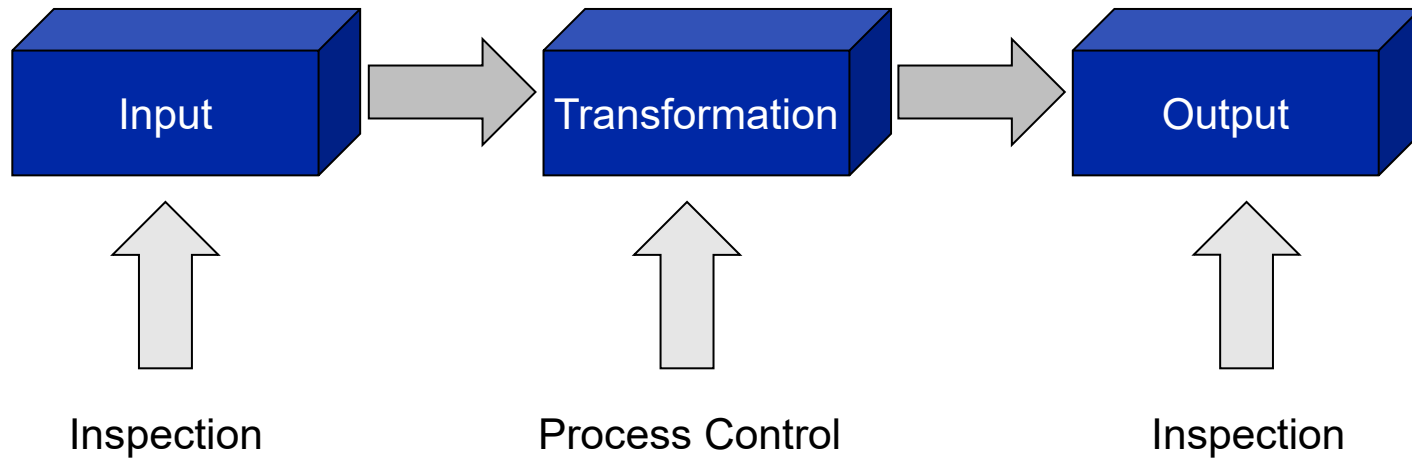
least progressive ──────────────→ most progressive

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

Input	Transformation	Output
Inspection	Process Control	Inspection

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.
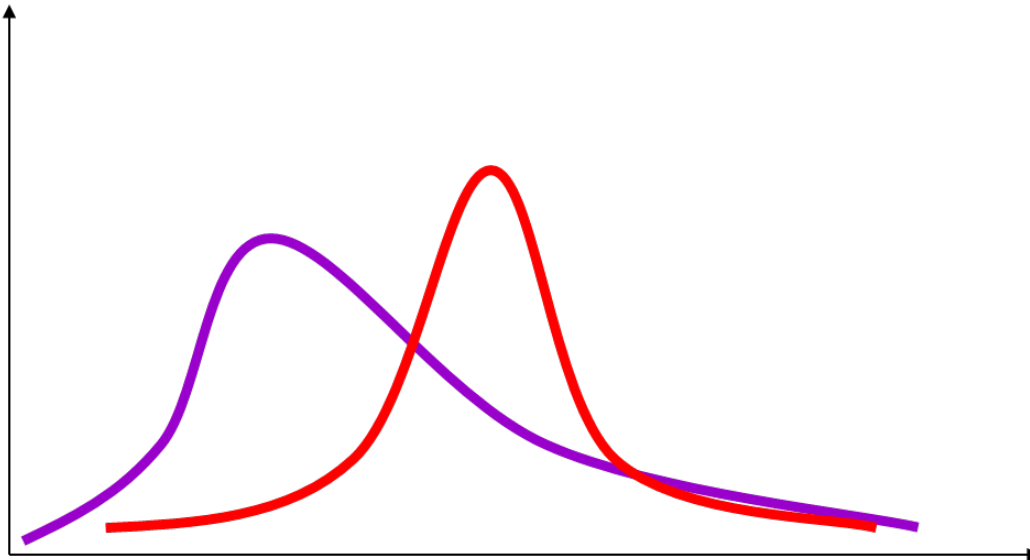
Samples Inspection: Why?

- 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
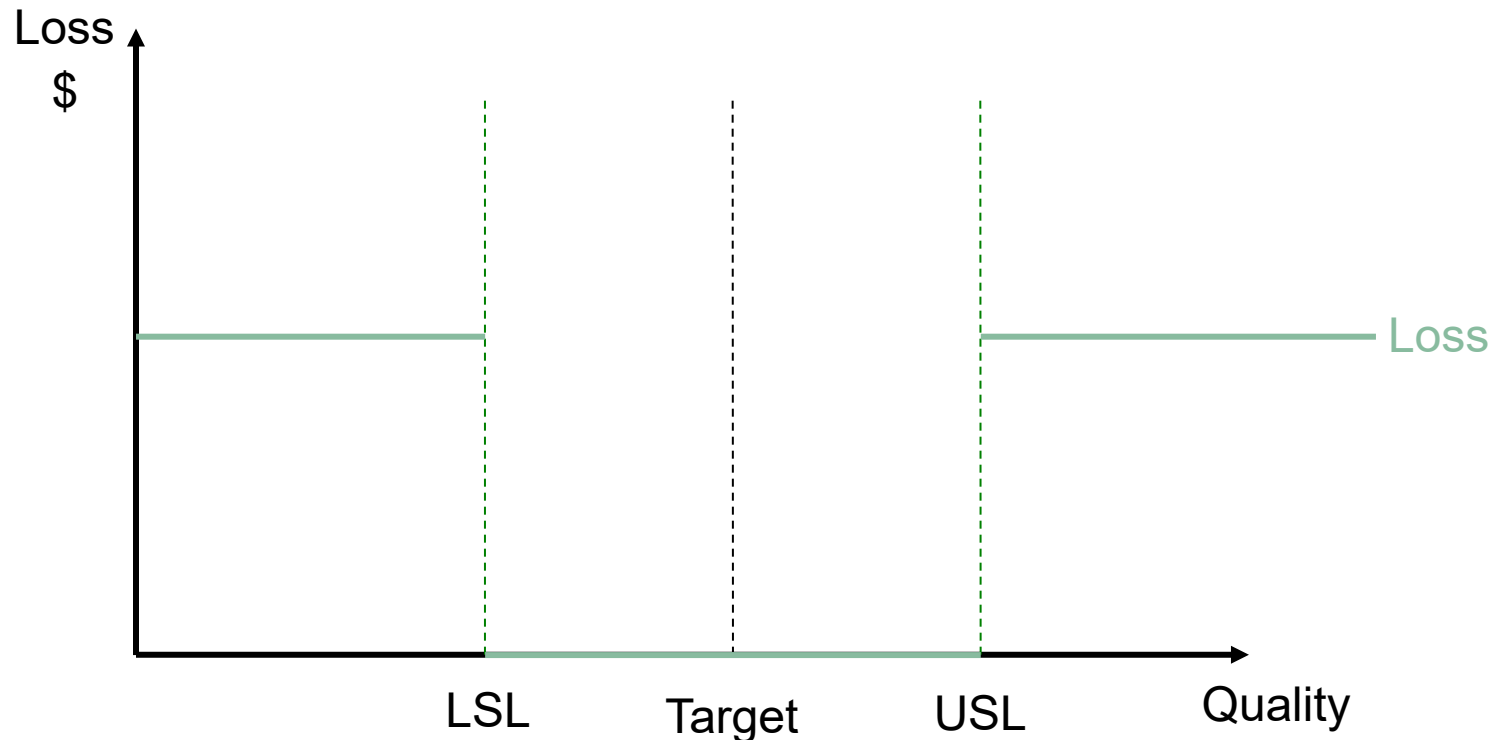
Taguchi Loss Function

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
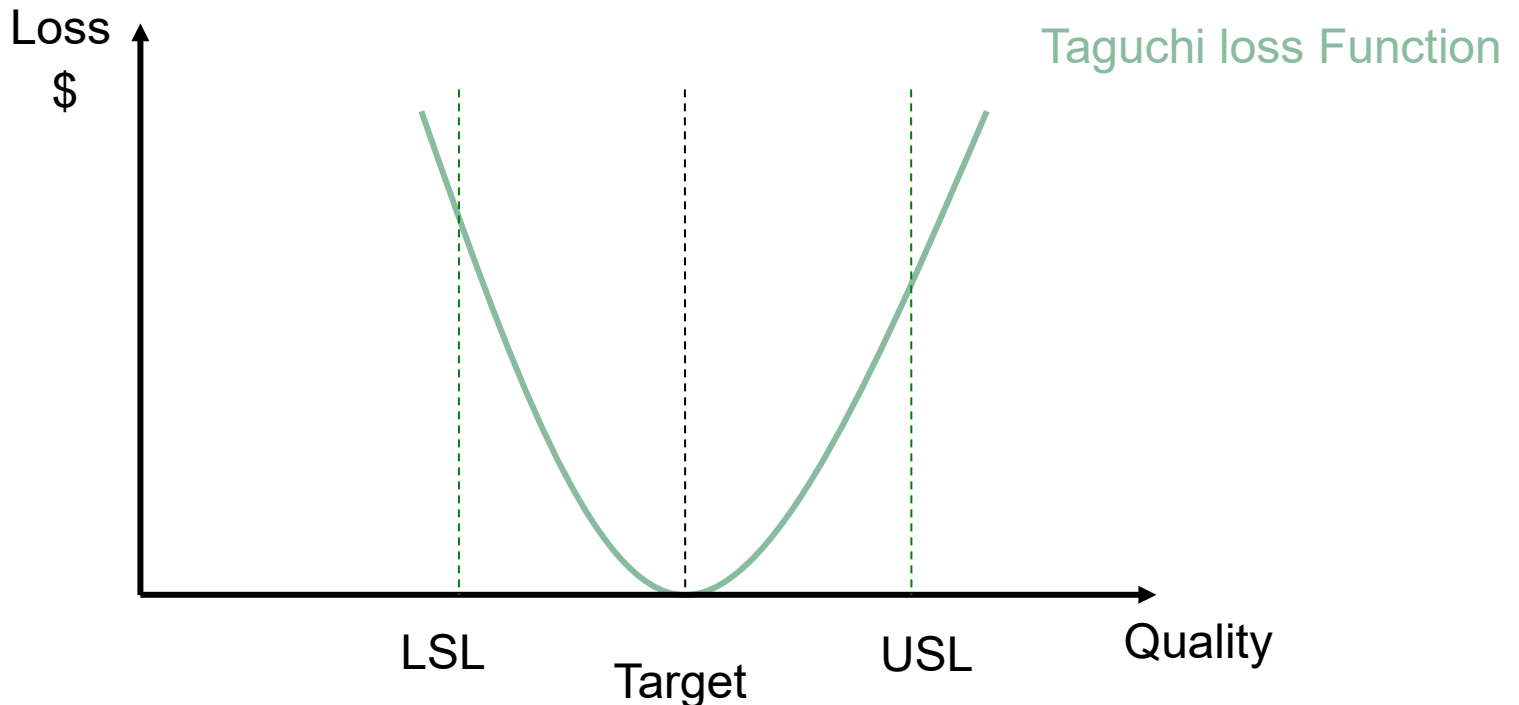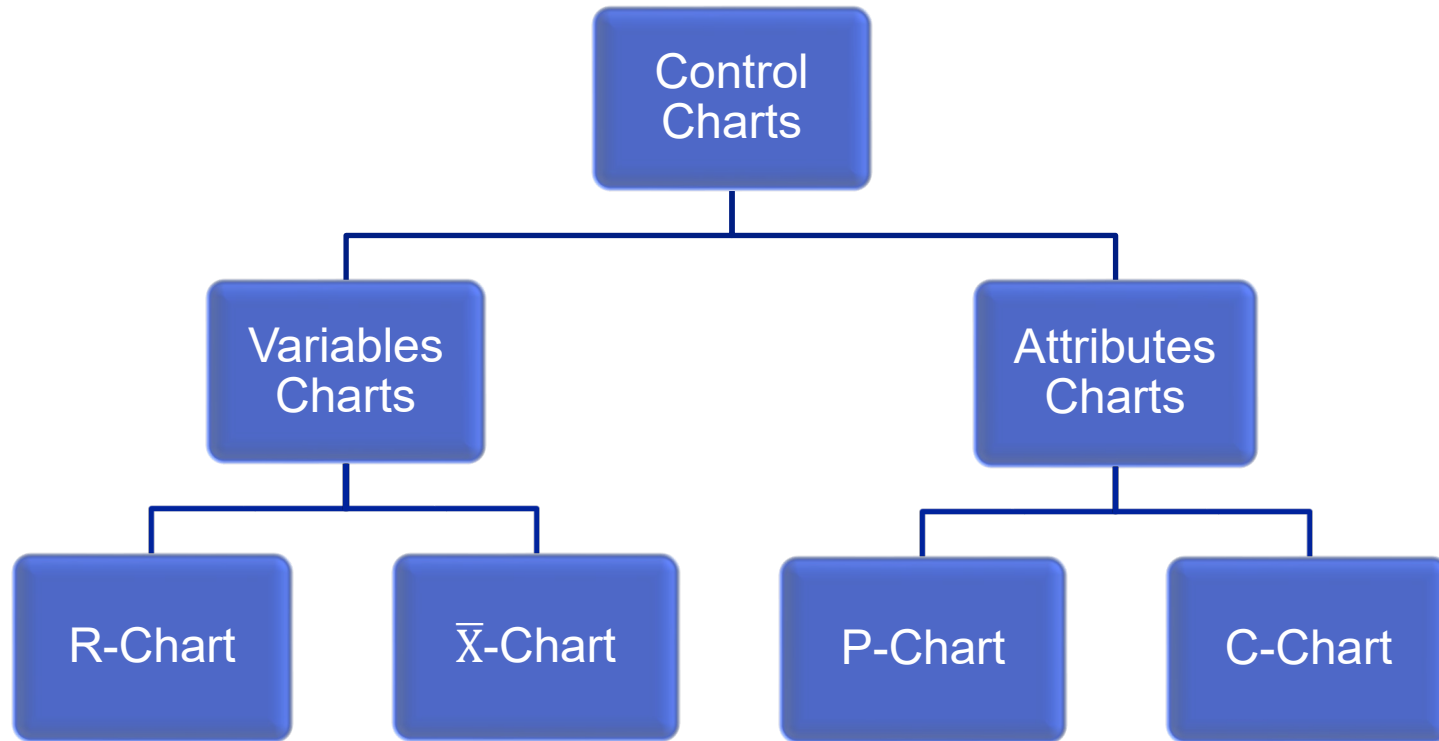
Statistical Process Control (SPC)

- 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

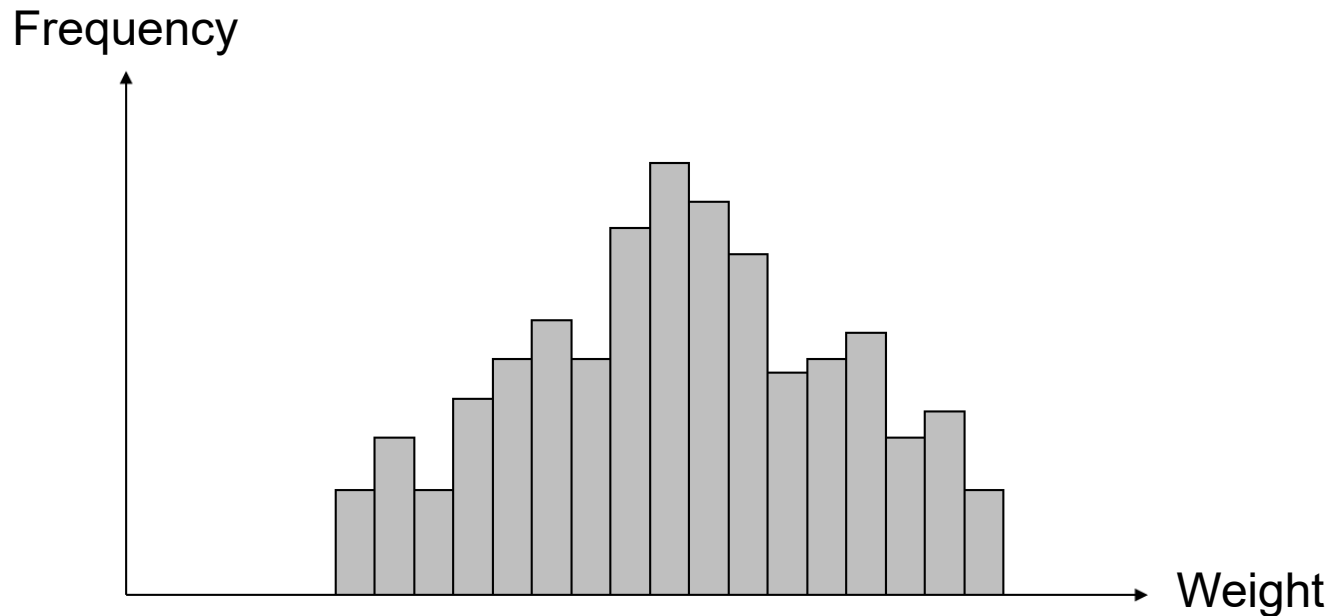 - Which quality level can be reliably achieved by the process?
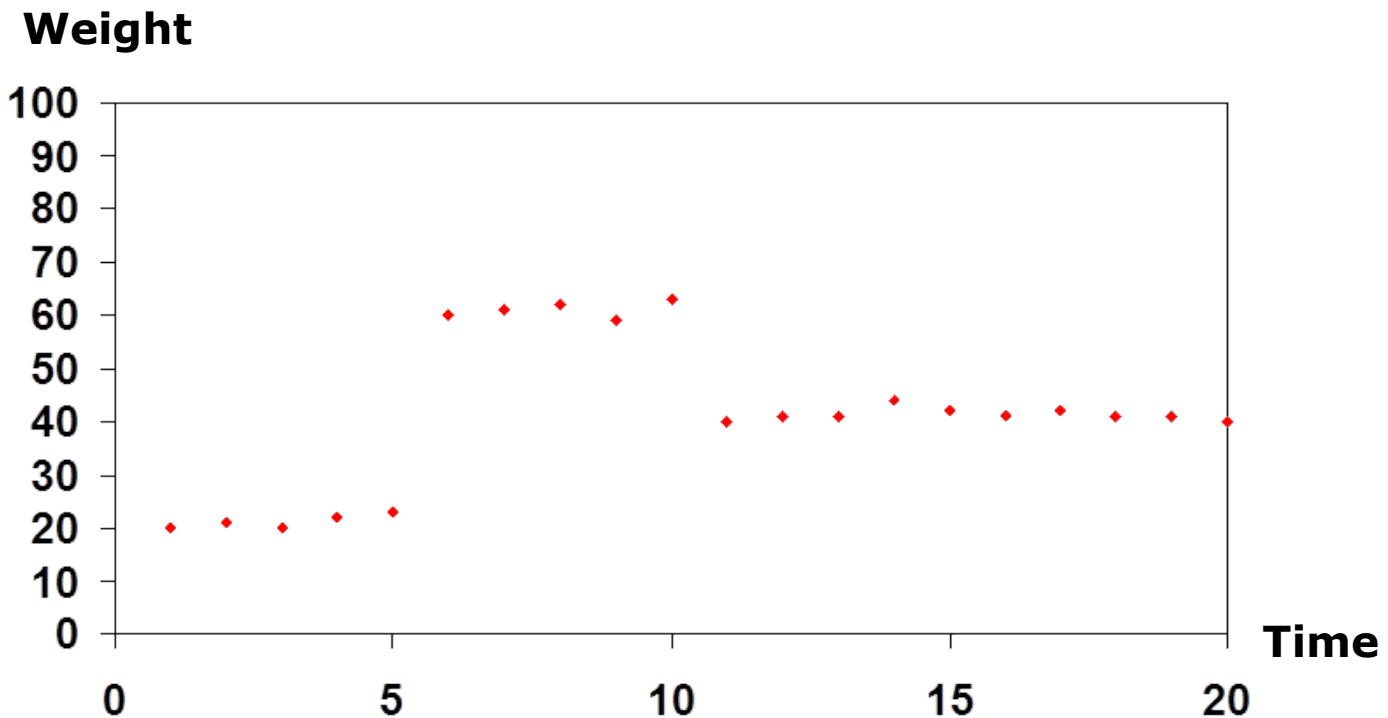
Control Charts

Why Histograms are Problematic
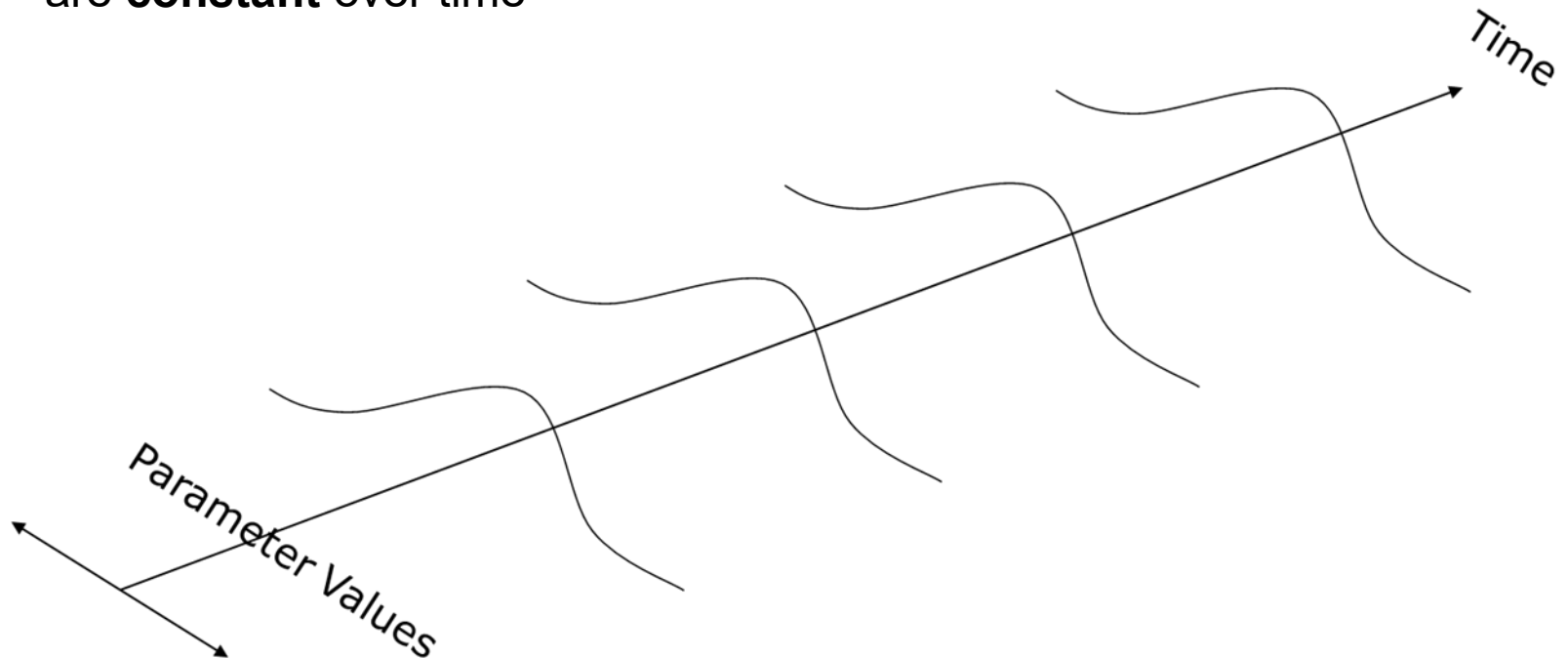

Problem: Histograms do not report variations over time

SPC Analyzes Quality Variations over Time
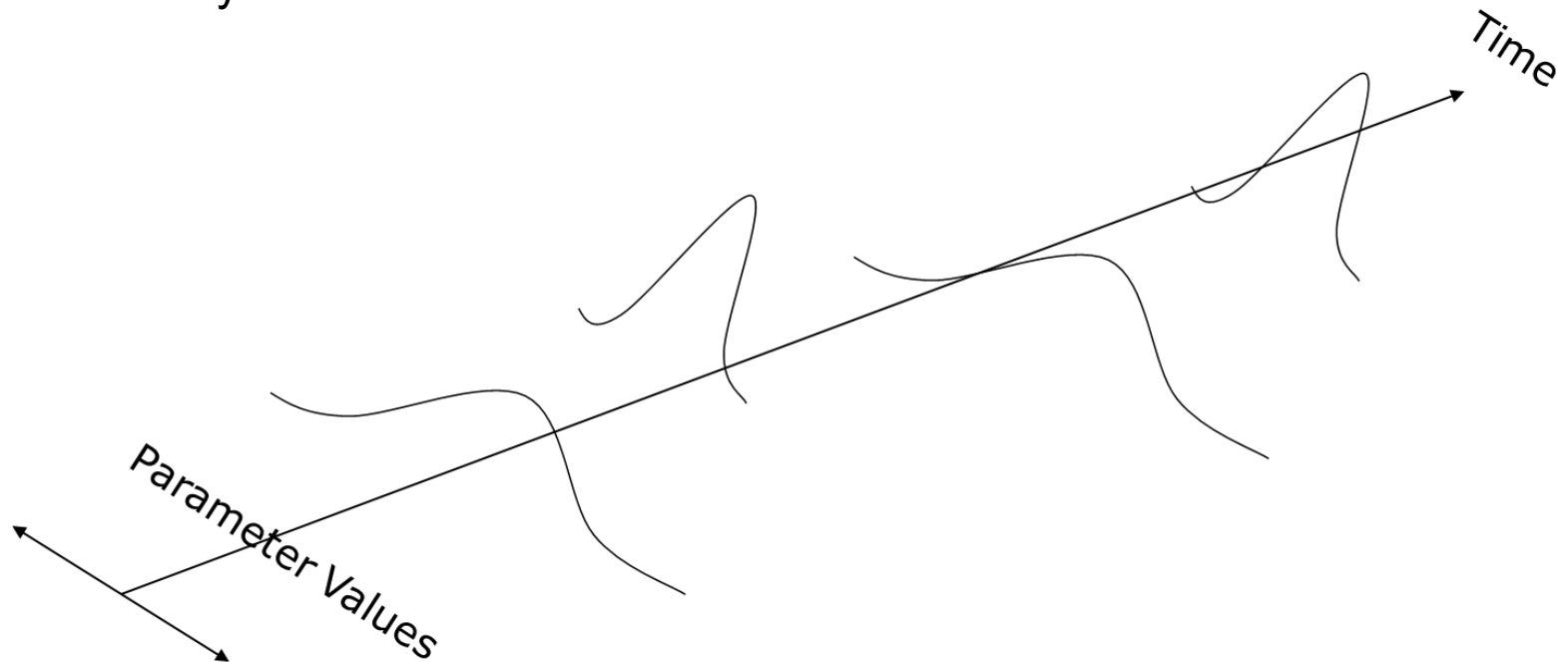
Weight

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

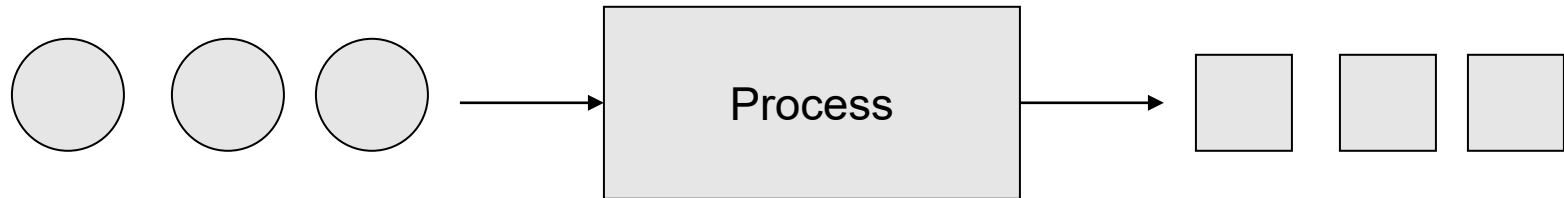Control Charts determine whether a process is statistically under control

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

μ = Mean

σ = 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

$\overline{\overline{X}}$ – Chart

- $\overline{\overline{X}} = \frac{0.47 + 0.53 + 0.58 + 0.45 + 0.65}{5} = 0.536$

- UCL $= 0.536 + 3 * \left(\frac{0.09}{\sqrt{4}}\right) = 0.536 + 0.135 = 0.671$

- LCL $= 0.536 - 0.135 = 0.401$

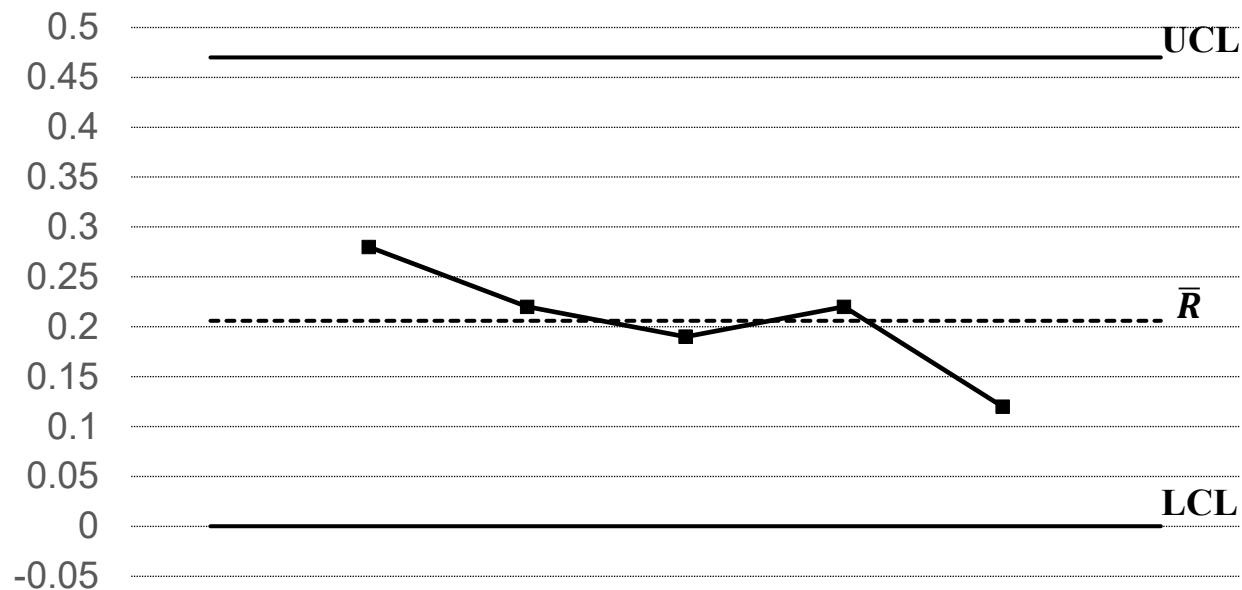→ Process is under control with respect to its means
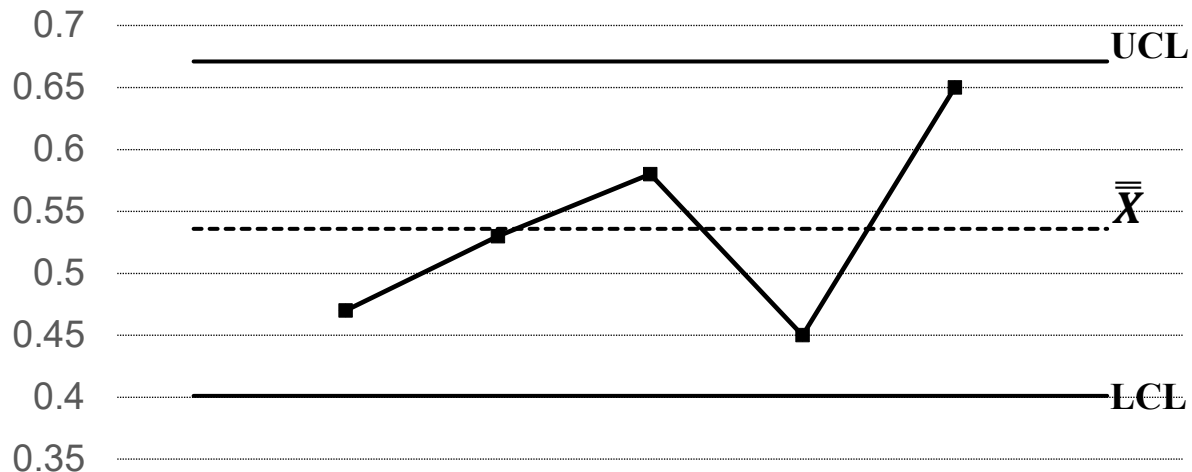
Example 1: R-Chart

R – Chart

- $\overline{\text{R}} = \dfrac{0.28+0.22+0.19+0.22+0.12}{5} = 0.206$
- 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

- $\overline{\overline{X}} = 95.398$

- $\overline{R} = 0.665$

- UCL ($\overline{X}$ – Chart) $= 95.398 + 0.31 * 0.665 = 95.60$

- LCL ($\overline{X}$ – Chart) $= 95.398 - 0.31 * 0.665 = 95.19$

- UCL (R – Chart) $= 1.78 * 0.665 = 1.18$
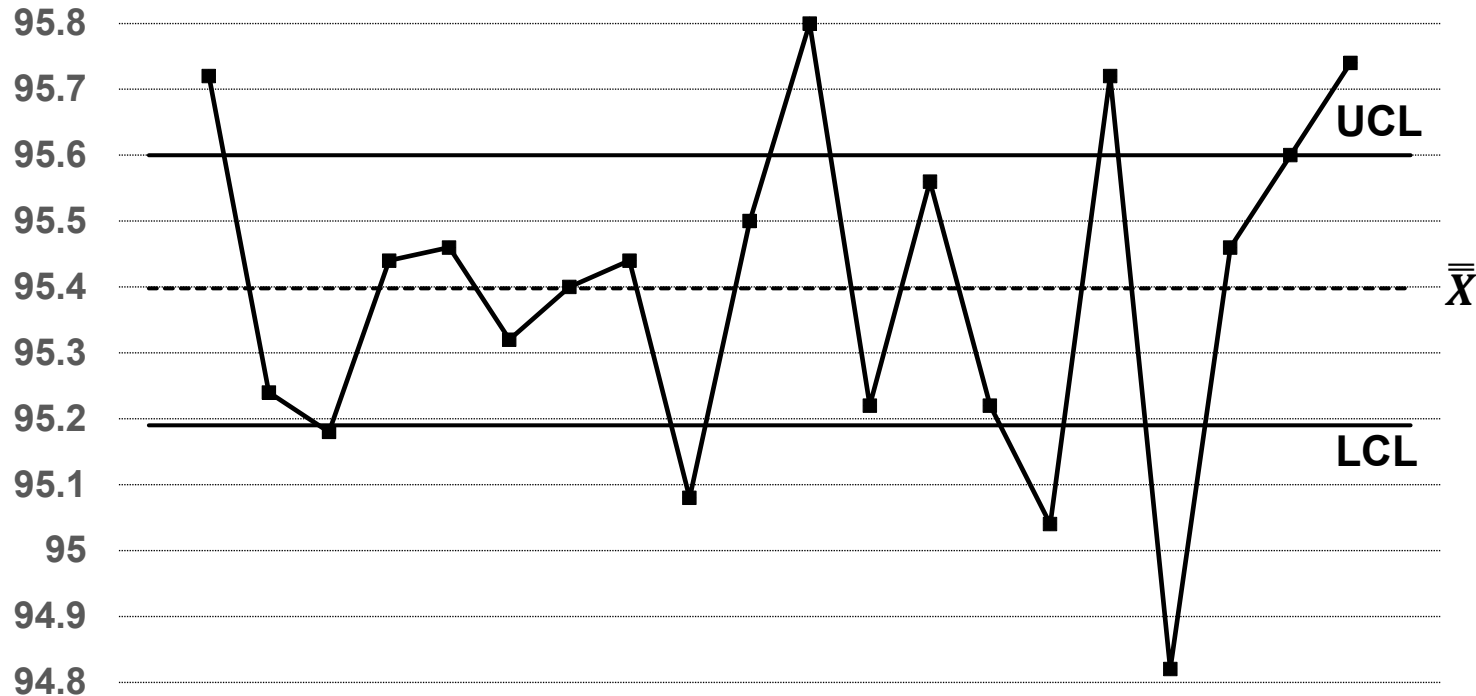
- LCL (R – Chart) $= 0.22 * 0.665 = 0.15$

Department of Business Administration

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
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 mean

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

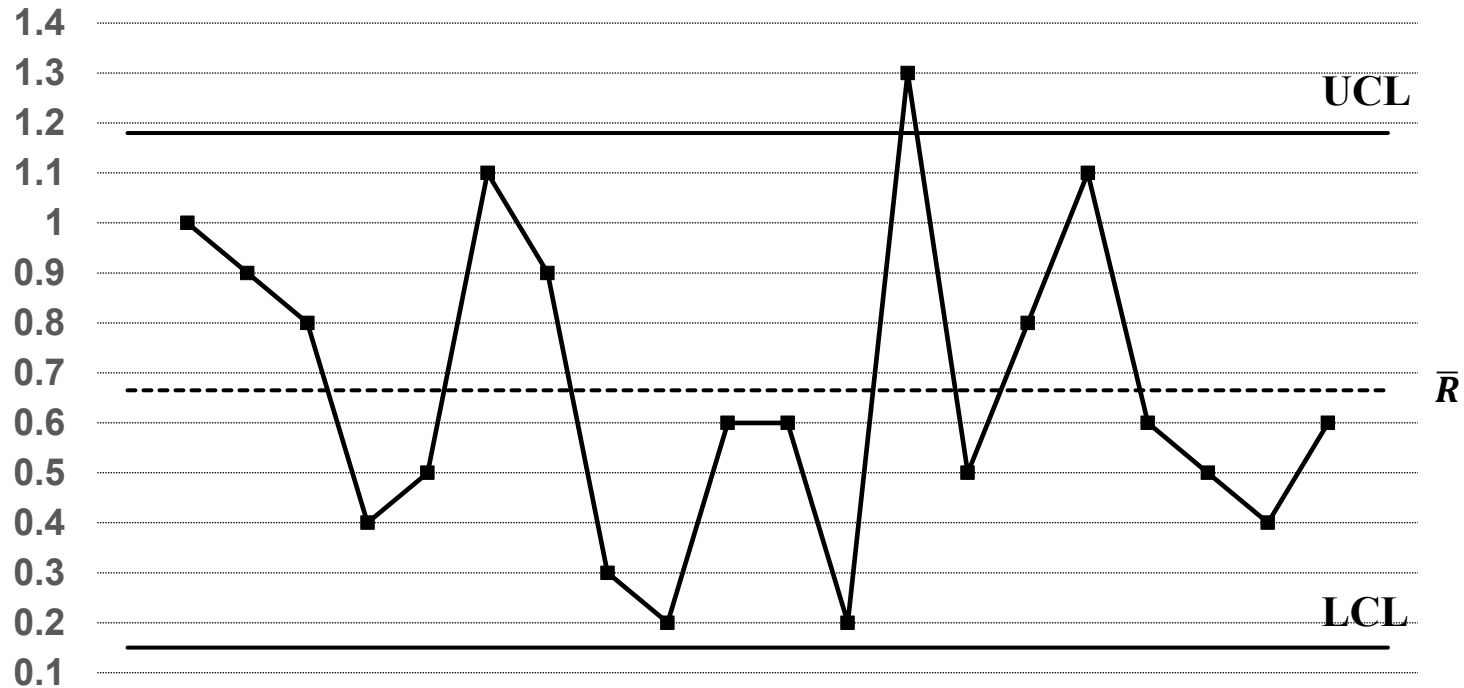→   Process is not under control with respect to its mean

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	$\overline{X}$	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

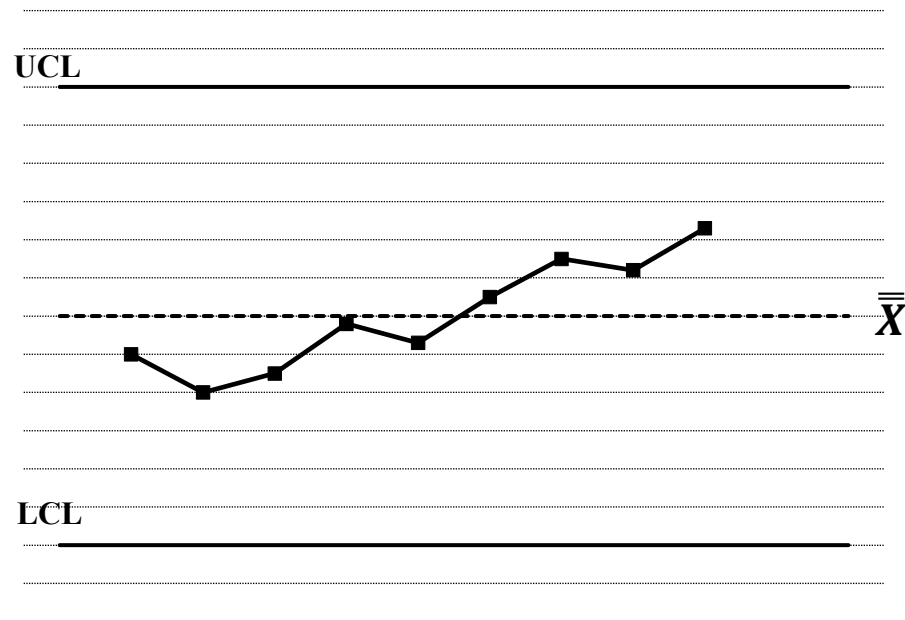# Example 3: $\overline{X}$-Chart
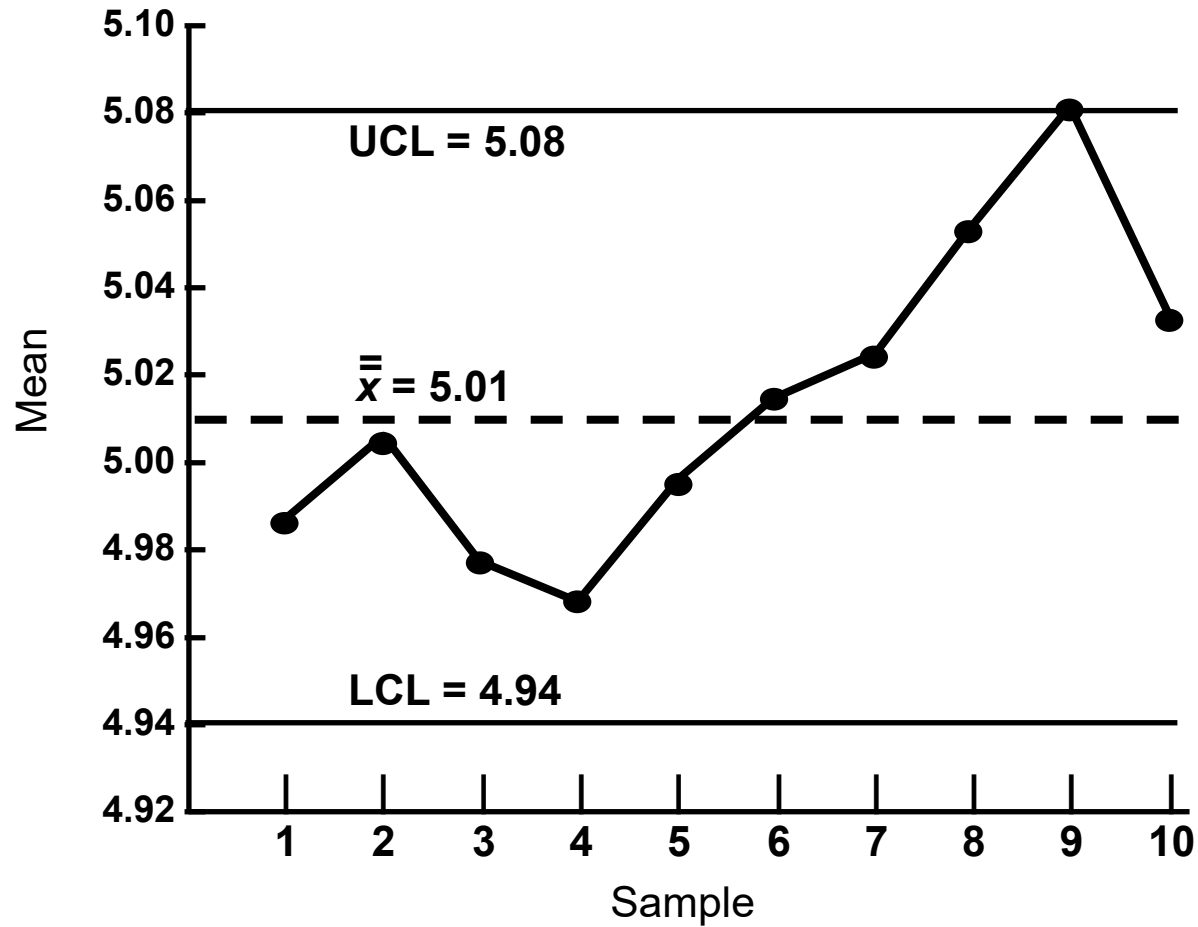
Example: R-Chart
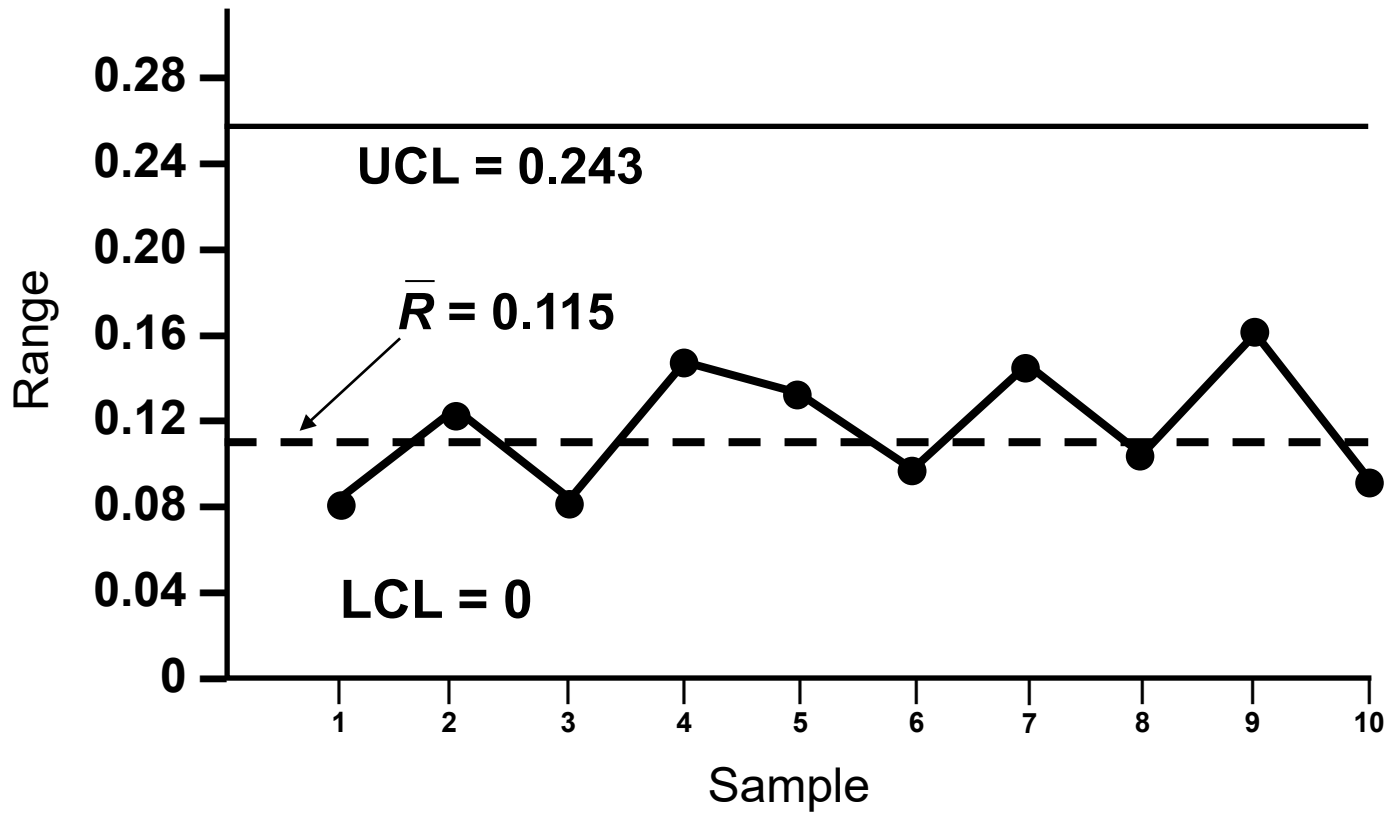
Analyzing Control Charts: Process 1
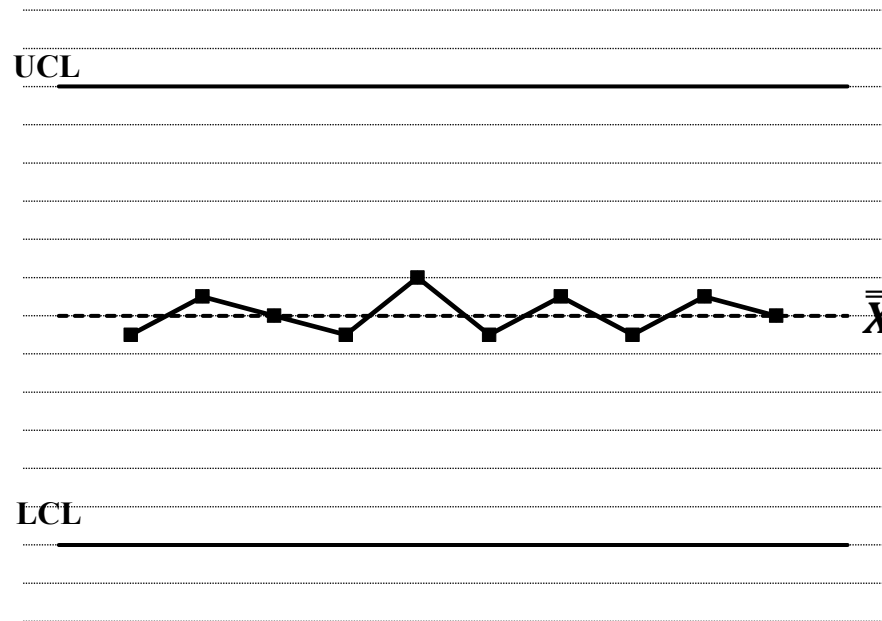
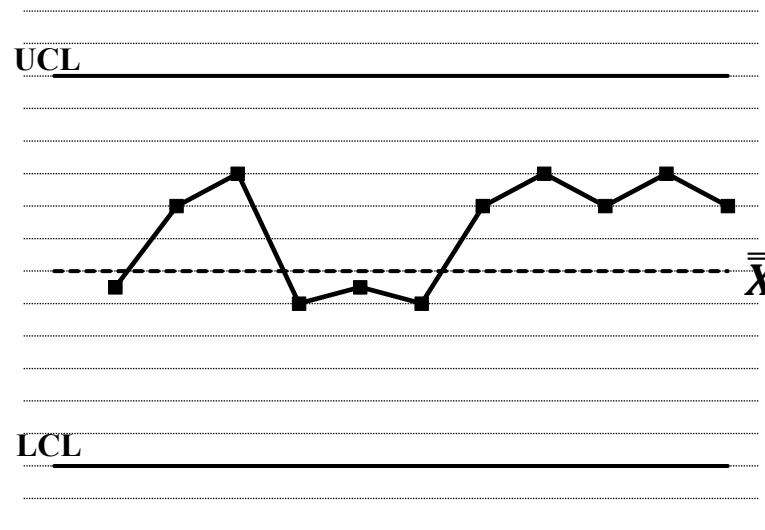Process 1 is an ideal process

Analyzing Control Charts: Process 2

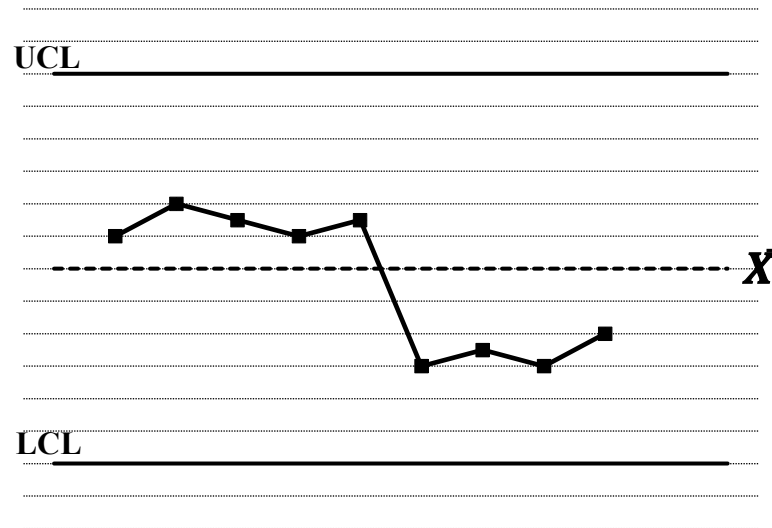Process 2 is under control, but problematic because
of an (upward) trend

Analyzing Control Charts: Process 3

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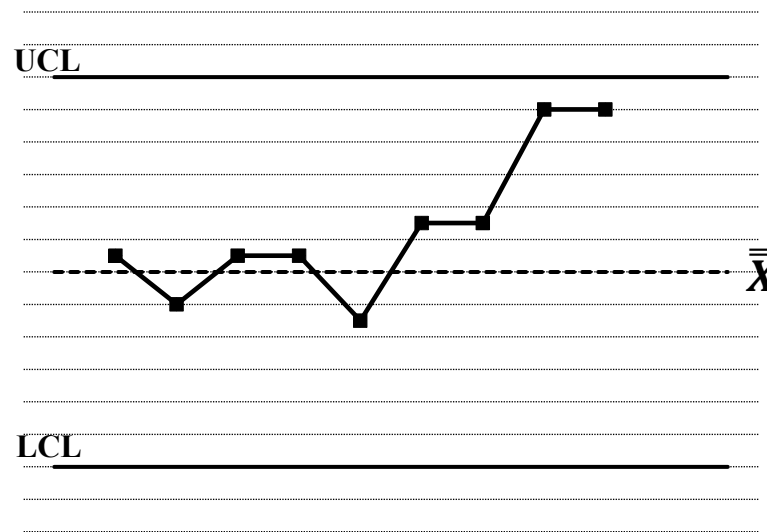of 5 subsequent observations above $\bar{\bar{X}}$

Analyzing Control Charts: Process 4

Process 4 is under control, but problematic because of a sudden shift
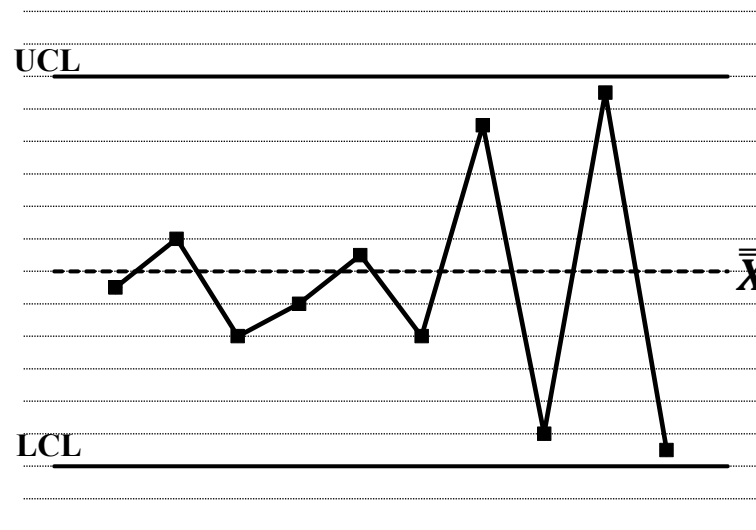
Analyzing Control Charts: Process 5

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:

$$\bar{p} = \frac{Number\ of\ Guests\ with\ Complaints}{Total\ Number\ of\ Guests} \qquad n_j = size\ of\ sample\ j$$

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

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

Calculation of upper and lower control limits:

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

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

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

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

=> 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	$\bar{p} = 91/925 = 0.1$		

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)
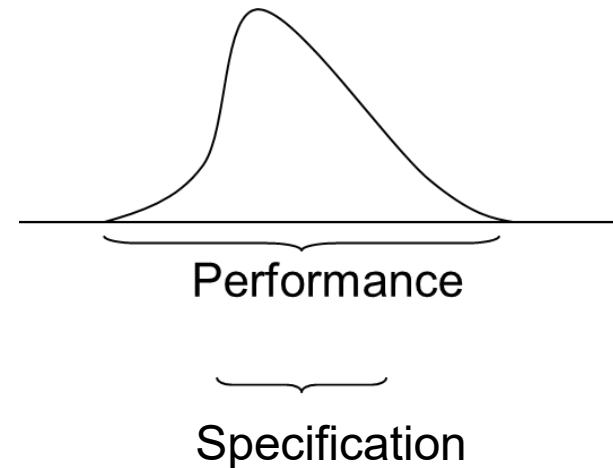
Performance Limits versus Specification Limits (1/2)
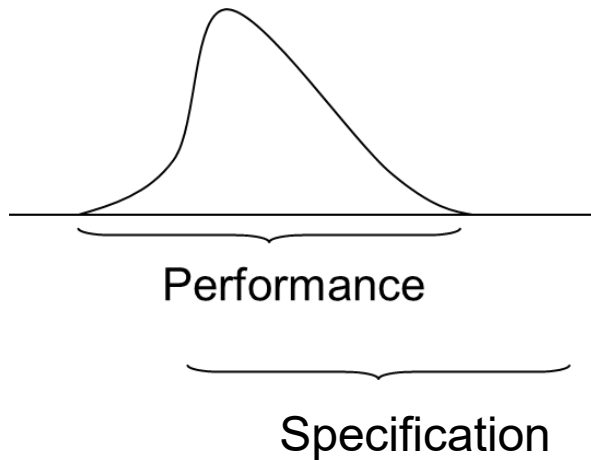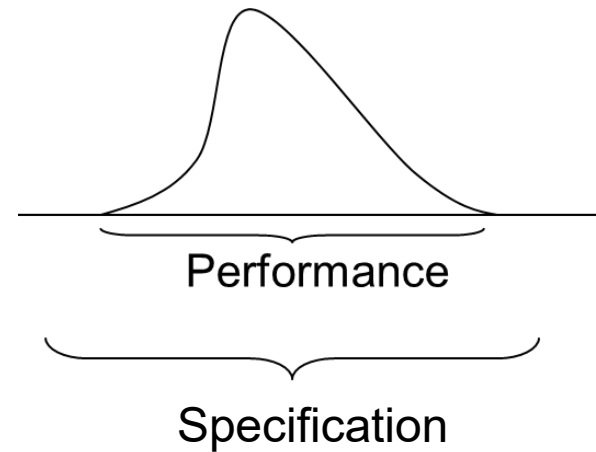
Undesirable situation: **Extremely undesirable situation:**

Performance Limits versus Specification Limits (2/2)

Vulnerable situation: **Highly desirable situation:**
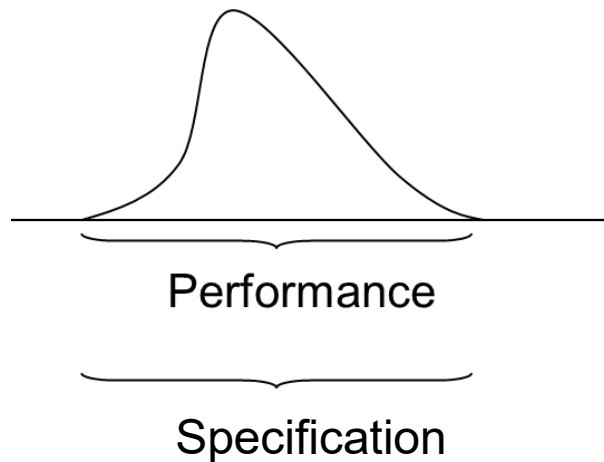
Capability Index (for symmetric processes)

Assumption: Process mean is centered between specification limits

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

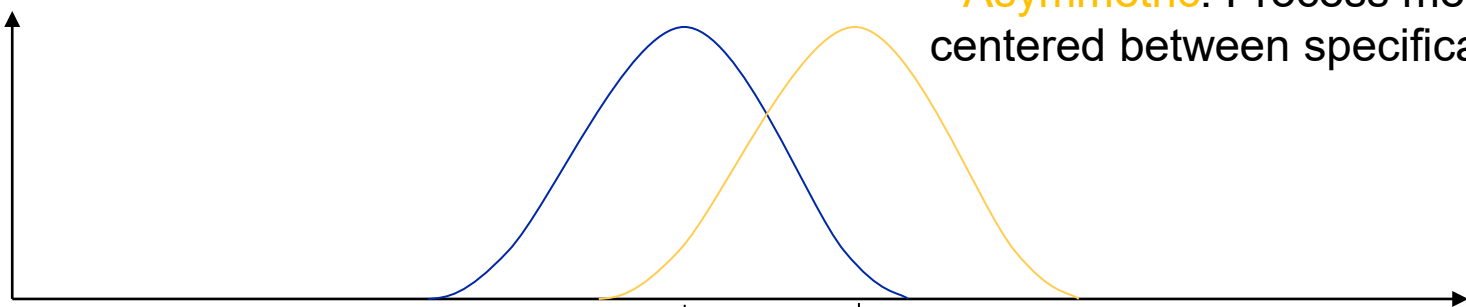Process is capable if $C_P \geq 1$

Recommended minimum $C_P = 1.33$

Six Sigma Quality process: $C_P = 2$

Symmetric vs. Asymmetric Processes

Symmetric: Process mean is
centered between specification limits

Asymmetric: Process mean is not
centered between specification limits

Special Case: Capability Index for Asymmetric Processes

If process mean is not centered between specification limits:

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

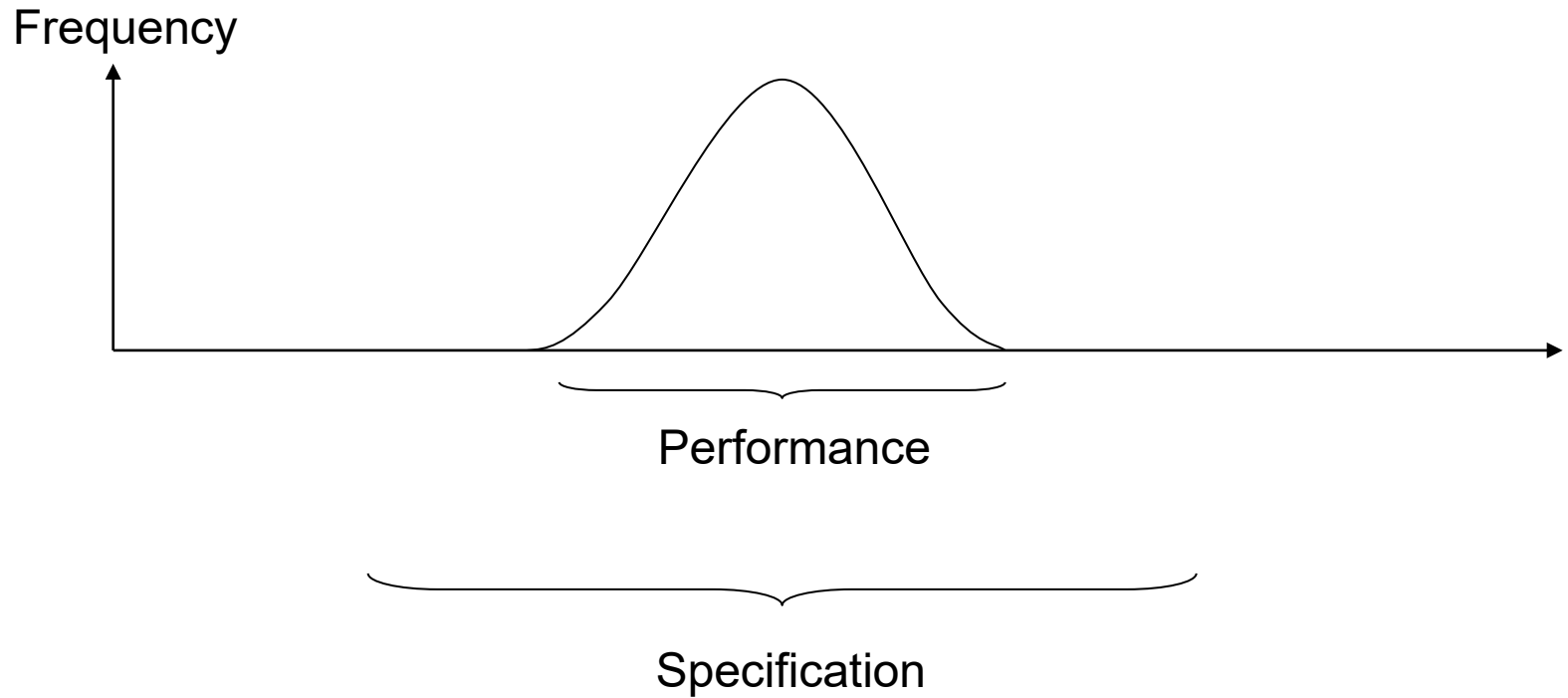C_{pk} Capability Index for asymmetric Processes

USL upper specification limit

LSL lower specification limit

μ mean of the process (center between *UCL* and *LCL*)
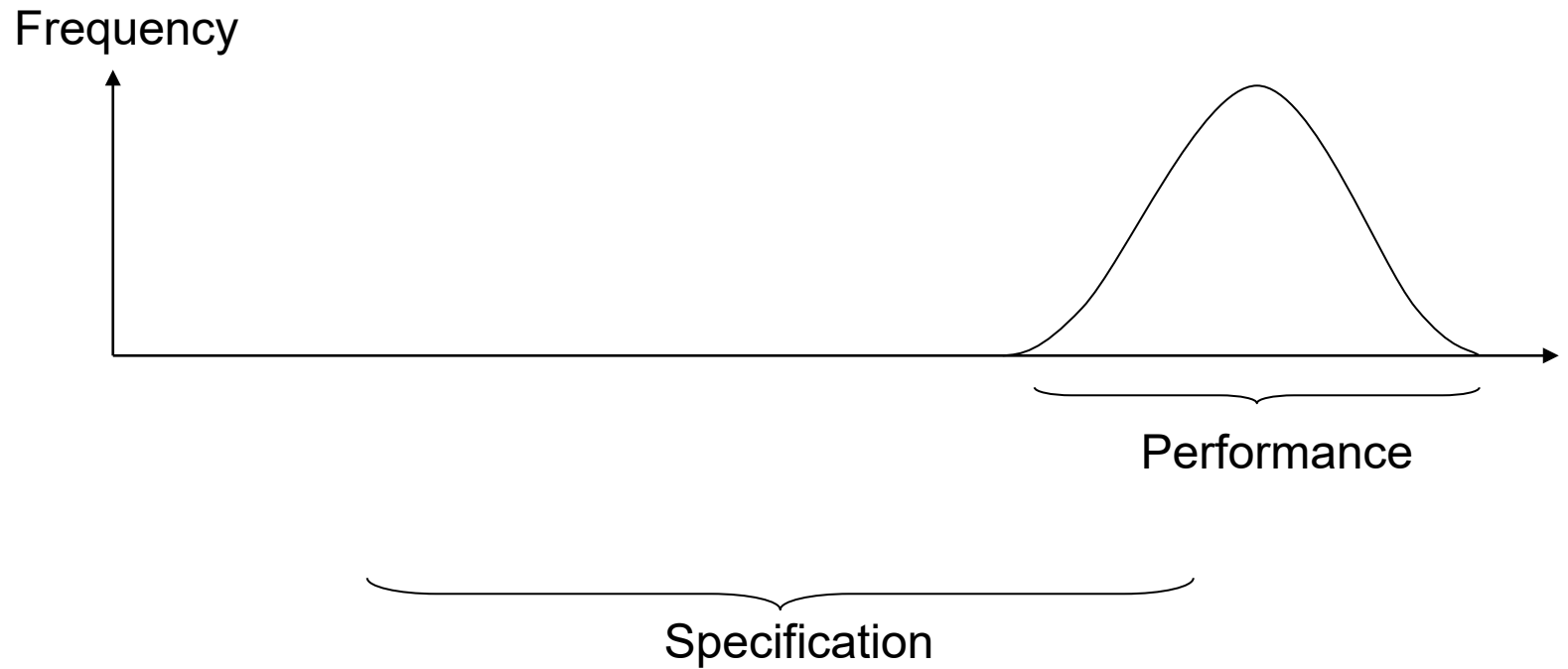
σ standard deviation of the process

Ideal Situation: CP>1

Bad, But Solvable: CP>1

Not Solvable: CP<<1

Frequency

Performance

Specification