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

After this lecture you should

- be able to calculate upper and lower control limits
- know whether a process is under control or not
- be able to bring a process under control
- be able to calculate performance limits
- be able to use the SPC method in real time
- know the cost effects of decisions in quality management

Process Control

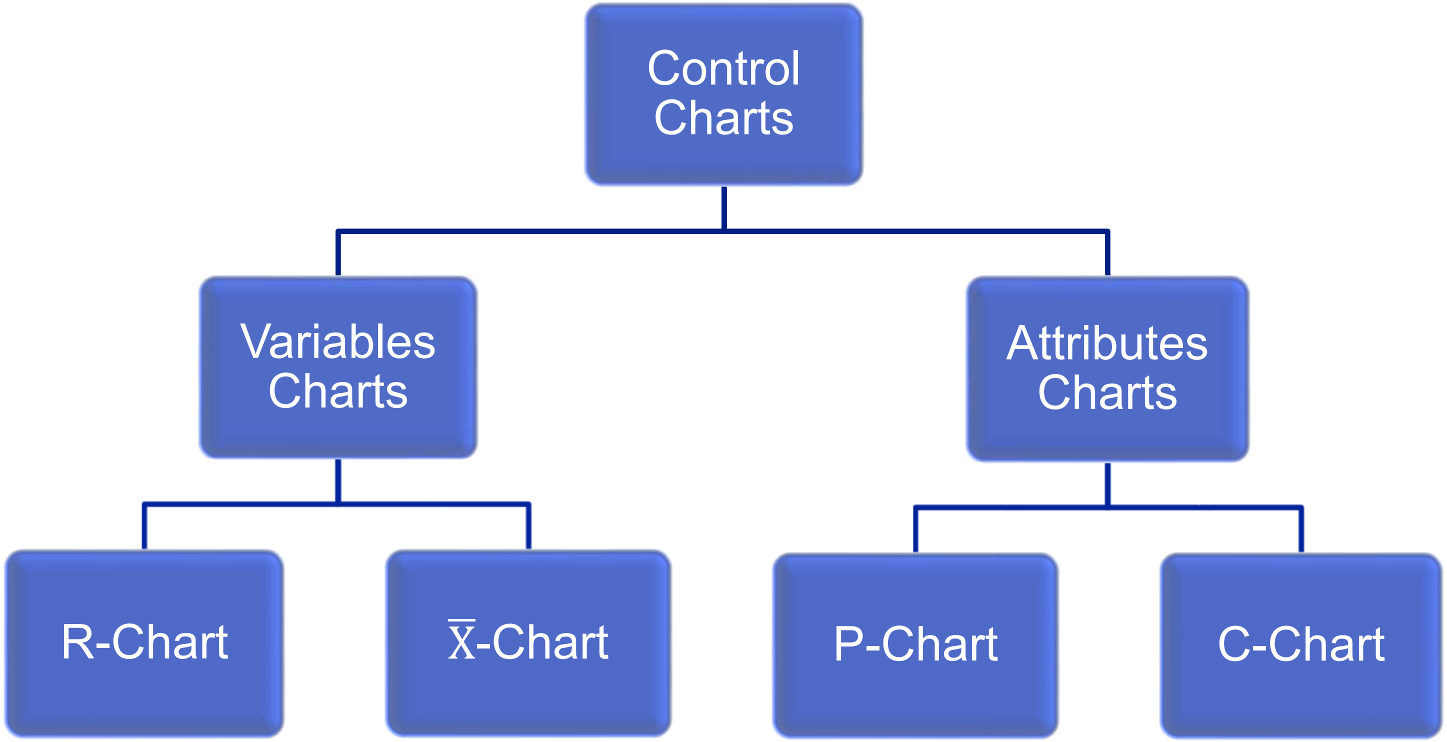
- Basic idea: Control the process that creates the quality
- SPC (statistical process control)
- Management and control of the quality dimensions (not just "good" vs. "bad" output)
  - How does the data change over time?
  - If a product / service is defective, how far are the values from the AQL (acceptable quality level)?

Statistical Process Control (SPC)

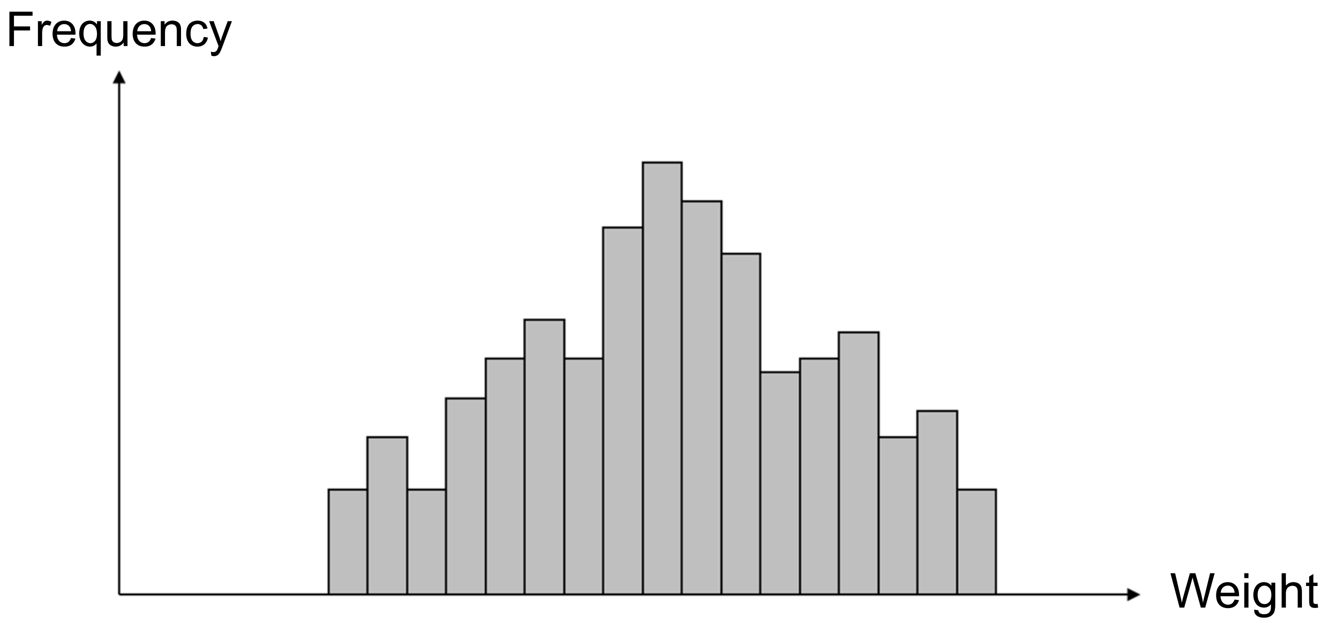
- SPC identifies the causes for process variations
  - General causes (lead to random variations)
    - affect the entire output
    - are process-immanent
    - avoidance requires new process design
  - Special causes (lead to systematic variations)
    - affect only part of the output
    - are based 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

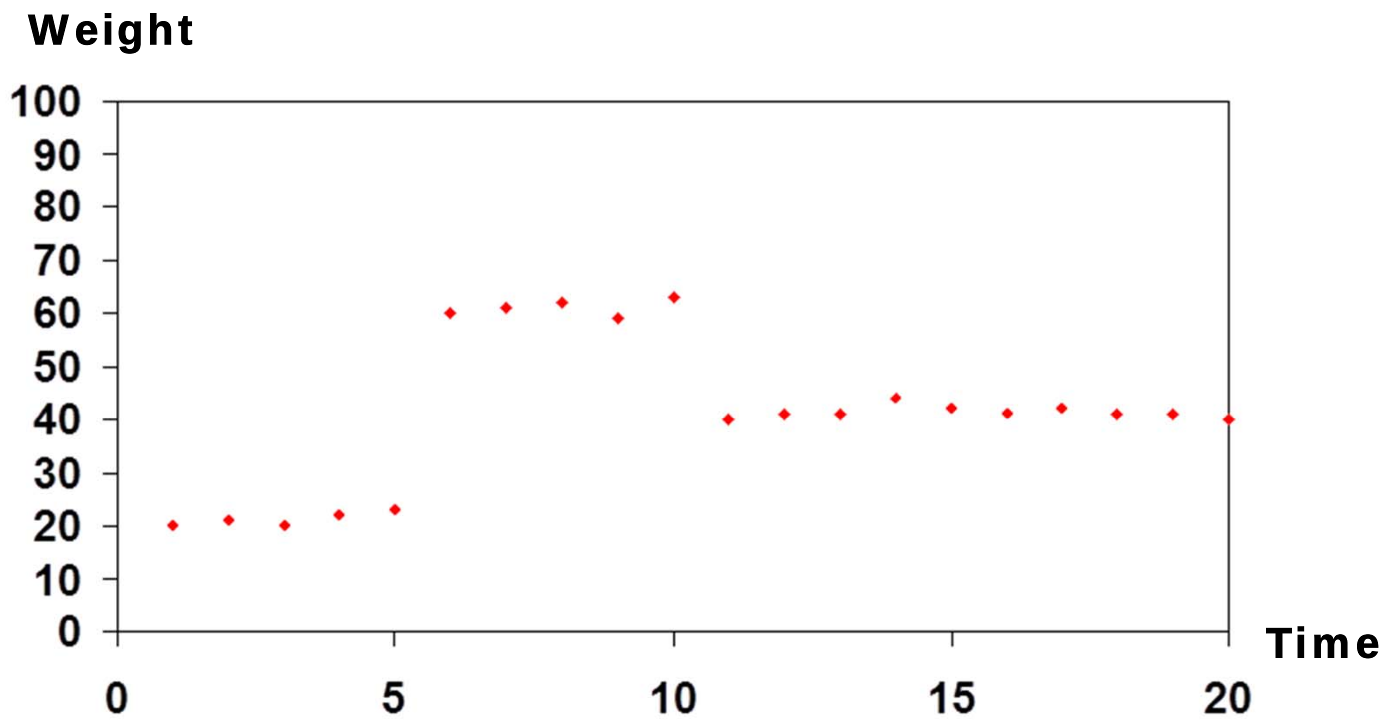


Why Histograms are Problematic



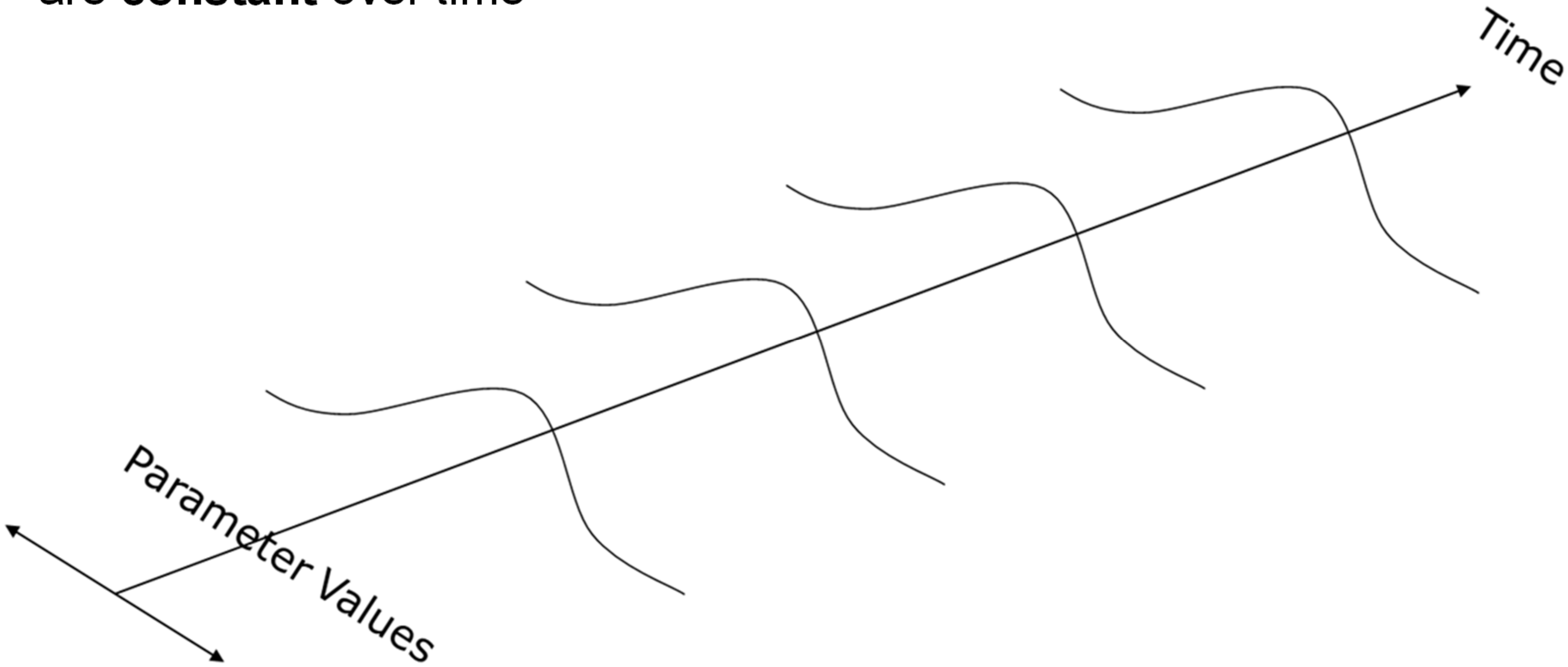
Problem: Histograms do not report variations over time

SPC Analyzes Quality Variations over Time



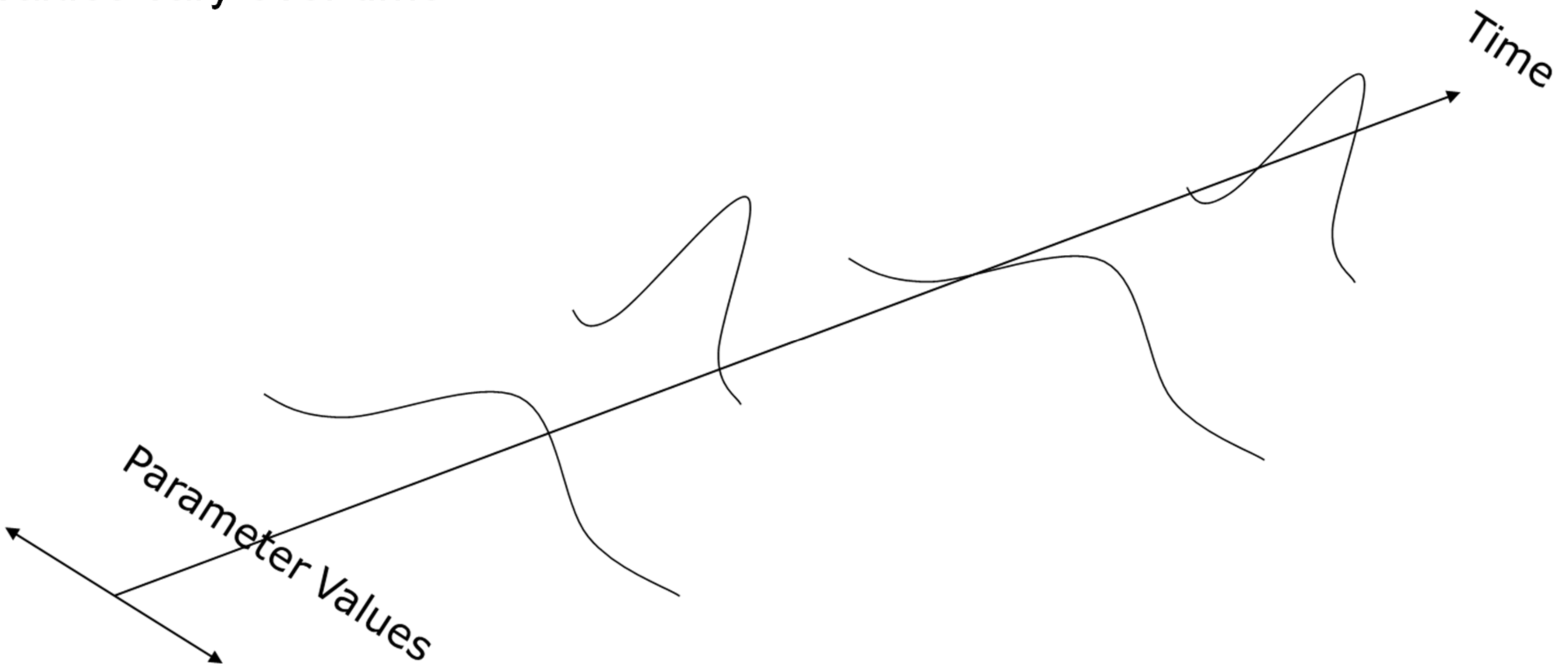
The Concept of SPC (1/2)

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

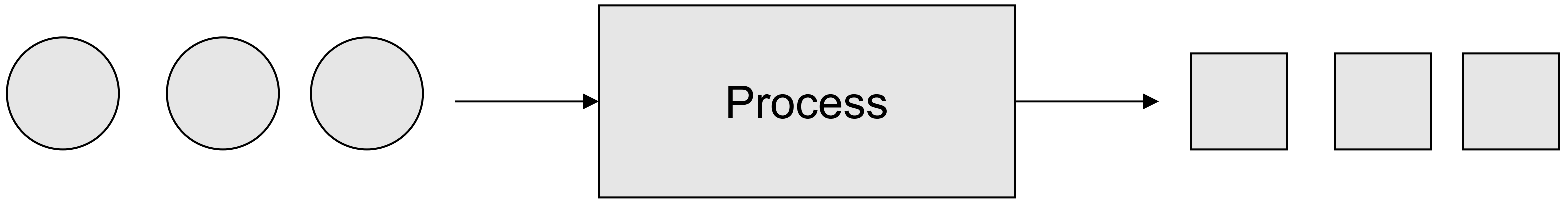
and

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

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: $\bar{X}$ – Chart and R – Chart

$\bar{X}$ – Chart

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

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

R – Chart

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

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

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

Quelle: 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?

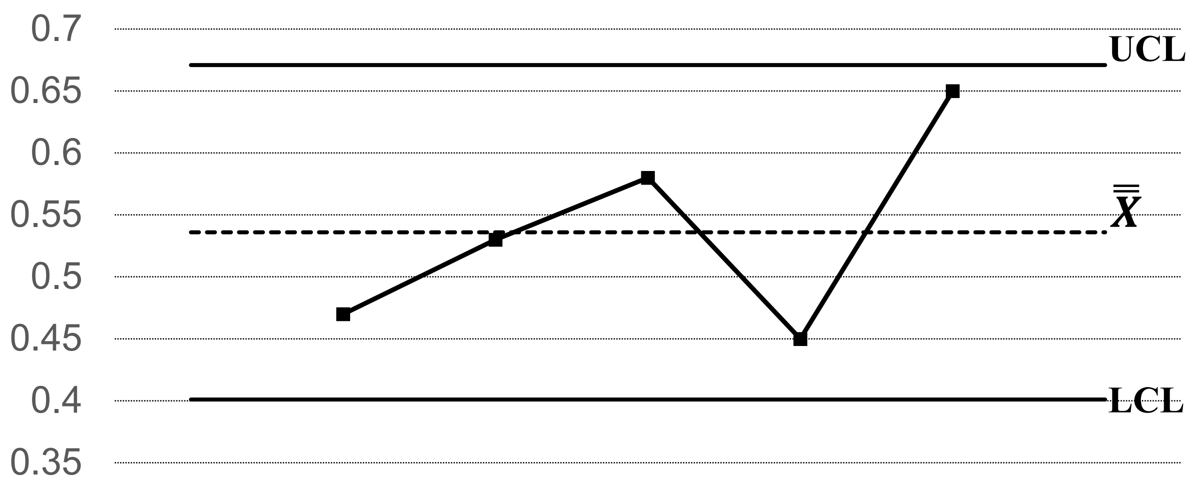
Sample	Observations				Mean	Range
	1	2	3	4		
1	0.51	0.63	0.39	0.35	0.47	0.28
2	0.50	0.56	0.42	0.64	0.53	0.22
3	0.68	0.49	0.53	0.62	0.58	0.19
4	0.45	0.33	0.47	0.55	0.45	0.22
5	0.70	0.58	0.64	0.68	0.65	0.12

Example 1: $\bar{X}$ – Chart

$\bar{X}$ – Chart

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

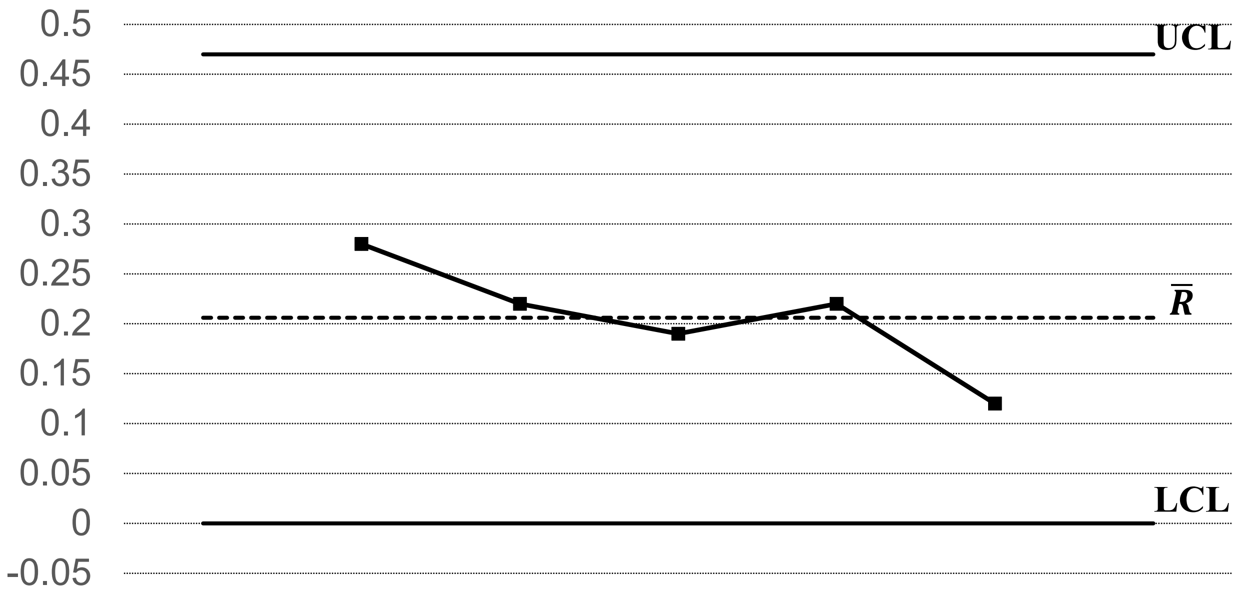


Example 1: R-Chart

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
4	95.44	0.4	14	95.22	0.5
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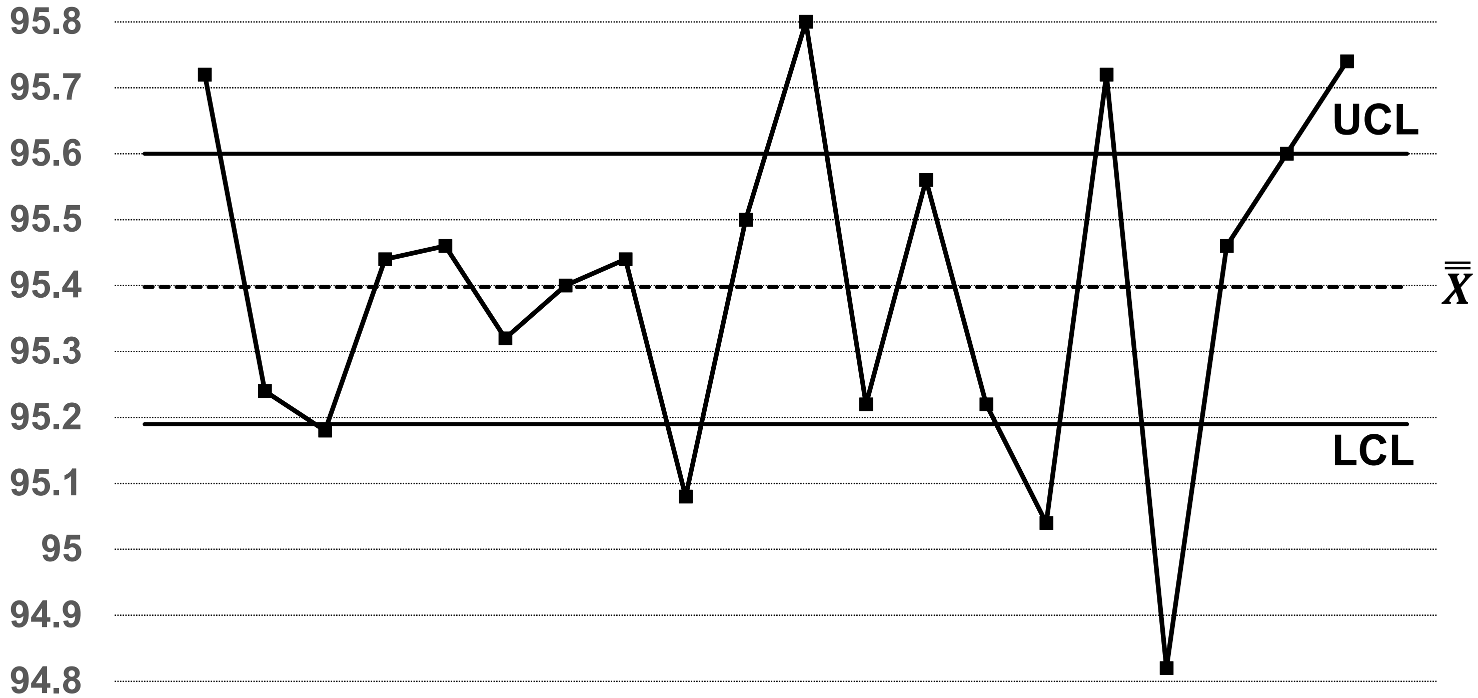
9	95.08	0.2	19	95.60	0.4
10	95.50	0.6	20	95.74	0.6

→ Process is not under control with respect to its mean

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



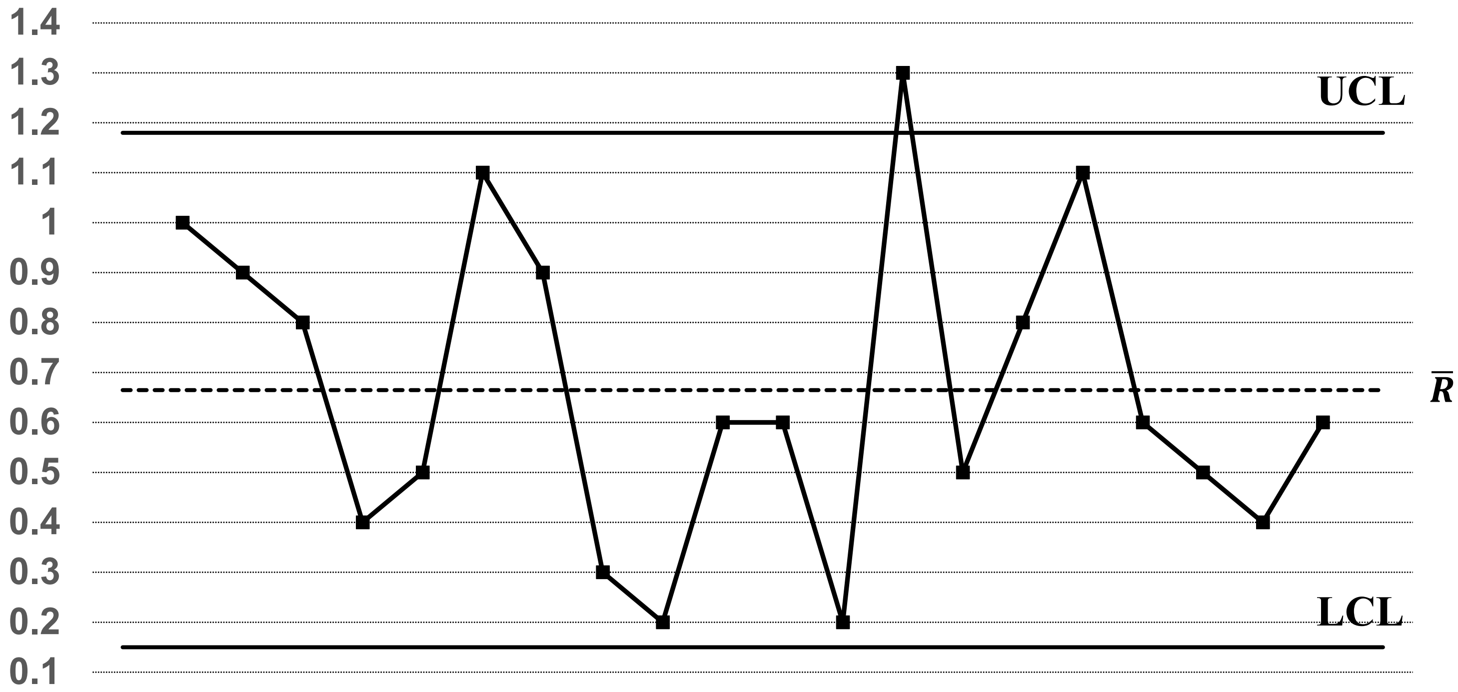
→ Process is not under control with respect to its mean

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

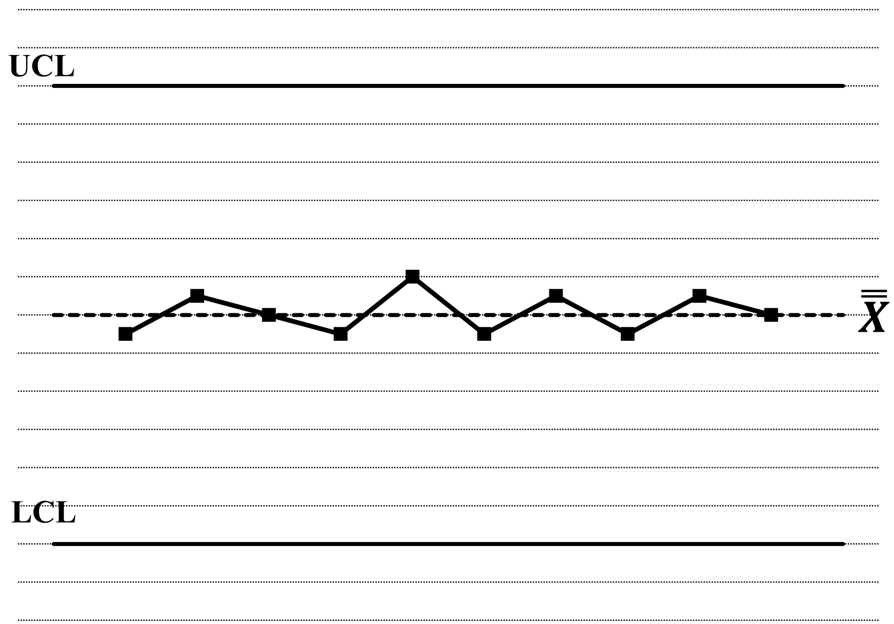
→ Process is not under control with respect to its range

Example 2: R-Chart



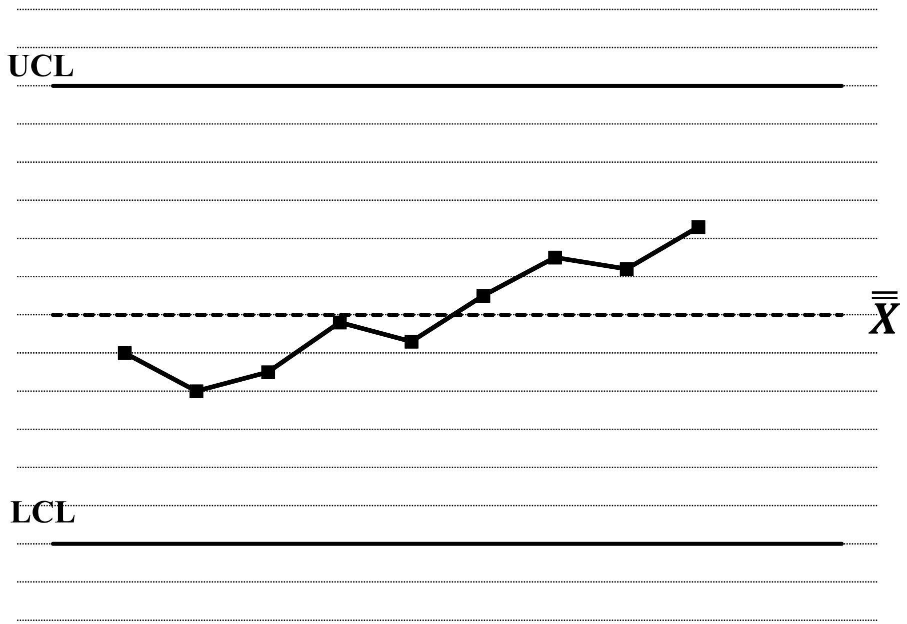
→ Process is not under control with respect to its range

Analyzing Control Charts: Process 1



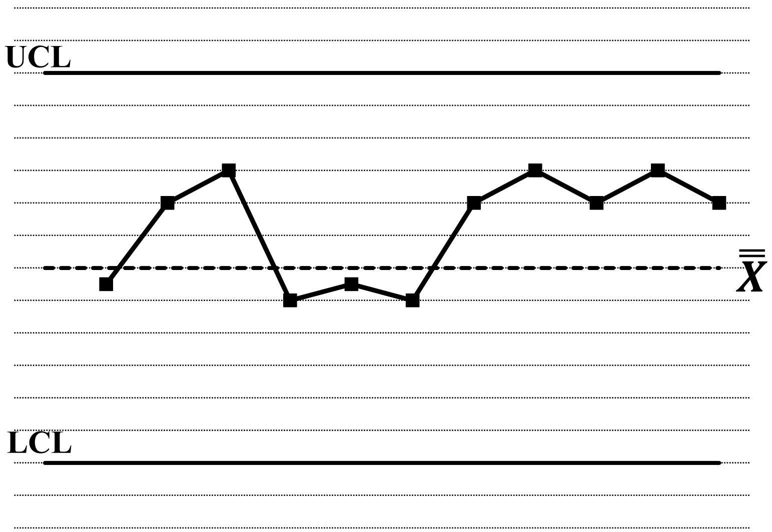
Process 1 is an ideal process

Analyzing Control Charts: Process 2



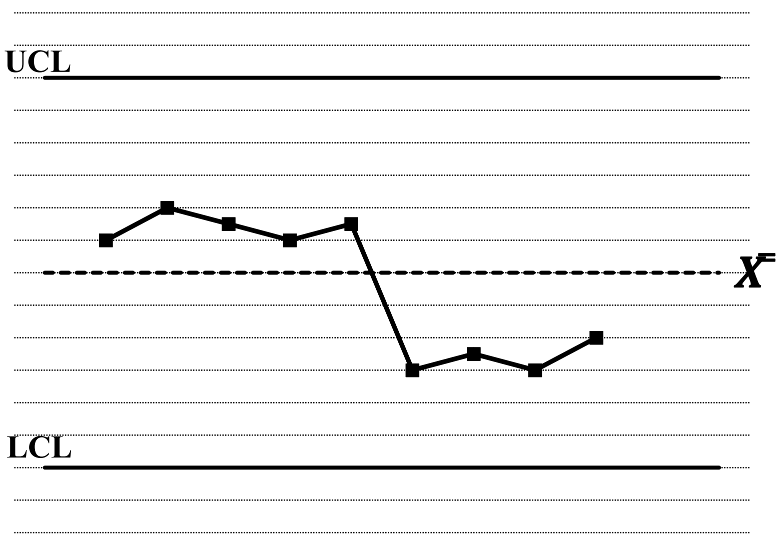
Process 2 is under control, but problematic because of an (upward) trend

Analyzing Control Charts: Process 3



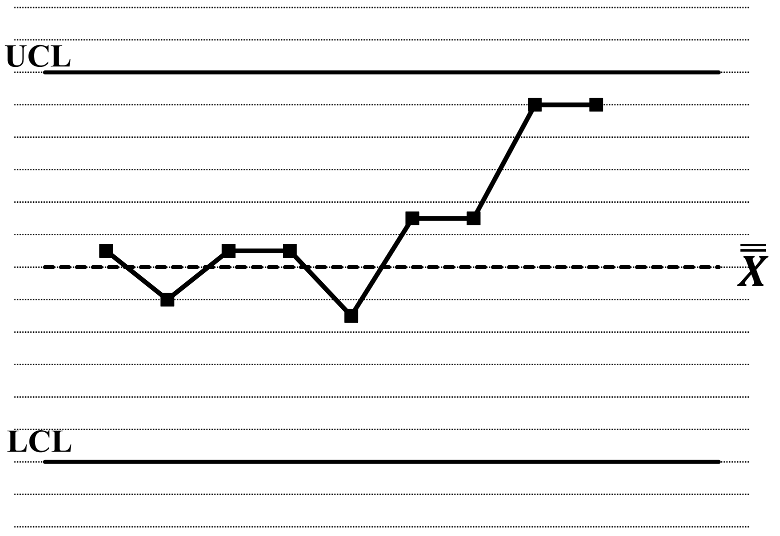
Process 3 is under control, but problematic because of 5 subsequent observations above $\bar{\bar{X}}$

Analyzing Control Charts: Process 4



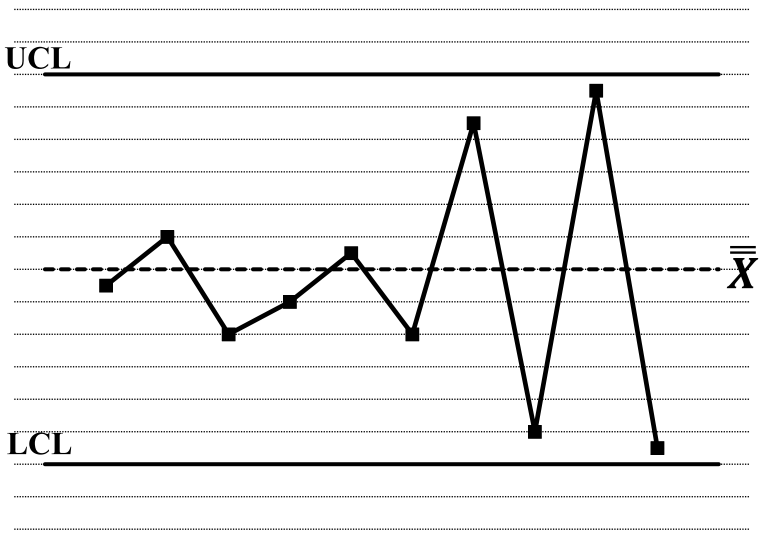
Process 4 is under control, but problematic because of a sudden shift

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

Performance Limits

Control limits

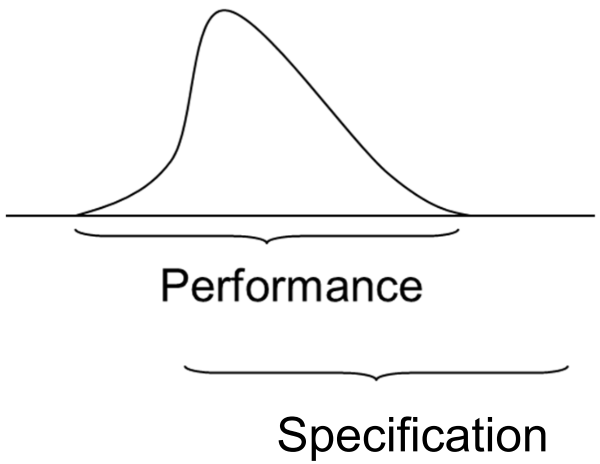
- are based on actual output data
- help to distinguish special from general (process immanent) causes of quality variations

Performance limits

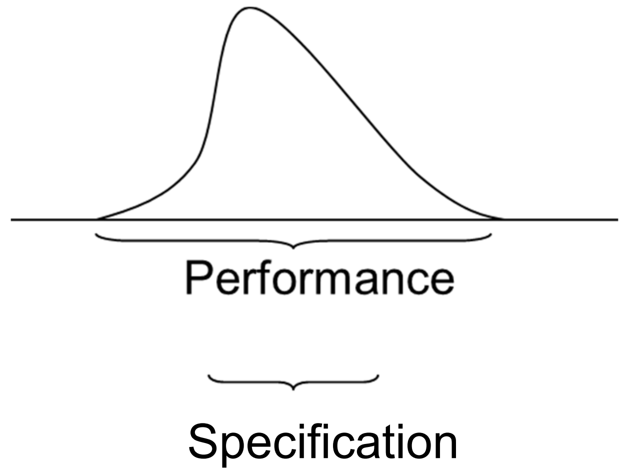
- predict future process performance
- are calculated for processes which are under control
- make no sense for processes which are not under control

Performance Limits versus Specification Limits (1/2)

Undesirable situation:

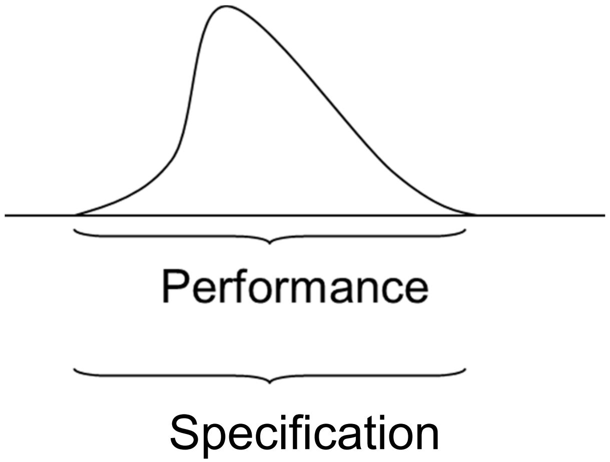


Extremely undesirable situation:

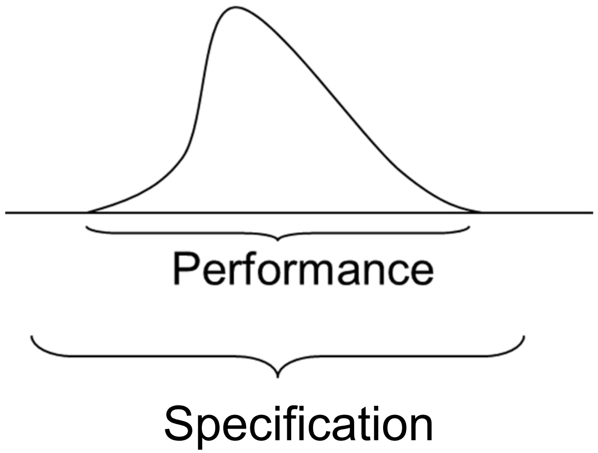


Performance Limits versus Specification Limits (2/2)

Vulnerable situation:



Highly desirable situation:



Capability Index (for symmetric processes)

Assumption: Process mean is centered between specification limits

$$C_P = \frac{Permissible\ range}{Actual\ range}$$

Respectively,

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

Process is capable if $C_P \geq 1$

Recommended minimum $C_P = 1.33$

Six Sigma Quality process: $C_P = 2$

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

Process Capability

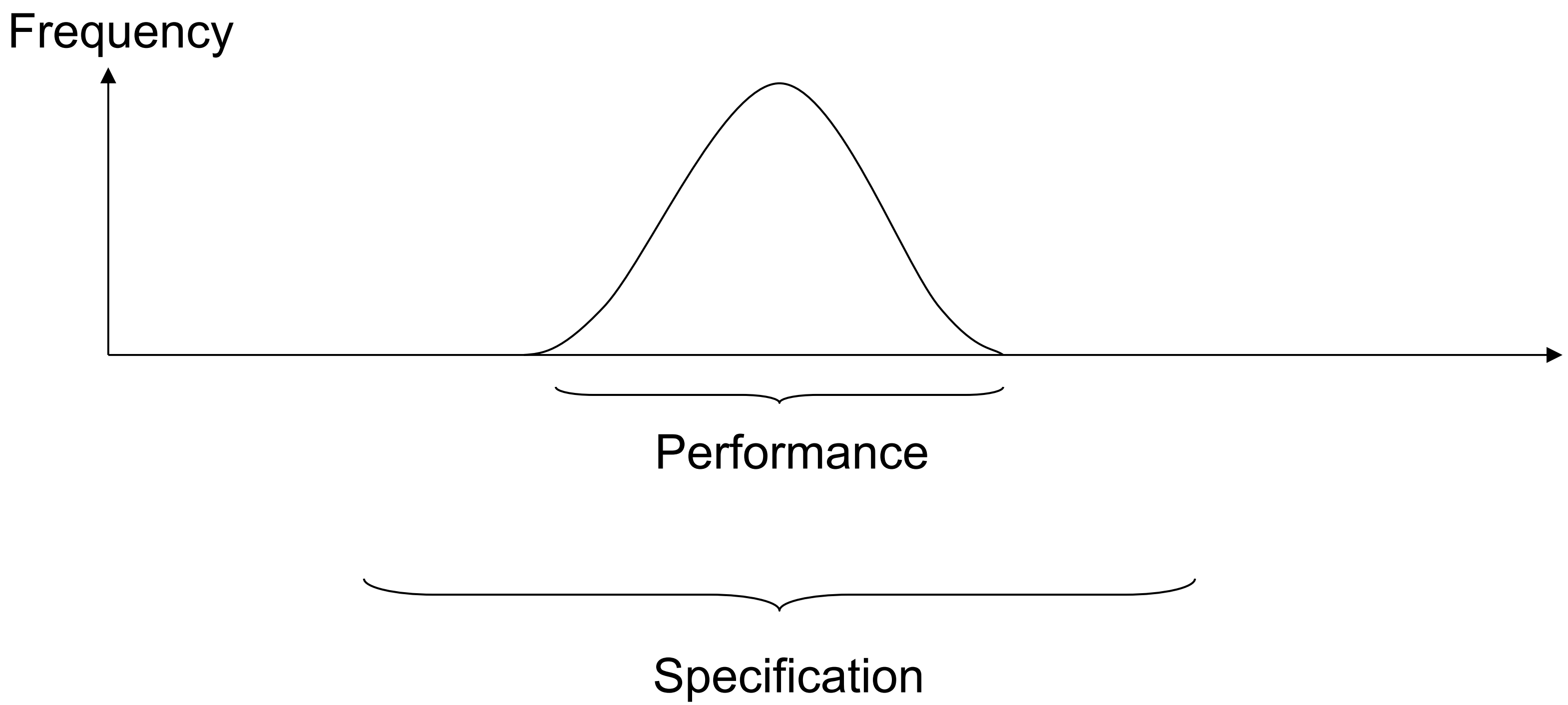
Specification Limits

- Describe desirable tolerance ranges
- Embody the quality demands of the customers

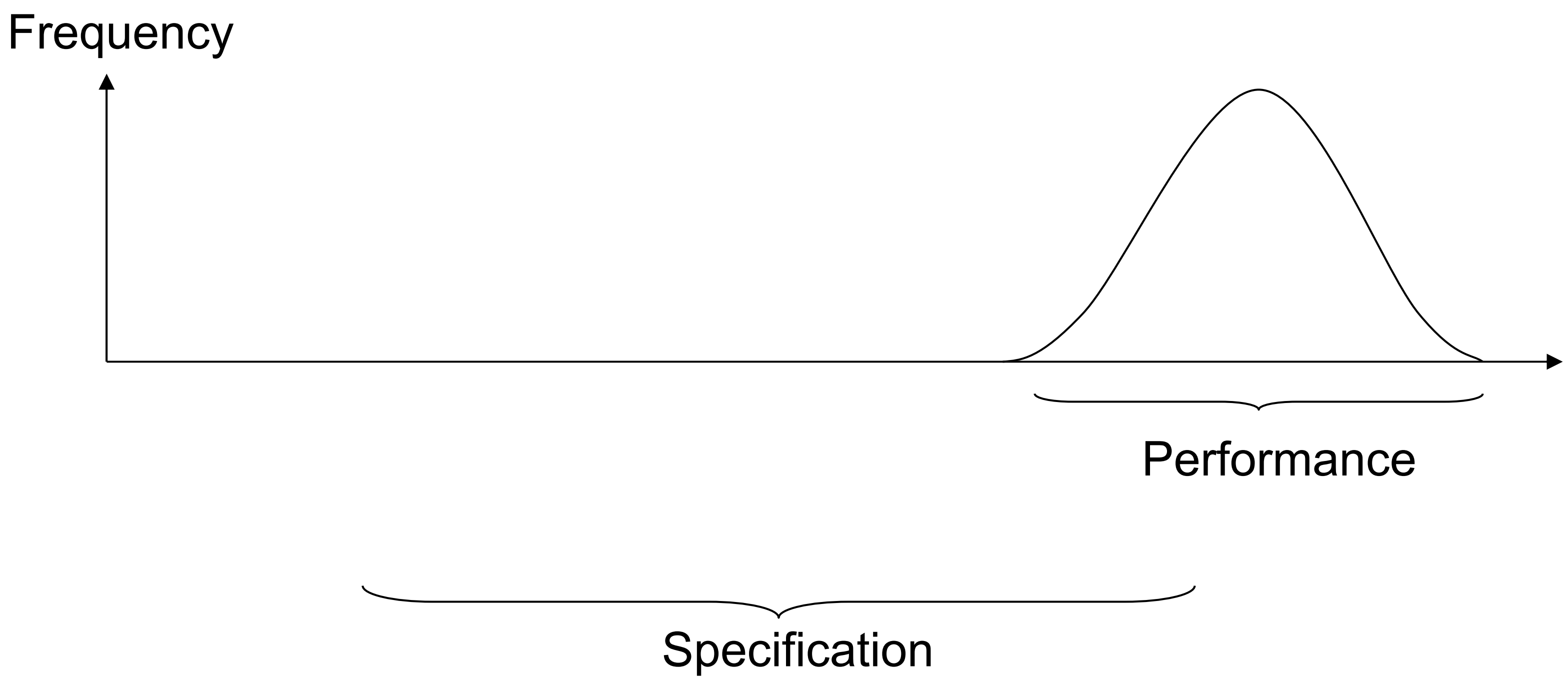
Process skills

- Can only be determined for processes that are under control. If there are uncontrolled special influences, the process capabilities cannot be reliably forecast
- A process that is under control has the ability to stay within performance limits
- But: Even a process that is under control may produce defective products (i.e. outside the specification limits)

Ideal Situation: CP>1



Bad, But Solvable: CP>1



Not Solvable: CP<<1