PROCESS IMPROVEMENT
QUALITY MANAGEMENT_6
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MELINDA KÖNYVES

DEPARTMENT OF MANAGEMENT AND BUSINESS ECONOMICS
FACULTY OF ECONOMIC AND SOCIAL SCIENCES
BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS
KONYVES.MELINDA@GTK.BME.HU

Memo – Quality Control

- Mass production
  - Shewhart: 1924 Bell Labs
- Measures conducted during the manufacturing process on an appropriate sample
- Main aim to control and regulate the processes, to prevent defective products

SPC methods to be learned

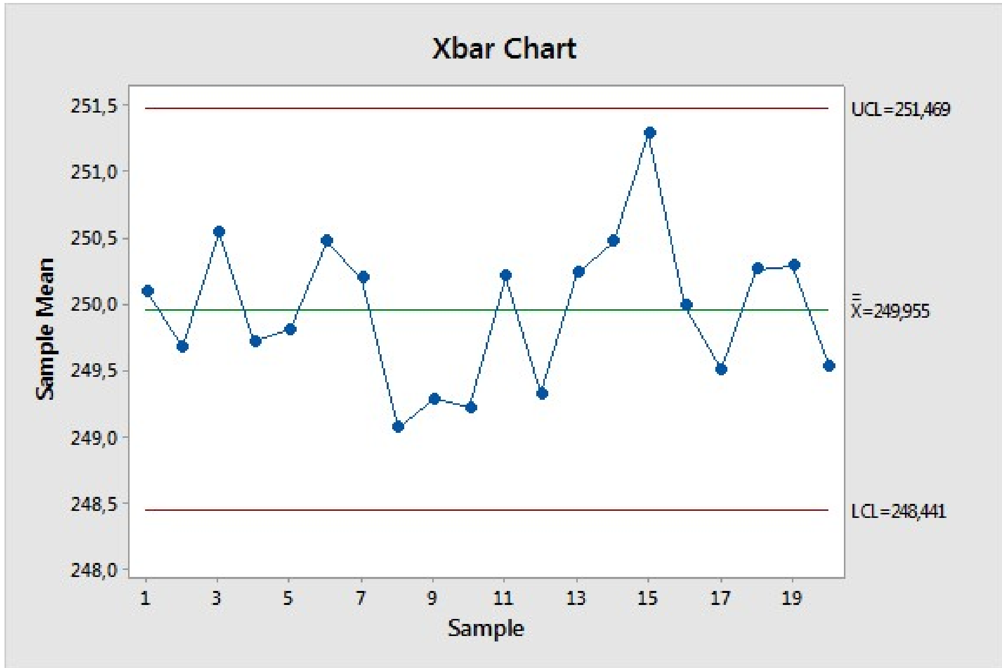
- Control charts
  - Detecting problems within the process
- Process capability indices
  - The process' ability to meet the customers' requirements

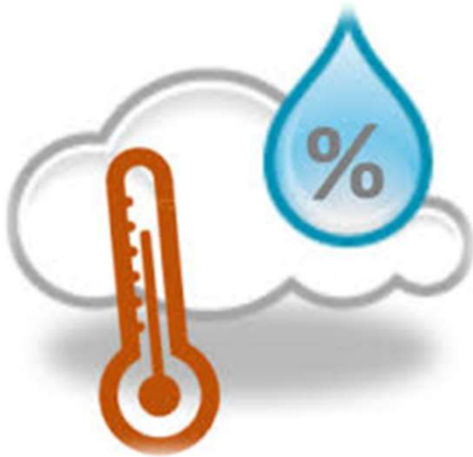
SPC methods

- **Control charts**
  - Achieving process stability
  - Checking whether the parameters are stable over time
  - Detecting deviations in the production process that would lead to nonconforming units
- **Process capability analysis**
  - Evaluating the process performance
  - Reducing the variability in order to continuously meet customers' requirements
  - Predicting the number of defective items

Common and special causes

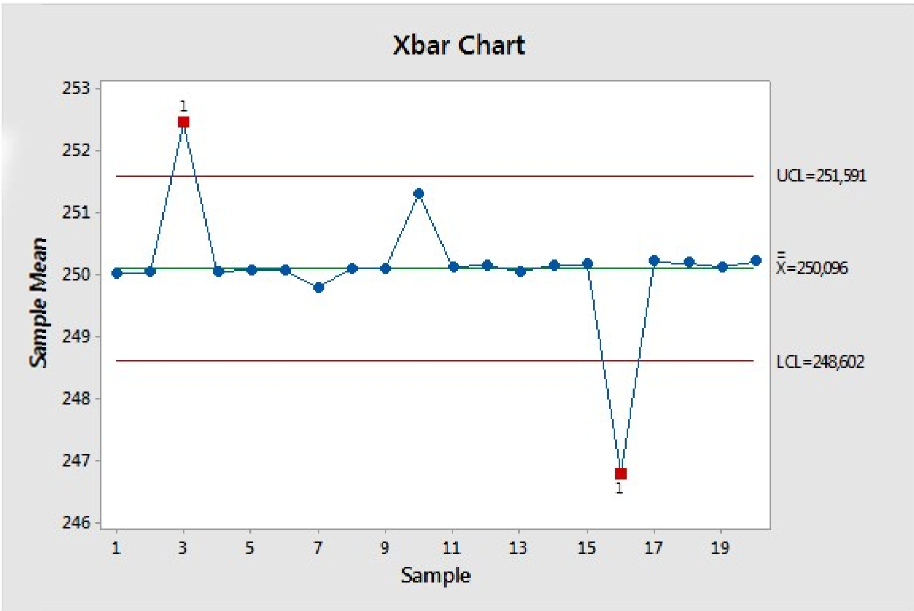
- Common causes (in-control process)
  - Cumulative effect of many, small, unavoidable causes
  - Always assumed to be present in the process
  - Humidity, temperature….

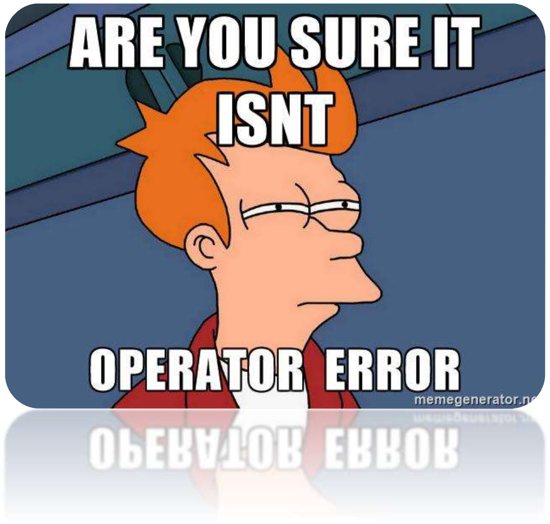




Common and special causes

- Special causes (out-of-control process)
  - Occasionally present
  - Result in an unacceptable level of process performance
  - Defective raw material, improperly adjusted machines, operator errors



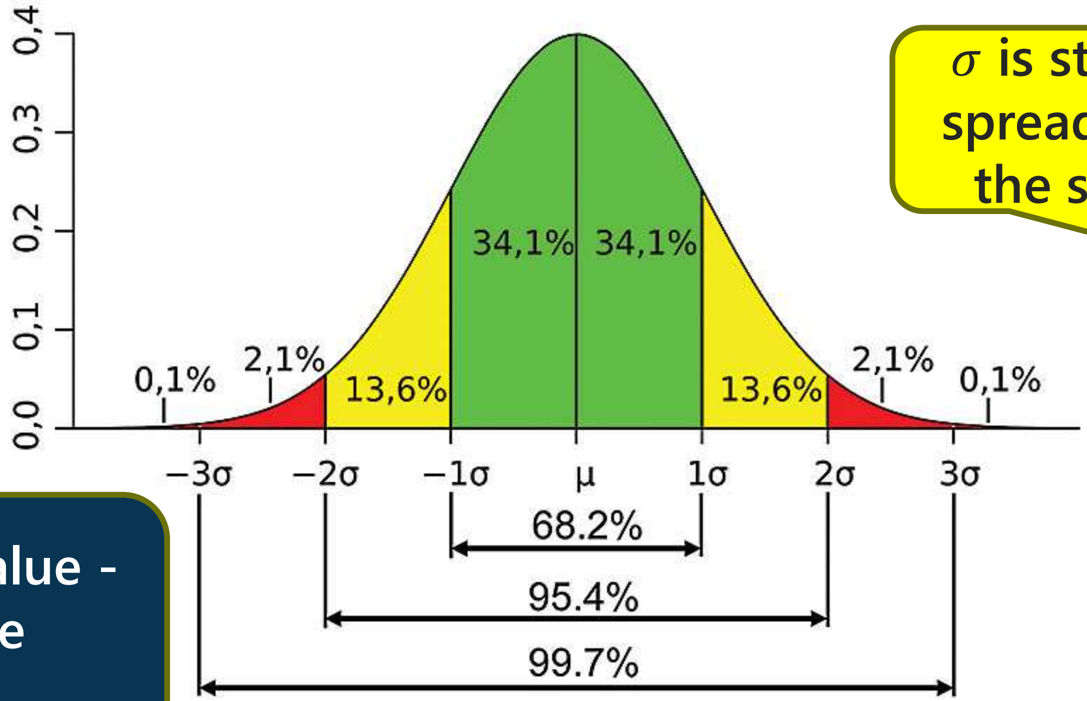


Objective of control charts

- Distinguish common and special causes
- Detect the occurrence of special causes
  - Operator action is necessary to eliminate them
- Prevent the production of flawful product

Mathematical background

- **Normal distribution** $N \sim (\mu; \sigma)$
  - Central limit theorem
  - Natural tolerance limits at $\mu - 3\sigma; \mu + 3\sigma$



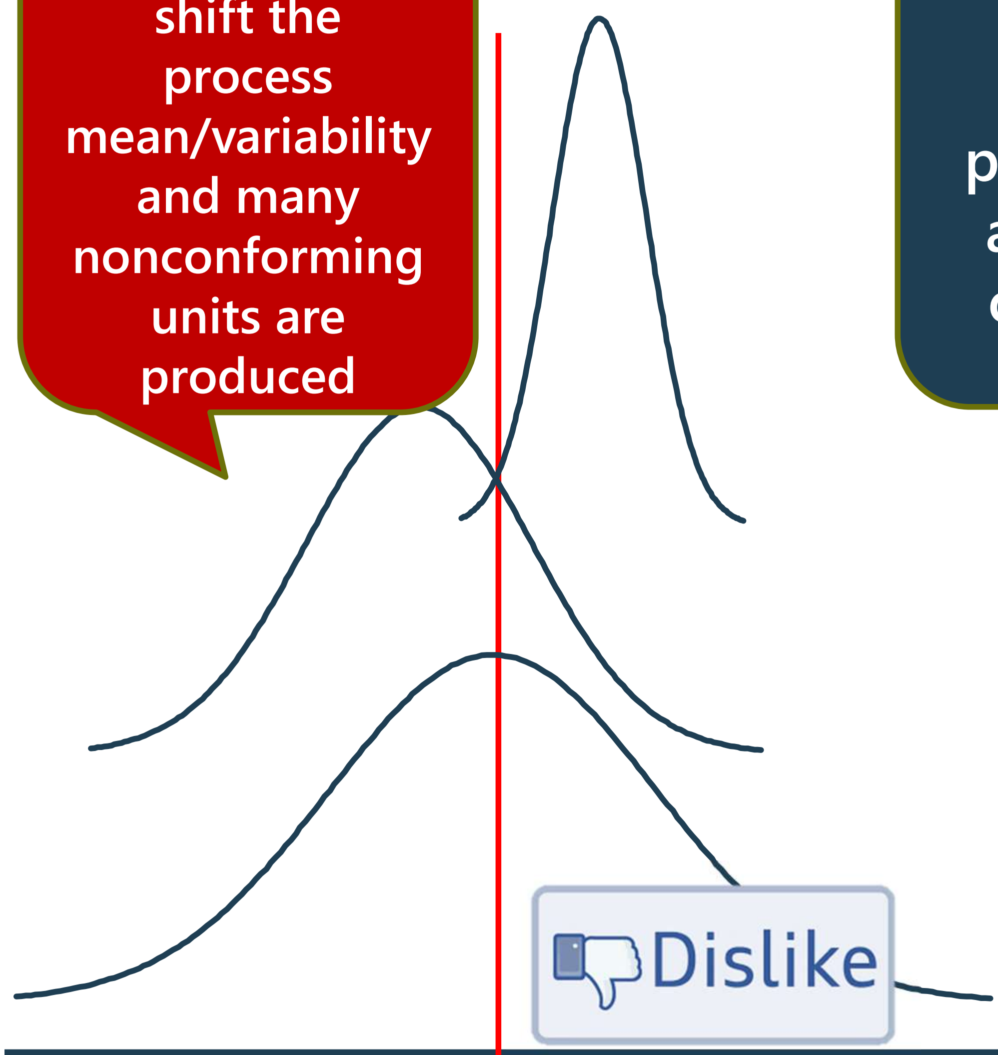
σ is standard deviation - spread around the mean; the shape of the curve

μ is the expected value - the center of the distribution

Processes in- and out-of control

Out-of-control process

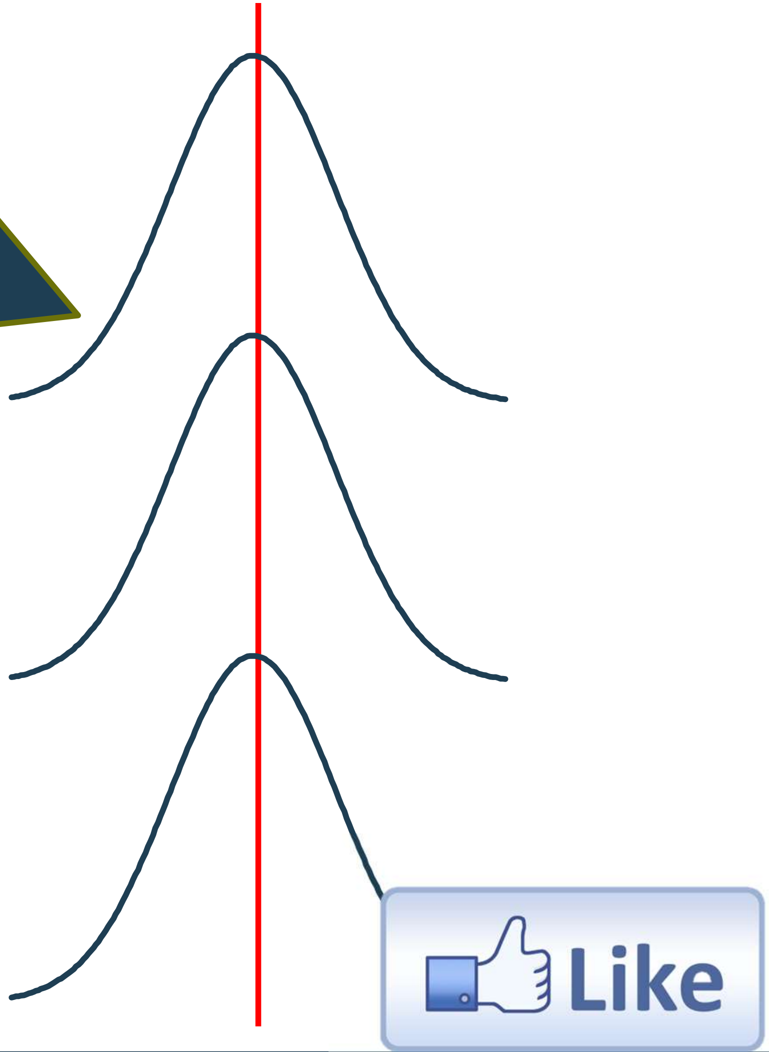
Special causes shift the process mean/variability and many nonconforming units are produced



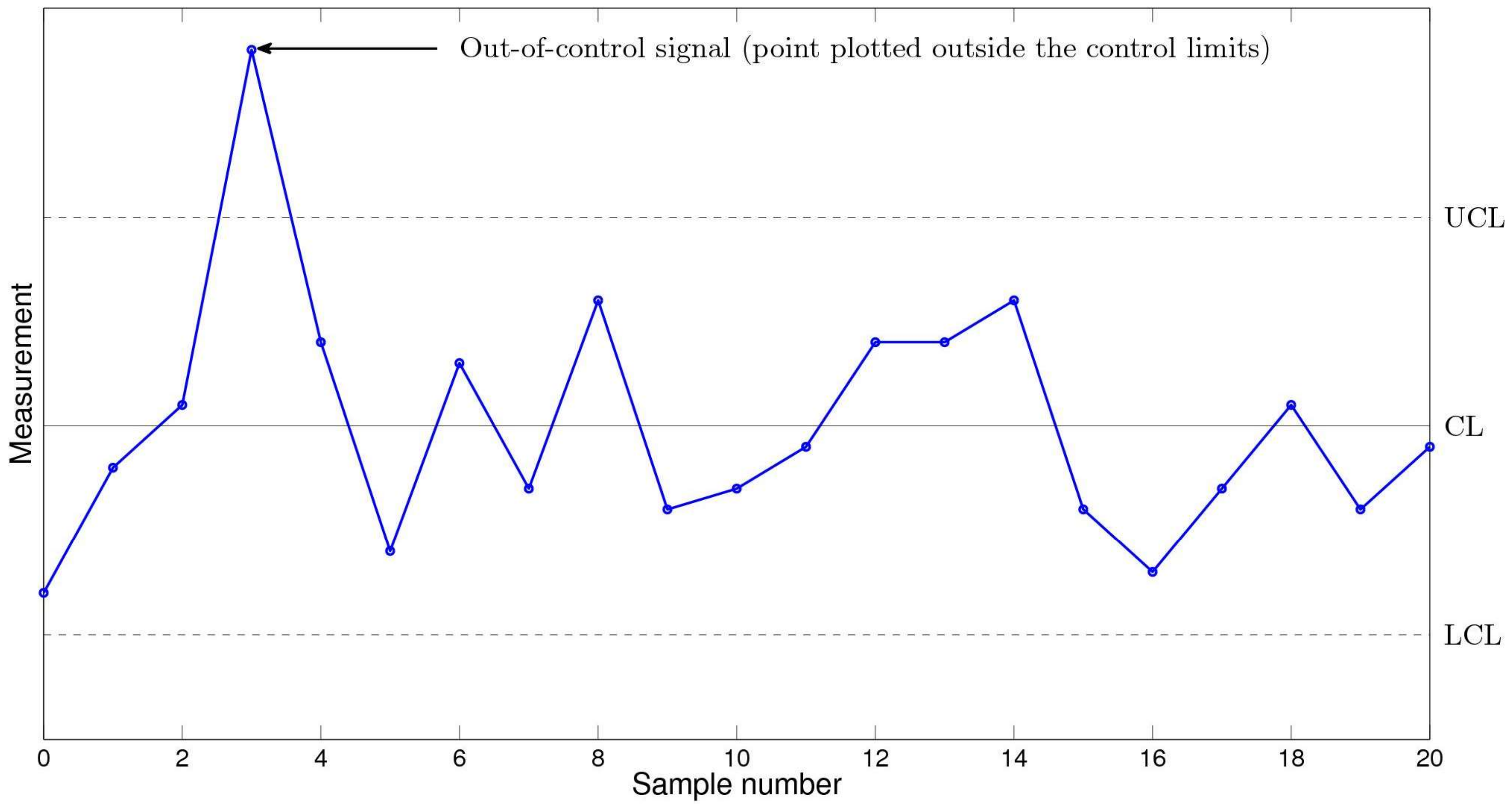
In-control process

Only common causes, parameters are stable over time

$\mu_0;\ \sigma_0$

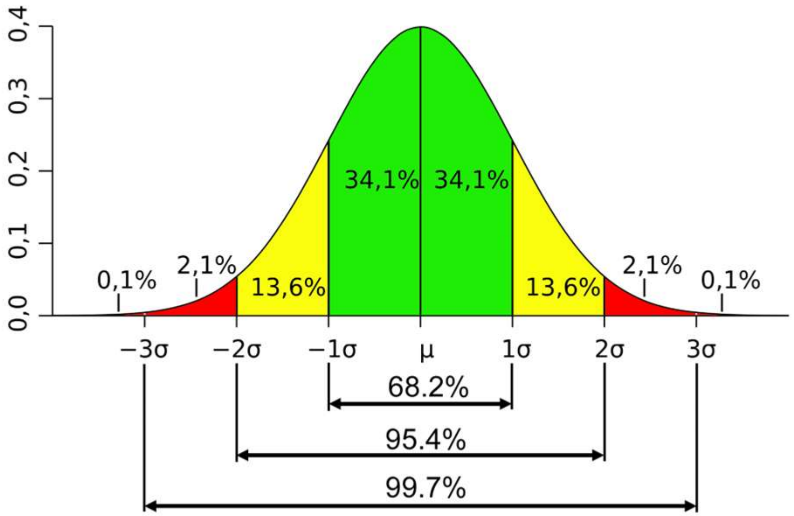


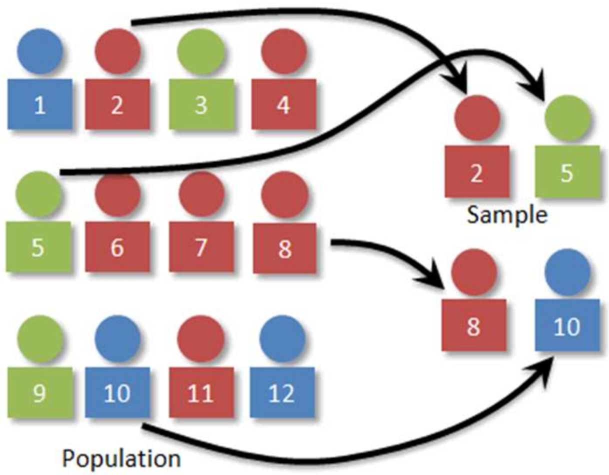
Control charts



Establishing the control charts

- m samples of size n: $x_{i,1}, x_{i,2}, \dots, x_{i,n}$
- R-chart for monitoring the standard deviation of the process
- $\bar{X}$-chart to monitor the expected value
- The control limits are dependent on the sampling distribution of the quality characteristics





Performance of control charts

- Due to sampling error
- Type I error, α-risk
  - In-control process is thought to be out-of control (false alarm)
  - Normally distributed process: $\alpha = 0{,}27\%$
  - Unnecessary process adjustments
- Type II error, β-risk
  - Out-of-control process is thought to be in-control
  - Not detecting a process shift

Phase I and II application of Control Charts

- Phase I.
  - Retrospective analysis
    - Based on 20-25 samples
  - Trial control limits
  - Bringing the process into the state of statistical control
- Phase II.
  - Monitoring process performance
  - OCAP: Out-of-control Action Plan
    - Actions necessary to eliminate the special causes

Control charts for $\bar{X}$ and $\boldsymbol{R}$

- m samples of size n: $x_{i,1}, x_{i,2}, \dots, x_{i,n}$
- Range of the sample: $R_i = X_{i,max} - X_{i,min}$
- Average range: $\bar{R} = \frac{\sum_{i=1}^{m} R_i}{m} = \frac{R_1 + R_2 + \cdots + R_m}{m}$
- Control limits for the R chart
  - $UCL = D_4 \bar{R}$
  - $Center\ line = \bar{R}$
  - $LCL = D_3 \bar{R}$

Control charts for $\bar{X}$ and R

- Average of the i-th sample:

$$\bar{X}_i = \frac{\sum_{j=1}^{n} X_{i,j}}{n} = \frac{X_{i,1}+X_{i,2}+\cdots+X_{i,n}}{n}$$

- Grand average (average of the averages):

$$\bar{\bar{X}} = \frac{\sum_{i=1}^{m} \bar{X}_i}{m} = \frac{\bar{X}_1+\bar{X}_2+\cdots+\bar{X}_m}{m}$$

- Control limits for the $\bar{X}$ chart:
  - Process variability must be in-control (check the R chart!)
  - $UCL = \bar{\bar{X}} + A_2\bar{R}$
  - $Center\ line: \bar{\bar{X}}$
  - $LCL = \bar{\bar{X}} - A_2\bar{R}$

Benefits of control chart application

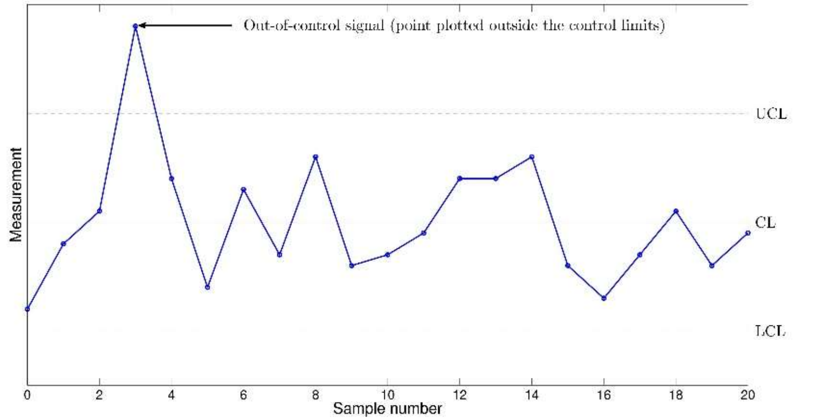
- Improving productivity
- Preventing defects
- Avoiding unnecessary process adjustments
- Providing diagnostic information
- Estimating process capability

Monitoring the process' performance

- ***m*** **samples of size *n***
- $R_i = X_{i,max} - X_{i,min}$
- $\bar{X}_i = \frac{\sum_{j=1}^{n} X_{i,j}}{n}$
- $\bar{R} = \frac{\sum_{i=1}^{m} R_i}{m}$
- $\bar{\bar{X}} = \frac{\sum_{i=1}^{m} \bar{X}_i}{m}$

Establishing the control limits

- R chart (standard deviation of the process)
  - $UCL_R = D_4\bar{R}$
  - $CL_R = \bar{R}$
  - $LCL_R = D_3\bar{R}$
- $\bar{X}$ chart (process' mean)
  - $UCL_{\bar{X}} = \bar{\bar{X}} + A_2\bar{R}$
  - $CL_{\bar{X}} = \bar{\bar{X}}$
  - $LCL_{\bar{X}} = \bar{\bar{X}} - A_2\bar{R}$



Estimating the parameters (example)- data sheet

Sample no.	Data on nominal output voltage					Sample range	Sample average
	X_1	X_2	X_3	X_4	X_5		
1	15,8	16,3	16,2	16,1	16,6	0,8	16,2
2	16,3	15,9	15,9	16,2	16,4	0,5	16,14
3	16,1	16,2	16,5	16,4	16,3	0,4	16,3
4	16,3	16,2	15,9	16,4	16,2	0,5	16,2
5	16,1	16,1	16,4	16,5	16	0,5	16,22
6	16,1	15,8	16,7	16,6	16,4	0,9	16,32
7	16,1	16,3	16,5	16,1	16,5		
8	16,2	16,1	16,2	16,1	16,3	0,2	16,18
9	16,3	16,2	16,4	16,3	16,5	0,3	16,34
10	16,6	16,3	16,4	16,1	16,5	0,5	16,38
11	16,2	16,4	15,9	16,3	16,4	0,5	16,24
12	15,9	16,6	16,7	16,2	16,5	0,8	16,38
13	16,4	16,1	16,6	16,4	16,1	0,5	16,32
14	16,5	16,3	16,2	16,3	16,4	0,3	16,34
15	16,4	16,1	16,3	16,2	16,2	0,3	16,24
16	16	16,2	16,3	16,3	16,2		
17	16,4	16,2	16,4	16,3	16,2	0,2	16,3
18	16	16,2	16,4	16,5	16,1	0,5	16,24
19	16,4	16	16,3	16,4	16,4	0,4	16,3
20	16,4	16,4	16,5	16	15,8	0,7	16,22
Average range							-----------
Grand average (average of the subgroups' average)						-----------	

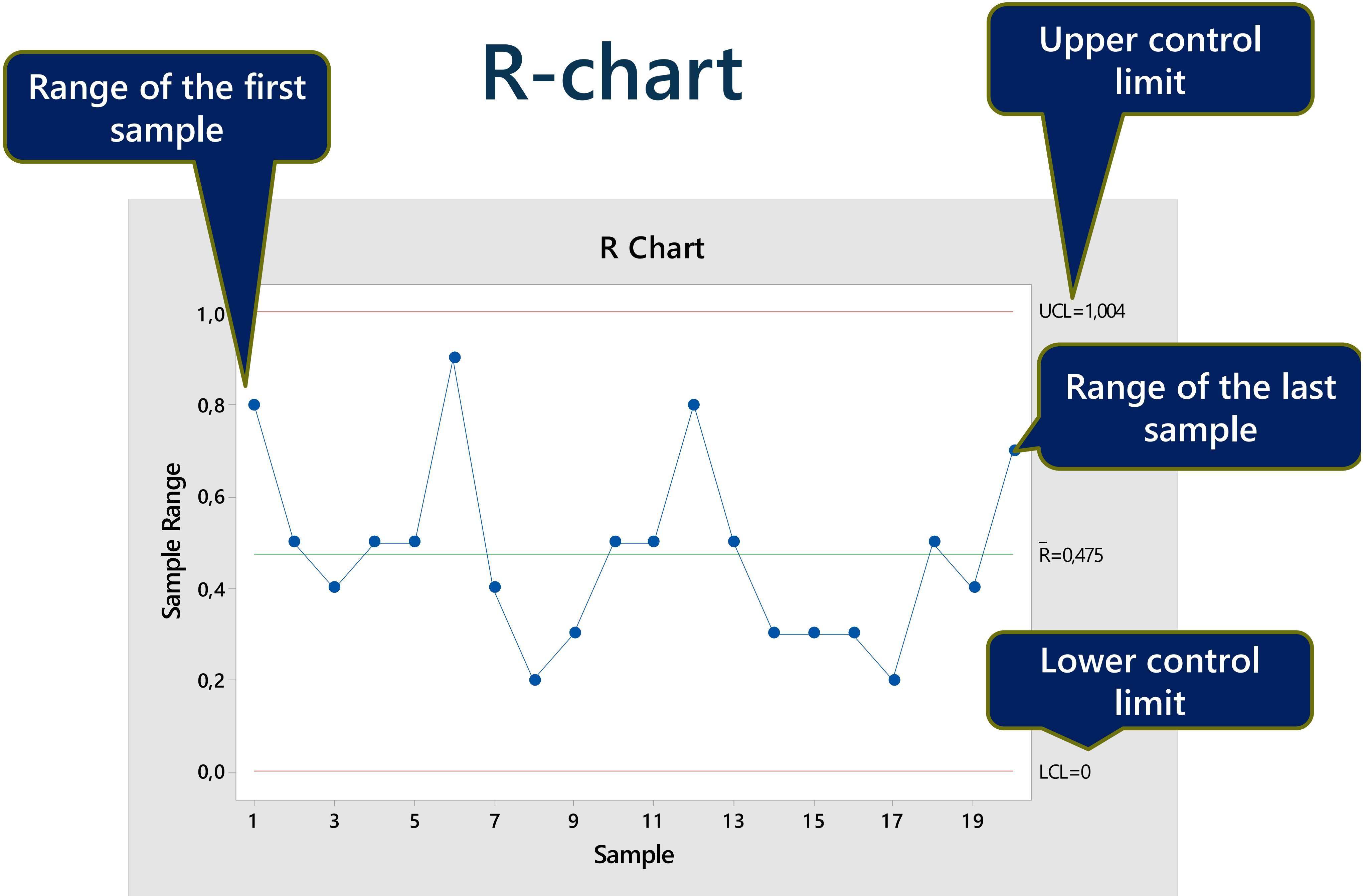
$$R_i = X_{i,max} - X_{i,min}$$

$$\bar{R} = \frac{\sum_{i=1}^{m} R_i}{m}$$

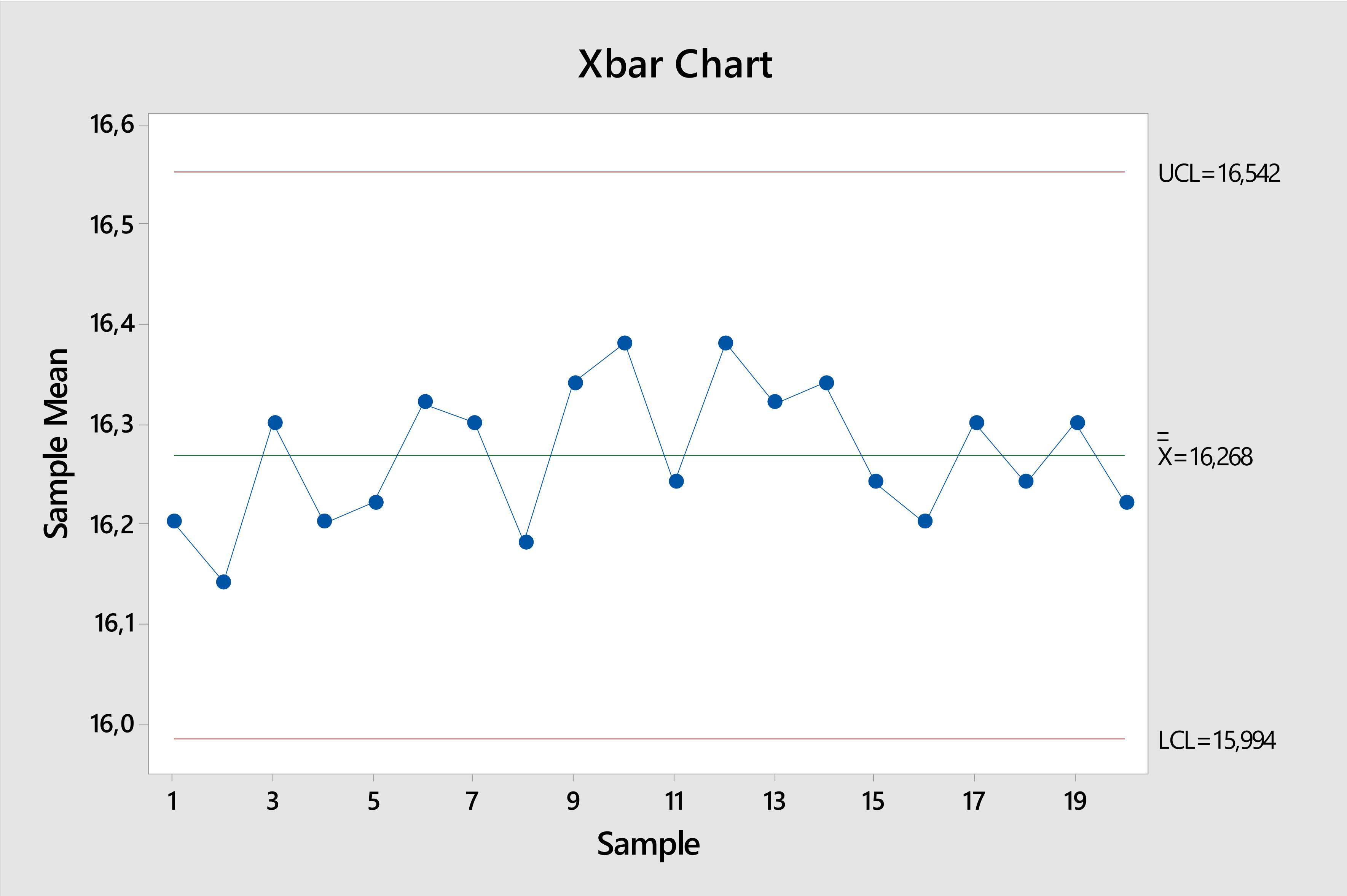
$$\bar{X}_i = \frac{\sum_{j=1}^{n} X_{i,j}}{n}$$

$$\bar{\bar{X}} = \frac{\sum_{i=1}^{m} \bar{X}_i}{m}$$

R-chart


Range of the first sample
Upper control limit
R Chart
1,0
0,8
0,6
0,4
0,2
0,0
Sample Range
UCL=1,004
Range of the last sample
$\bar{R}$=0,475
Lower control limit
LCL=0
1
3
5
7
9
11
13
15
17
19
Sample

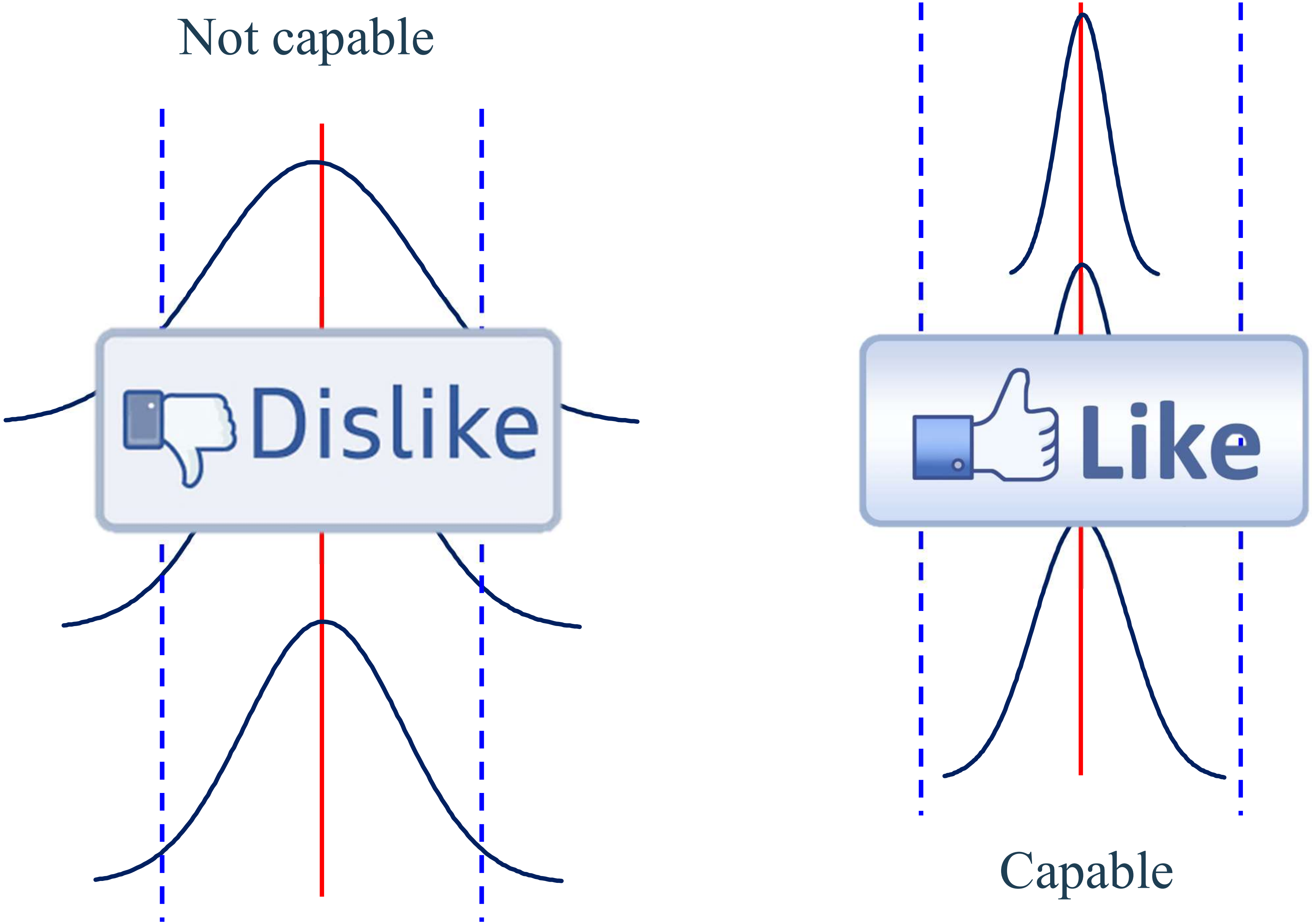
$\overline{X}$ chart



Process capability analysis

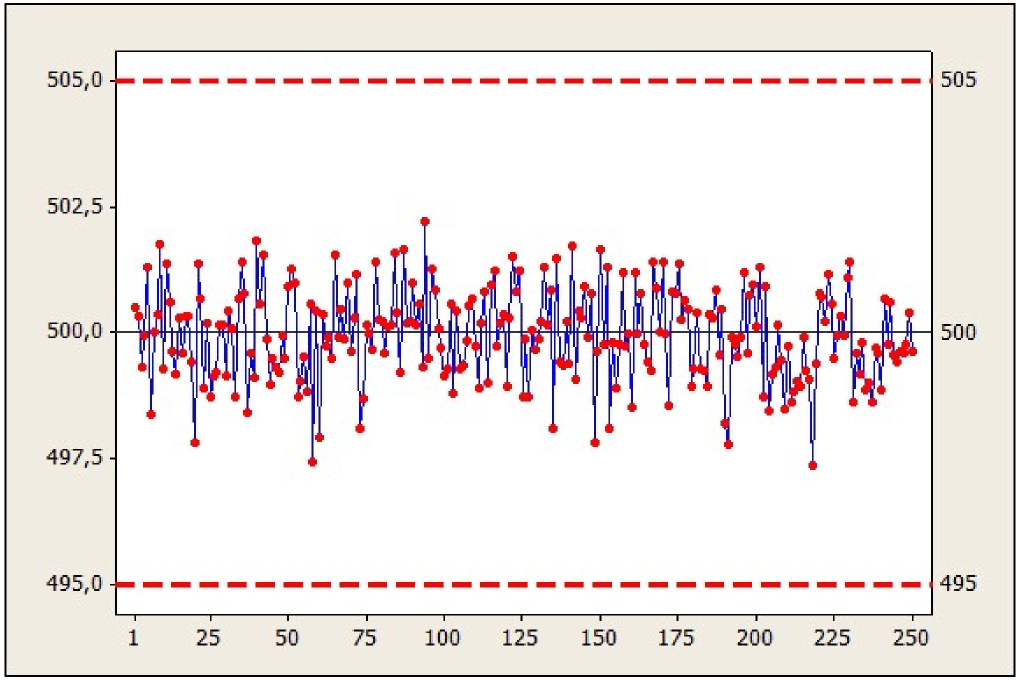
- Only for in-control process
- Analyzing the process' variability relative to product requirements
- Main objectives:
  - Predicting the number of nonconformities
  - Selecting between suppliers
  - Reducing the variability of the process
    - Meeting customers' expectations
    - Decreasing the number of nonconforming products

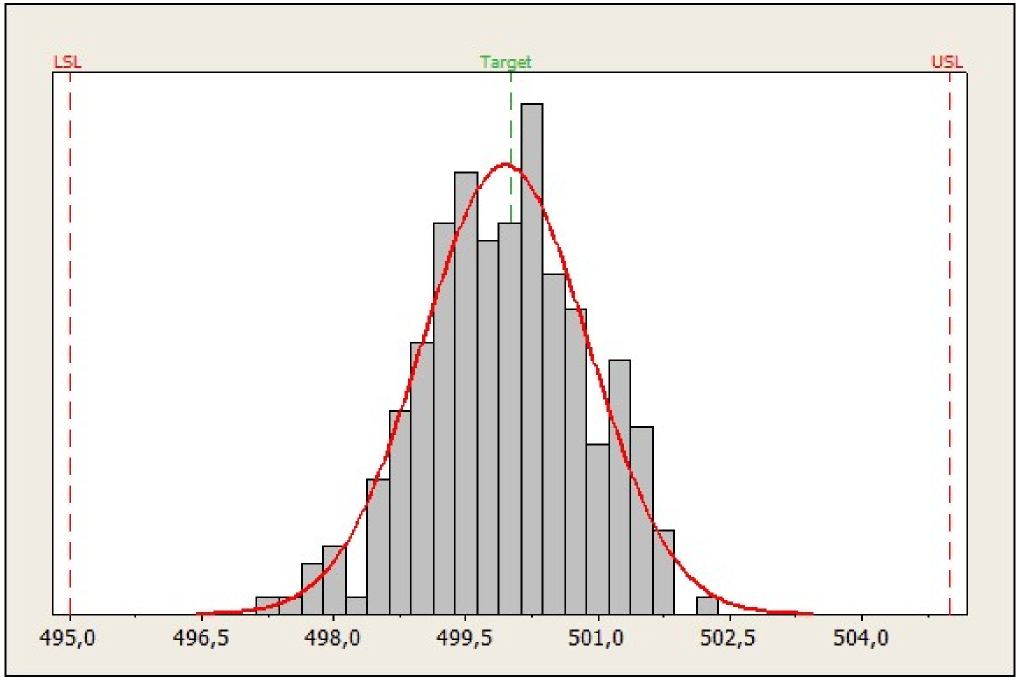
Capability of our process



Histograms

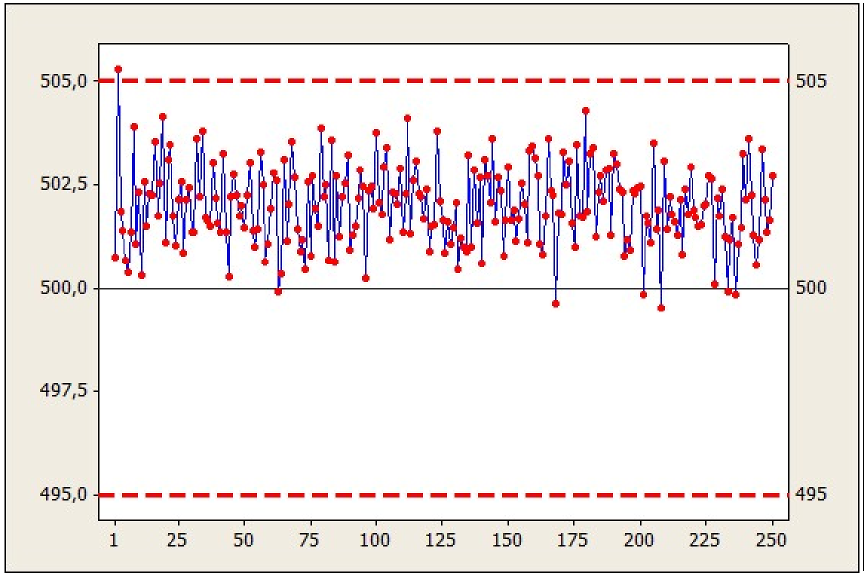
- Visual impression of the process performance

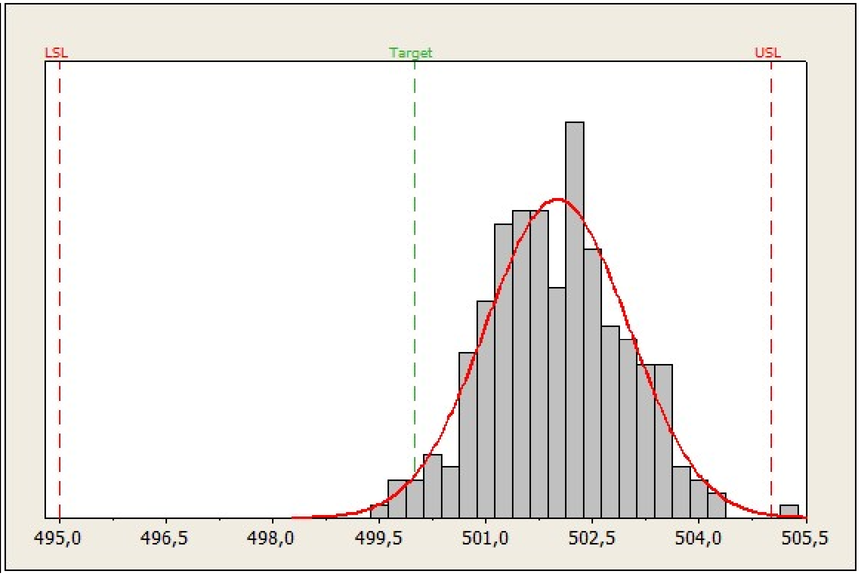




Histograms

- Possible causes of poor process performance
  - Poorly located center (shift in the mean)
  - Excess variability

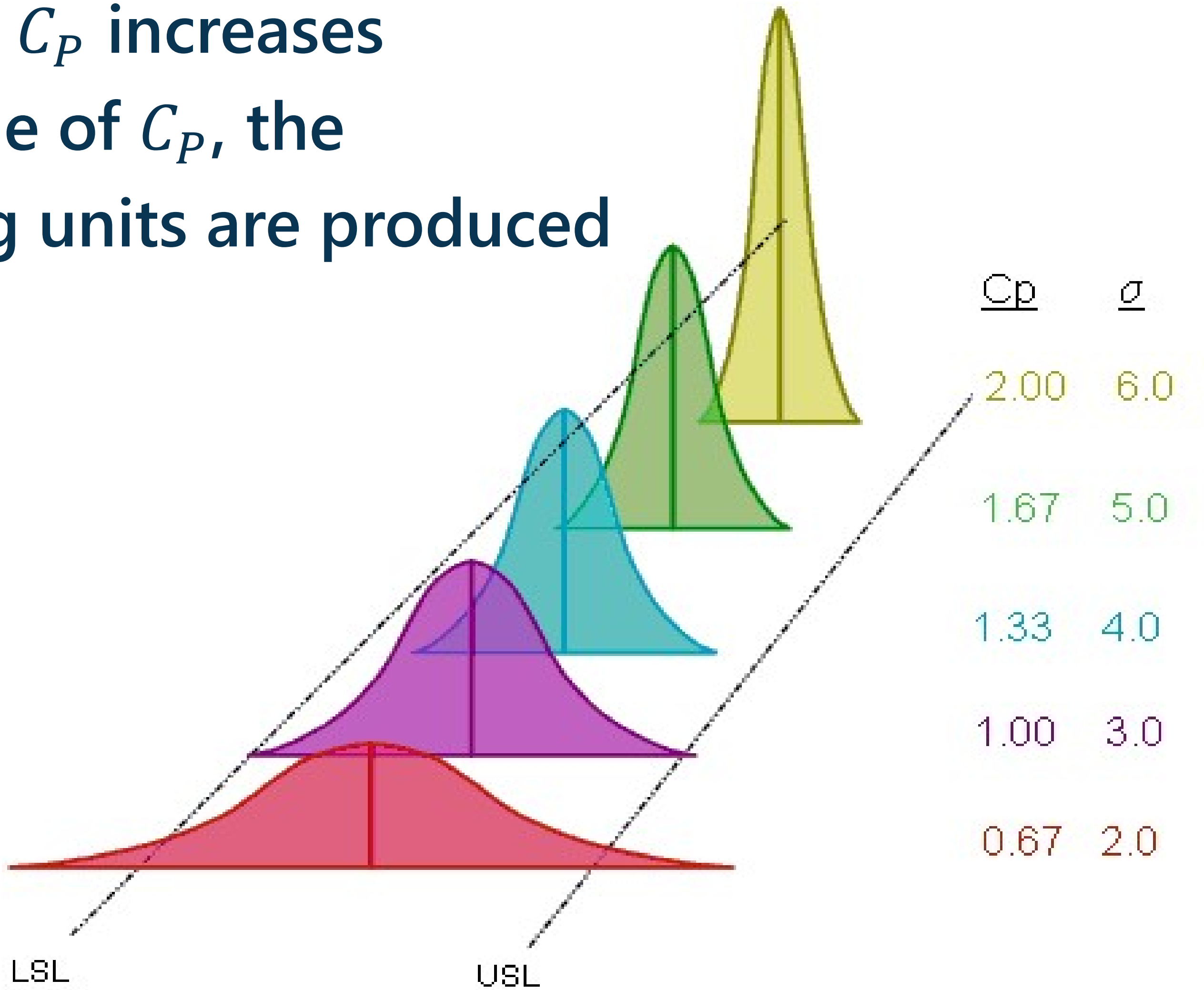




Process capability ratio

- As σ decreases, the C_P increases
- The higher the value of C_P, the less nonconforming units are produced

$$C_p = \frac{USL - LSL}{6 \cdot \sigma}$$

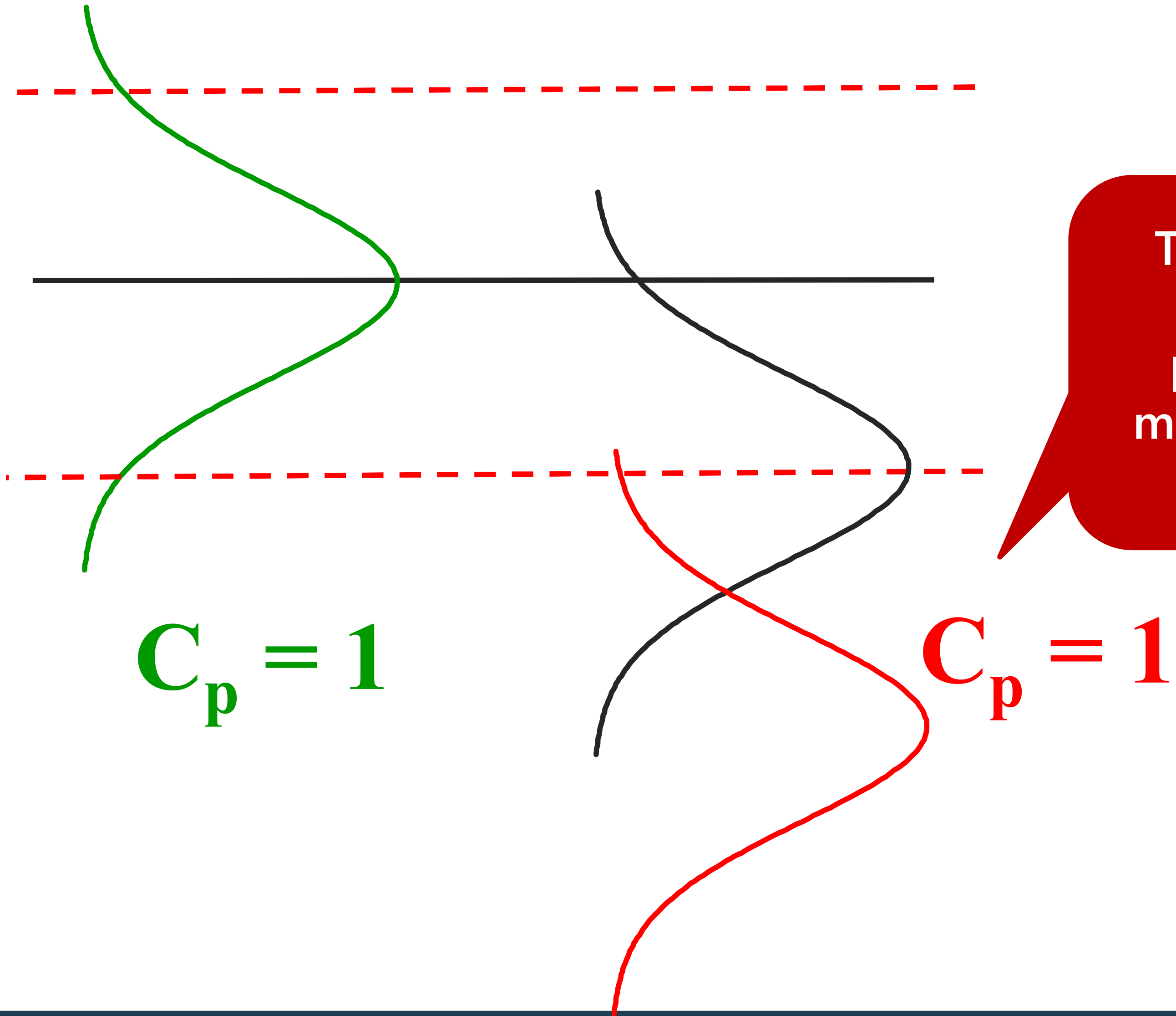


Process capability ratio
Requirements and process fallout

C_p	Sigma level ($SL = 3C_p$)	ppm (process fallout)	
1,00	± 3	2700	
1,33	± 4	63,5	Standard minimum value in most industries
1,67	± 5	0,57	Parameters related to safety
2,00	± 6	0,002	Word-class organizations, SixSigma

Process capability indices

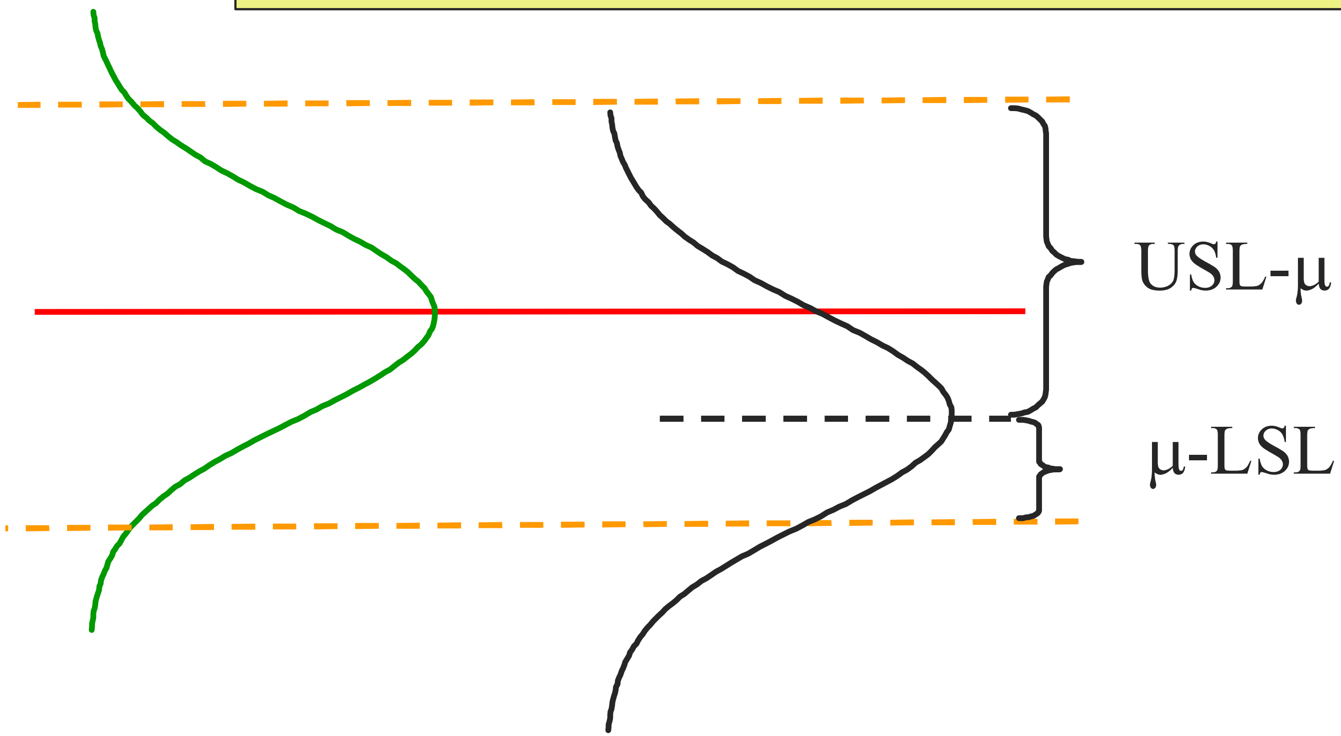
$$C_p = \frac{USL - LSL}{6 \cdot \sigma}$$



The C_p index does not take into account whether the process is centered at the midpoint of the specification interval or not

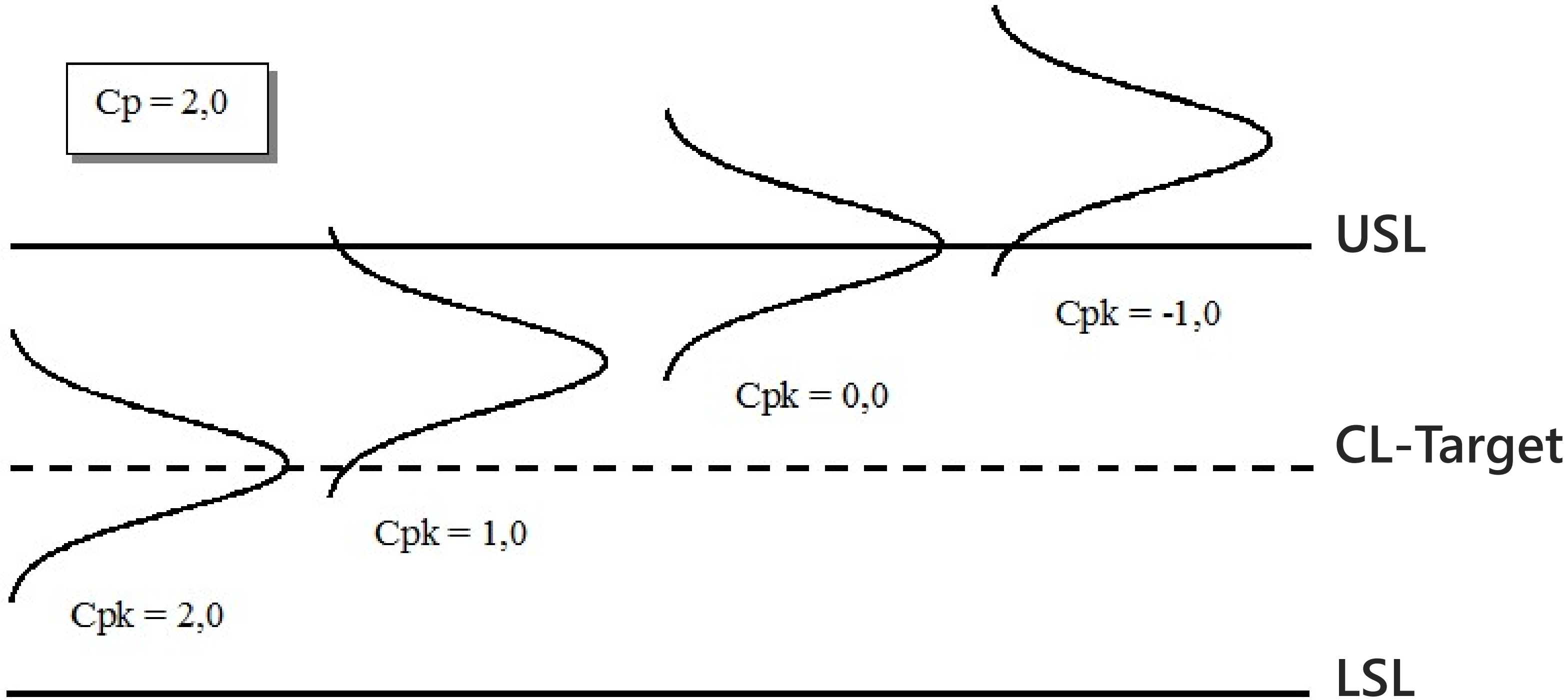
C_{pk} index – off-center process

$$C_{pk} = \min\{C_{pl}, C_{pu}\} = \left\{\frac{\mu - LSL}{3\cdot\sigma}; \frac{USL - \mu}{3\cdot\sigma}\right\}_{\min}$$



Relationship between C_p and C_{pk}

- C_{pk}: Current capability of the process
- C_p: Potential capability of the process
  - Can be achieved by centering the process



Control vs. specification limits

- Control limits
  - Determined based on the current variability of the process
  - A point outside the control limit indicates that there is a shift in the process mean / standard deviation, that is, the process is NOT stable over time
  - **In-control process: its parameters are stable over time**
- Specification limits
  - Determined externally
  - The 3 sigma deviation of the process is compared to the specification limits
  - The area outside of the specification limits is proportional to the process fallout
  - **A capable process: able to meet the customers' requirements**

MSA – Measurement System Analysis

- Measurement system: the totality of the measuring devices, environment, measuring persons, measurement method, procedure and measured component.
- Features:
  - Accuracy: if the mean value of the measured value is the same as the true value of the measured characteristic
  - Resolution: the smallest difference that the measurement system can consistently detect
  - Display resolution: the smallest difference that that the measuring device can display
  - Stability: if the measurements are repeated at different intervals, the same result is obtained
  - Repeatability: inherent fluctuation in measurement results in the case of a measuring person
  - Reproducibility: inherent fluctuation in measurement results in the case of several measuring persons

R&R

R&R%	Evaluation
> 30%	Not acceptable
10%<R&R%<30%	Partly acceptable
< 10%	Acceptable

Thank you for your attention.

Melinda Könyves