MICHEL INSTITUT
Unternehmensberatung

Staff Training

Statistics for Quality Management

Our Schedule

- Greetings, Objectives
- Historic Overview
- Basics and Terminology
- Calculation of Shewhart QRK
- Machine Capability
- Process Capability
- Target Orientation vs. Tolerance Orientation
- *Interim Coffee Break*
- Practical Examples and Exercises
- Feedback-Round and Leave Taking

Automotive CORE-Tools: Module 5 - SPC

SPC – Statistical Process Control

Participants learn...

- Process monitoring with statistical methods
- Which processes are suitable for monitoring with SPC
- The introduction and calculation of Quality Control Charts

What do the letters „SPC“ stand for?

Statistical Process Control

S = Statistical methods for the Process Variation Test

P = Processes e.g. production as well as service process

C = Process control through active management

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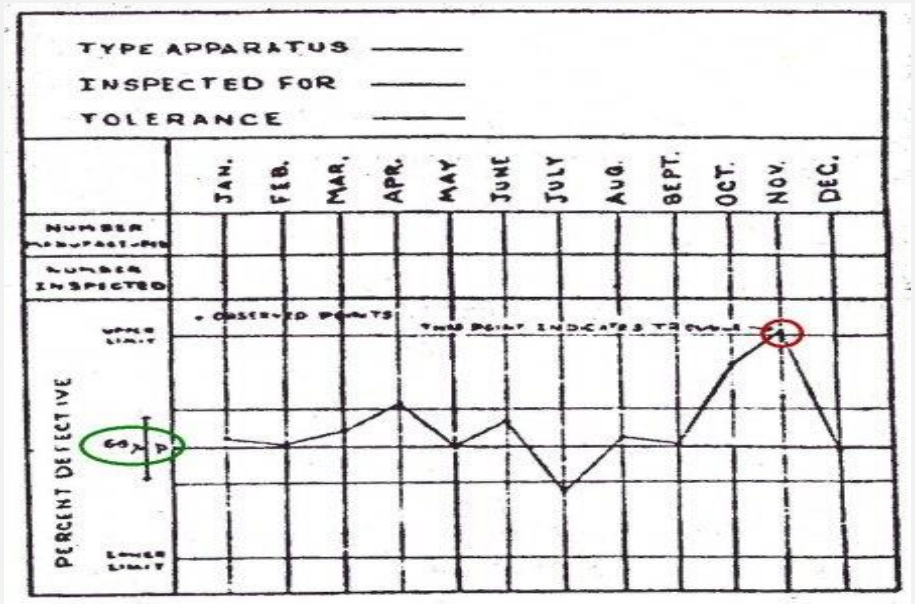
Where does SPC come from?

Statistical process control was developed in the year 1924 by Dr. Walter Shewhart with the goal:

To be able to tell the difference between random and systematic variation as soon as possible, therefore to be able to distinguish clear process signals from „background noise".

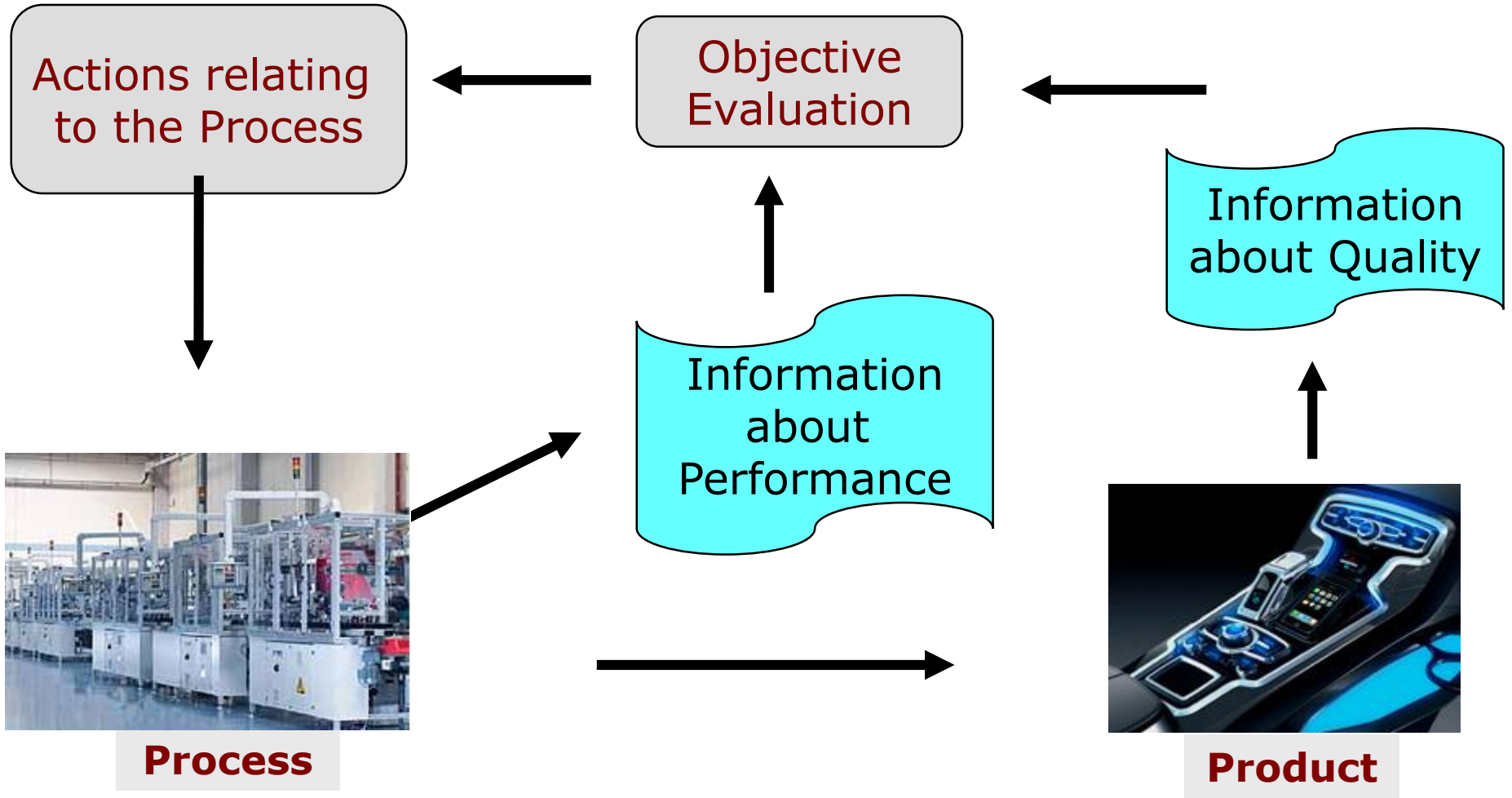
One of the first quality control charts by von Walter Andrew Shewhart



Walter Andrew Shewhart
1891 -1967 , Illinois USA

What is SPC?

A Process Control System with Feedback - A CONTROL LOOP.



Terminology relating to SPC

- Random variation influences
- Systematic variation influences
- Controlled process
- Out-of-control process
- Machine capability
- Process capability
- Calculation of Shewhart quality control charts
- Tolerance oriented process control
- Target oriented process control

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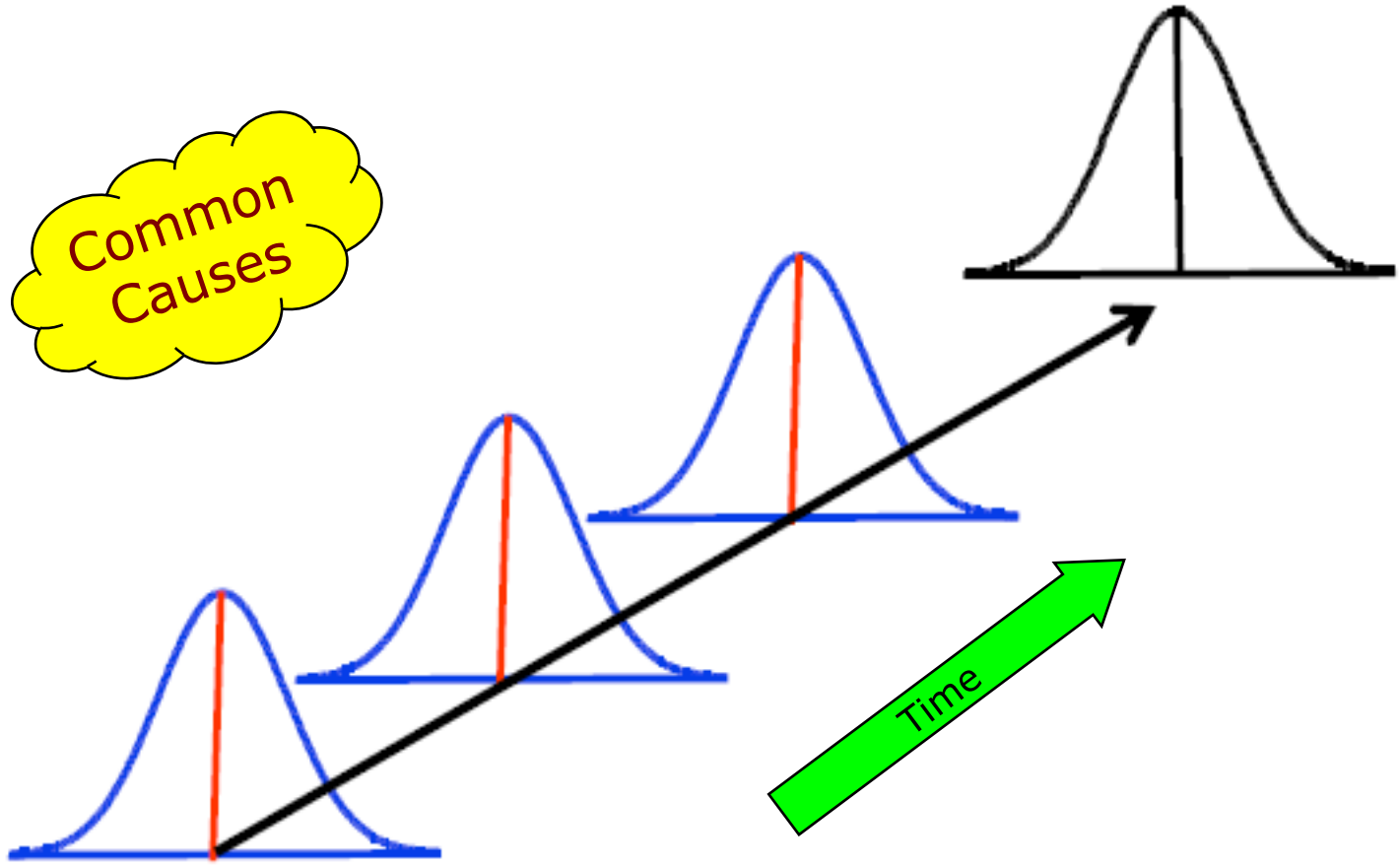
Random Variation Influences



If only random variation influences are present, the process results form a controlled and predictable distribution over time.

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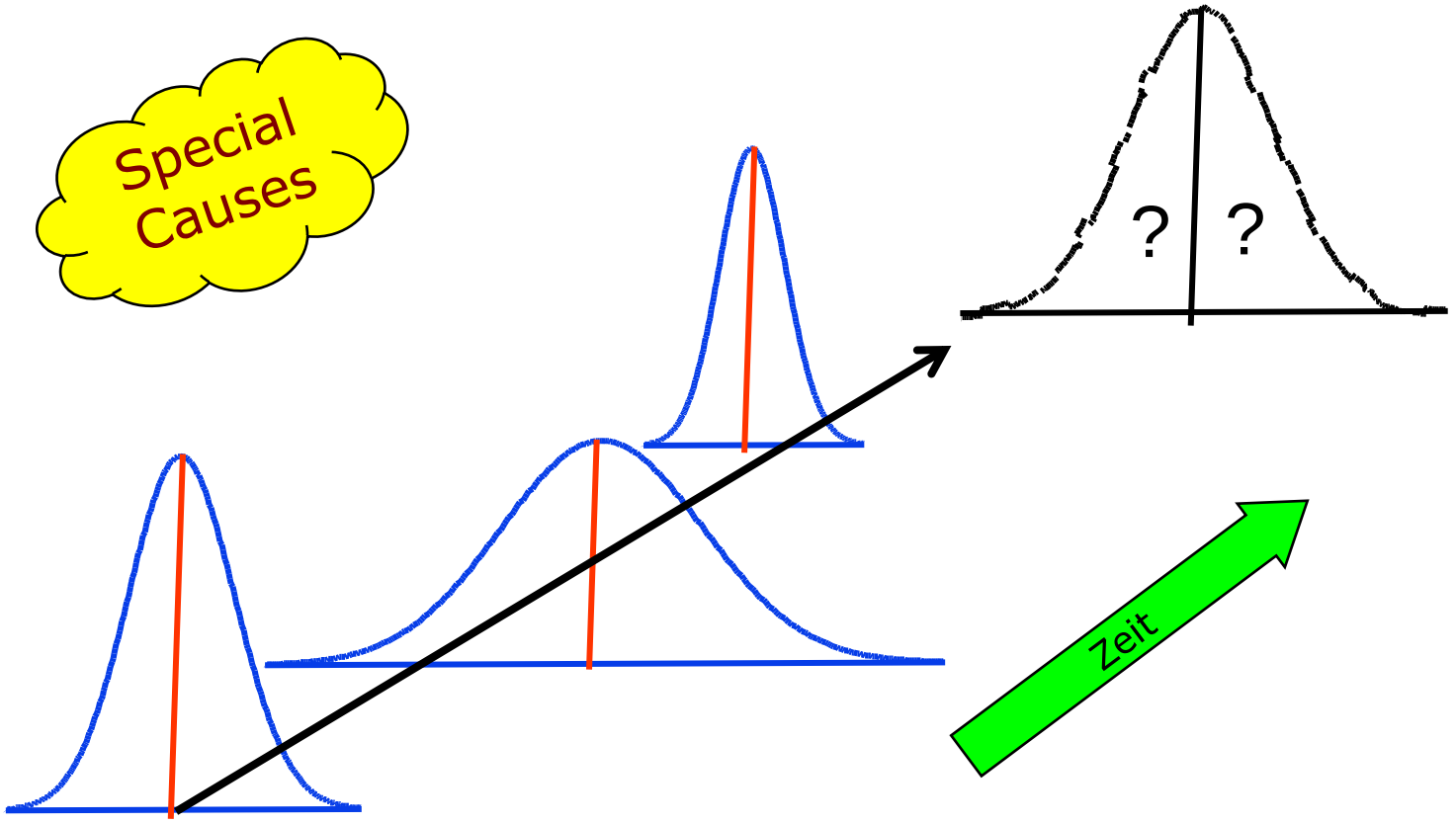
Systematic Variation Influences



If systematic variation influences are present, the process results form an out-of control and unpredictable distribution over time.

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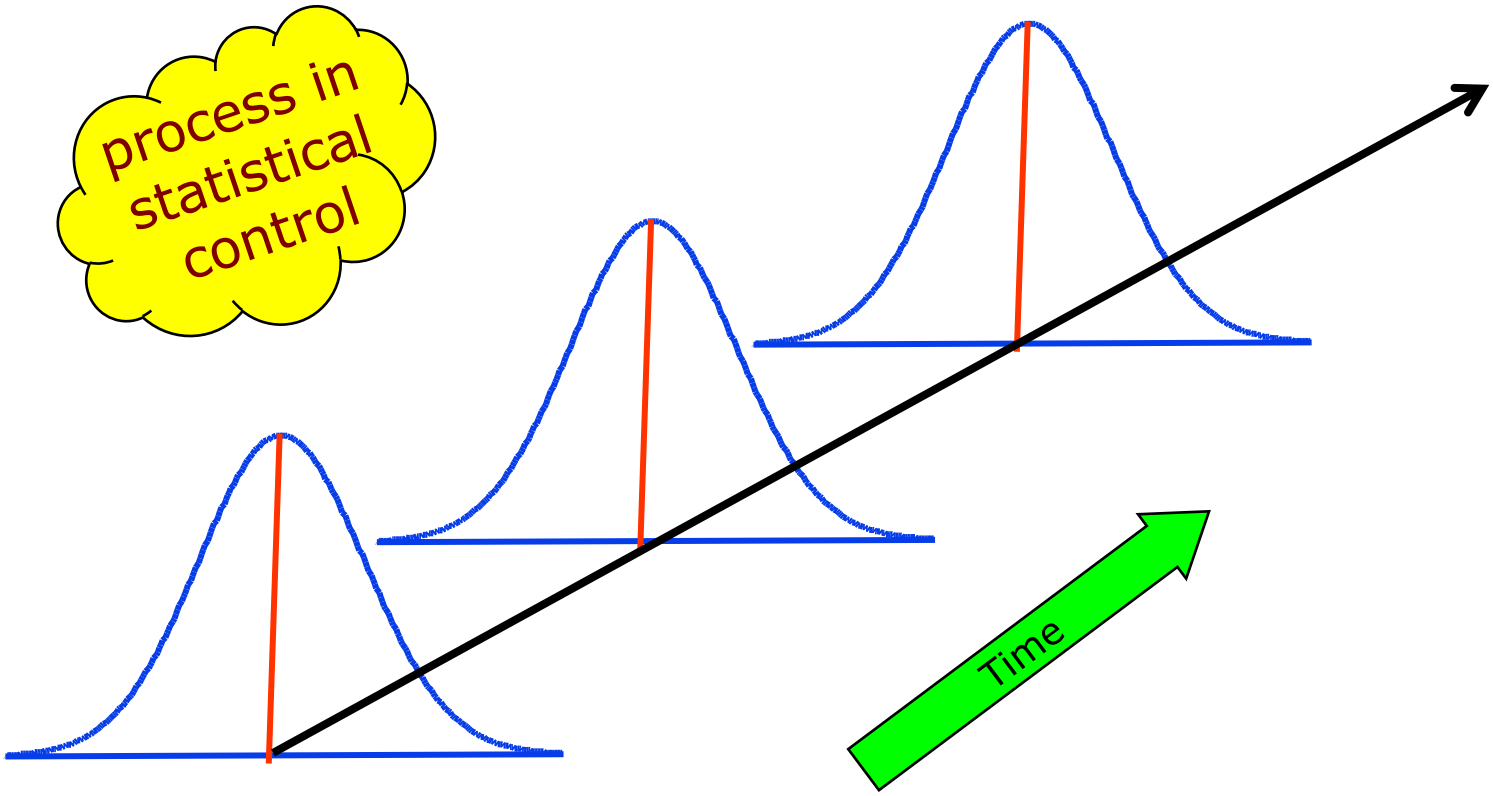
Statistically "Controlled Process"



A process is statistically controlled if only random variation influences are present and systematic variation has been eliminated.

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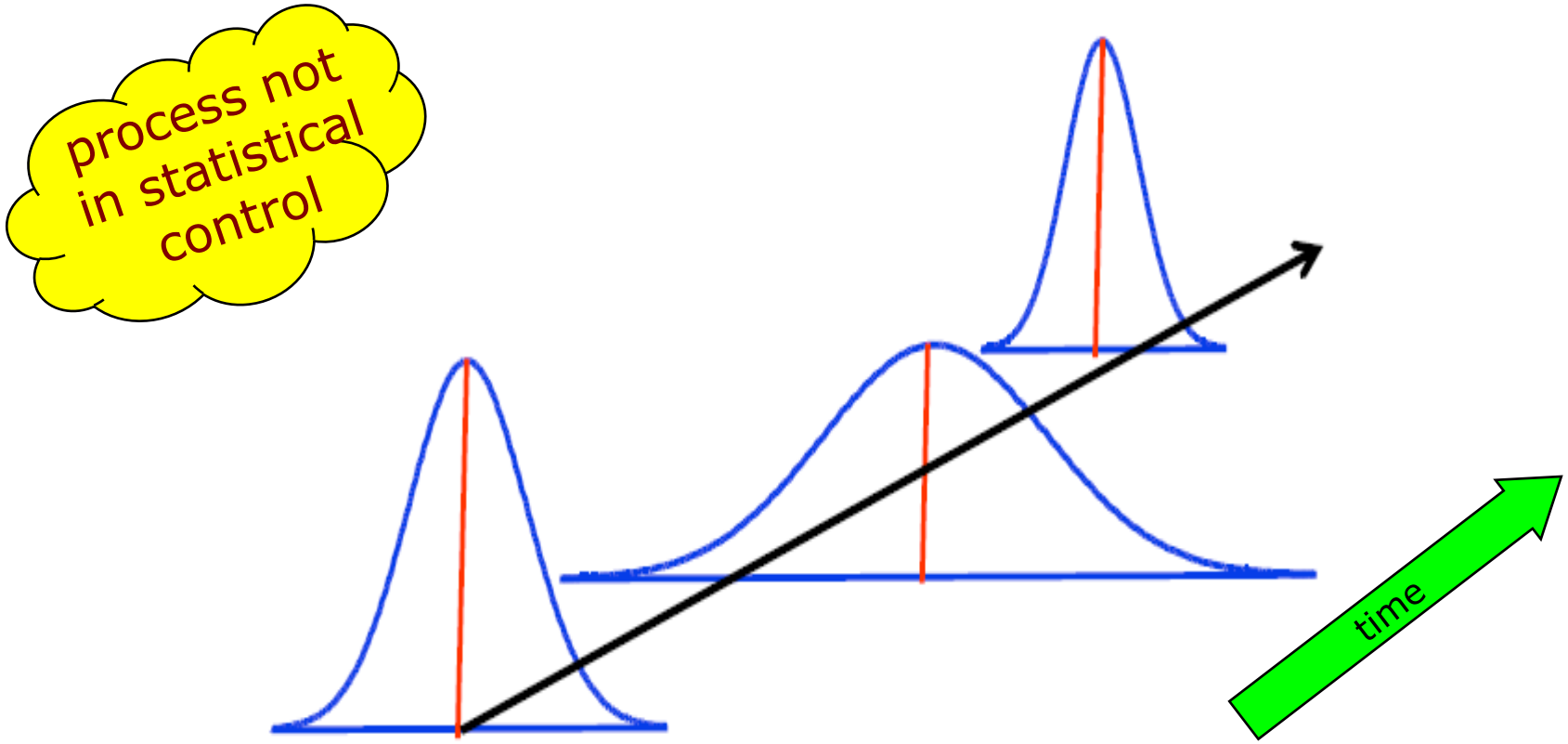
Statistically "Out-of-Control Process"



A process is statistically out of control if systematic variation is present. The distribution of the process results is out-of control over time.

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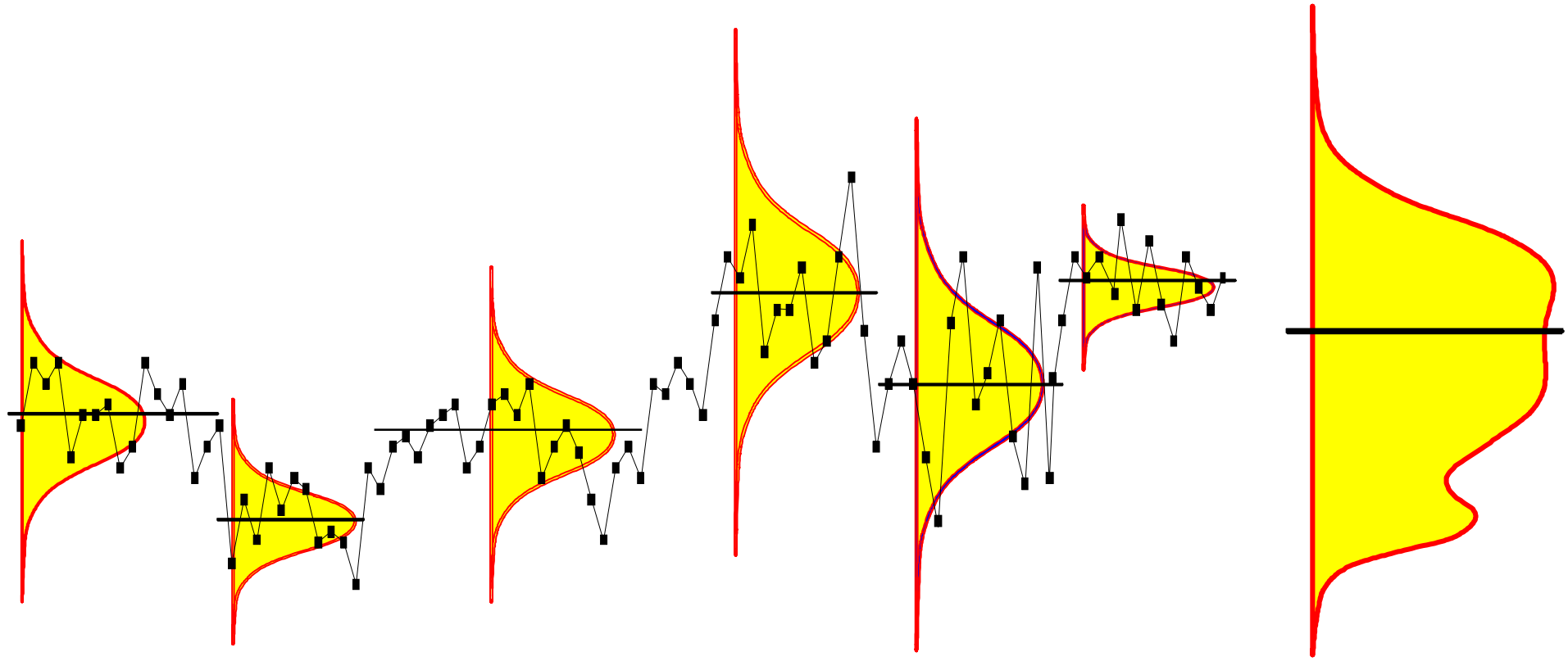
Process Progression: Out-of-control process



The widening of the distribution through out-of-control processes has serious consequences for process capability .

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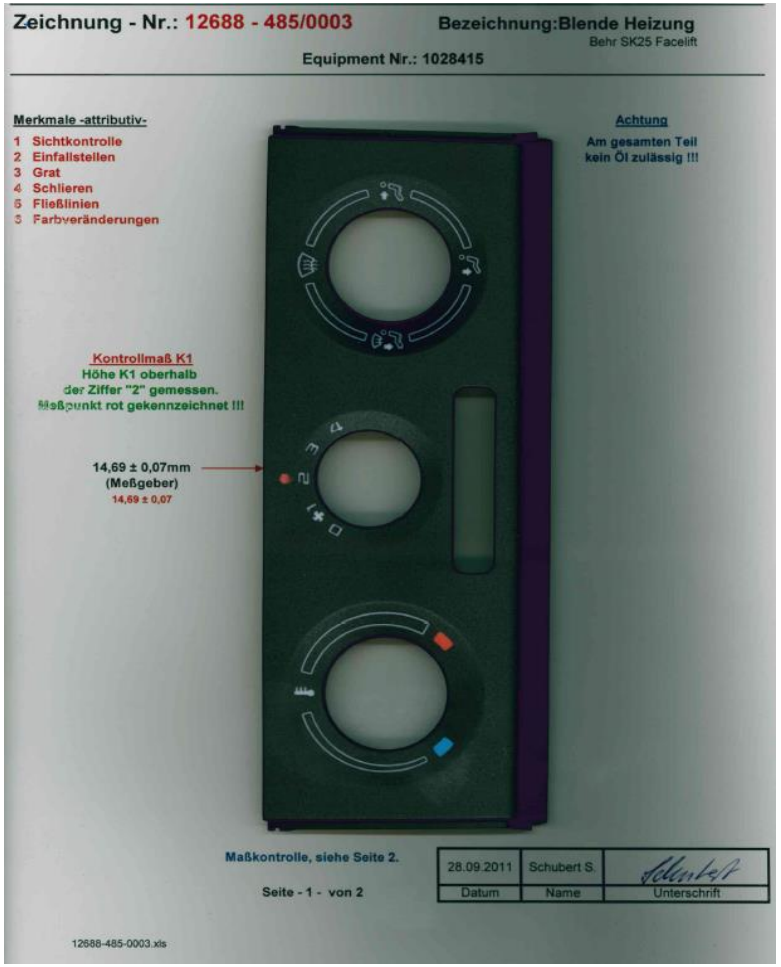
SPC – Case Example: Faceplate Heater



Characteristic 0030

Faceplate - Heater 5JO.819.075 B

Plan group 50047806 1

Material 12688-485/0003 SK25 FL

Description:

Control dimension height K1

USL	14,76 mm
Specified Value	14,69 mm
LSL	14,62 mm

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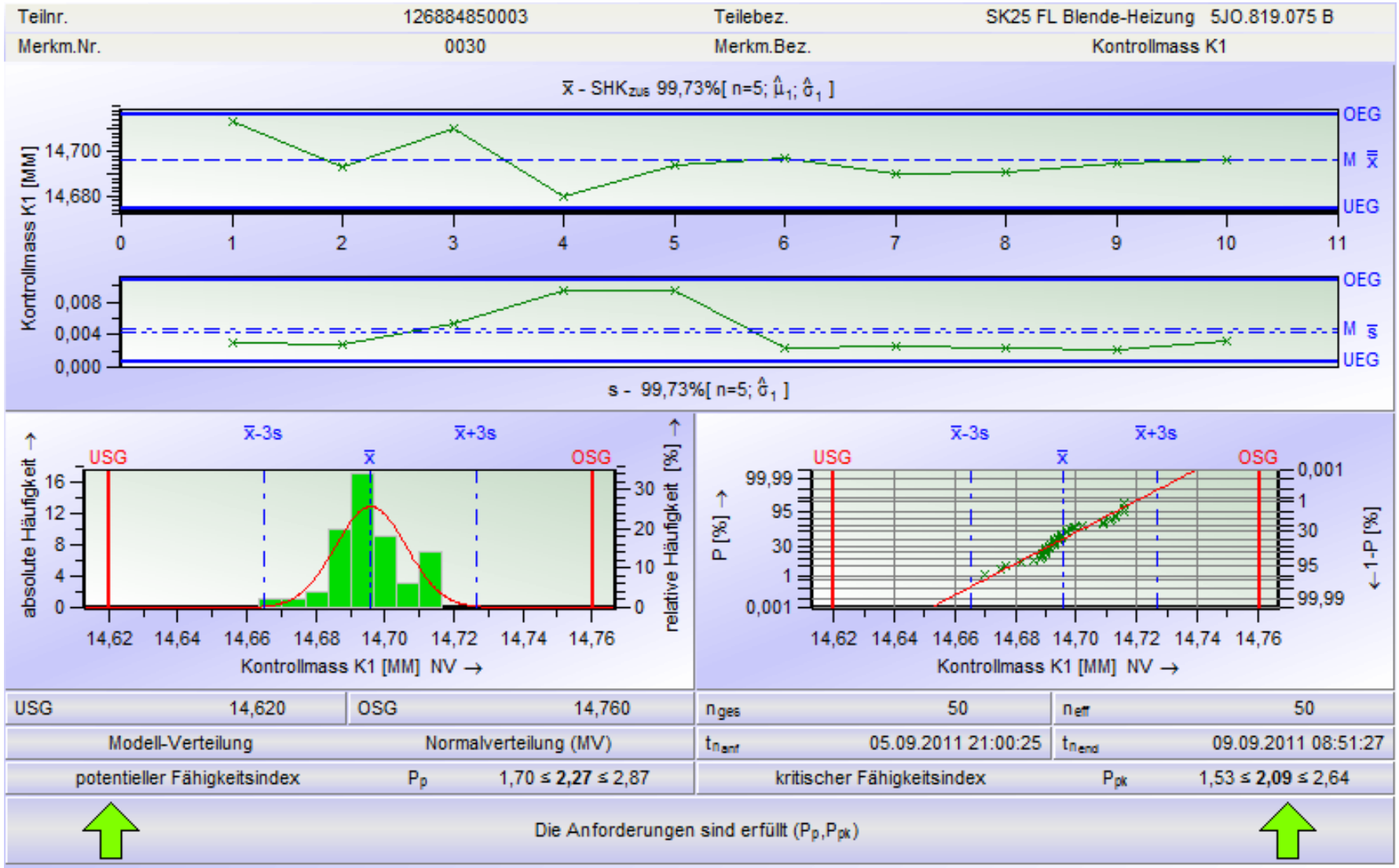
SPC – Case Example : Faceplate Heater



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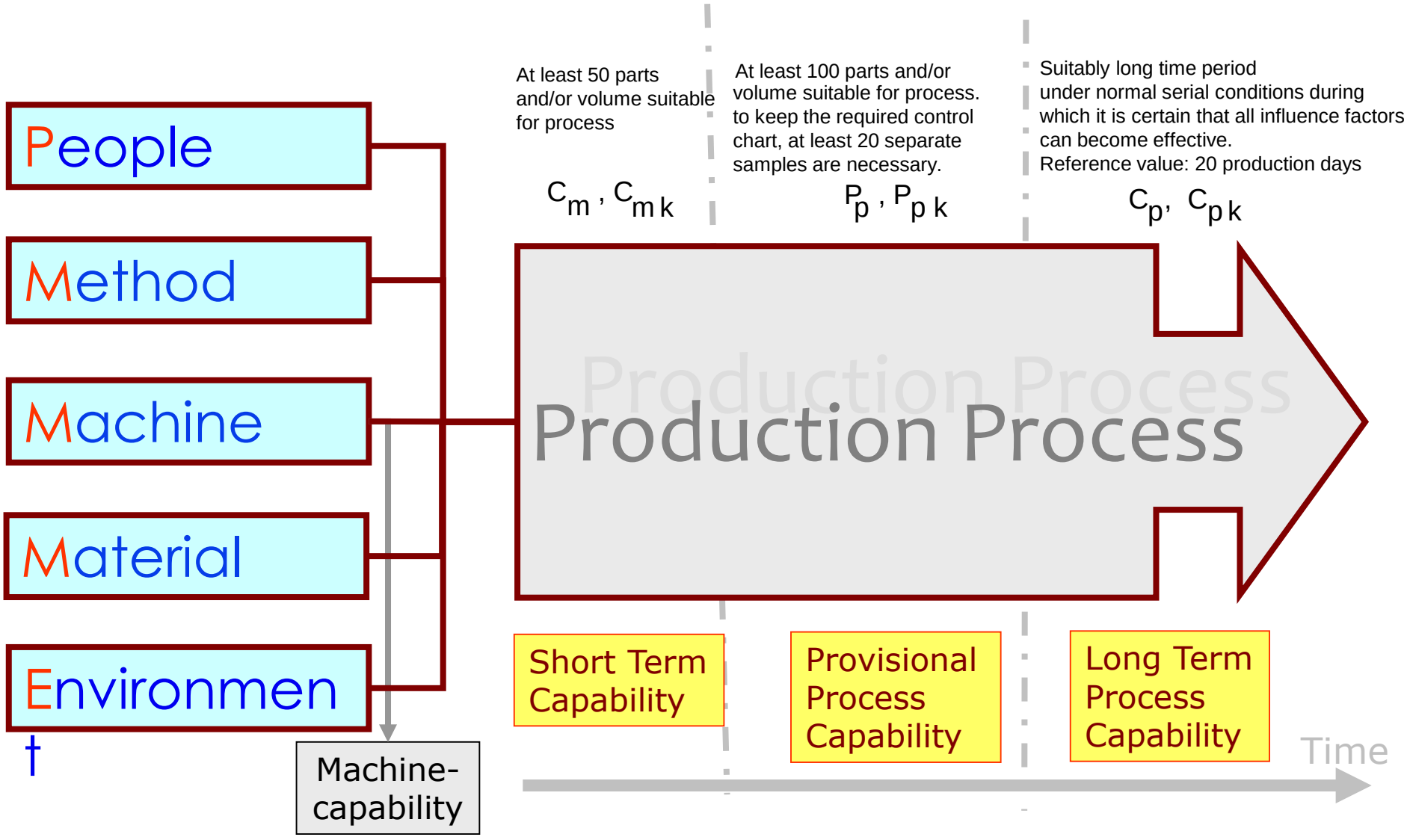
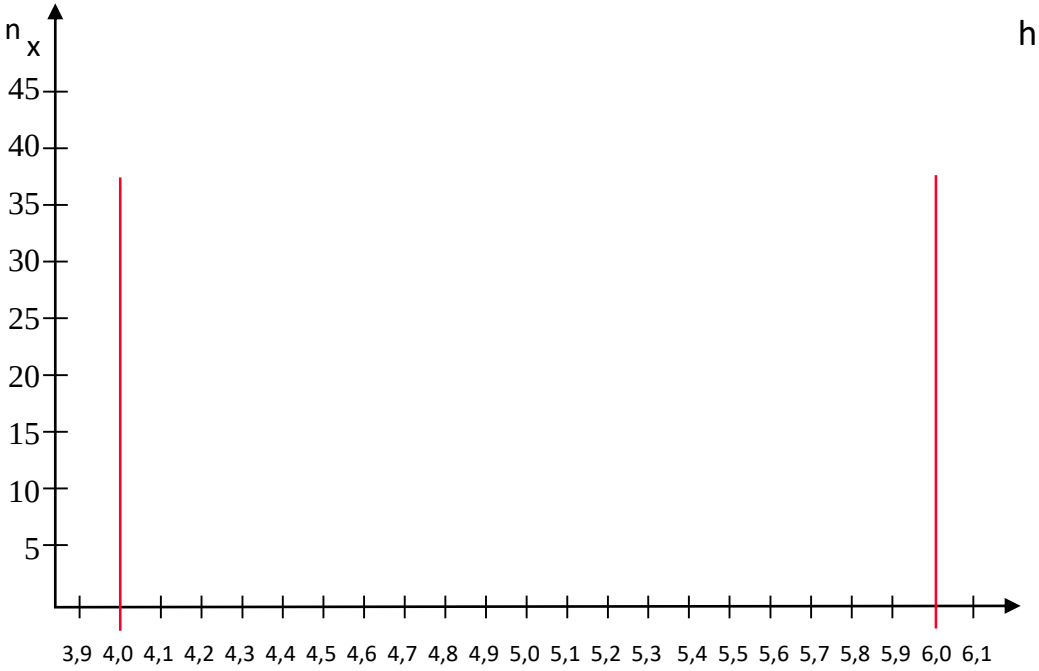
When to carry out Capability Test

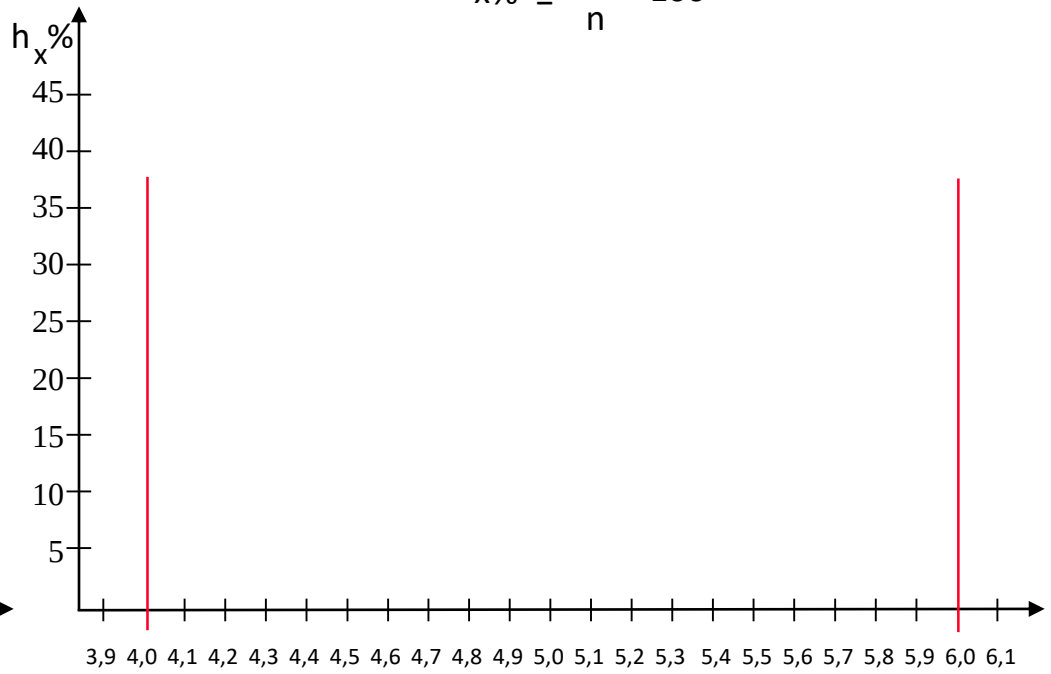


Machine capability example

USL 6,0
LSL 4,0

$$h_{x\%} = \frac{n_x}{n} \cdot 100$$





Important characteristics

$\bar{x}$, s, s^2 → Calculator

$\tilde{x}$ = 1 - 2 - 3 - 4 - 5 = 3

or. 1 - 2 - 3 - 4 - 5 - 6 = 3,5

R = x_{max} - x_{min}

$\bar{X}$ =

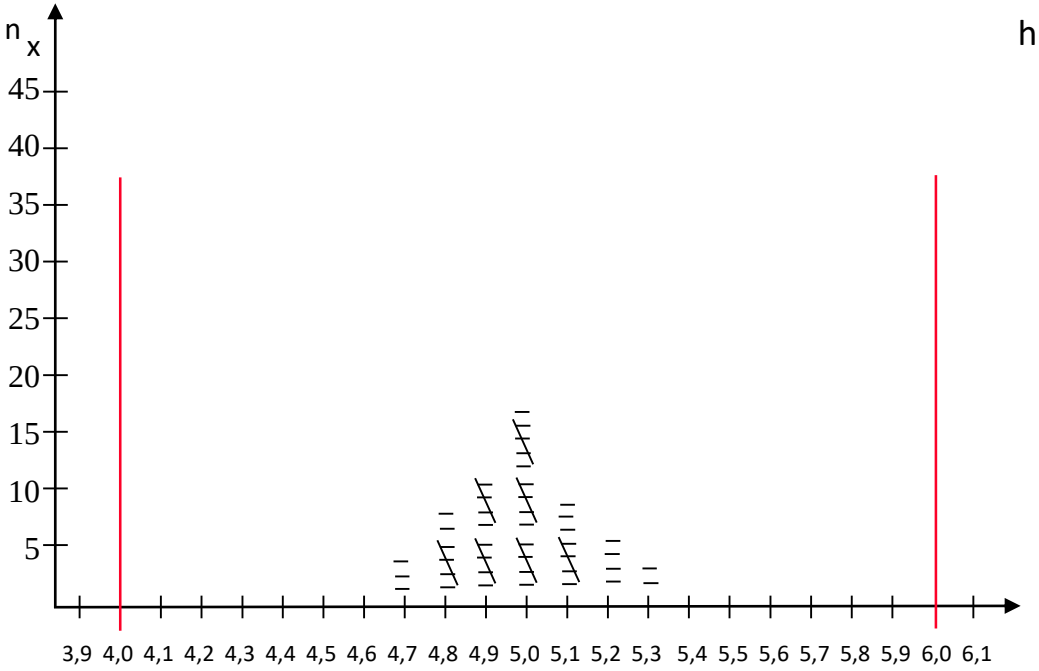
s =

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

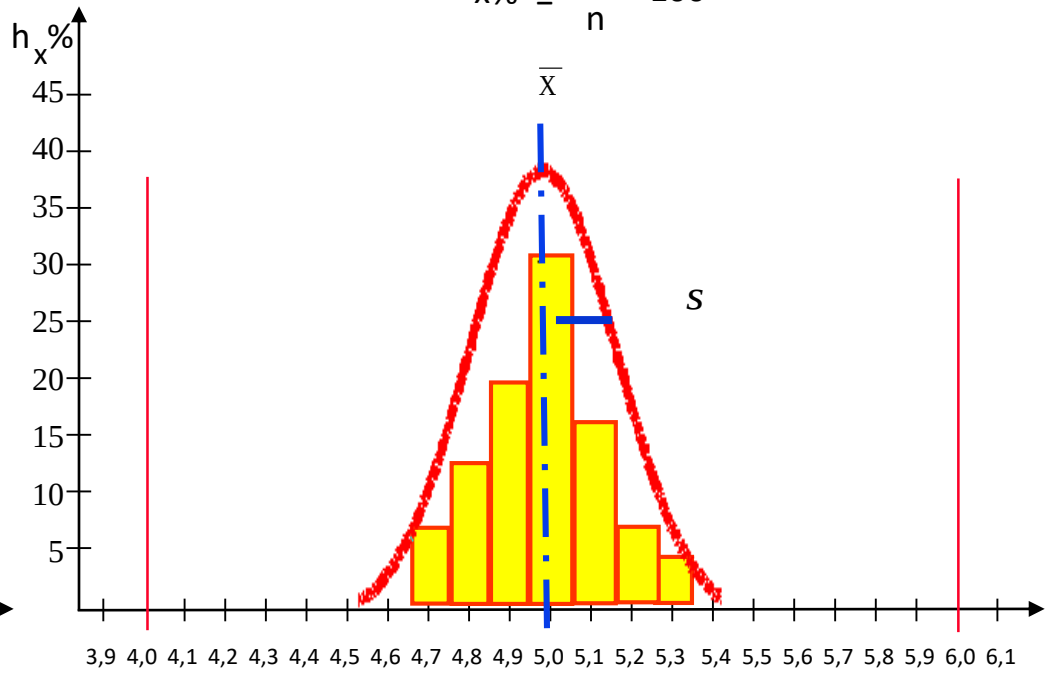
$$C_{mk} = Min\left\{\frac{\bar{X} - LSL}{3s}; \frac{USL - \bar{X}}{3s}\right\} =$$

Machine capability example

USL 6,0
LSL 4,0



$$h_{x\%} = \frac{n_x}{n} \cdot 100$$



Important characteristics

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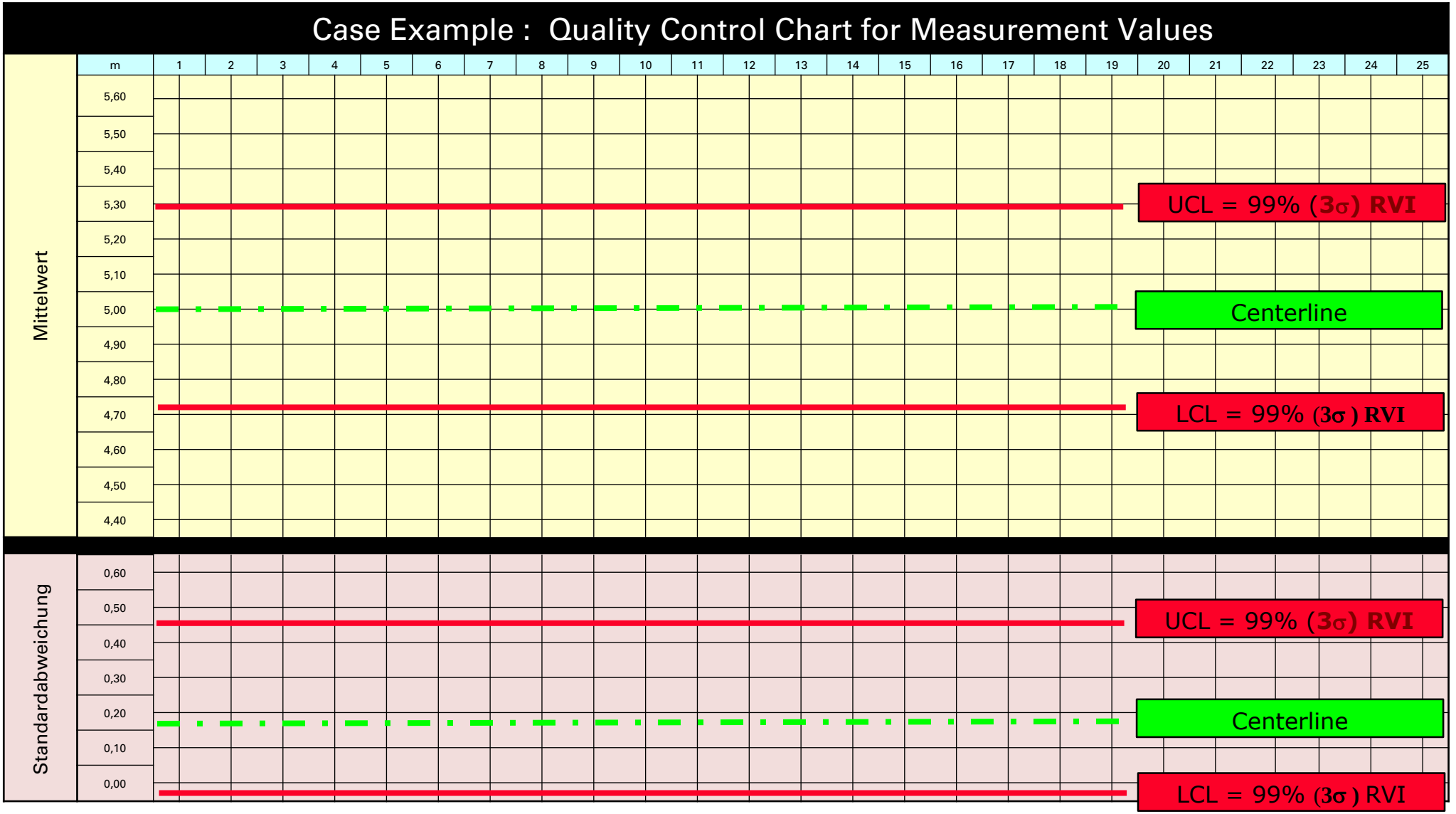
Automotive CORE-Tools: Module 5 - SPC

SPC – Case Example : Faceplate Heater



Automotive CORE-Tools: Modul 5 - SPC

Process capability example

Determination of the process parameters

	m_1	m_2	m_3	m_4	m_5	m_6	m_7	m_8	m_9	m_{10}	m_{11}	m_{12}	m_{13}	m_{14}	m_{15}	m_{16}	m_{17}	m_{18}	m_{19}	m_{20}	m_{21}	m_{22}	m_{23}	m_{24}	m_{25}	
1																										
2																										
3																										
4																										
5																									averages	
mean																									Mean average	
R																									R-average	
s																									s-average	
s^2																									s^2-average	

s - Method		R - Method		Variance - Method		s-gesamt	

$$C_p = \frac{USL - \text{LSL}}{6\,\hat{\sigma}} =$$

$$C_{pk} = Min\left\{\frac{\hat{\mu} - LSL}{3\,\hat{\sigma}}; \frac{USL - \hat{\mu}}{3\,\hat{\sigma}}\right\} =$$

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Calculation of Process Variation

- From the forerun data the estimates for average μ and standard deviation σ are calculated:
- Estimator for the mean: →

$$\hat{\mu} = \bar{\bar{x}} = \frac{\sum_{i=1}^{k} \bar{x}_i}{k}$$

- Estimator for the standard deviation σ:

$$\hat{\sigma} = \sqrt{\bar{s^2}}; \quad \bar{s^2} = \frac{\sum_{i=1}^{m} s_i^2}{m}$$

or

$$\hat{\sigma} = \frac{\bar{s}}{a_n}; \quad \bar{s} = \frac{\sum_{i=1}^{m} s_i}{m}$$

or

$$\hat{\sigma} = \frac{\bar{R}}{d_n}; \quad \bar{R} = \frac{\sum_{i=1}^{m} R_i}{m}$$

n	a_n	d_n
2	0,798	1,128
3	0,886	1,693
4	0,921	2,059
5	0,940	2,326

Automotive CORE-Tools: Modul 5 - SPC

Process capability example

Process Control chart

																														USL	6,0
																														LSL	4,0

Sample #		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Mean	5,20																									
	5,15																									
	5,10																									
	5,05																									
	5,00																									
	4,95																									
	4,90																									
	4,85																									
	4,80																									
Standard Deviation	0,35																									
	0,30																									
	0,25																									
	0,20																									
	0,15																									
	0,10																									
	0,05																									
	0,00																									
Shift																										
Time/Date																										
Employee ID																										
x1																										
x2																										
x3																										
x4																										
x5																										
Mean																										
Range																										
Standard Deviation																										
Variance s^2																										

Average Chart

$$UCL = \hat{\mu} + 2{,}58 \cdot \frac{\hat{\sigma}}{\sqrt{n}}$$

$$LCL = \hat{\mu} - 2{,}58 \cdot \frac{\hat{\sigma}}{\sqrt{n}}$$

UCL =

LCL =

s–Chart

$$UCL = 1{,}93 \cdot \hat{\sigma}$$

$$LCL = 0{,}23 \cdot \hat{\sigma}$$

UCL =

LCL =

Process Capability

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

$$C_{pk} = Min\left\{\frac{\hat{\mu} - LSL}{3\hat{\sigma}}; \frac{USL - \hat{\mu}}{3\hat{\sigma}}\right\} =$$

cp:

cpk:

Average	Process parameter
	$\hat{\mu} = \frac{\sum \bar{x}_i}{m}$
	$\hat{\sigma} = \sqrt{\bar{s}^2}$; $\bar{s}^2 = \frac{\sum s_i^2}{m}$

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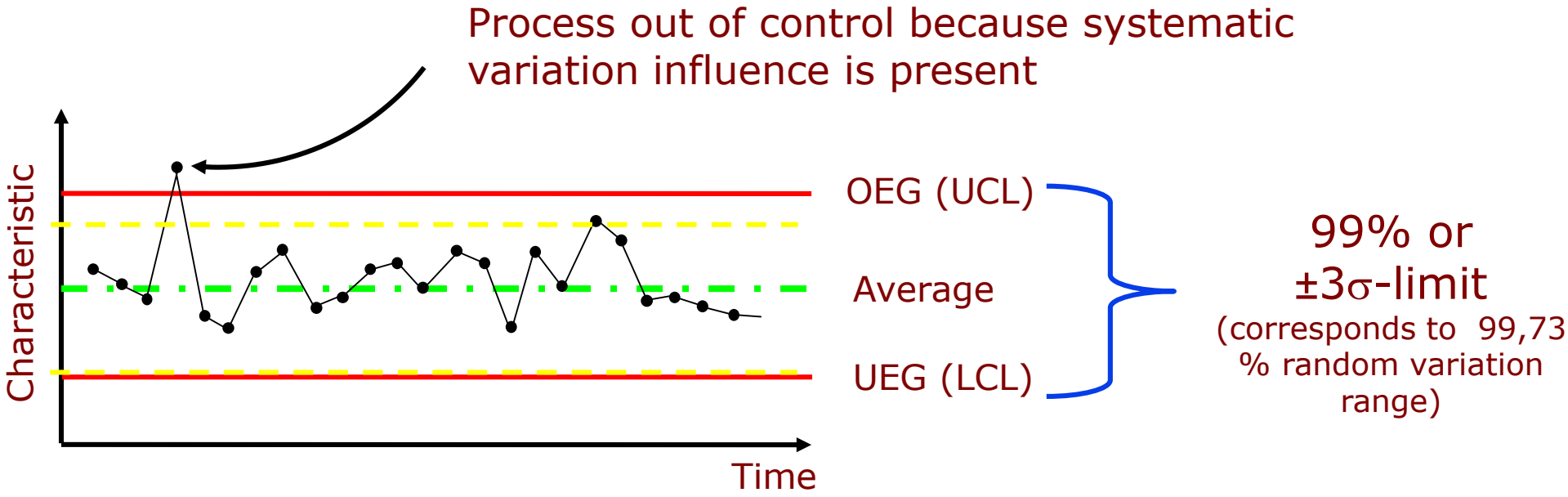
Basic Idea of SPC



Basic Idea:

No intervention as long as process moves within the range of natural variation: Distinction between random and systematic variation influences e.g. a test to check if the process is controlled.

Important:

Shewhart quality control charts do not take into account the specification limits.

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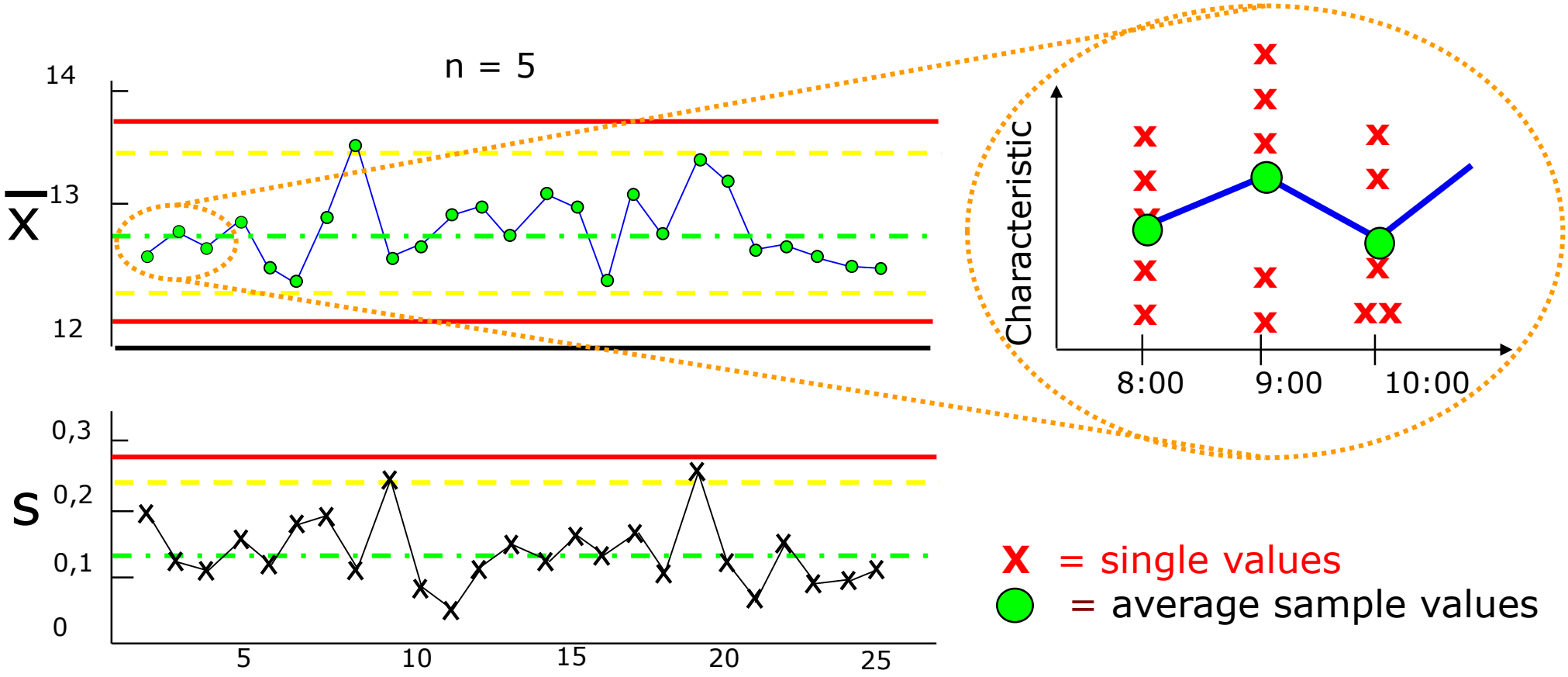
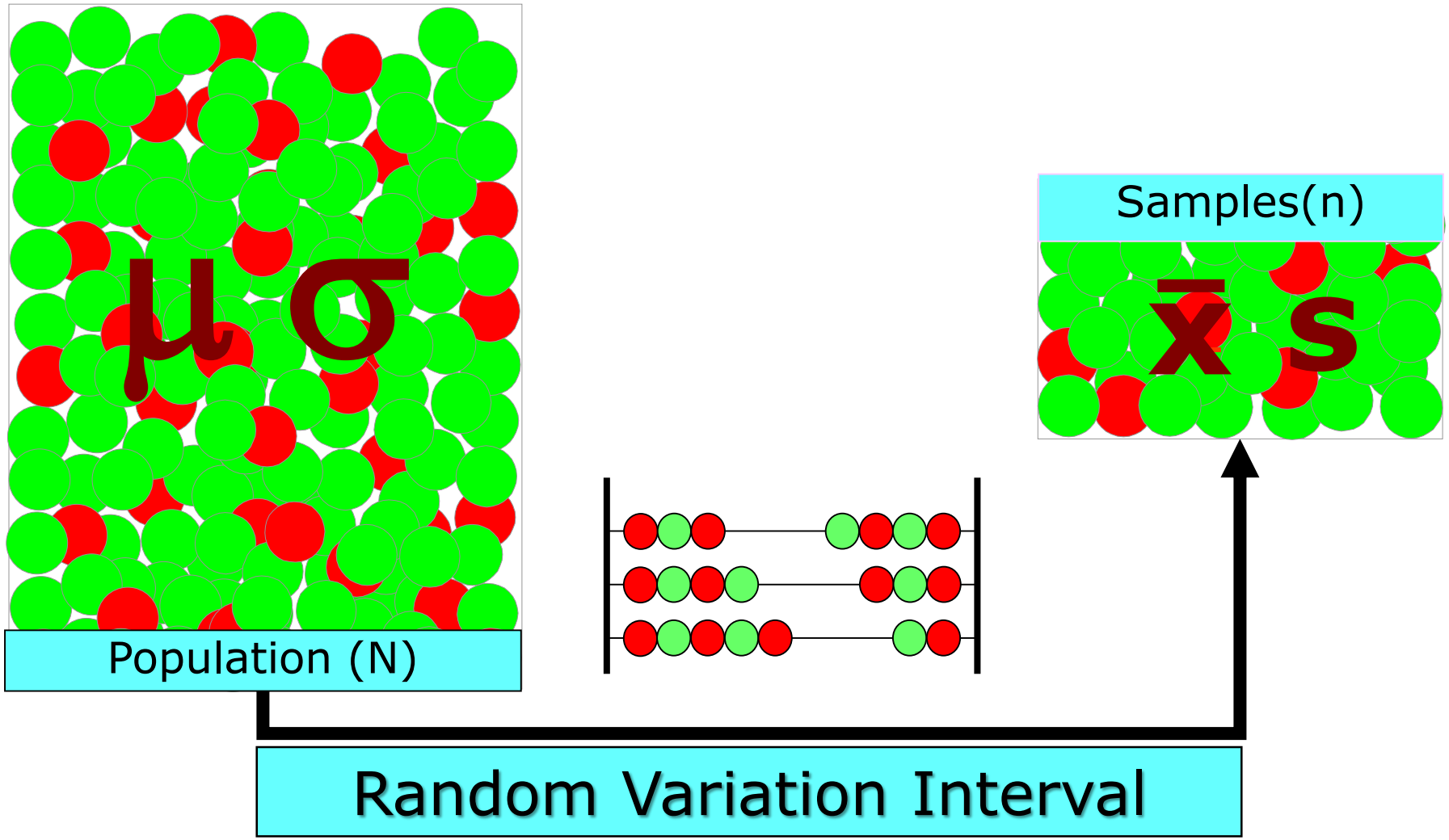
Entry into the QRK



Entered in a QRK are only the characteristic values
(averages, medians, standard deviation, range)
and the intervention limits; the specification limits are normally not shown.

Structure of the Random Variation Range



Formula for Intervention Limits

Average Chart

$$UCL = \hat{\mu} + u_{1-\frac{\alpha}{2}} \cdot \frac{\hat{\sigma}}{\sqrt{n}}$$

$$LCL = \hat{\mu} + u_{\frac{\alpha}{2}} \cdot \frac{\hat{\sigma}}{\sqrt{n}}$$

- The probability of non-intervention to be selected (1-α) is generally 99 % or 99,73 % (± 3 σ).

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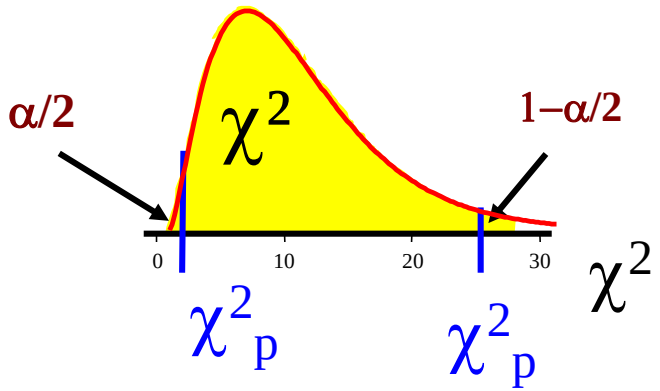
Formula for Intervention Limits

Standard Deviation Chart

$$UCL = \sqrt{\frac{\chi^2_{f;1-\alpha/2}}{f}} \cdot \hat{\sigma}$$

$$LCL = \sqrt{\frac{\chi^2_{f;\alpha/2}}{f}} \cdot \hat{\sigma}$$



The probability of non-intervention1-α is generally 99 % or 99,73 %.

- χ^2 = Quantile of χ^2-distribution for $\alpha/2$ and $1-\alpha/2$
- f = Number of degrees of freedom = Number of samples – 1

Friedrich Robert Helmert
1843 bis 1917

Simpler Formulae for intervention Limits

The intervention limits for the variation chart with a confidence of (1-α) = 99% result from following formulae:

$$UCL = B'_{Eob} \cdot \hat{\sigma}$$

$$LCL = B'_{Eun} \cdot \hat{\sigma}$$

For the sample n = 5 applies; (1-α) = 99%:

B'_{Eun} ; B'_{Eob}
0,23 ; 1,93

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Exercise: Intervention Limit

(1-α) = 99%:

Given:

$\hat{\sigma} = 0.2$

$\hat{\mu} = 5{,}0$

$n = 5$

$u_{(99\%)} = 2{,}58$

Average Chart

$$UCL = \hat{\mu} + 2{,}58 \cdot \frac{\hat{\sigma}}{\sqrt{n}}$$

$$LCL = \hat{\mu} - 2{,}58 \cdot \frac{\hat{\sigma}}{\sqrt{n}}$$

s–Chart

$$UCL = 1{,}93 \cdot \hat{\sigma}$$

$$LCL = 0{,}23 \cdot \hat{\sigma}$$

Solution:

Average Chart

UCL =

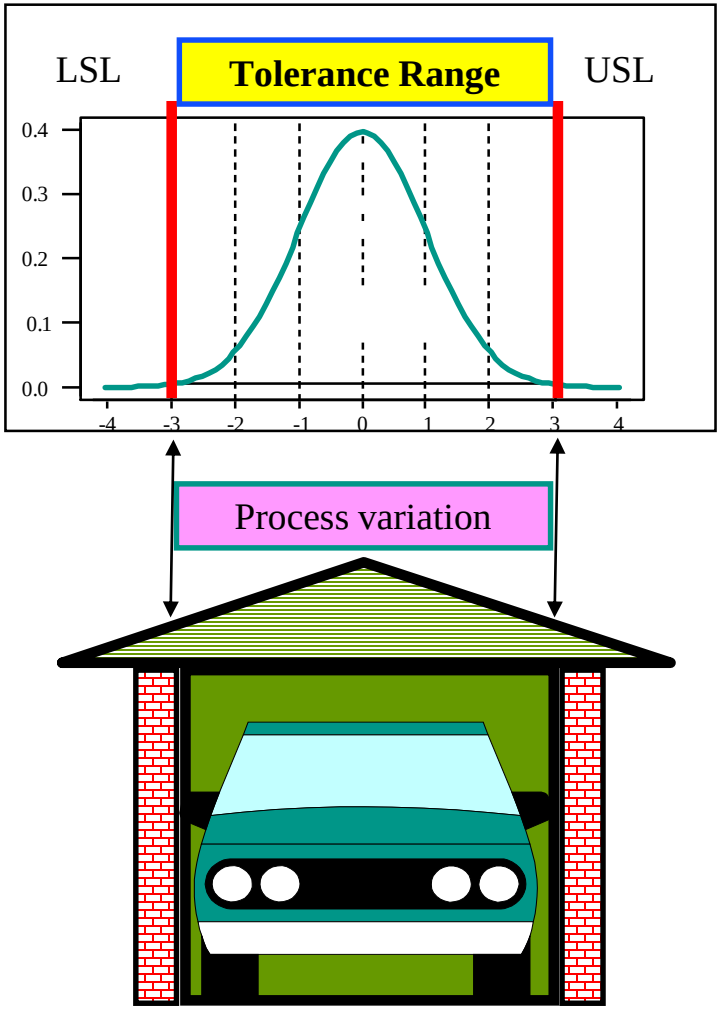
LCL =

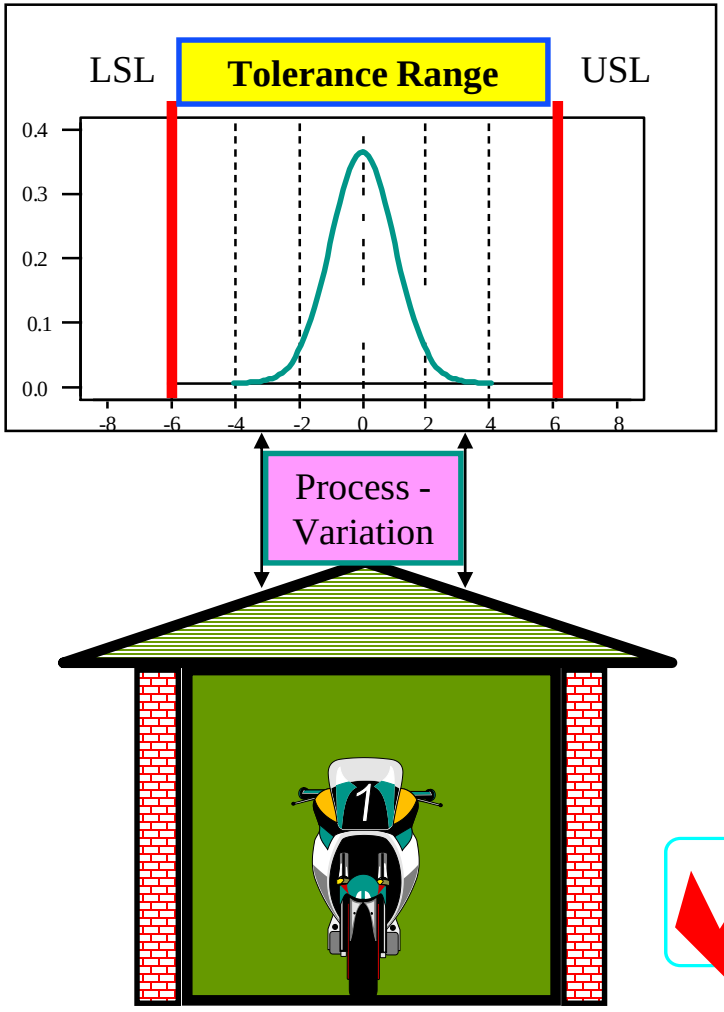
S-Chart

UCL =

LCL =

Automotive CORE-Tools: Module 5 - SPC
Practical Exercise





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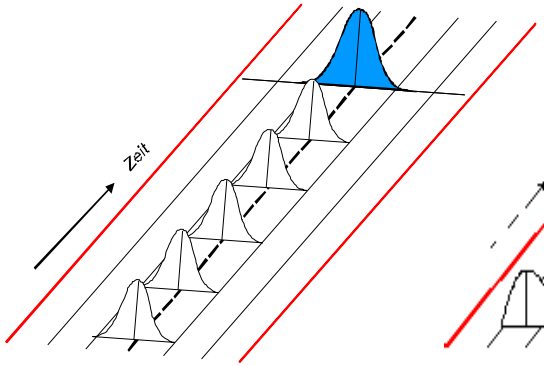
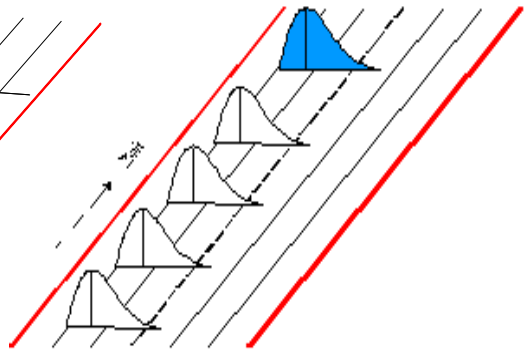
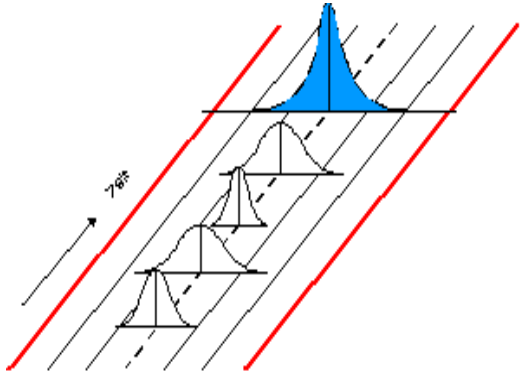
Distribution Models in Operational Praxis



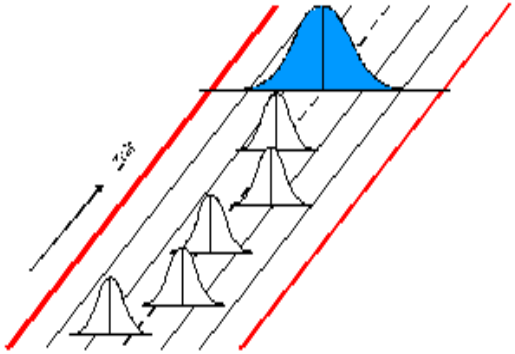
A1



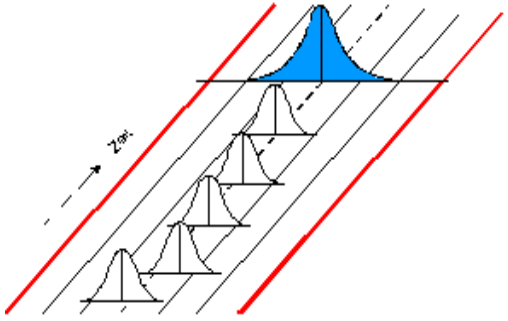
A2



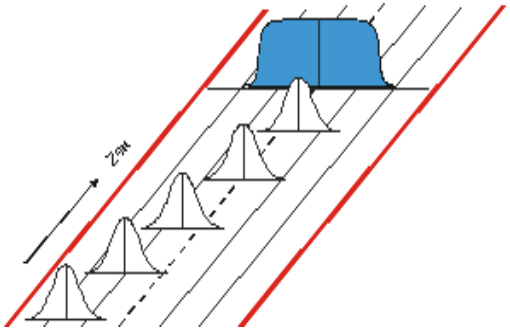
B



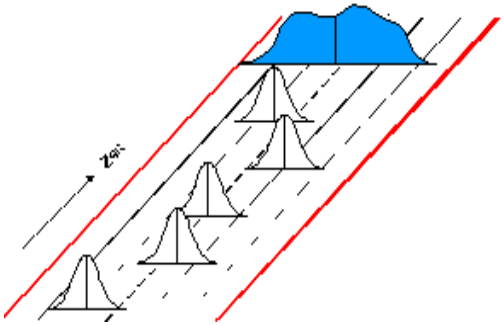
C1



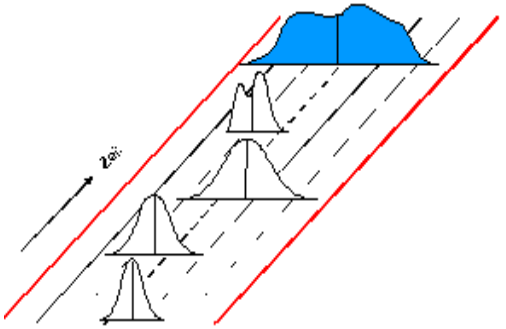
C2



C3



C4

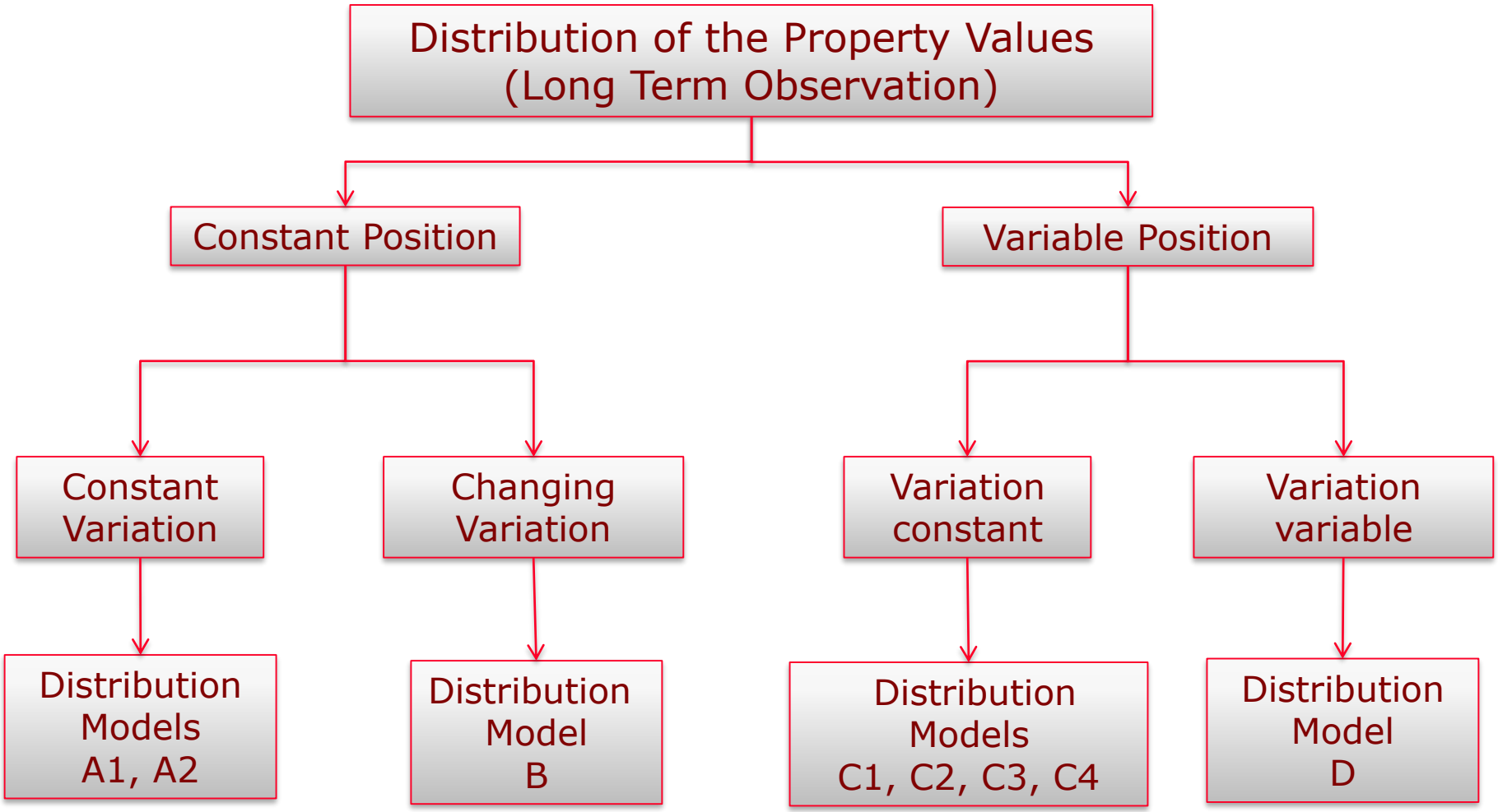


D

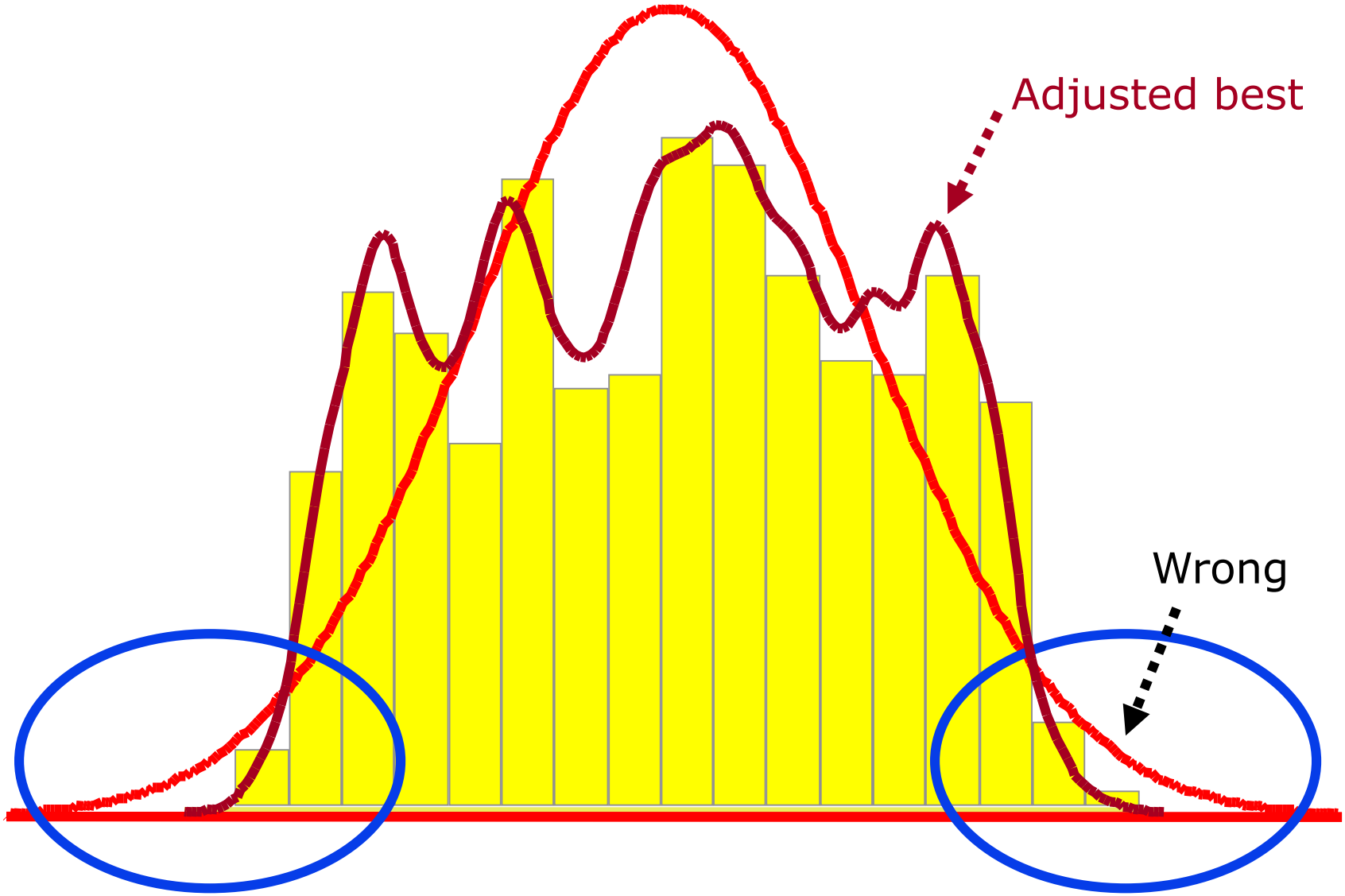
Distribution Models in Operational Praxis

Distribution	Distribution Model	Frequency
Normal Distribution	A1	1,8 %
Amount Distribution Weibull Distribution Log. Normal Distribution	A2	2,4%
Mixed Distribution with constant position	B	0,4%
Mixed Distribution	C1, C2, C3, C4, D	95,4%

SPC – Statistical Process Control

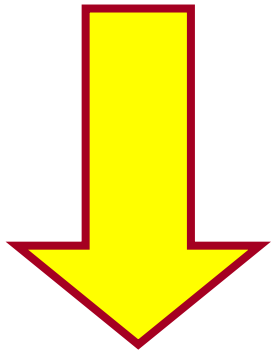


Correct Distribution Model

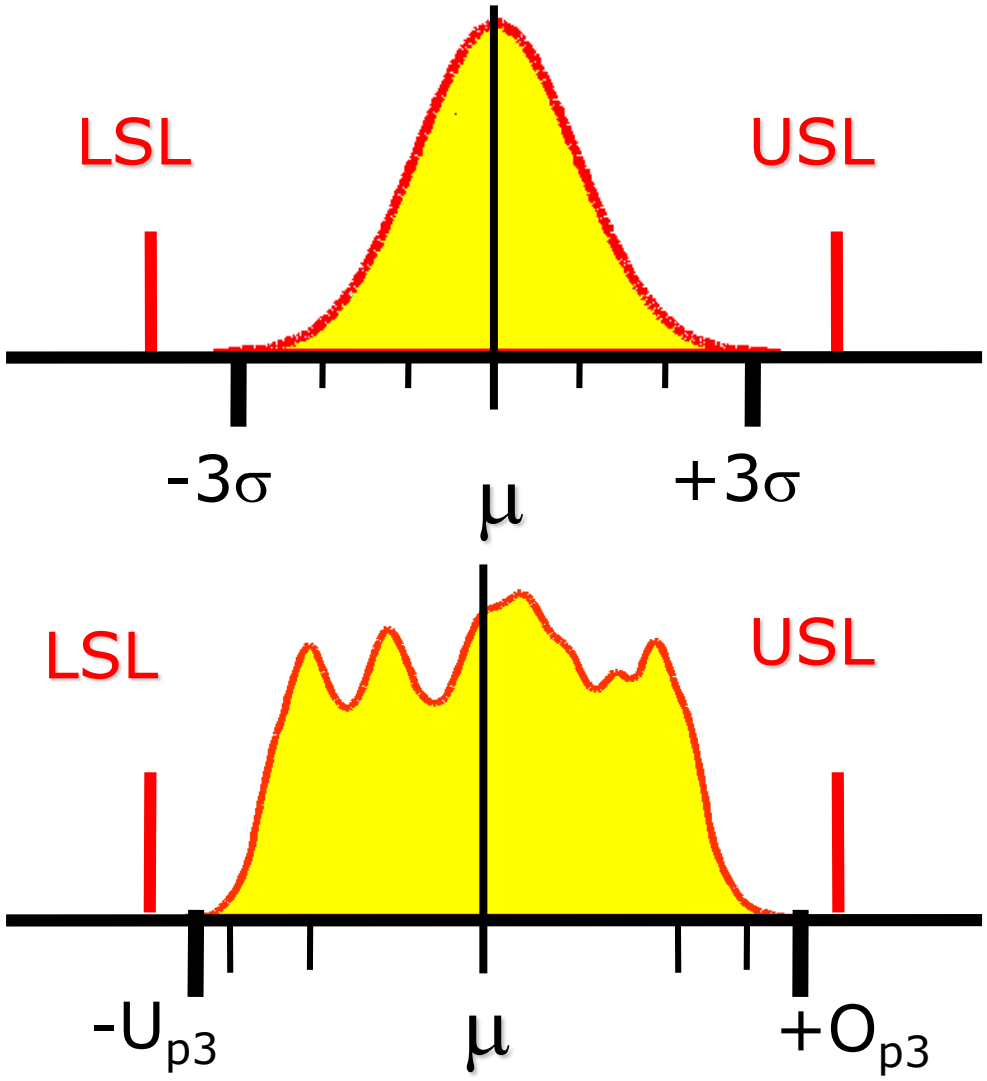


Distribution Models

Normal Distribution

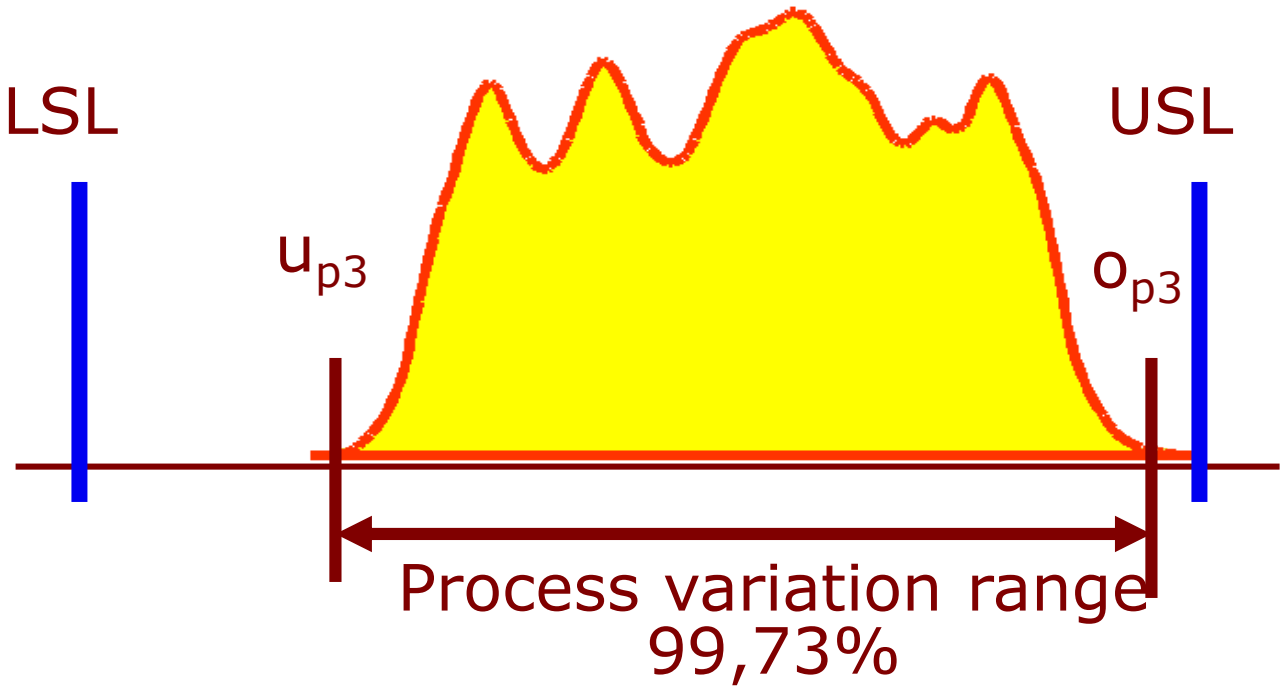


Other Distributions



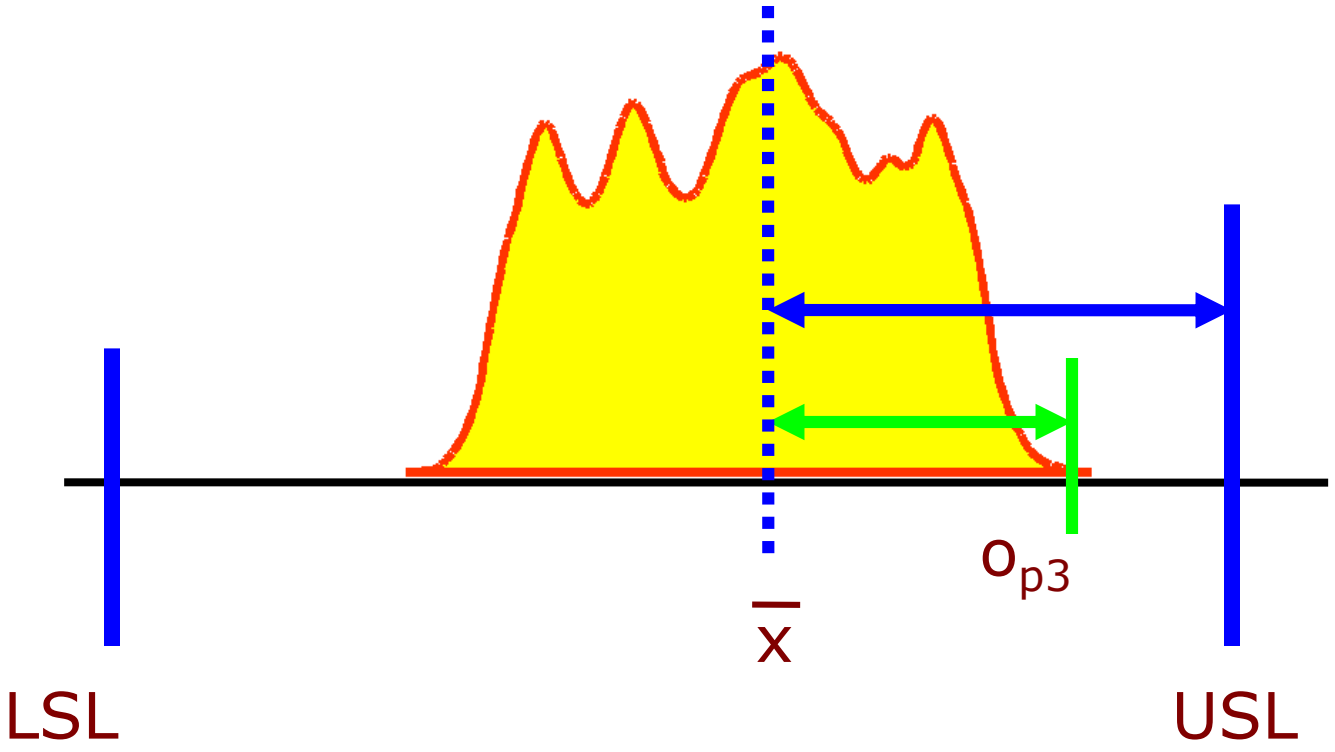
SPC – Capability Indices C_m, P_p, C_p

$$\text{Potential/Performance} = \frac{\text{USL - LSL}}{u_{p3} - o_{p3}}$$



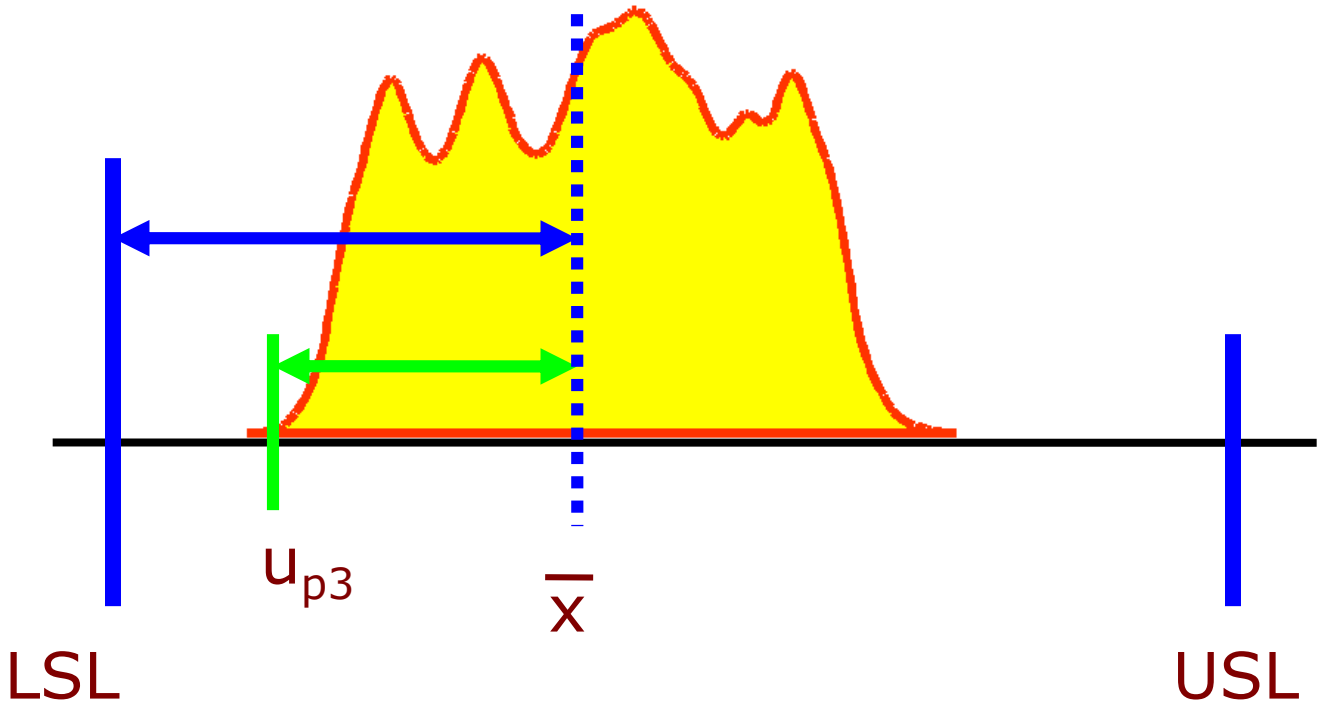
Critical Capability Indices USL

$$C_{mko},\ P_{pko},\ C_{pko} = \frac{USL - \bar{x}}{o_{p3} - \bar{x}}$$



Critical Capability Indices LCL

$$C_{mku},\ P_{pku},\ C_{pku} = \frac{\bar{x} - LSL}{\bar{x} - u_{p3}}$$



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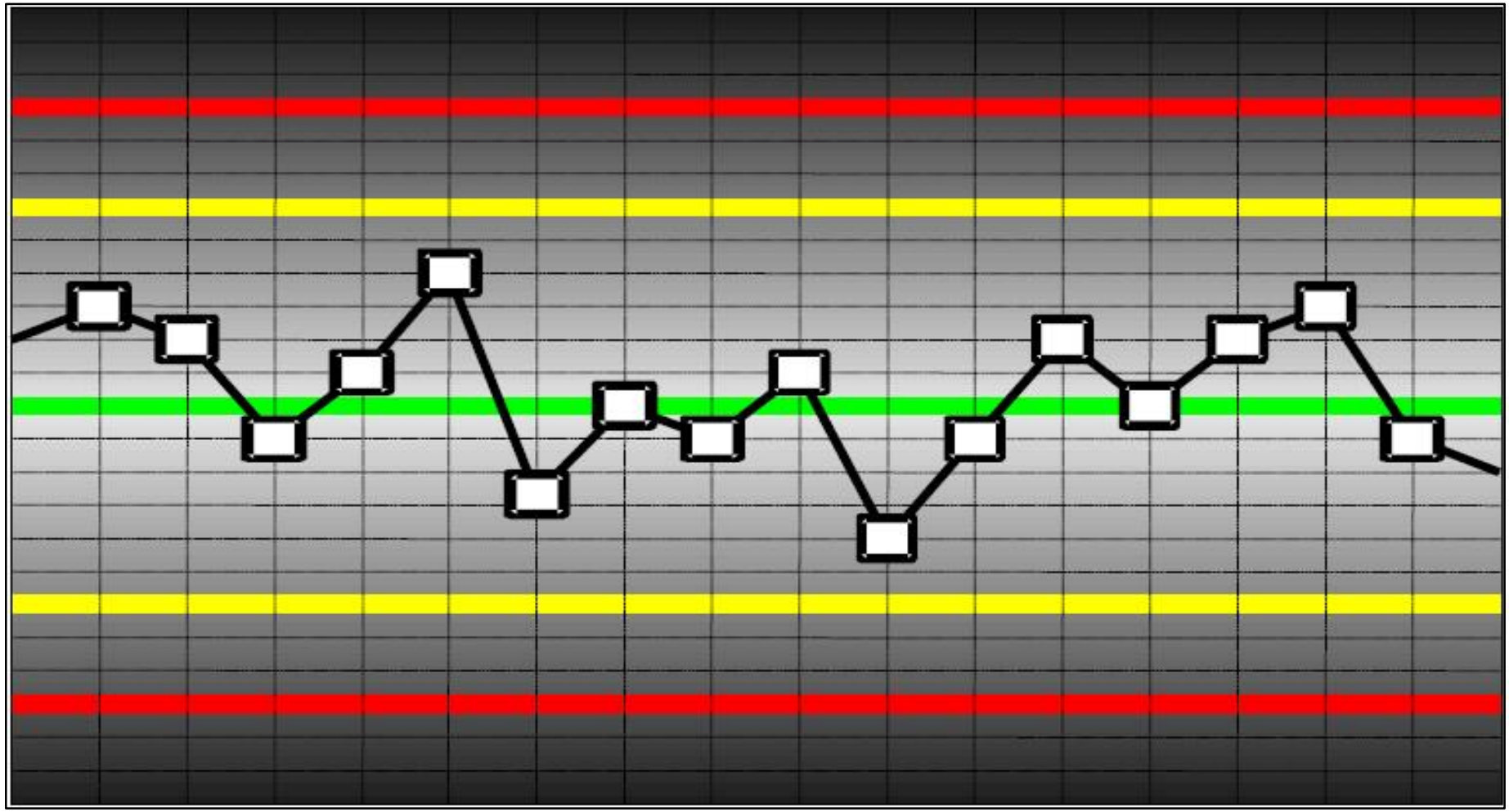
Controlled Process



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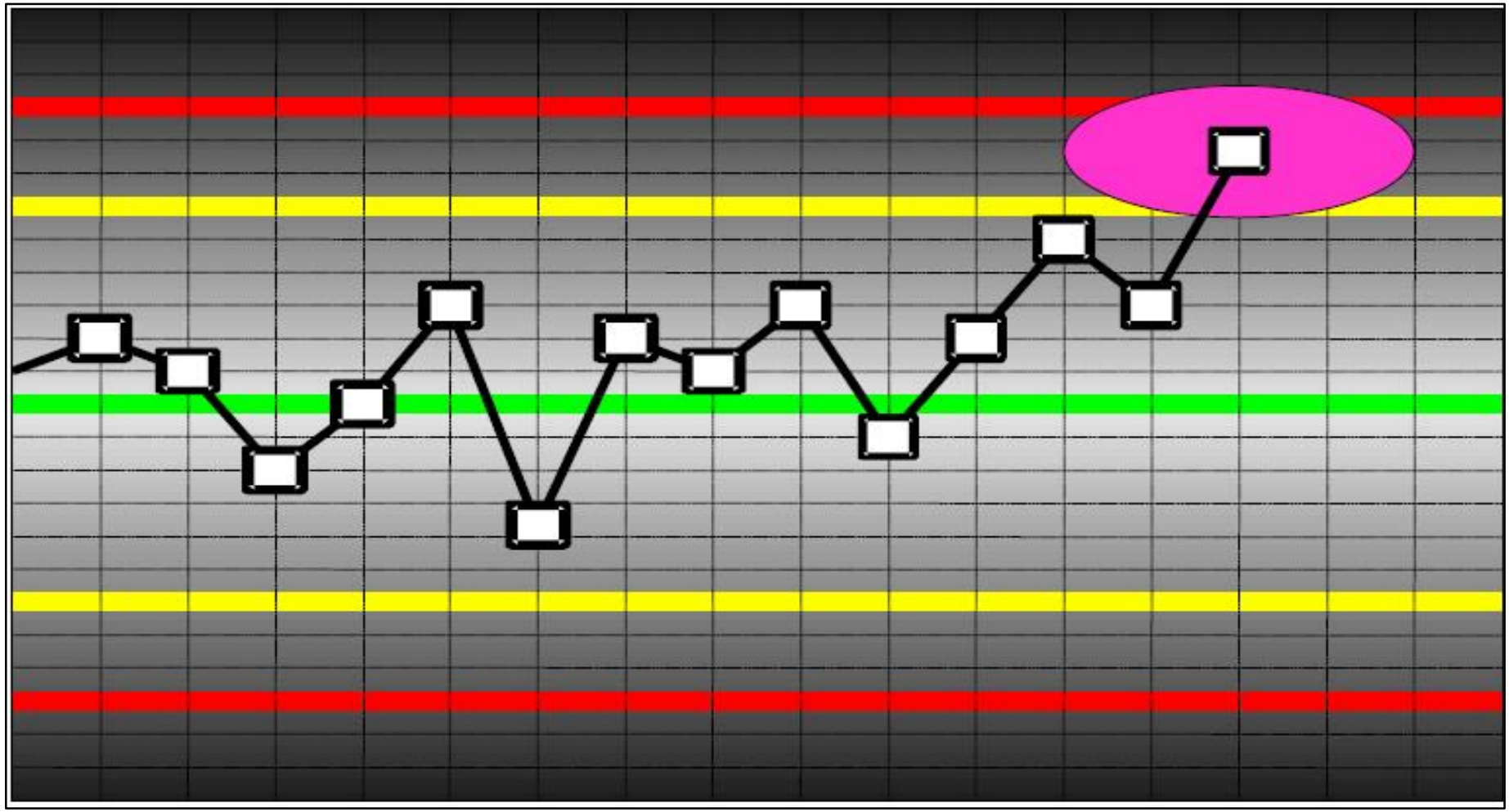
Warning Limit Exceeded



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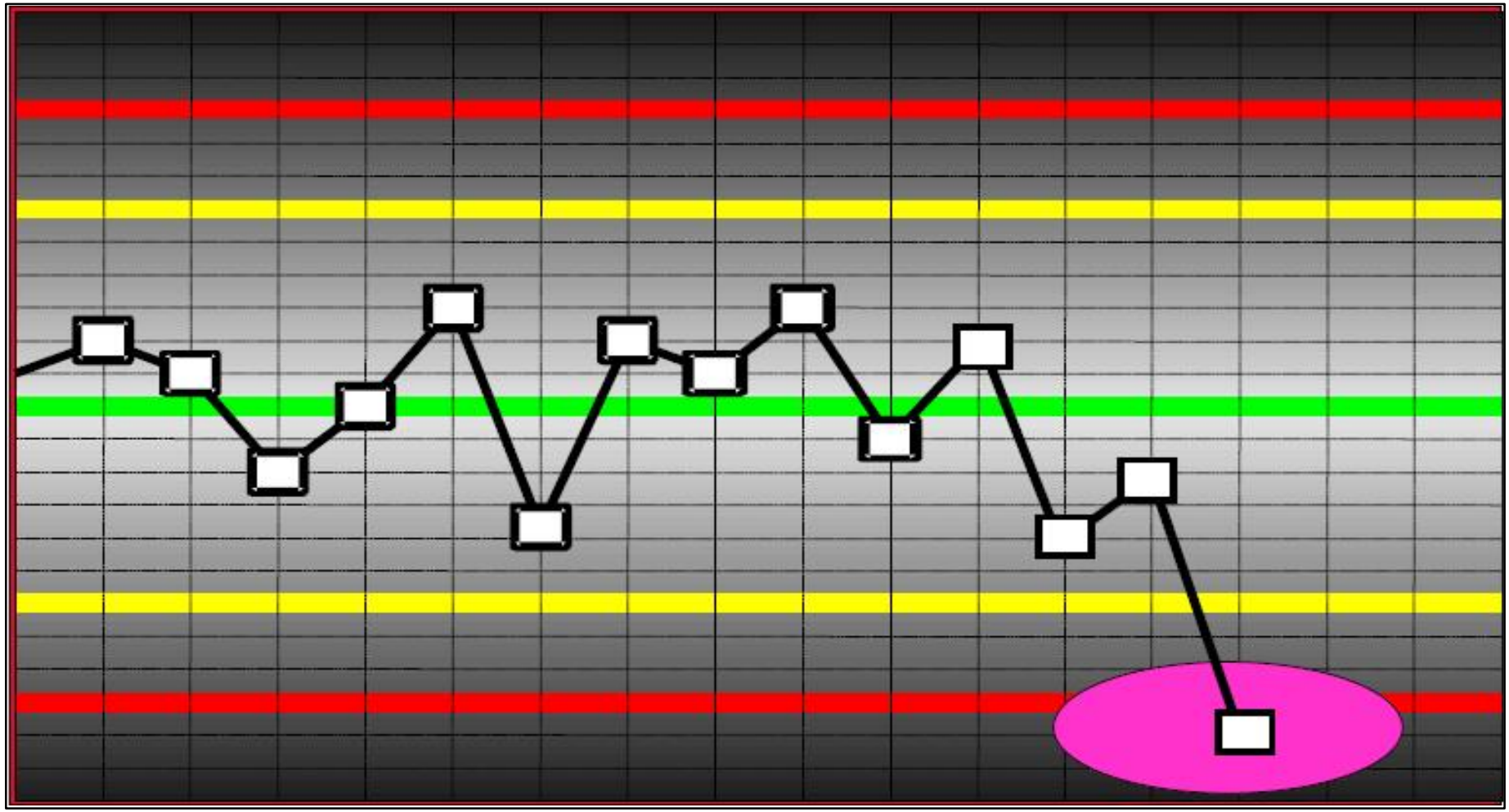
Interception Limit Exceeded



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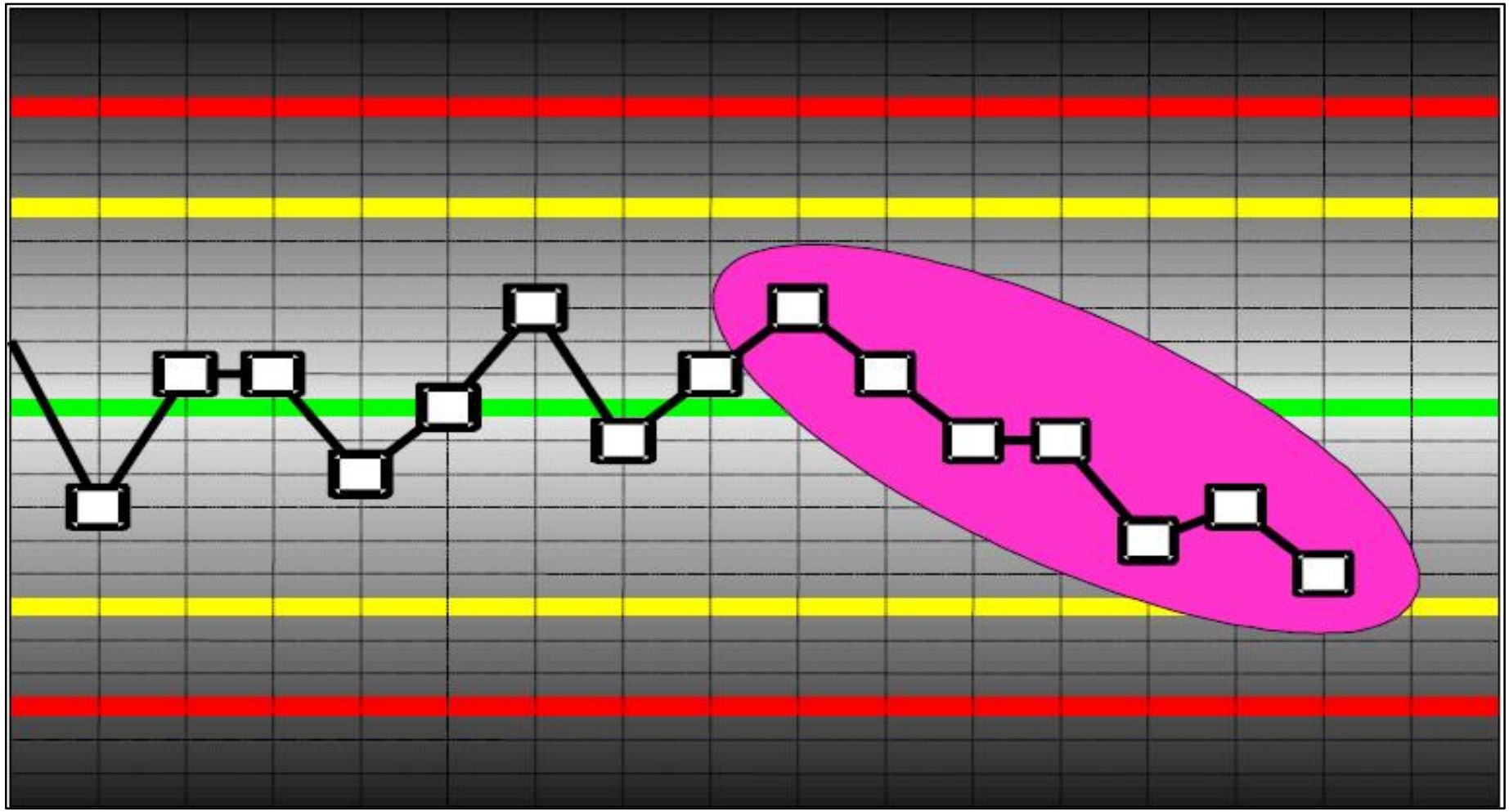
7 Values In- or Decreasing (Trend)



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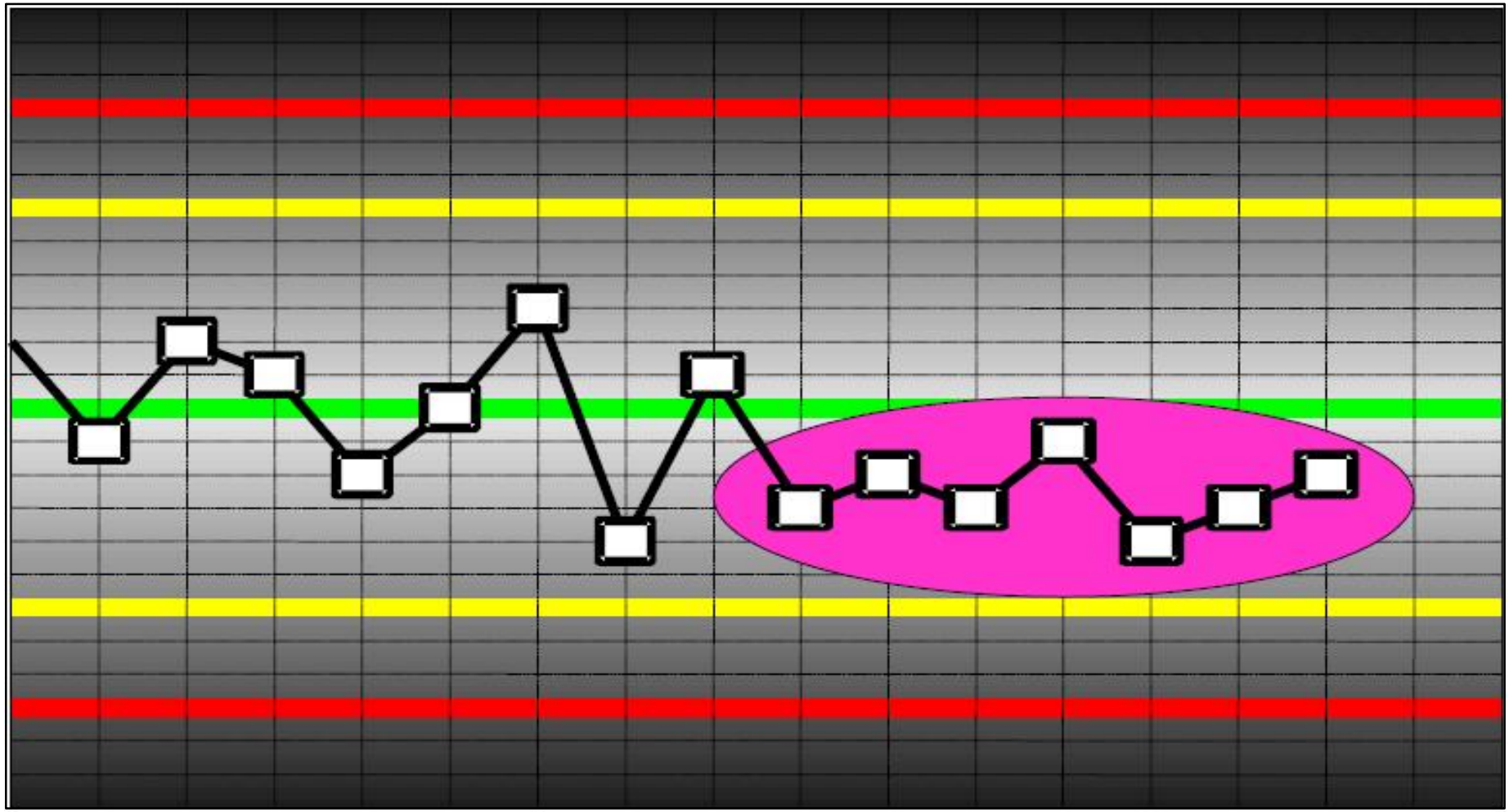
7 Values above or below the Specified Value (Run)



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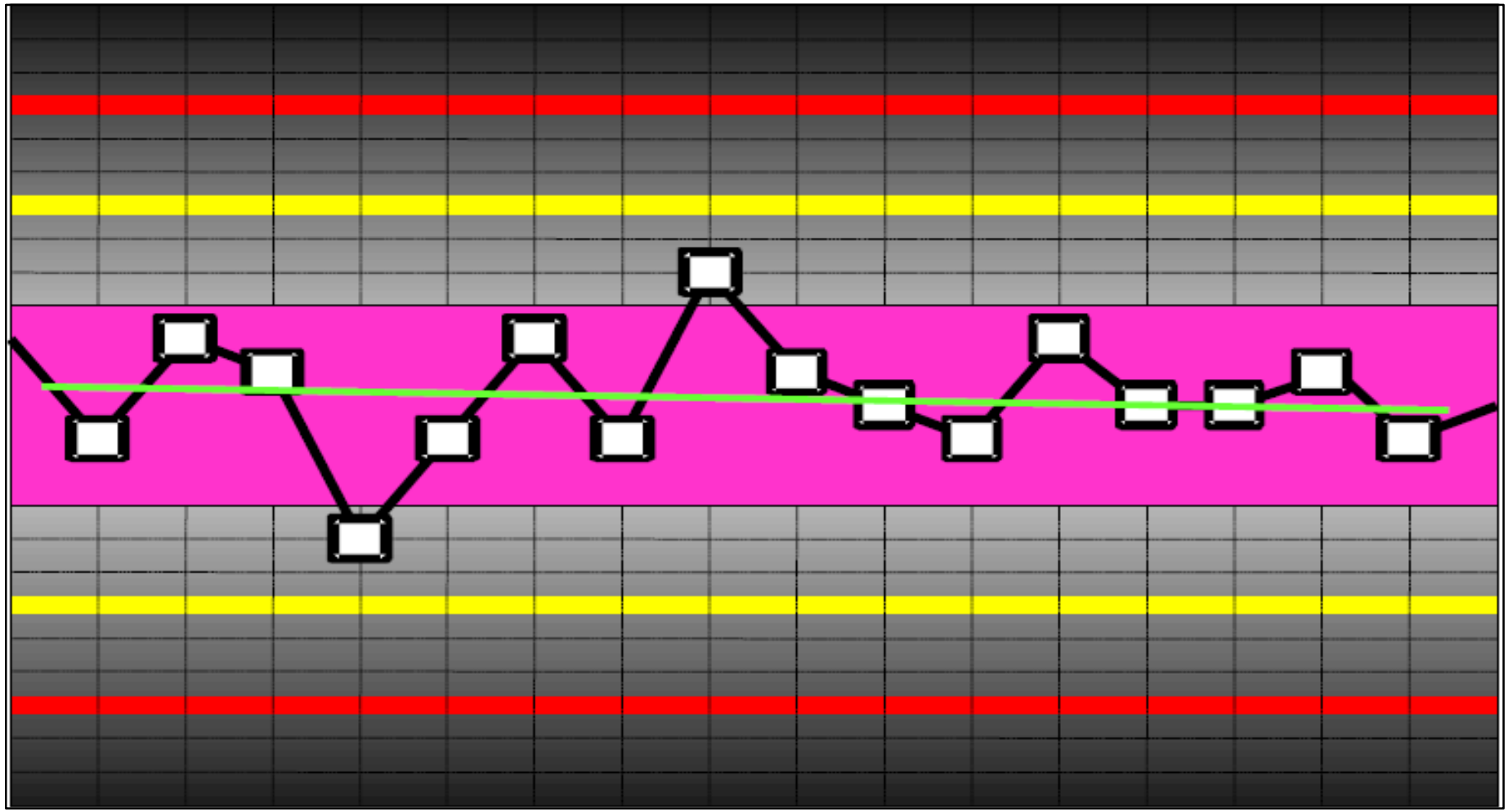
Middle Third



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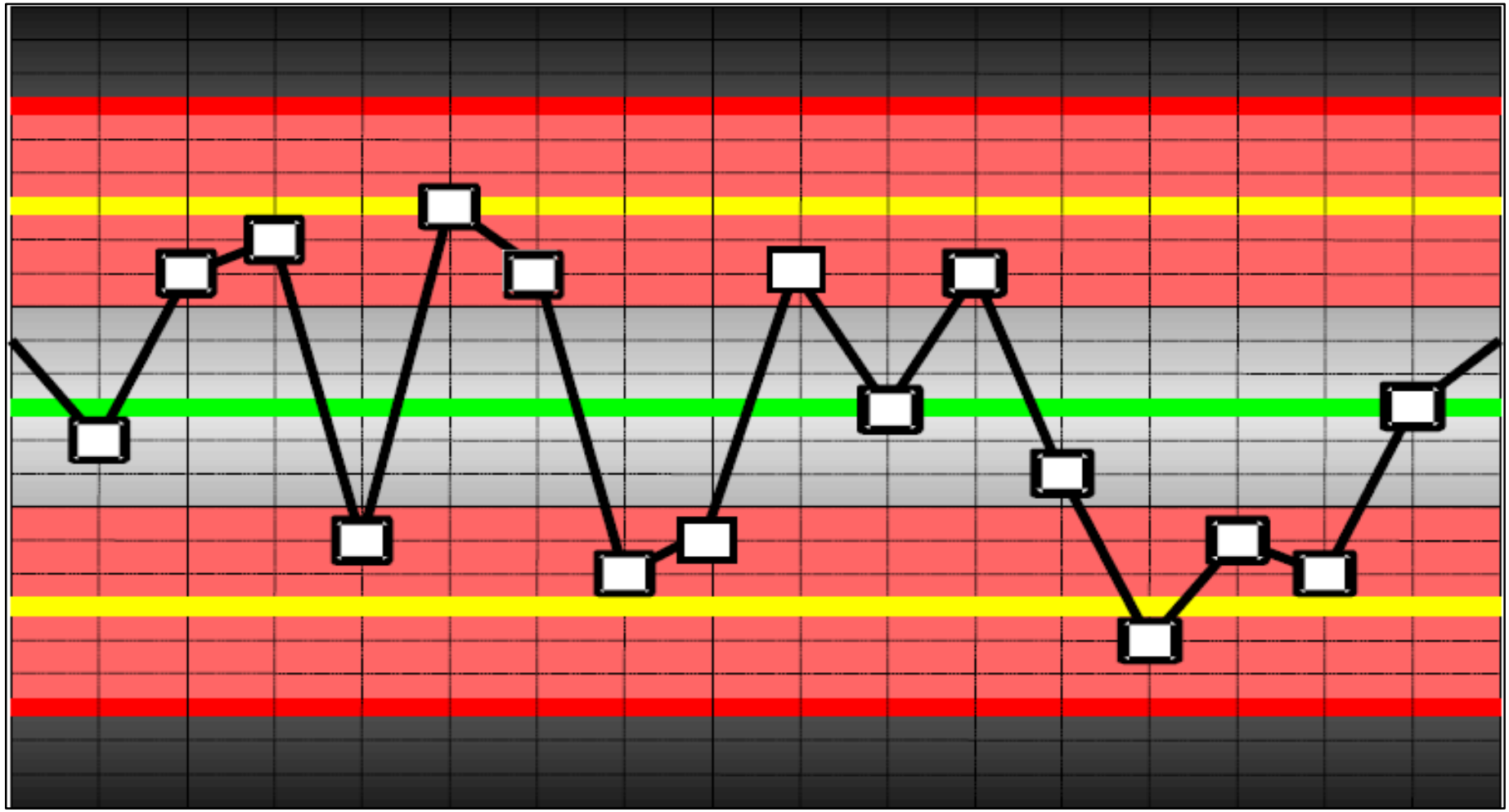
Outer Third



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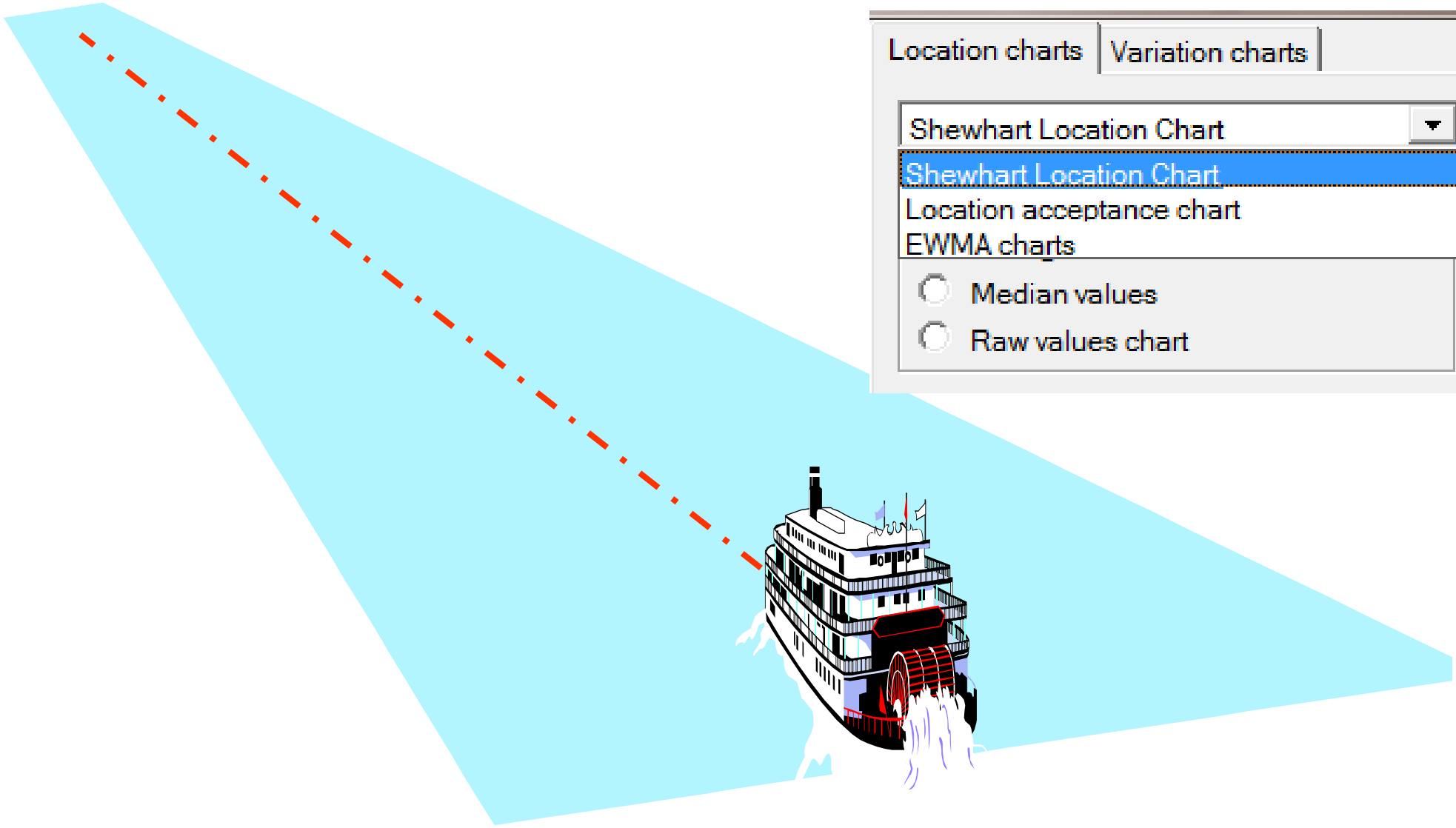
Target Oriented Process Control



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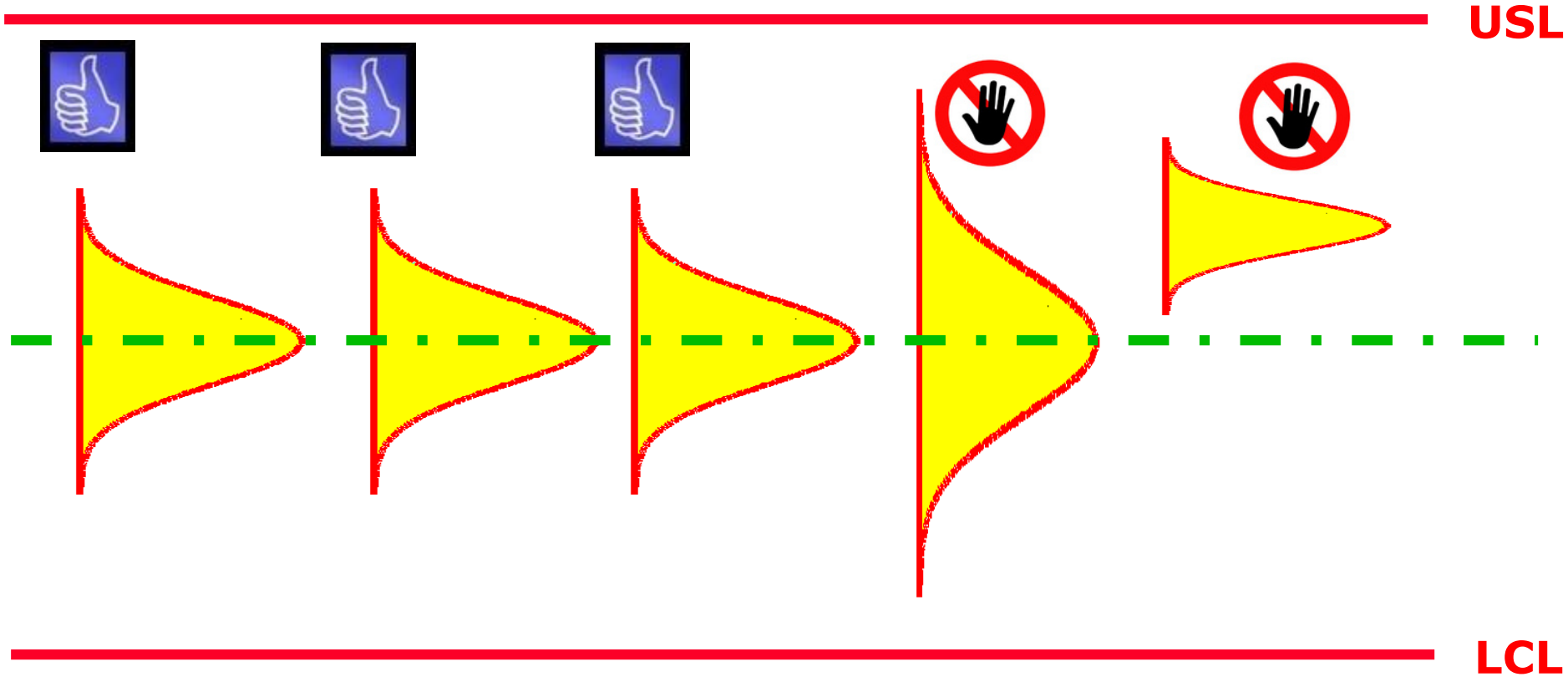
Target Oriented Process Control



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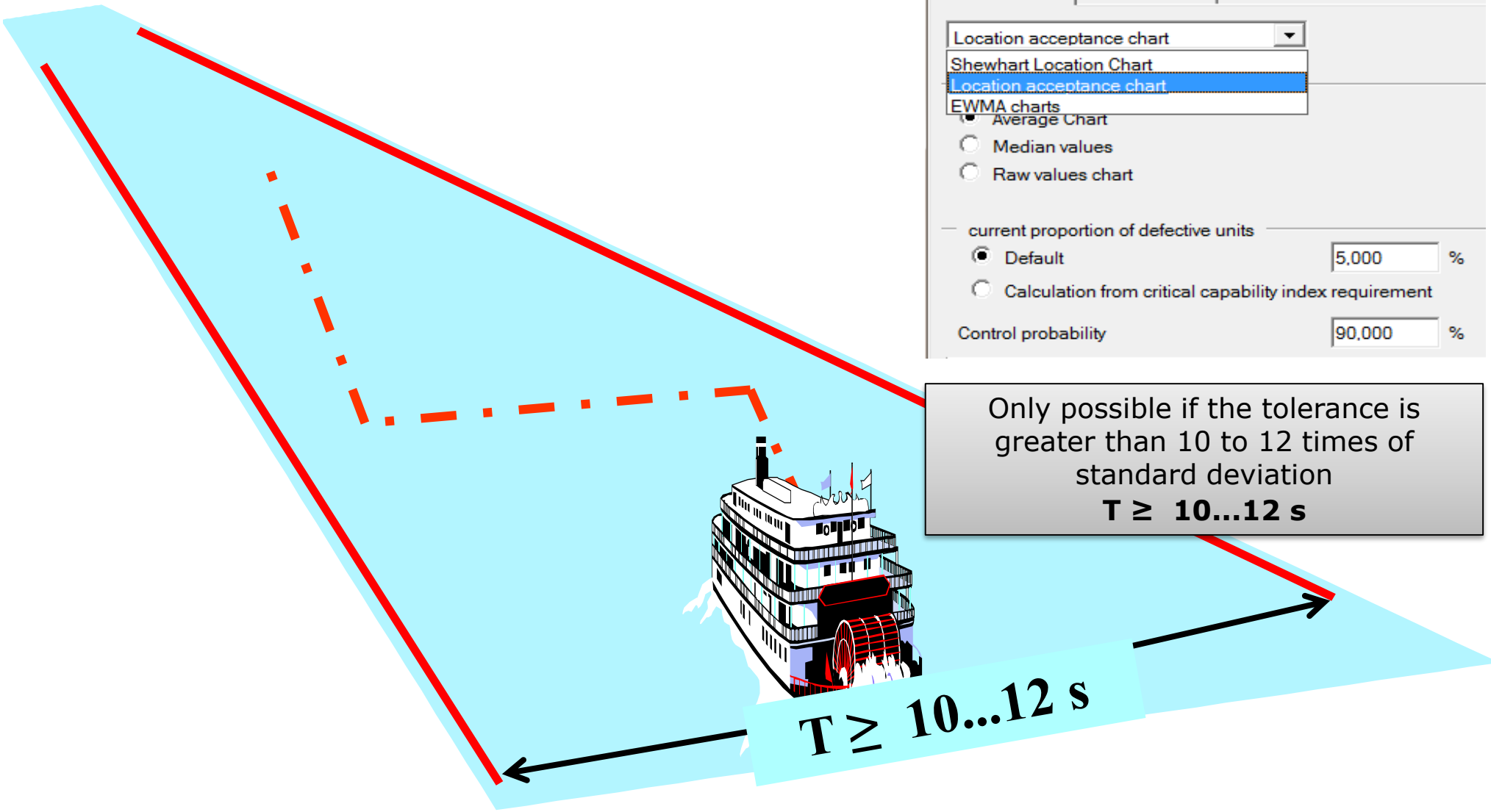
Tolerance Oriented Process Control



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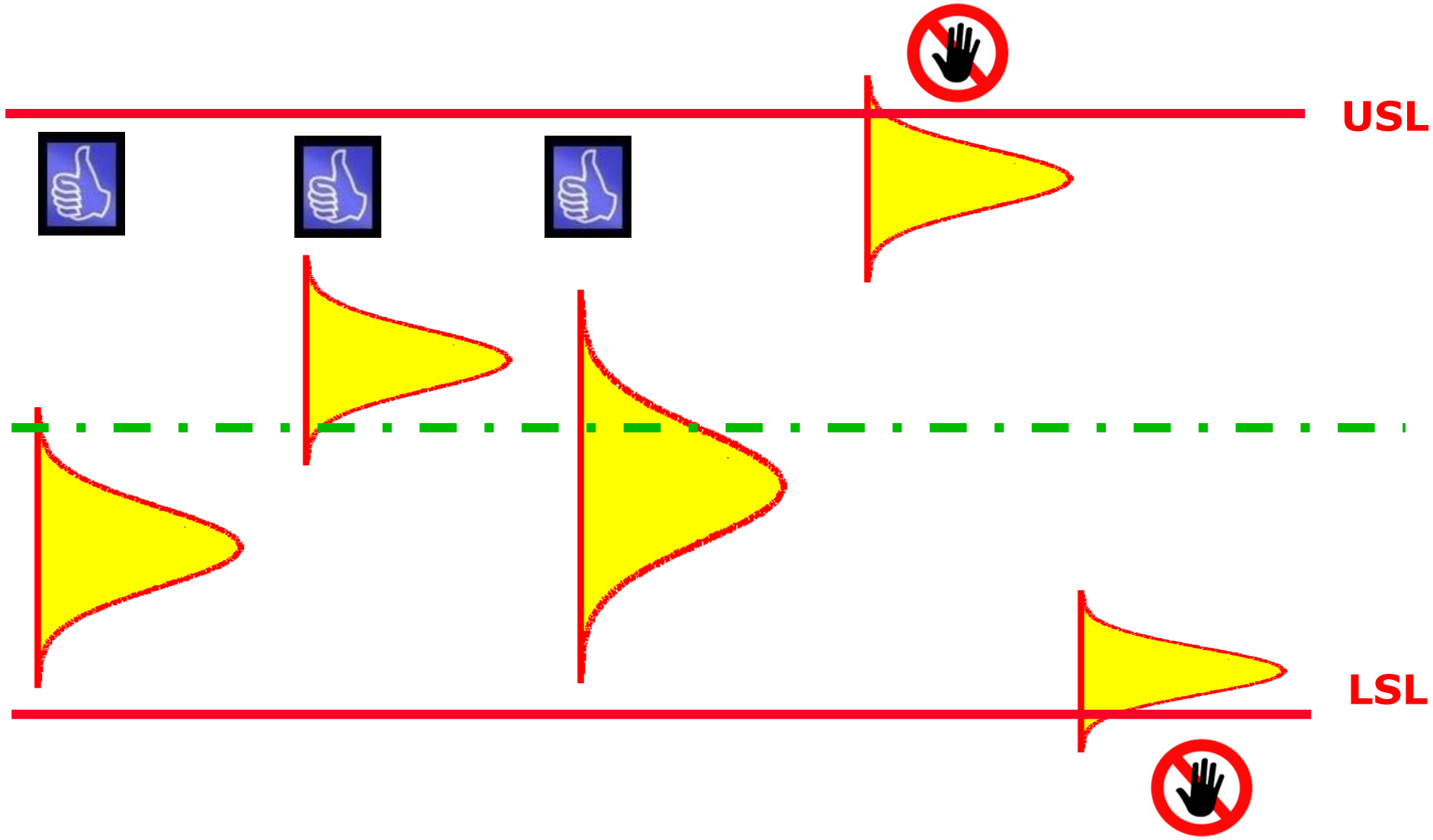
Tolerance Oriented Process Control



Automotive CORE-Tools: Module 5 - SPC

SPC – Control Chart Types

QCC for Position	➢Singe Value Chart (Original Value Chart) ➢Average Chart ➢Median Chart
QCC for Variation	➢Standard Deviation Chart (s- Chart) ➢Range Chart (R-Chart)
Other QCC	➢Two tracked Shewhart – QCC ($\bar{x}$/s – Chart) ➢Shewhart – Chart with extended limits ➢Pearson- Chart

Advantages and Disadvantages of each QRK

Single Value Chart:

- React very late to process changes (see next slide)

Average Chart:

- More sensitive than single value chart

Two tracked Shewhart-QCC:

- Is used most often

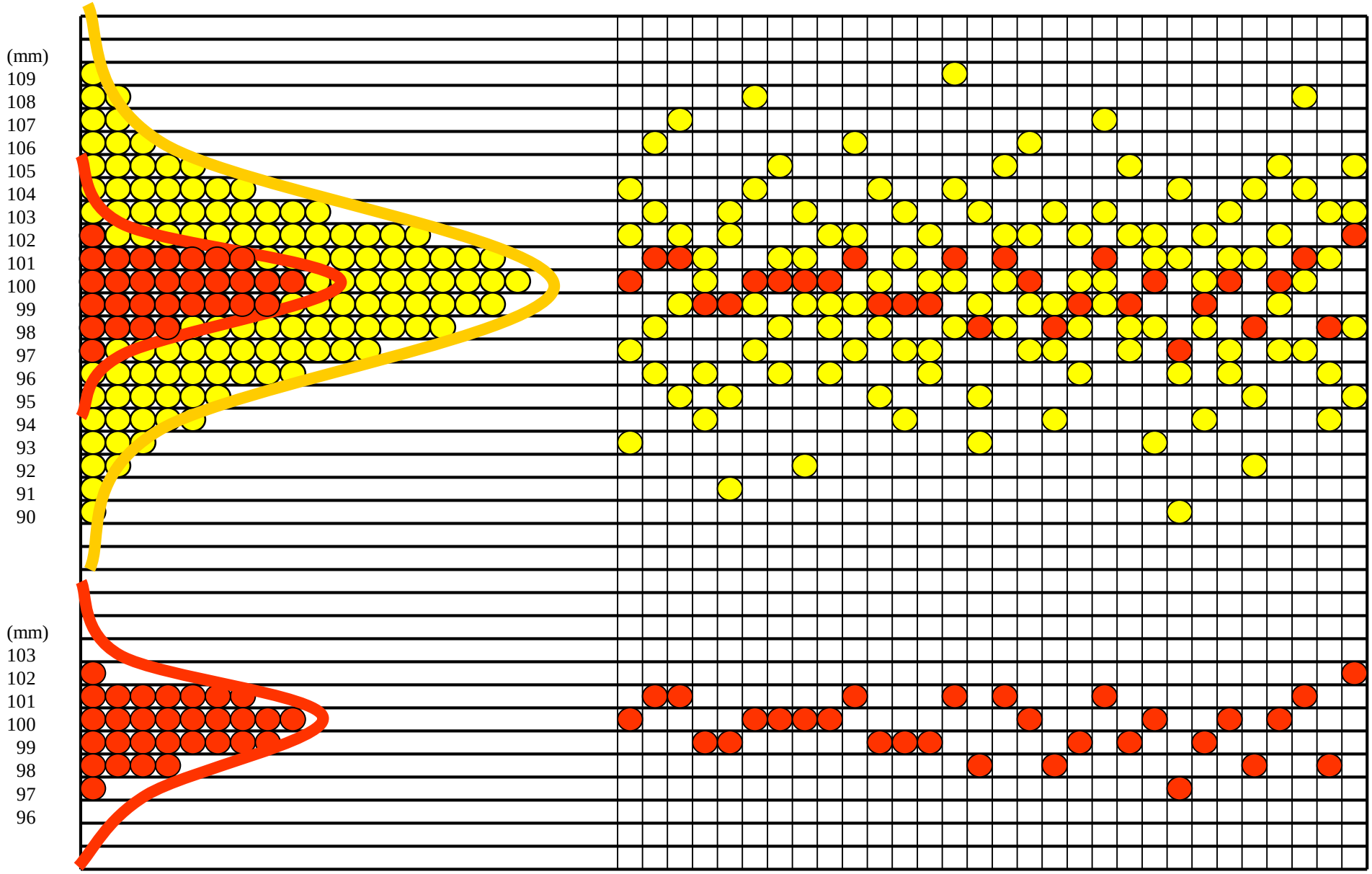
Chart with extended limits:

- If mean variation of the population can be explained and are they considered acceptable, the interception limits can be extended by a certain amount.

Pearson- Chart:

- For processes with one peaked, skewed distribution models

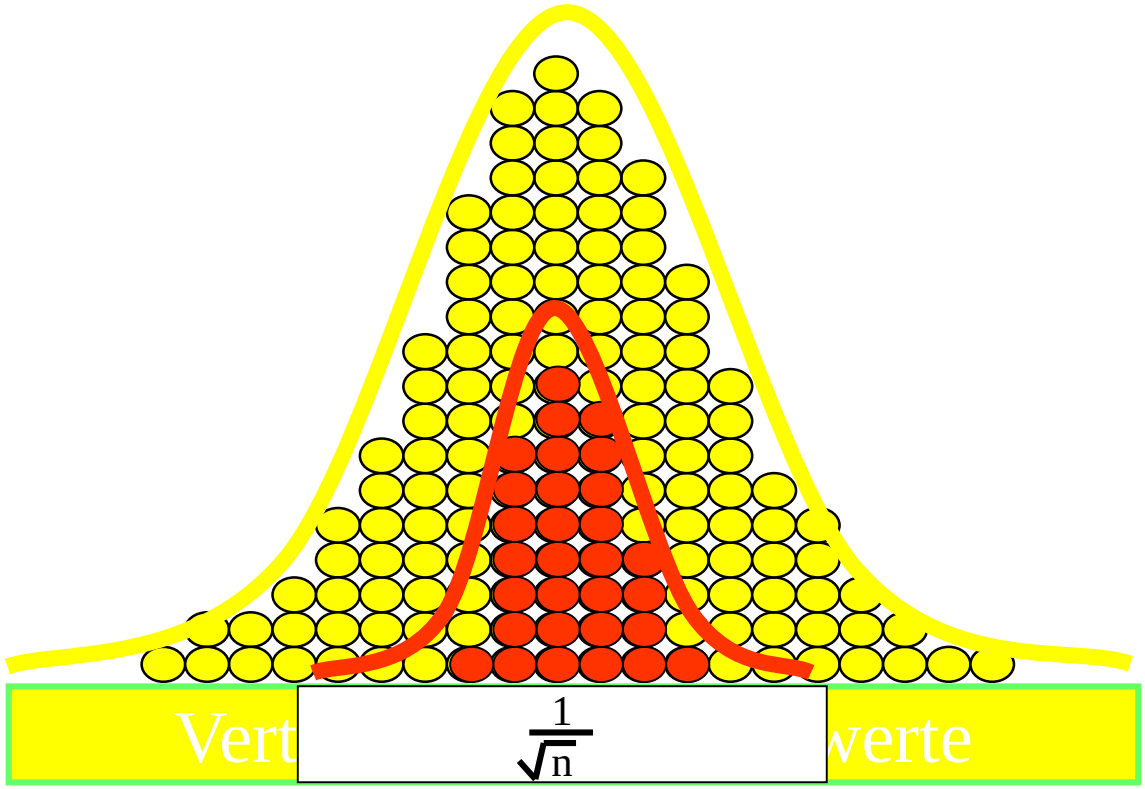
The secret of the control chart



The secret of the control chart

150

30



The secret of the control chart

150

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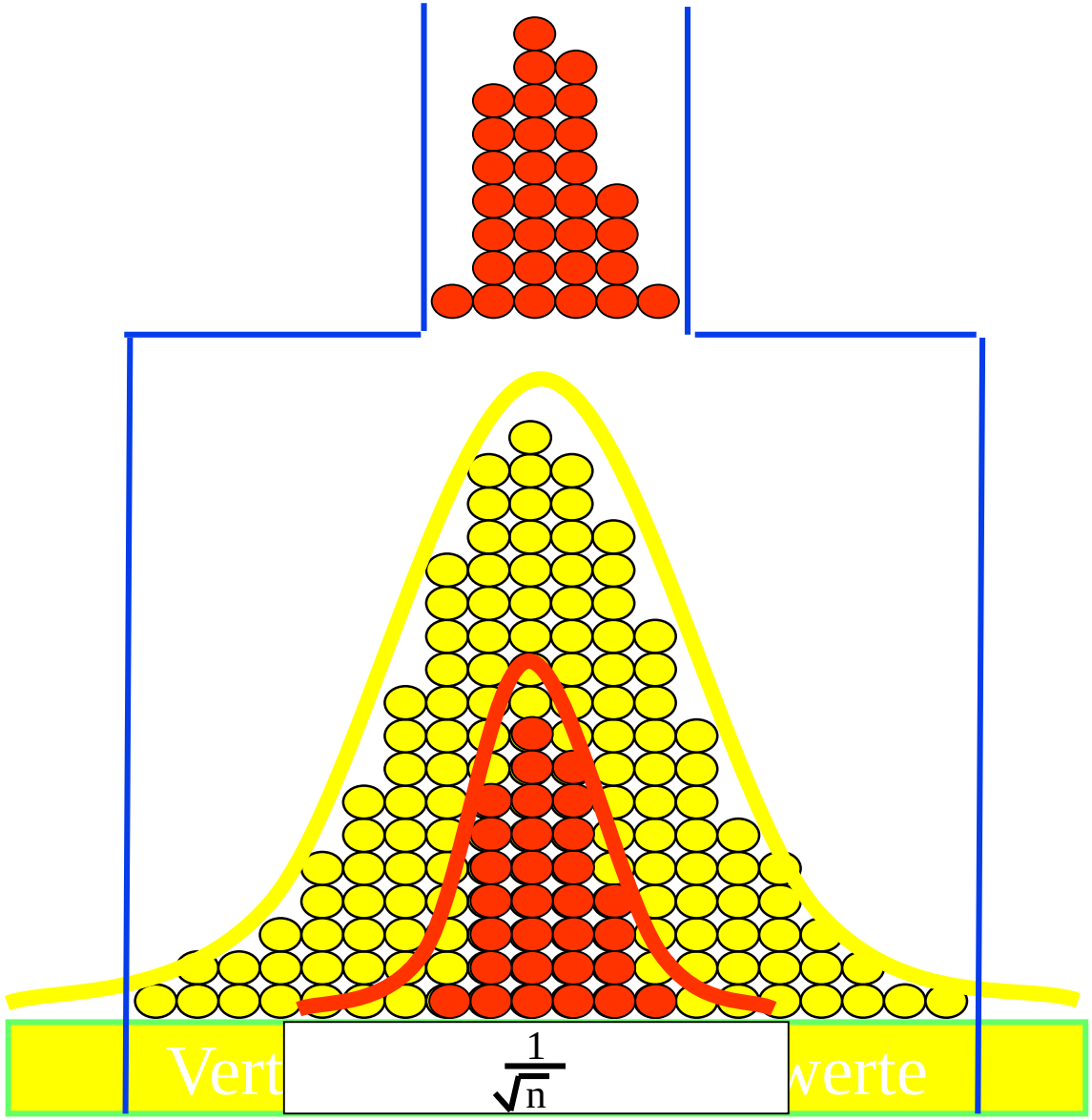

The secret of the control chart

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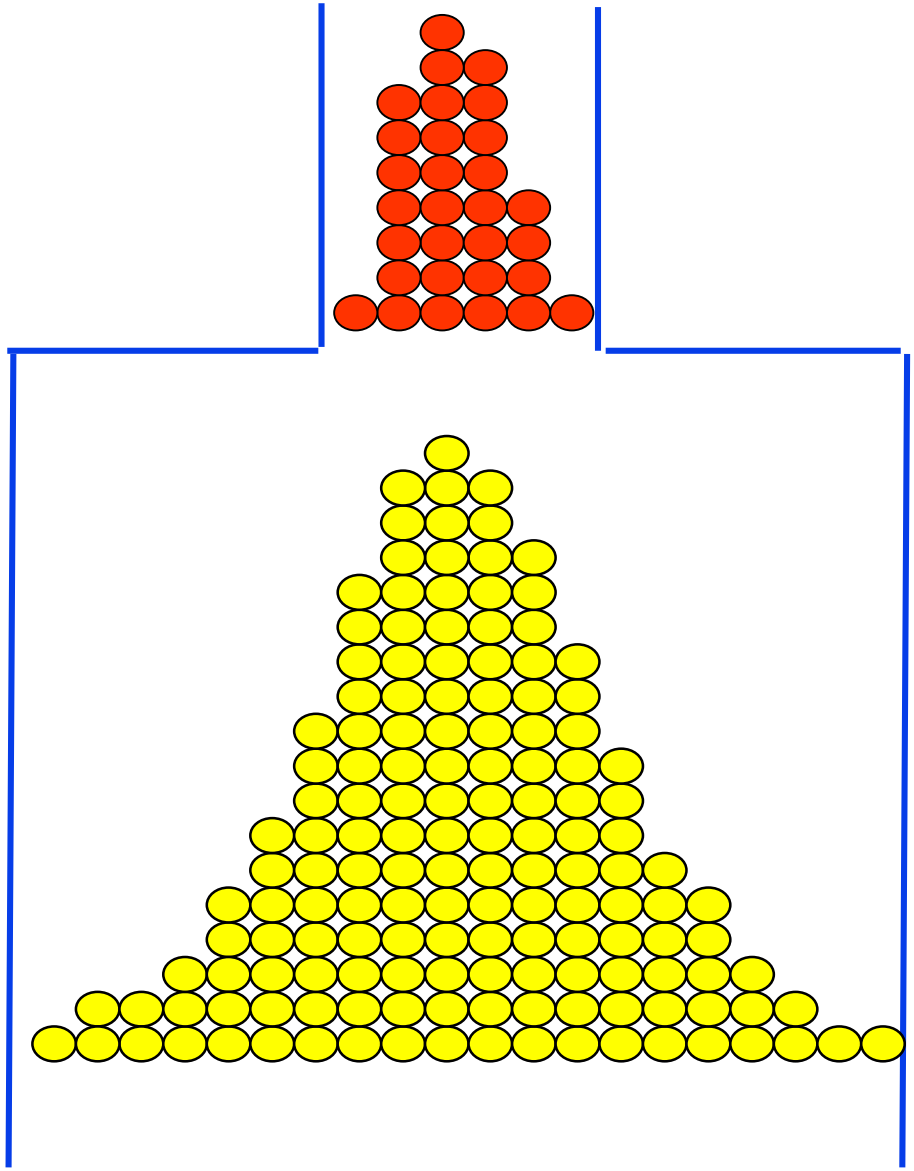

The secret of the control chart

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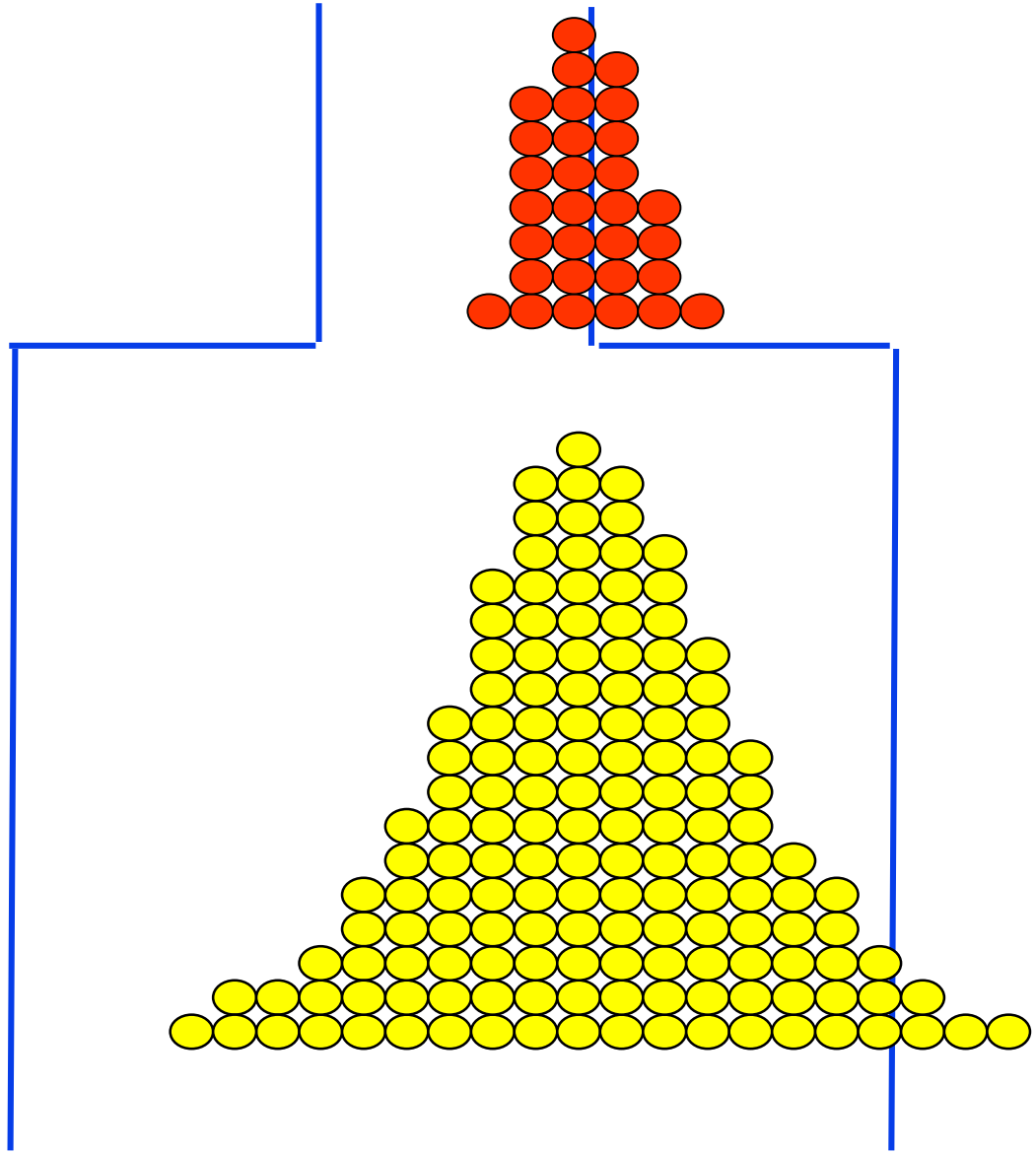
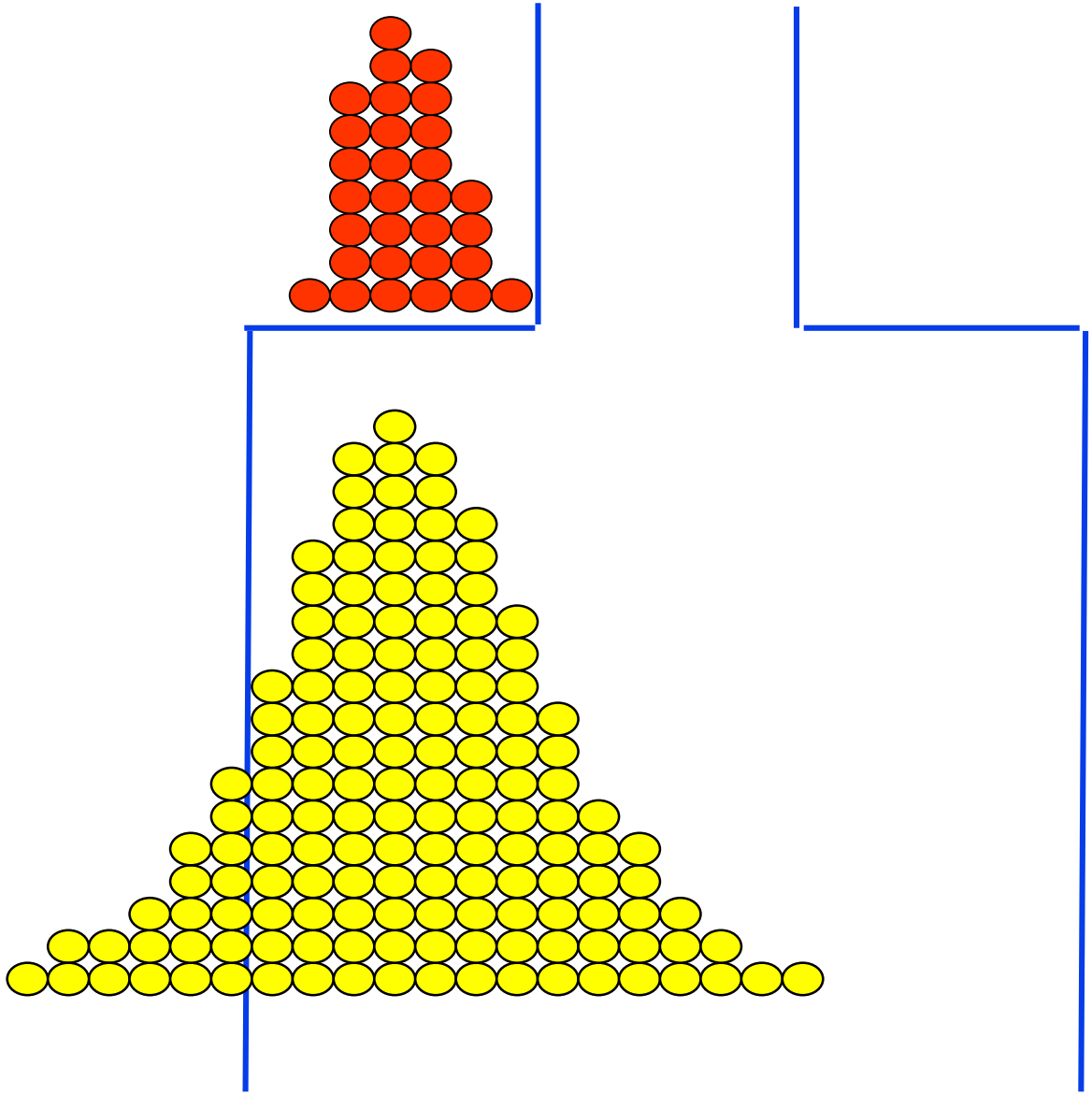
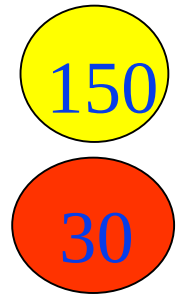


The secret of the control chart





Goodbye

and thank you for your attention!

MICHEL-INSTITUT® Unternehmensberatung GmbH
Untere Sandstraße 53
D-96049 Bamberg

Tel.: +49 (0)951-5193933-0 Fax.: -55
www.michel-institut.de
s.schlee@mi-gmbh.de