Welcome!

The "Control Chart and Capability 101" webinar will begin shortly

Presented by

Matt Savage

PQ Systems

Webinar Goals

Webinar Goals

Central tendency

Variability

Webinar Goals

SYSTEMS

34.64 18.243 11.245 1.34 1.5 34.64 1.34

20 7.657 12.85 1.394 20 18.243

2.245 5.08 .08 1.394 2.245 5.08

10.45 1.34 6.357 17.998 34.64

36.10 .015 10.45 6.357

Data

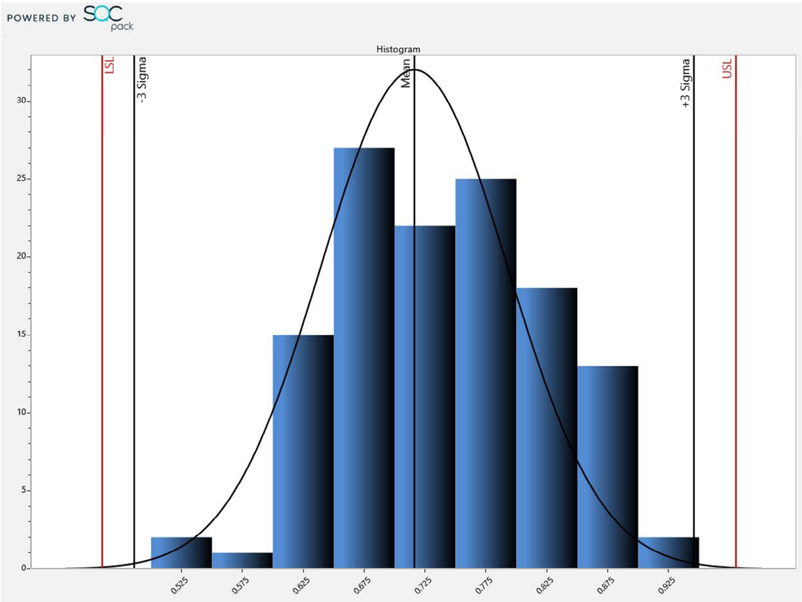
34.64 2.536 .015 18.243

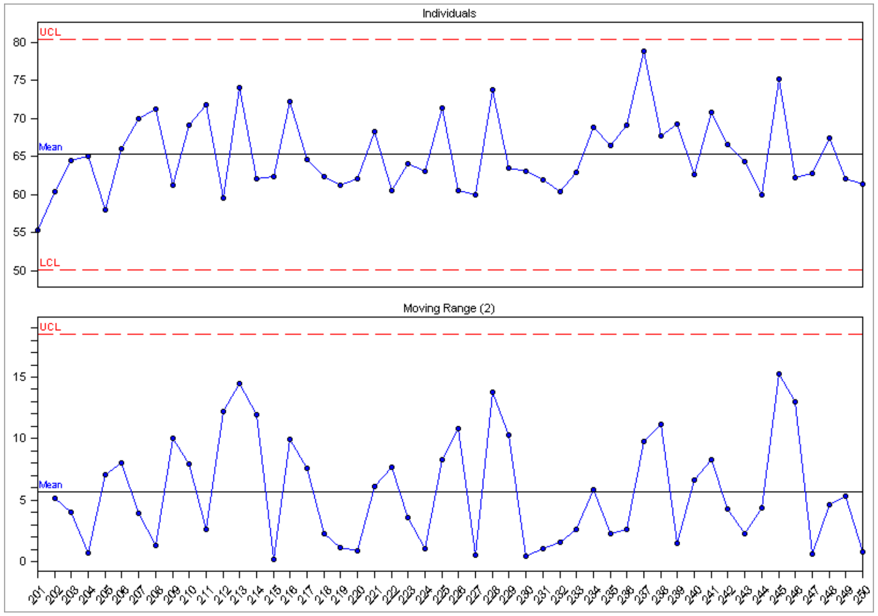
50.4 .08 4.698 .049 .08

17.8 15.24 7.657 2.245 15.24 50.4 7.657 12.85

34.64 11.245 17.998 17.8 11.245

Webinar Goals

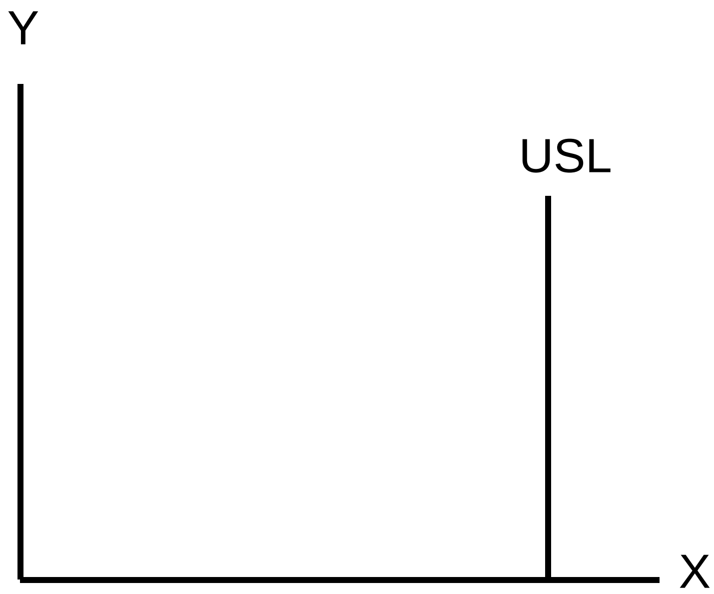


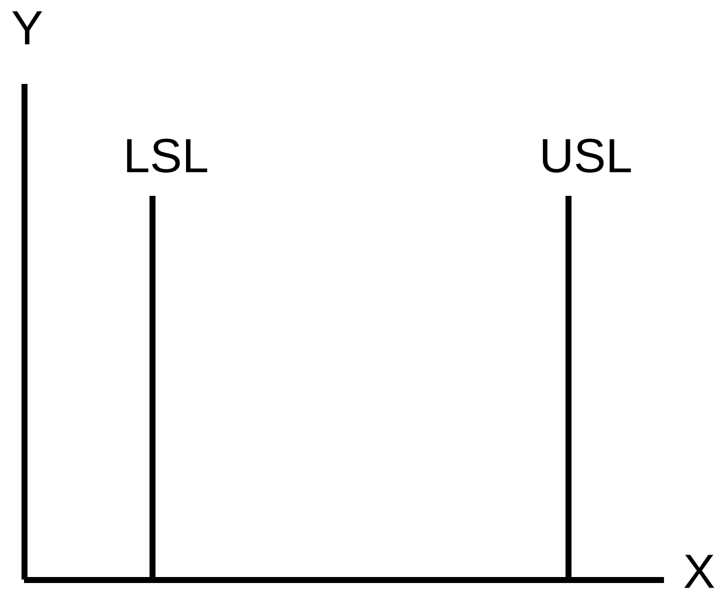


Webinar Goals

What is Capability Analysis?

Requirement





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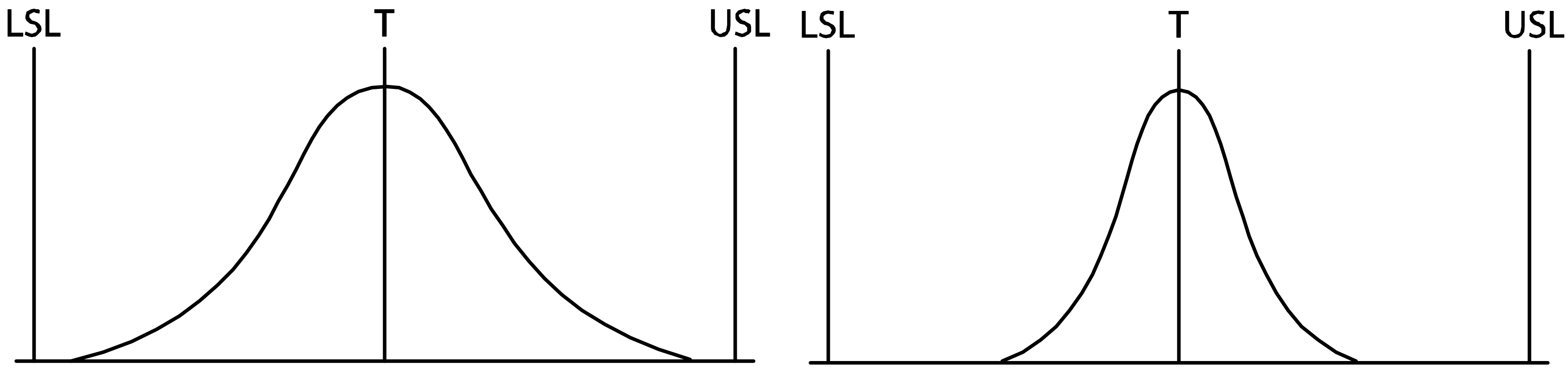
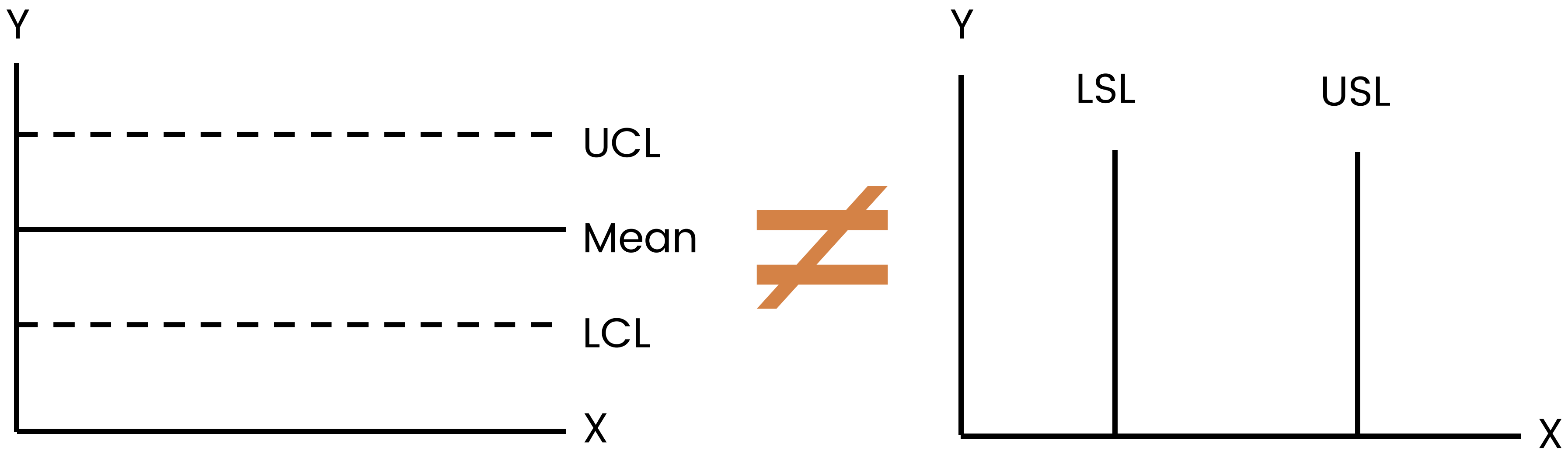


Control vs. Spec Limits



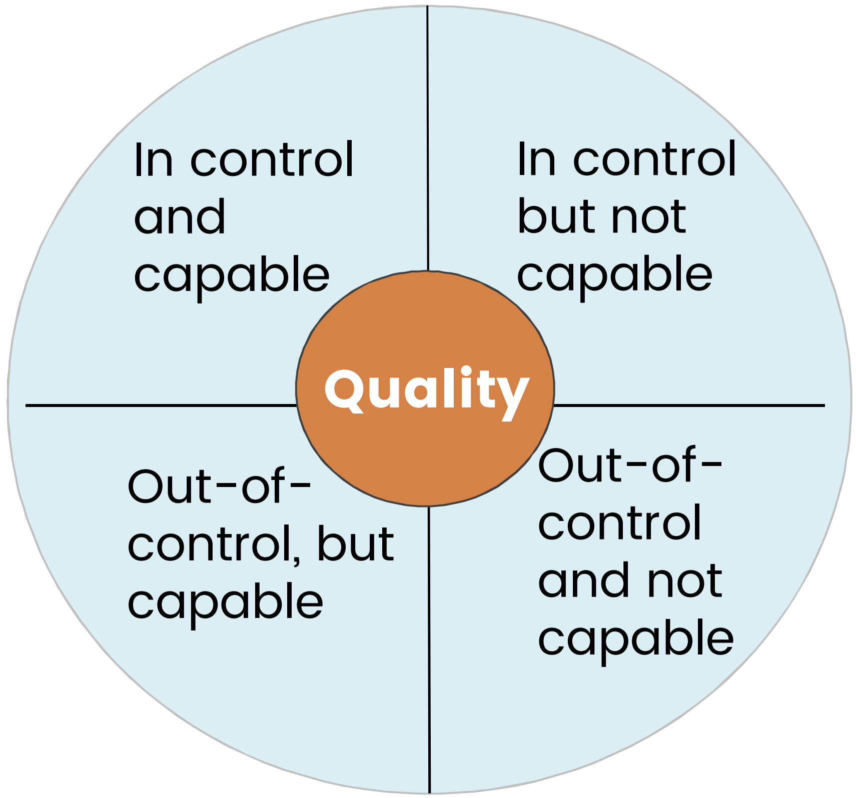
Control limits reflect actual process variation

Voice of the Process

Specification limits reflect allowable process variation

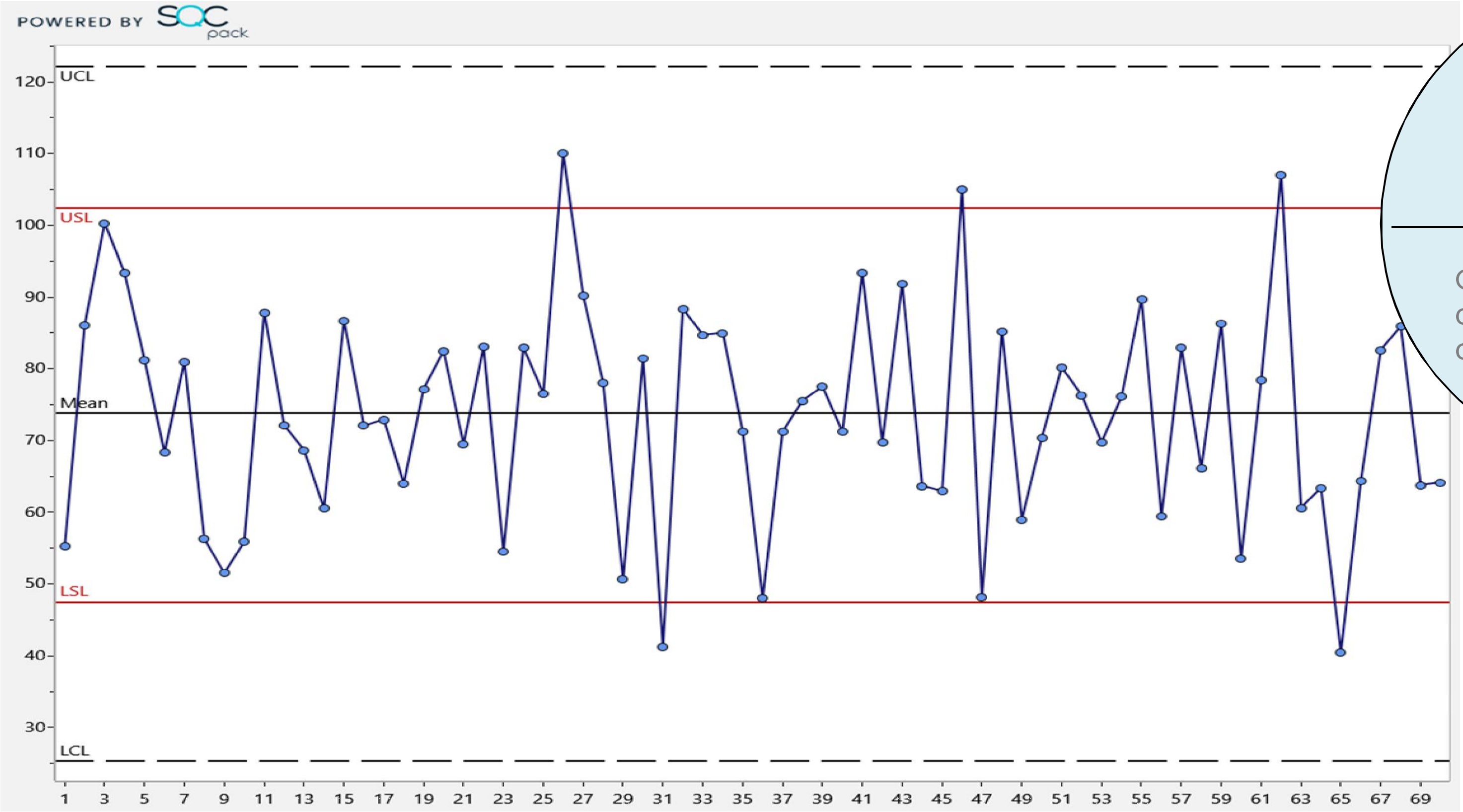
Voice of the Customer

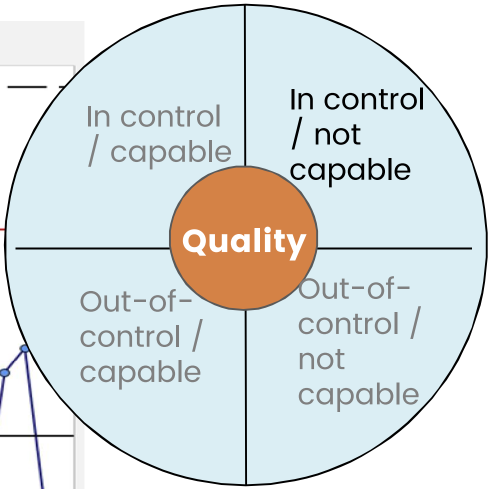
Four States of Quality



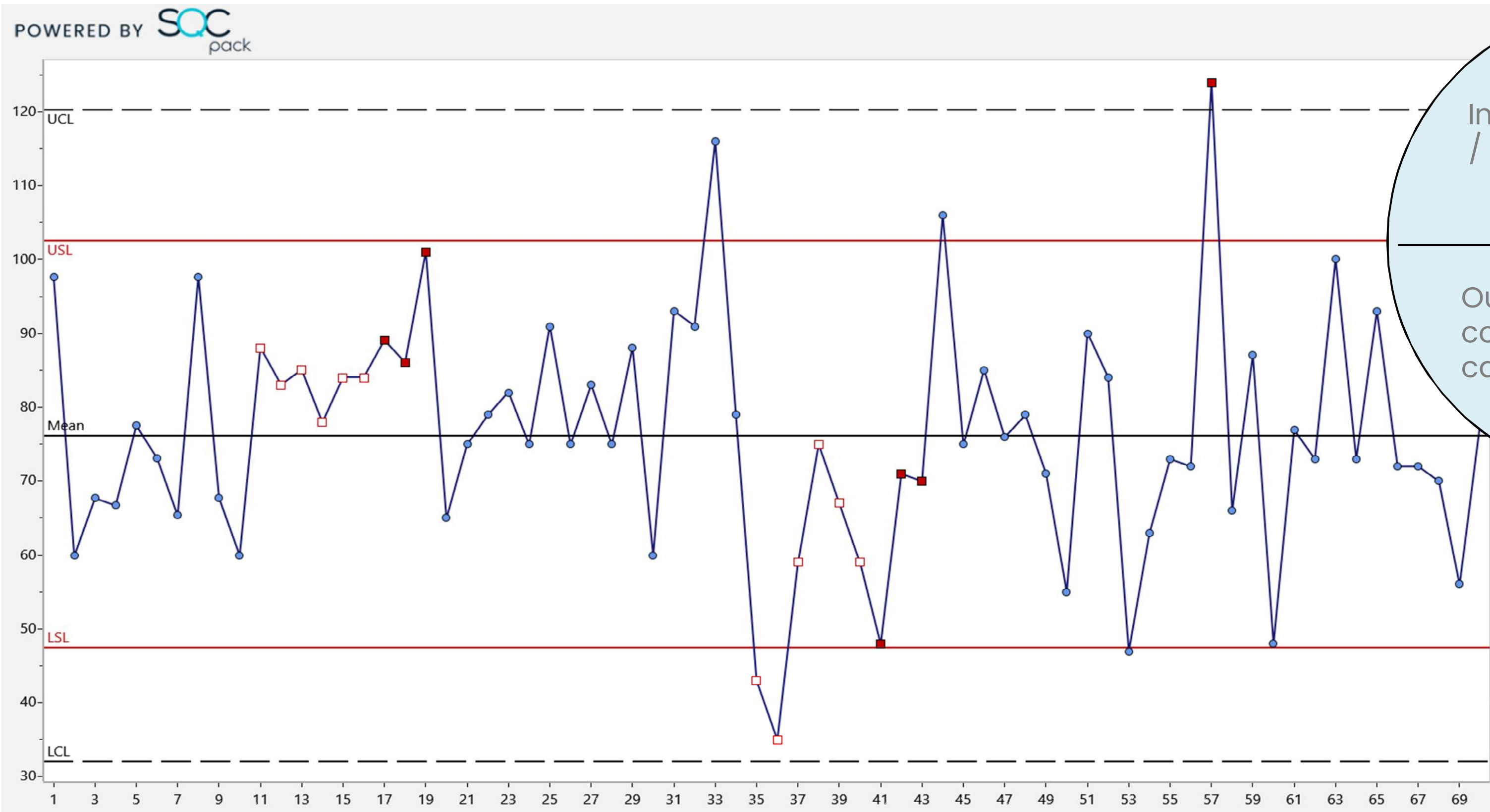
In Control & Not Capable

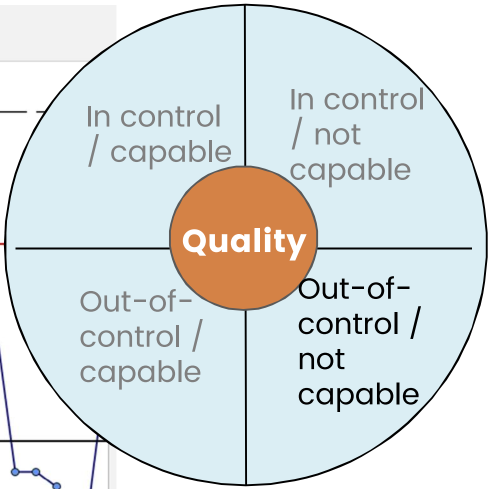
SYSTEMS



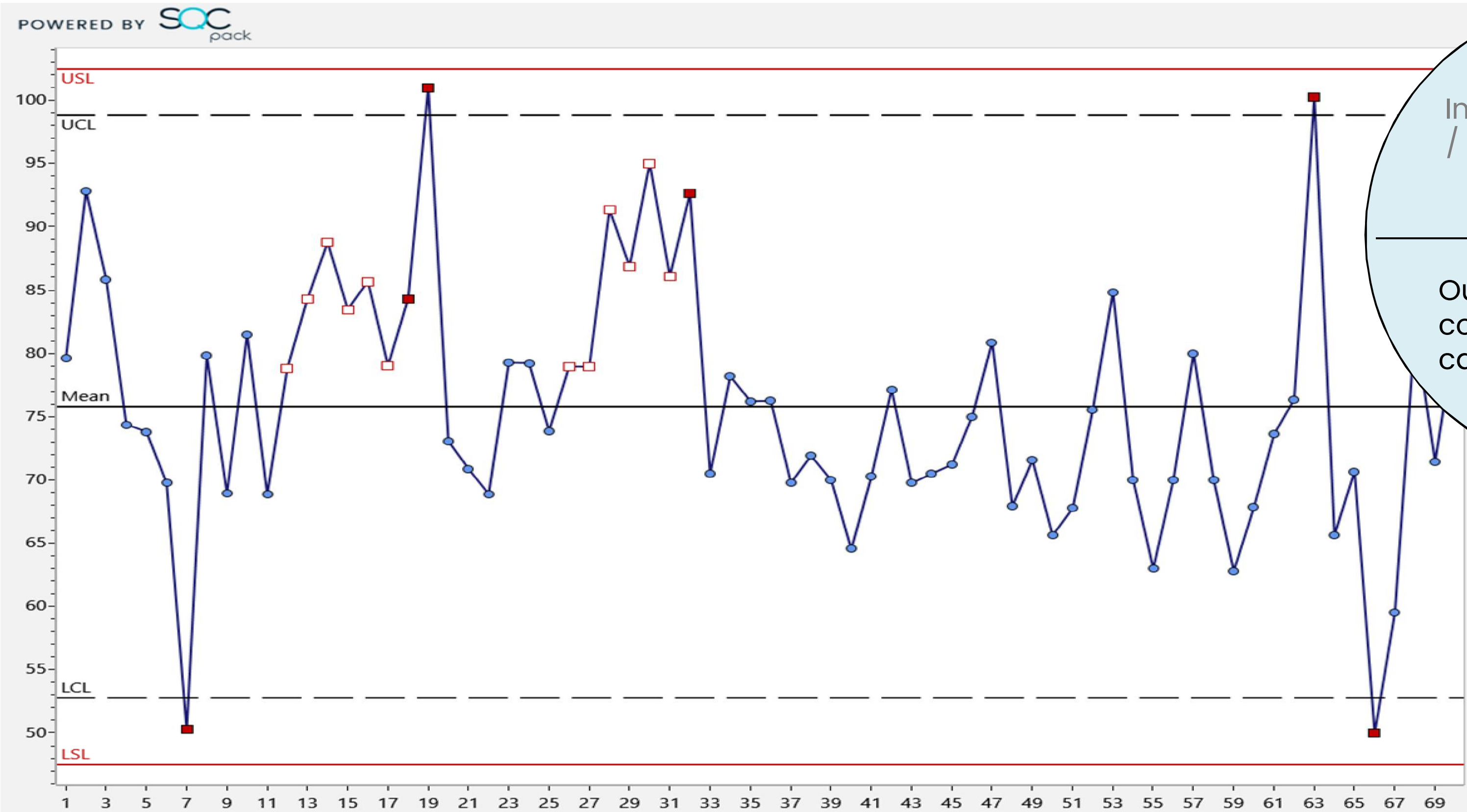


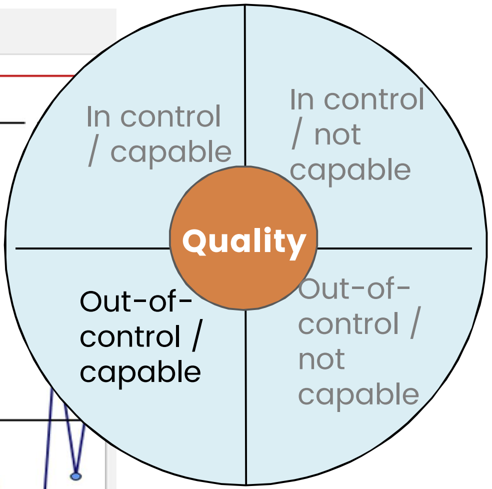
Out-of-Control & Not Capable



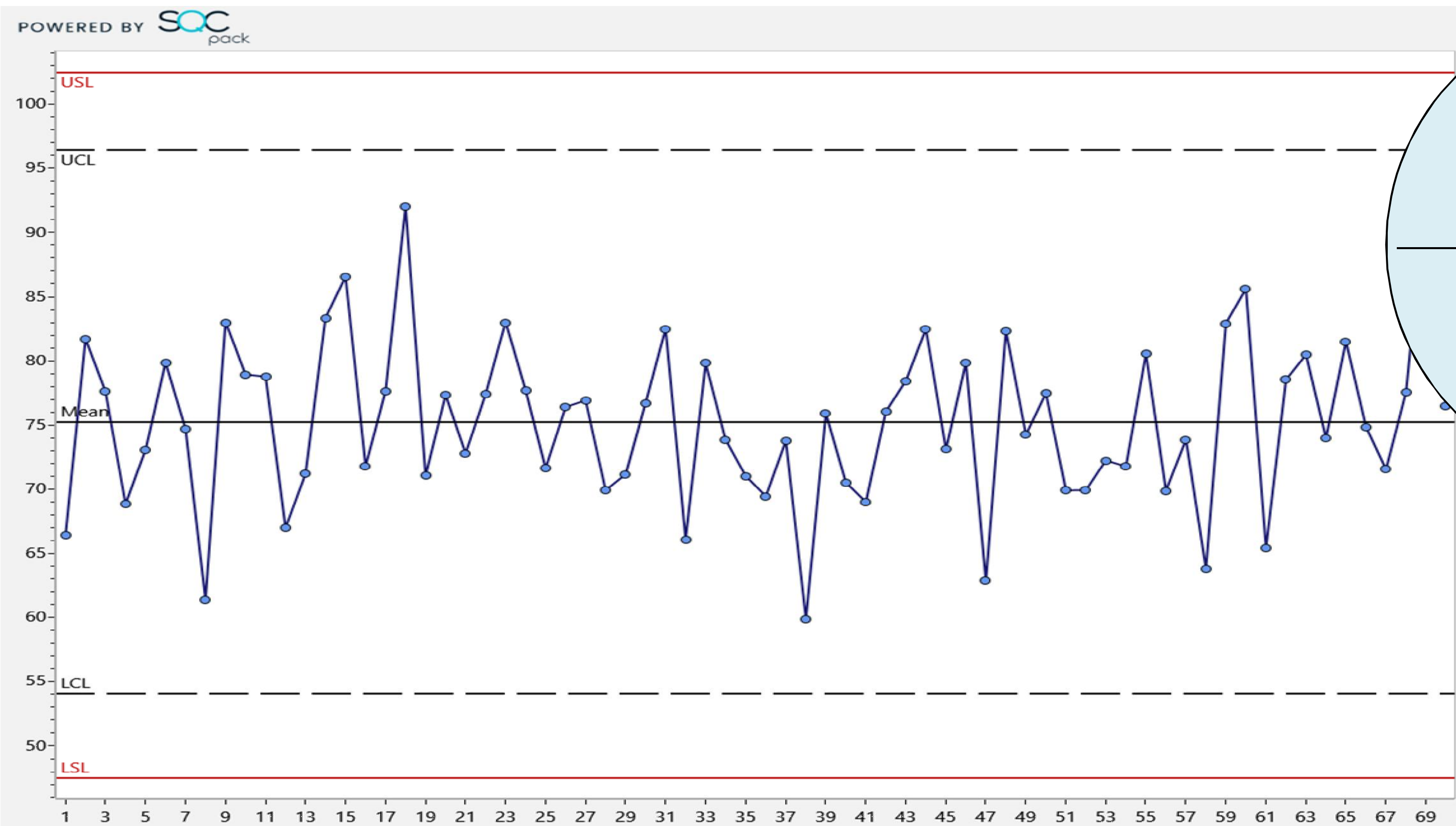


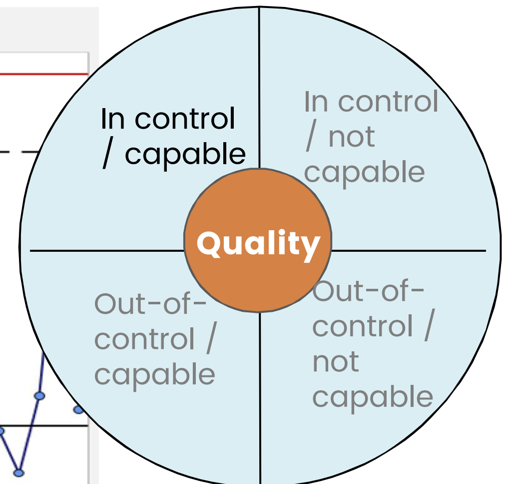
Out-of-Control, but Capable





In Control & Capable





Control Charts for Count Data

Nonconforming or Defective

- p-chart
- np-chart

Nonconformities or Defects

- c-chart
- u-chart

Control Charts – Measurement Data

- X - Individuals
- MA - Moving average
- X-bar

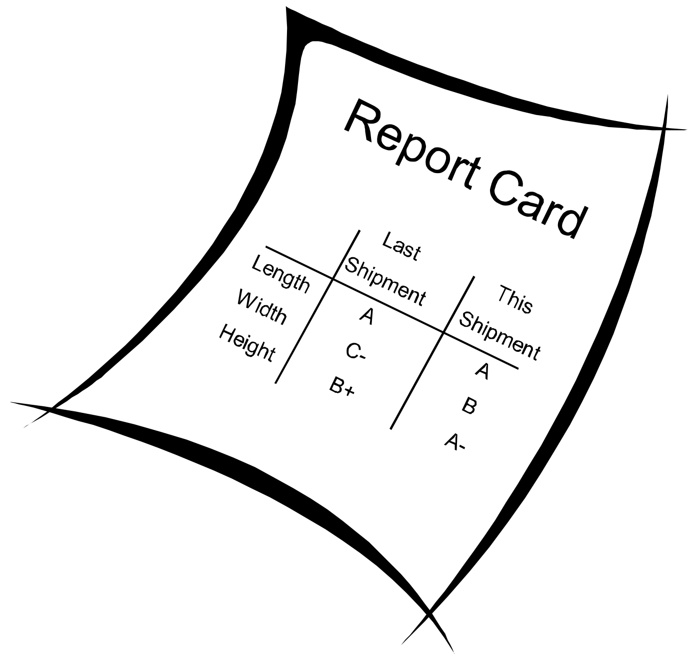
- MR - Moving range
- R - Range
- S - Sigma

Purpose of Process Control

Control charts are used to:

- Determine central tendency
- Monitor variability
- Spot trends
- To determine stability and therefore predictability

Purpose of Capability Analysis



Control Chart Intro / Refresher

- What is it?
- What does it look like?
- When is it used?
- How is it made?

$\bar{X}$-R / X-MR Control Chart

What is it?

Average / Individuals and variability

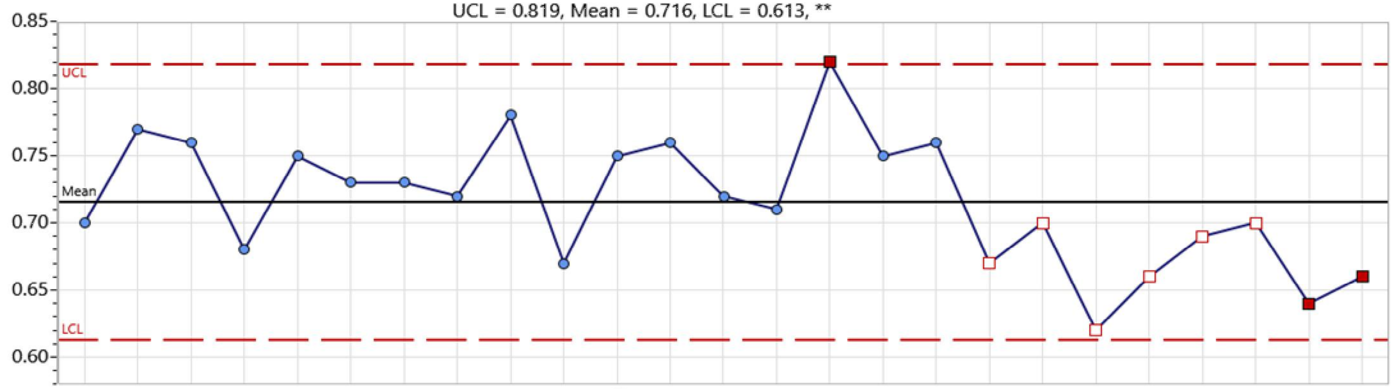
– Monitors how a system changes over time
– Monitors averages to show trends and shifts
– Monitors range to indicate changes in variation
– Used for measurement data

POWERED BY SQC pack

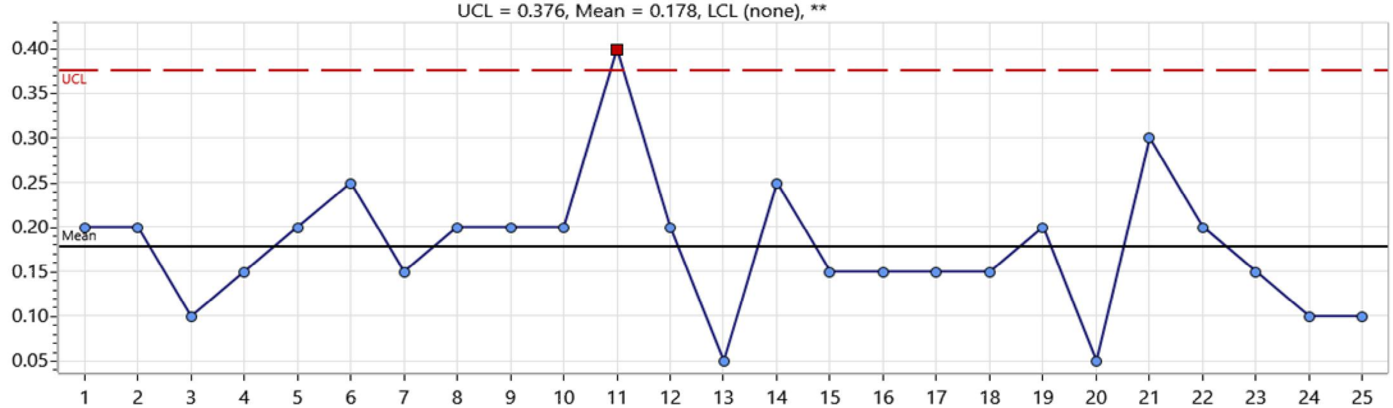
Characteristic: Gap of Dimension A

Gap of Dimension A(1)	0.65	0.75	0.75	0.60	0.70	0.60	0.75	0.60	0.65	0.60	0.80	0.85	0.70	0.65	0.90	0.75	0.75	0.75	0.65	0.60	0.50	0.60	0.80	0.65	0.65
Gap of Dimension A(2)	0.70	0.85	0.80	0.70	0.75	0.75	0.80	0.70	0.80	0.70	0.75	0.75	0.70	0.70	0.80	0.80	0.70	0.70	0.65	0.60	0.55	0.80	0.65	0.60	0.65
Gap of Dimension A(3)	0.65	0.75	0.80	0.70	0.65	0.75	0.65	0.80	0.85	0.60	0.90	0.85	0.75	0.85	0.80	0.75	0.85	0.60	0.85	0.65	0.65	0.65	0.75	0.65	0.60
Gap of Dimension A(4)	0.65	0.85	0.70	0.75	0.85	0.85	0.75	0.75	0.85	0.80	0.50	0.65	0.75	0.75	0.75	0.80	0.70	0.70	0.65	0.60	0.80	0.65	0.65	0.60	0.70
Gap of Dimension A(5)	0.85	0.65	0.75	0.65	0.80	0.70	0.70	0.75	0.75	0.65	0.80	0.70	0.70	0.60	0.85	0.65	0.80	0.60	0.70	0.65	0.80	0.75	0.65	0.70	0.70
X-bar	0.700	0.770	0.760	0.680	0.750	0.730	0.730	0.720	0.780	0.670	0.750	0.760	0.720	0.710	0.820	0.750	0.760	0.670	0.700	0.620	0.660	0.690	0.700	0.640	0.660
Range	0.200	0.200	0.100	0.150	0.200	0.250	0.150	0.200	0.200	0.200	0.400	0.200	0.050	0.250	0.150	0.150	0.150	0.150	0.200	0.050	0.300	0.200	0.150	0.100	0.100

X-bar
USL = 0.90, LSL = 0.50
UCL = 0.819, Mean = 0.716, LCL = 0.613, **



Range
UCL = 0.376, Mean = 0.178, LCL (none), **



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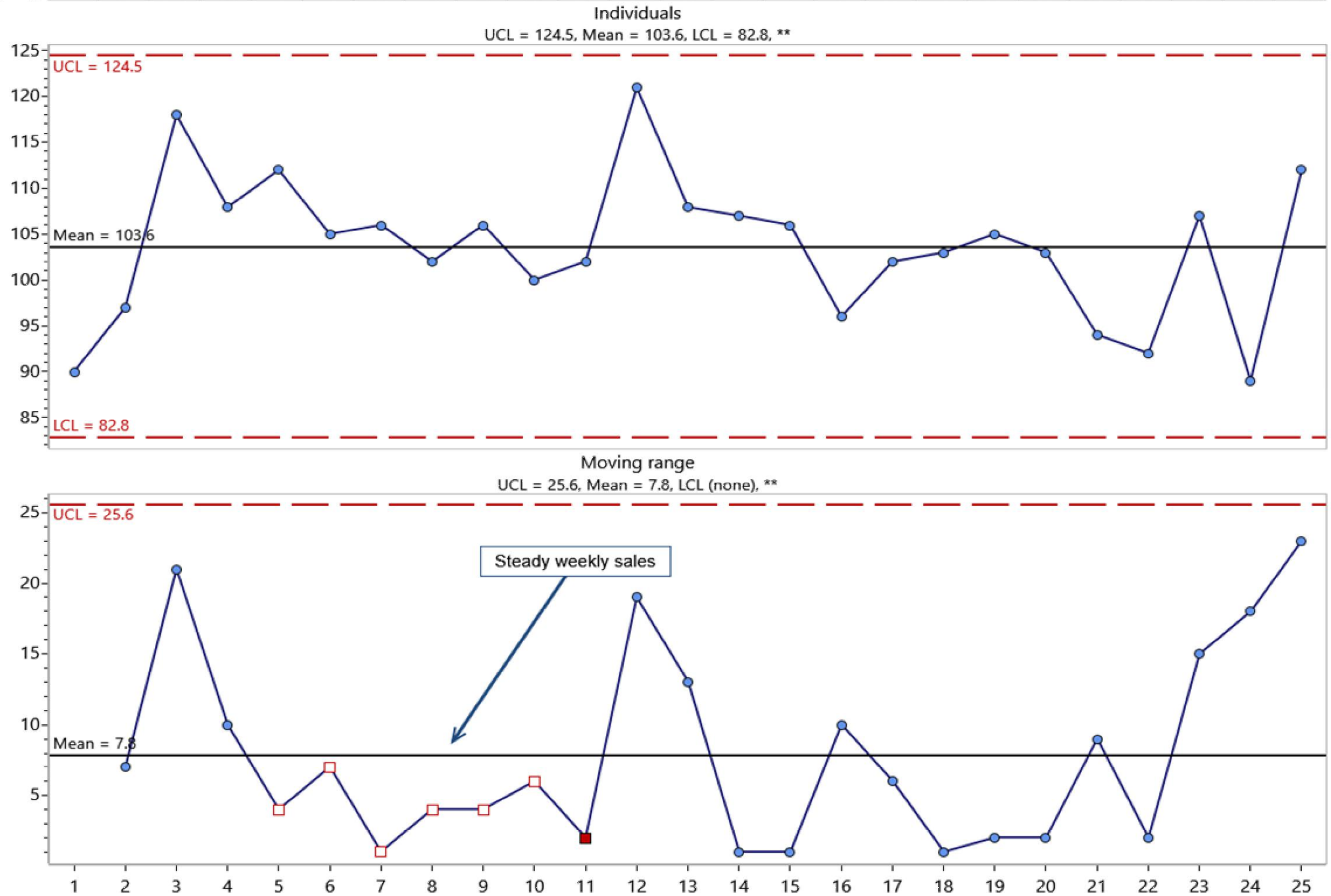
X - MR CHART

Sales	90	97	118	108	112	105	106	102	106	100	102	121	108	107	106	96	102	103	105	103	94	92	107	89	112
Moving Range		7.0	21.0	10.0	4.0	7.0	1.0	4.0	4.0	6.0	2.0	19.0	13.0	1.0	1.0	10.0	6.0	1.0	2.0	2.0	9.0	2.0	15.0	18.0	23.0



$\overline{X}$-R / X-MR Control Chart

When is it used?

Answer "yes" to the following:

– Do you need to assess the variability in the system?
– Can the data be collected or does a collection of data already exist?
– Is the time order of the data preserved?
– Is the data in variables format?
– Is the data collected in an appropriate subgroups size?

$\bar{X}$-R / X-MR Control Chart

How is it made?

- Assumes data has been collected
  - Ideally 25 or more data points.
- Any unusual occurrences observed during data collection should have been noted.

$\bar{X}$-R / X-MR Control Chart

How is it made?

1. Complete the header information.
2. Record the data.
3. Calculate the statistics for each subgroup.
4. Calculate the overall averages.
5. Calculate the control limits.
6. Scale the control chart.
7. Draw the average line and control limits.
8. Plot the values on the control chart.
9. Interpret the control chart.

$\overline{X}$-R / X-MR Control Chart

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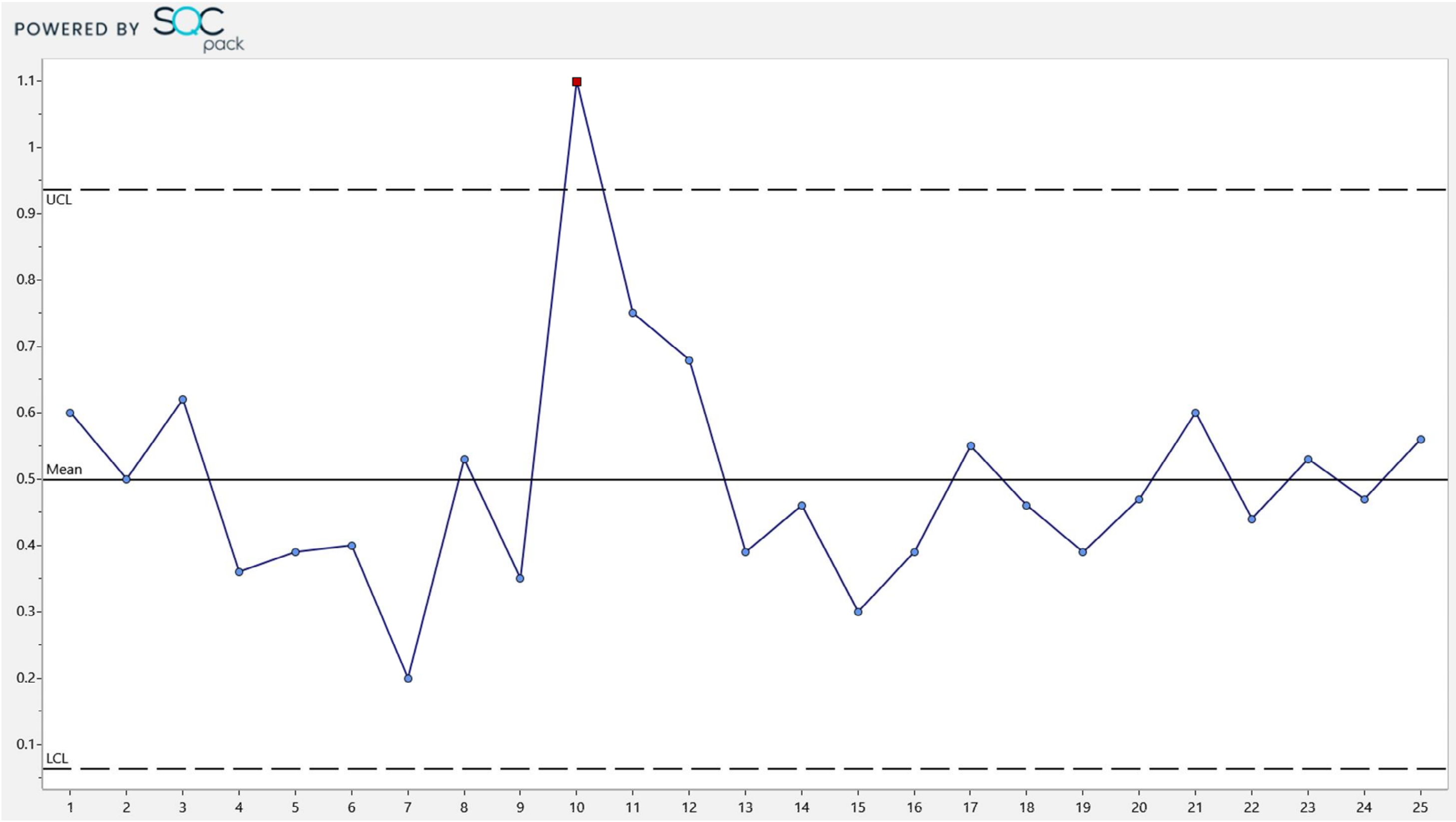
$\overline{X}$-R / X-MR Control Chart

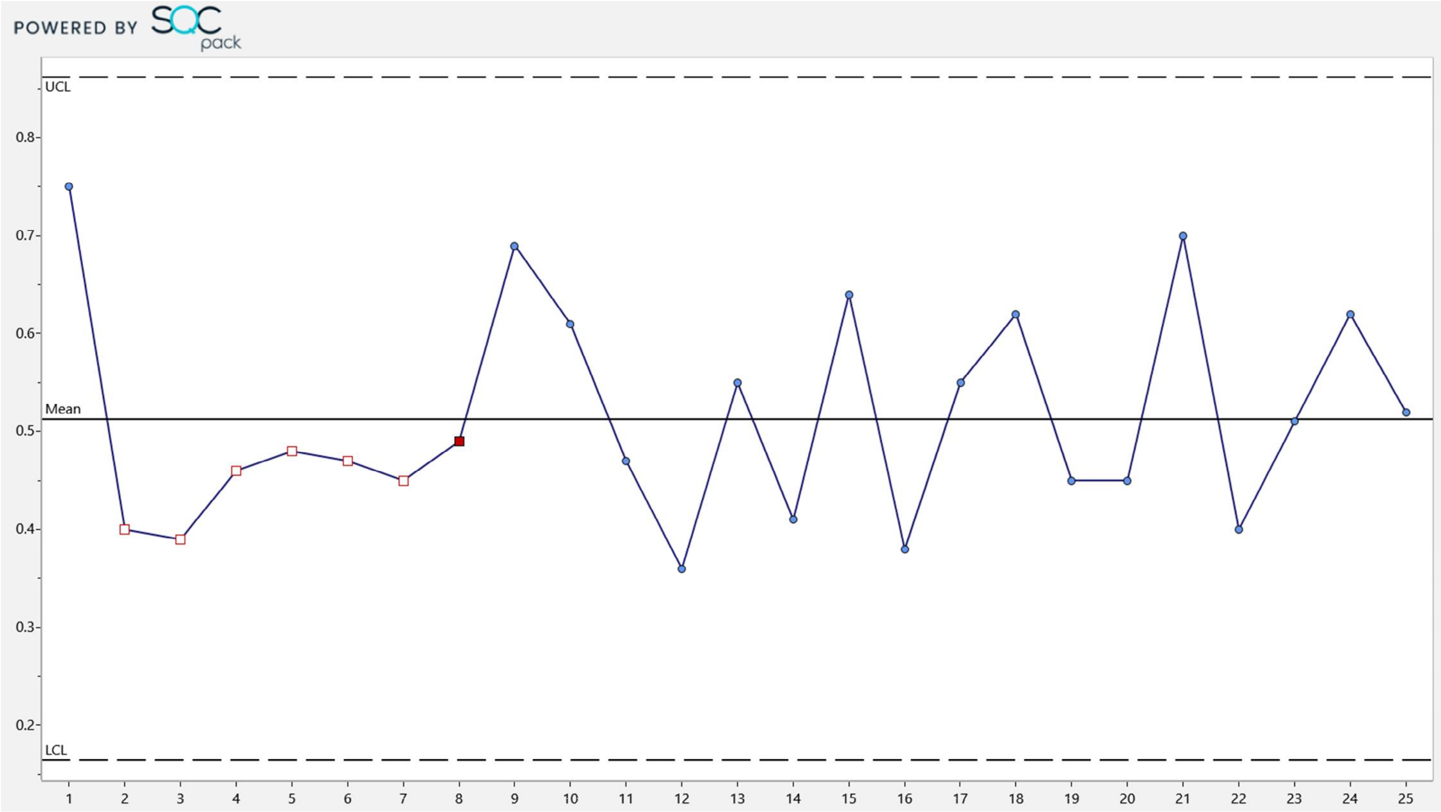
9. Interpret the control chart.

- *Basic rules for interpretation*
  - Any point lying outside the control limits.
  - Run of seven points:
    - » Seven or more points in a row above or below the center line.
    - » Seven or more points in a row going in one direction, up or down.
  - Any non-random pattern, including the following typical cases:
    - » Too close to the average.
    - » Too far from the average.
    - » Cycles.

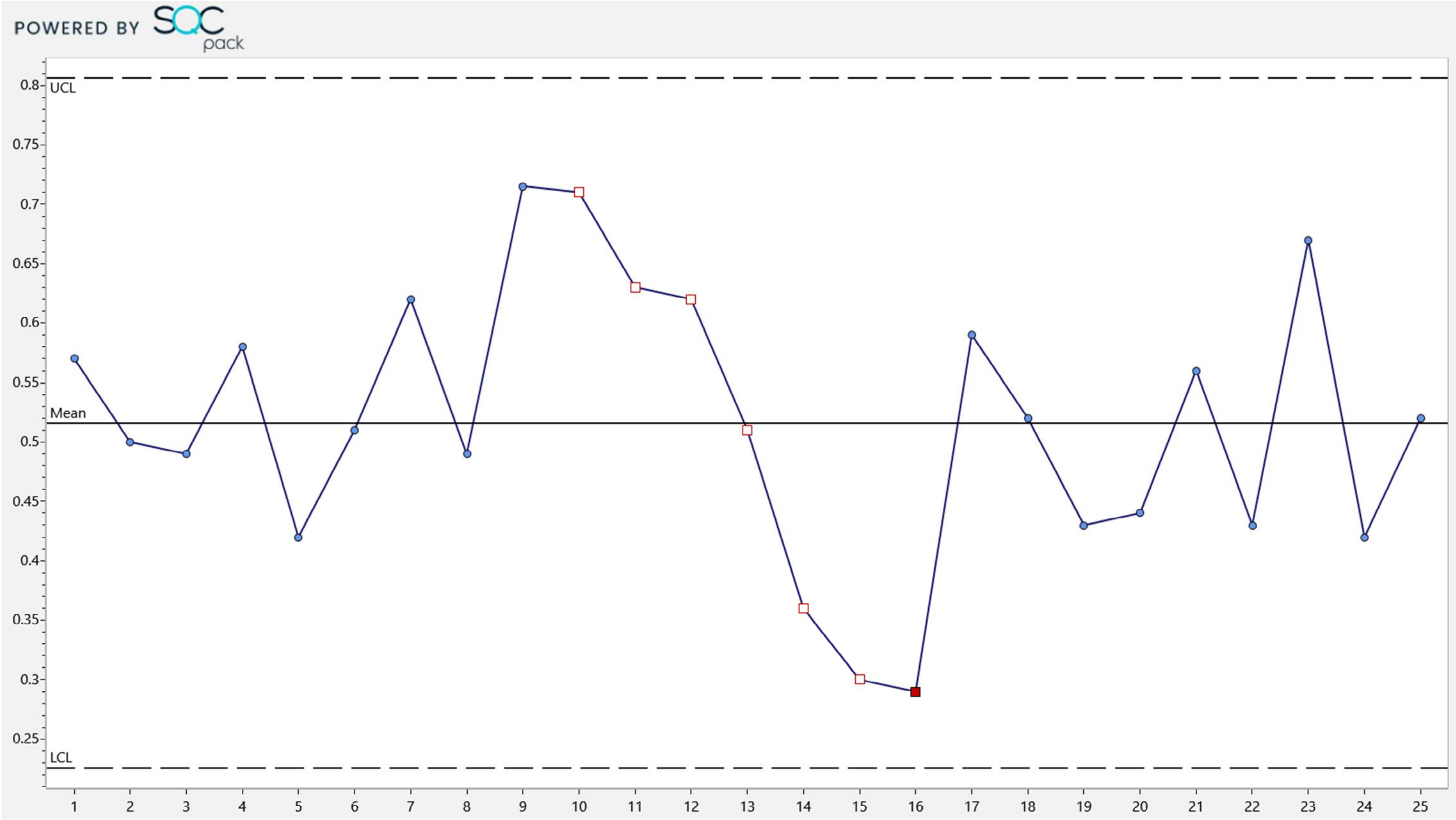
Any point beyond the control limits



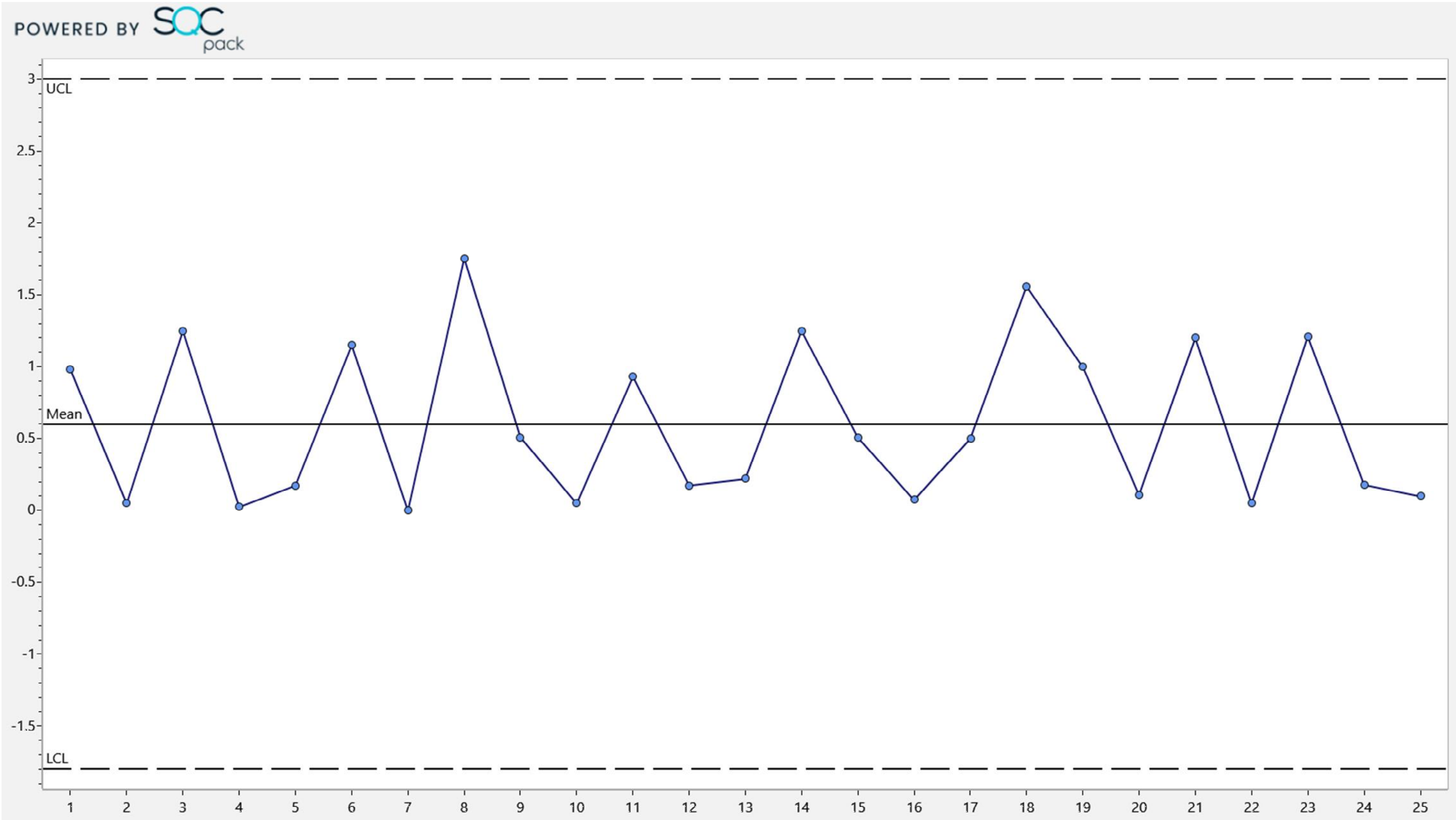
Seven consecutive below the mean



Seven consecutive decreasing



Too far from the average, cycles, …

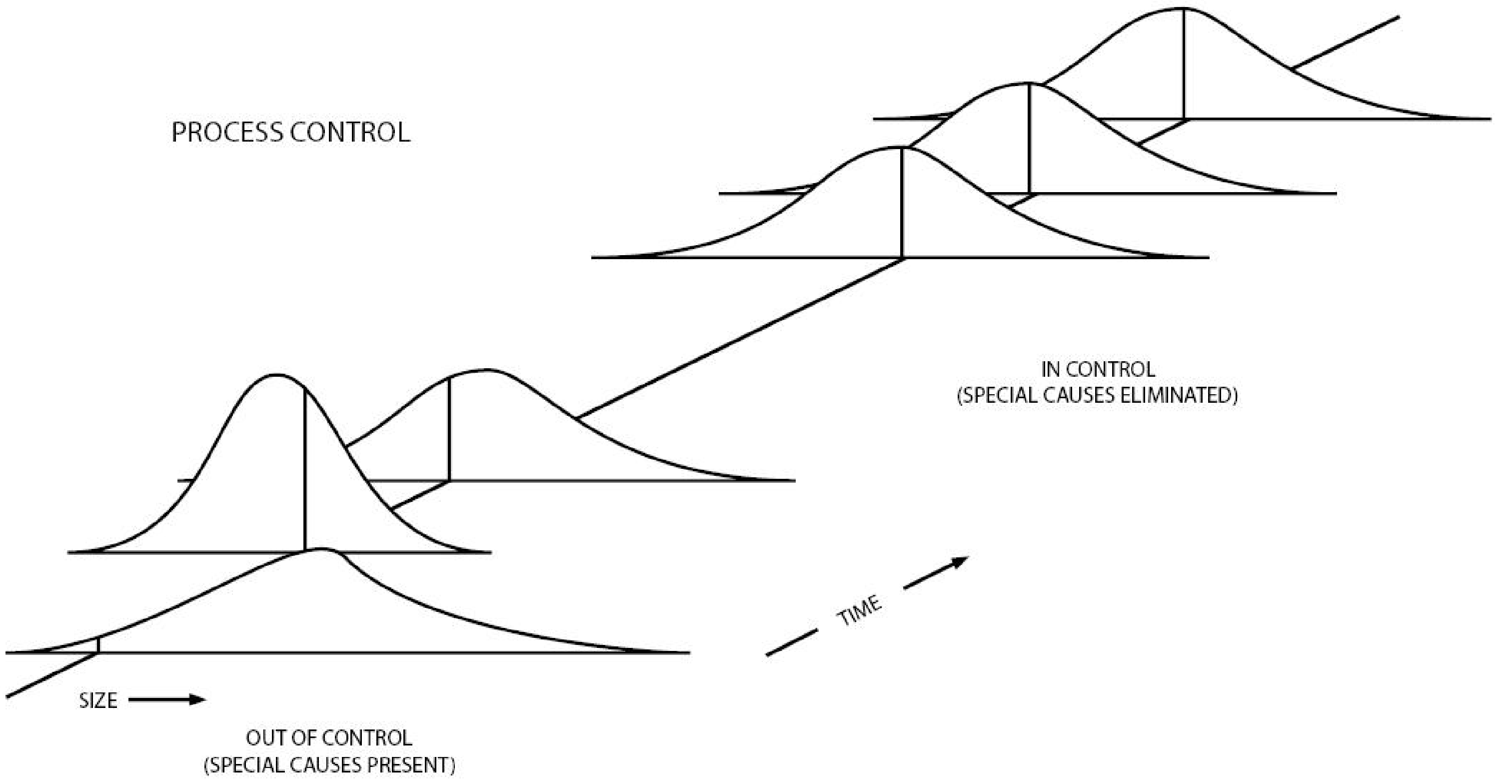


Tip: Use enough data

- How much data is necessary for control limits on a control chart?
- “An X-mr chart can be made with as few as four original values without an undue risk of a false alarm.” Donald J. Wheeler, Ph.D.
- Data beyond a control limit? Investigate it — even with only a few samples.

Purpose of a Control Chart

Common and Special Cause Variation



Types of Capability Indices

- Cr
- Cp
- Cpk
- Cpu
- Cpl

- Pr
- Pp
- Ppk
- Ppu
- Ppl

- Cpm

Symbols and Formulas

Symbols and Formulas

- Sigma-e = estimated sigma $\hat{\sigma}_e = \dfrac{\bar{R}}{d_2}$

- Sigma-i = standard deviation of the individual readings
  (Excel uses the STDEV function) $\hat{\sigma}_i = \sqrt{\dfrac{\sum\left(X_i - \bar{X}\right)^2}{n-1}}$

Symbols and Formulas - Cp

$$Cp = \frac{USL - LSL}{6 * \hat{\sigma}_e} = \frac{\text{Voice of the Customer}}{\text{Voice of the Process}}$$

Symbols and Formulas - Cp

$$Cp = \frac{USL - LSL}{6 * \hat{\sigma}_e}$$

Symbols and Formulas - Cp

- Cp = 1.0

- The allowable spread is the same as the actual spread

Symbols and Formulas - Cp

- Cp > 1

- The allowable spread is w than actual spread

Symbols and Formulas - Cp

- Cp > 1
- The vehicle *can* fit

Symbols and Formulas - Cp

- Cp < 1.0

- The space is too narrow

Symbols and Formulas

$$Cpu = \frac{(USL - \bar{X})}{(3 * \hat{\sigma}_e)}$$

$$Cpl = \frac{(\bar{X} - LSL)}{(3 * \hat{\sigma}_e)}$$

Cpk = Smaller of Cpu and Cpl

Key Assumptions

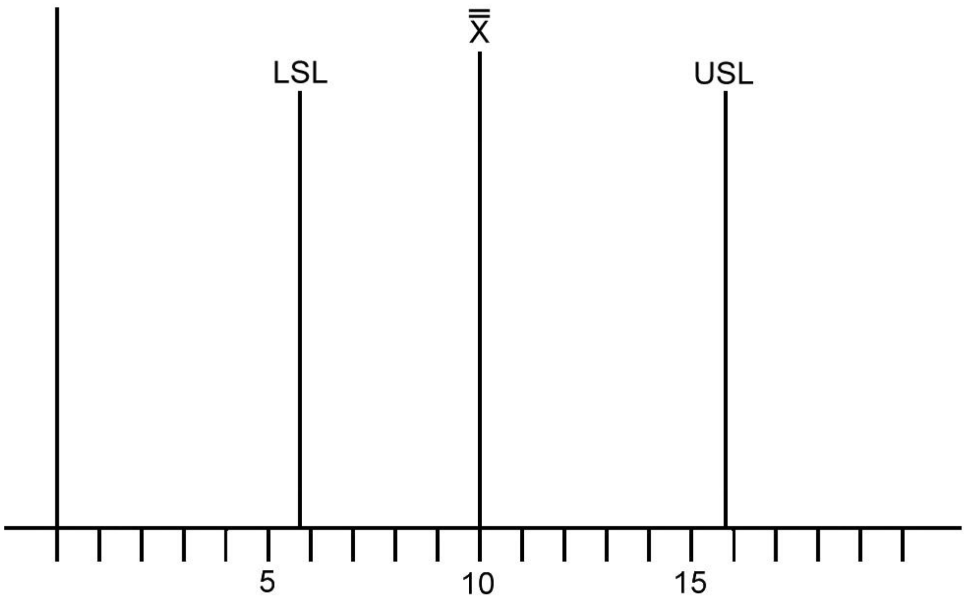
- A control chart is completed
- The control chart shows no special causes
- One or both specifications exist
- The distribution of the data is bell-shaped

How Capability Analysis is Performed

- Calculate the mean and the standard deviation
- Sketch the distribution & specification line(s)
- Calculate Z-values
- Determine expected percent out-of-spec
- Calculate the Cp, Cpk and/or Pp, Ppk

How Capability Analysis is Performed

- Sketch the distribution (optional, but helpful)



$\bar{\bar{X}} = 10.0$

$\bar{R} = 5.81$

USL = 15.8

LSL = 5.73

$n = 5$

How Capability Analysis is Performed

- Calculate the standard deviation

$$\text{Estimated sigma} = \frac{\bar{R}}{d_2}$$

$$\text{Est. sigma} = \frac{5.81}{2.326} \sim 2.50$$

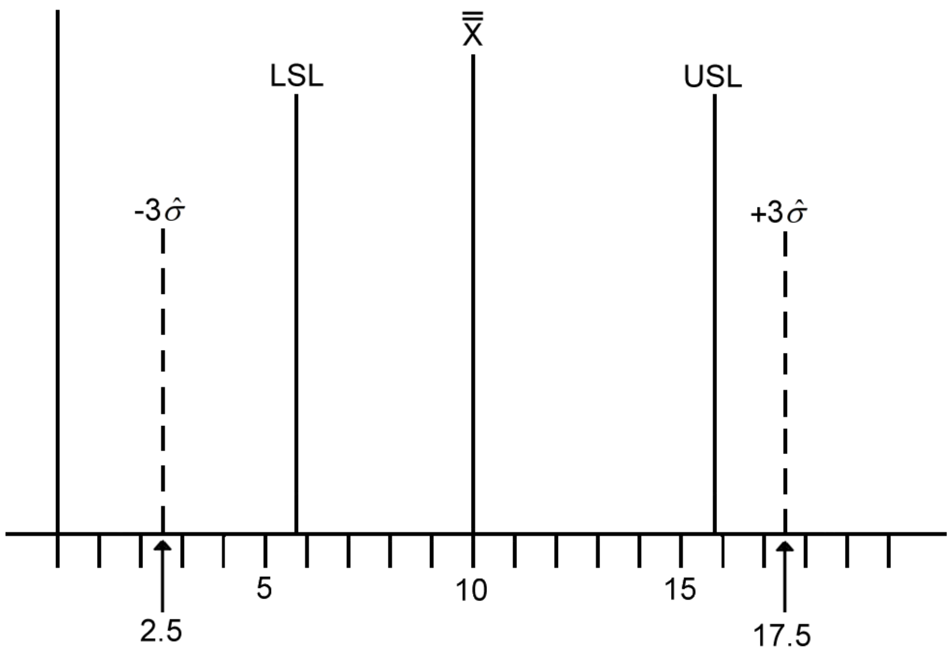
3 x sigma = 7.50

Mean +/- 3sigma = 17.50, 2.50

Subgroup size	d_2 values
2	1.128
3	1.693
4	2.059
5	2.326
6	2.534
7	2.704
8	2.847
9	2.970
10	3.078

How Capability Analysis is Performed

- Sketch the distribution (optional, but helpful)



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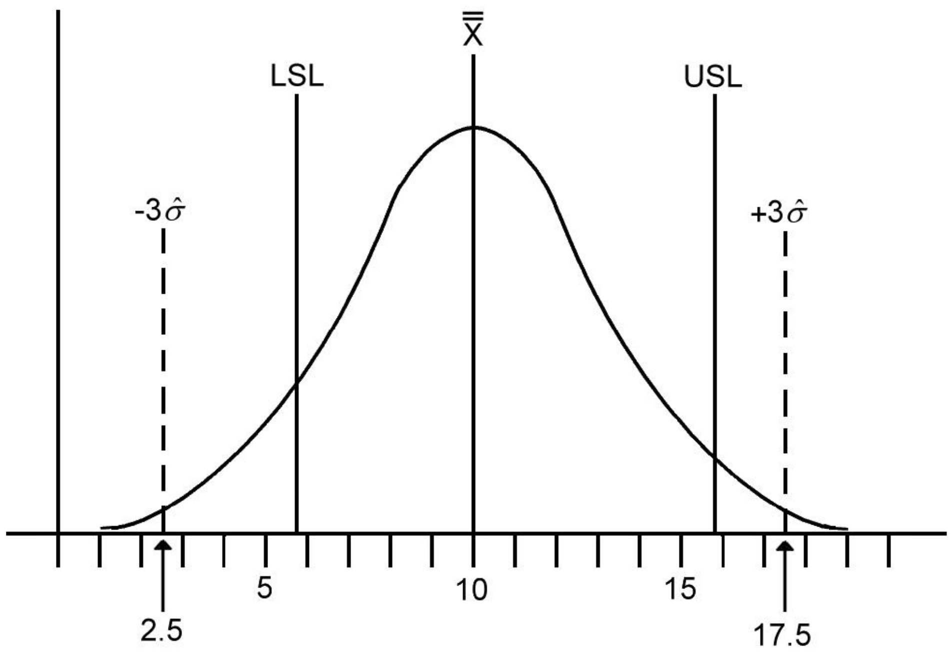

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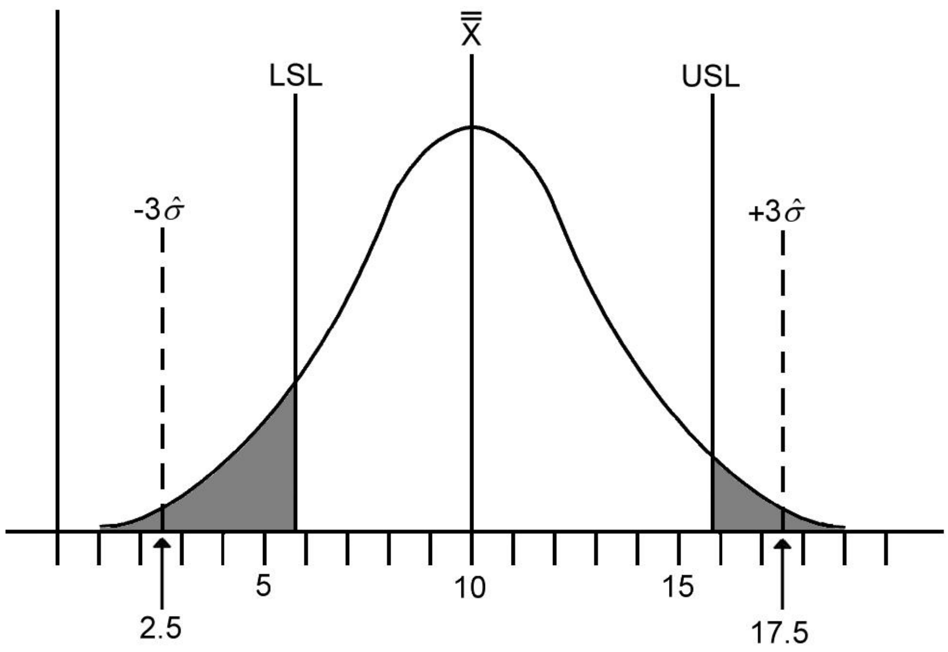


$\bar{\bar{X}} = 10.0$

$\bar{R} = 5.81$

USL = 15.8

LSL = 5.73

$n = 5$

How Capability Analysis is Performed

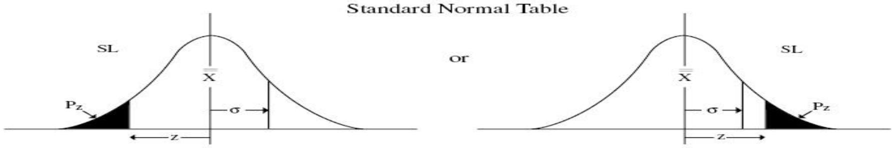
- Calculate Z_{upper} and Z_{lower}

$$Z_{upper} = \frac{(\text{USL} - \text{Mean})}{\text{sigma}} = \frac{(15.8 - 10.0)}{2.50} = 2.32$$

$$Z_{lower} = \frac{(\text{Mean} - \text{LSL})}{\text{sigma}} = \frac{(10 - 5.73)}{2.50} =\sim 1.71$$

Standard Normal Table

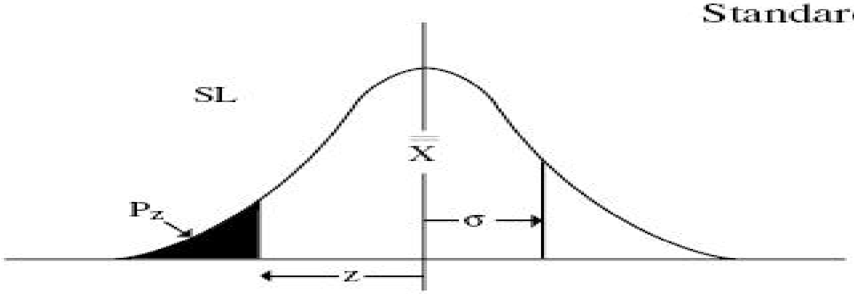
Standard Normal Table



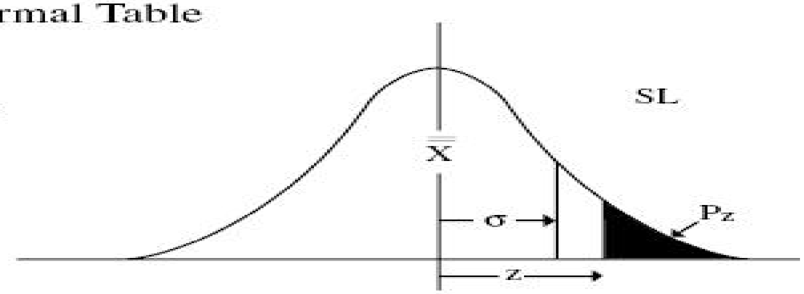
z	x.x0	x.x1	x.x2	x.x3	x.x4	x.x5	x.x6	x.x7	x.x8	x.x9
4.0	.00003									
3.9	.00005	.00005	.00004	.00004	.00004	.00004	.00004	.00004	.00003	.00003
3.8	.00007	.00007	.00007	.00006	.00006	.00006	.00006	.00005	.00005	.00005
3.7	.00011	.00010	.00010	.00010	.00009	.00009	.00008	.00008	.00008	.00008
3.6	.00016	.00015	.00015	.00014	.00014	.00013	.00013	.00012	.00012	.00011
3.5	.00023	.00022	.00022	.00021	.00020	.00019	.00019	.00018	.00017	.00017
3.4	.00034	.00032	.00031	.00030	.00029	.00028	.00027	.00026	.00025	.00024
3.3	.00048	.00047	.00045	.00043	.00042	.00040	.00039	.00038	.00036	.00035
3.2	.00069	.00066	.00064	.00062	.00060	.00058	.00056	.00054	.00052	.00050
3.1	.00097	.00094	.00090	.00087	.00084	.00082	.00079	.00076	.00074	.00071
3.0	.00135	.00131	.00126	.00122	.00118	.00114	.00111	.00107	.00104	.00100
2.9	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.0014
2.8	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
2.7	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
2.6	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
2.5	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
2.4	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064
2.3	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
2.2	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
2.1	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
2.0	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
1.9	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
1.8	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.0294
1.7	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
1.6	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
1.5	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
1.4	.0808	.0793	.0778	.0764	.0749	.0735	.0721	.0708	.0694	.0681
1.3	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
1.2	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
1.1	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
1.0	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
0.9	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
0.8	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1922	.1894	.1867
0.7	.2420	.2389	.2358	.2327	.2297	.2266	.2236	.2206	.2177	.2148
0.6	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
0.5	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
0.4	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
0.3	.3281	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483
0.2	.4207	.4168	.4129	.4090	.4052	.4013	.3974	.3936	.3897	.3859
0.1	.4602	.4562	.4522	.4483	.4443	.4404	.4364	.4325	.4286	.4247
0.0	.5000	.4960	.4920	.4880	.4840	.4801	.4761	.4721	.4681	.4641

SYSTEMS

Standard Normal Table



or

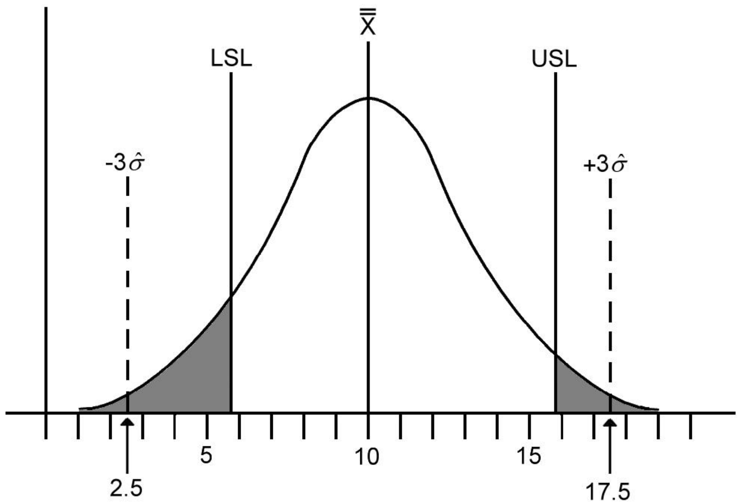


z	x.x0	x.x1	x.x2	x.x3	x.x4	x.x5	x.x6	x.x7	x.x8	x.x9
4.0	.00003									
3.9	.00005	.00005	.00004	.00004	.00004	.00004	.00004	.00004	.00003	.000
3.8	.00007	.00007	.00007	.00006	.00006	.00006	.00006	.00005	.00005	.000
3.7	.00011	.00010	.00010	.00010	.00009	.00009	.00008	.00008	.00008	.000
3.6	.00016	.00015	.00015	.00014	.00014	.00013	.00013	.00012	.00012	.000
3.5	.00023	.00022	.00022	.00021	.00020	.00019	.00019	.00018	.00017	.000
3.4	.00034	.00032	.00031	.00030	.00029	.00028	.00027	.00026	.00025	.000
3.3	.00048	.00047	.00045	.00043	.00042	.00040	.00039	.00038	.00036	.000
3.2	.00069	.00066	.00064	.00062	.00060	.00058	.00056	.00054	.00052	.000
3.1	.00097	.00094	.00090	.00087	.00084	.00082	.00079	.00076	.00074	.000
3.0	.00135	.00131	.00126	.00122	.00118	.00114	.00111	.00107	.00104	.001
2.9	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.001
2.8	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.001
2.7	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.002
2.6	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.003
2.5	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.004
2.4	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.006
2.3	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.008
2.2	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.011
2.1	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.014
2.0	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.018
1.9	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.023
1.8	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.029

How Capability Analysis is Performed

Z_{upper} = 2.32 → 0.0102 → 1.02%

Z_{lower} = 1.71 → 0.0436 → 4.36%



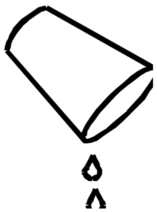
We expect 1.02% + 4.36% of data to be outside the specification limits.

How Capability Analysis is Performed

- Cp = spec spread / process spread
- Cp = (15.8 – 5.73) / (6 * 2.50)
- Cp = 0.67

- Cpk = Smallest Z value / 3
- Cpk = 1.71 / 3
- Cpk = 0.57

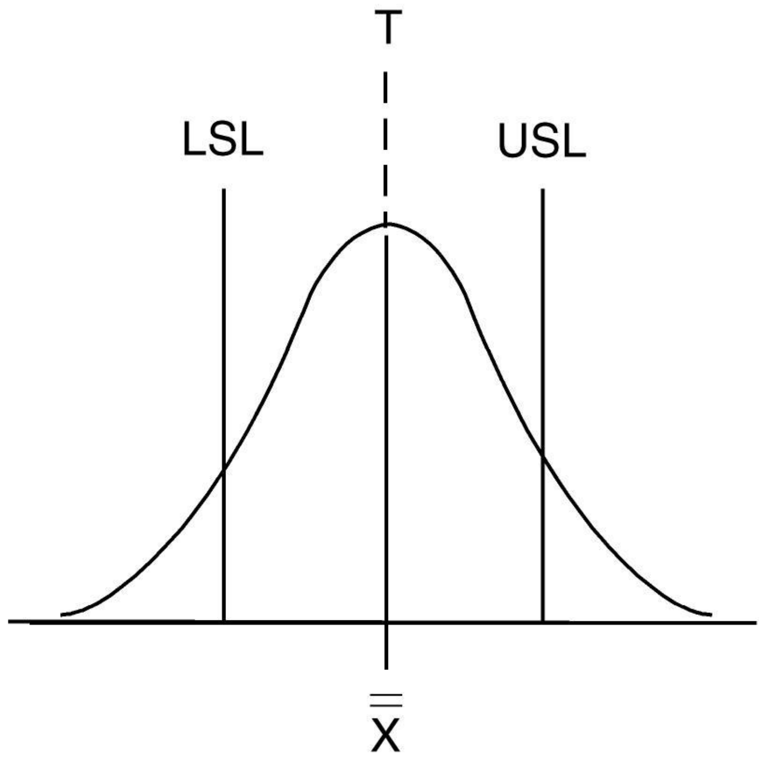
Getting the Most from Capability Analysis



$$Cpm = \frac{USL - LSL}{6\,\hat{\boldsymbol{\sigma}}_{Cpm}}$$

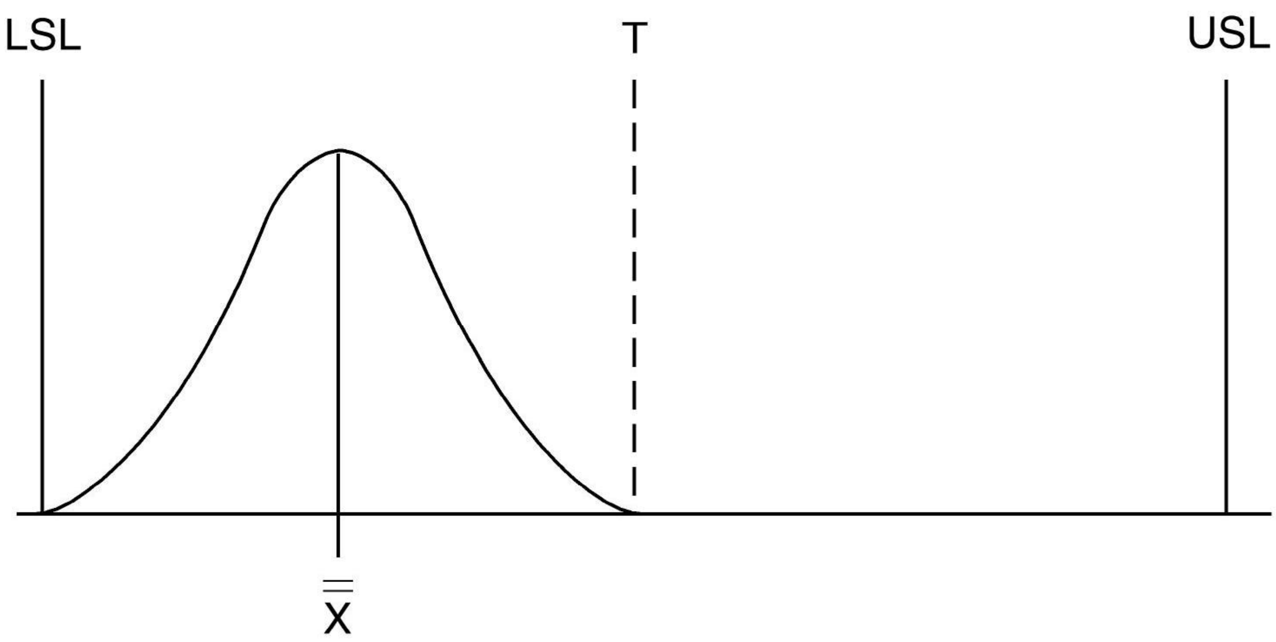
$$\hat{\sigma}_{Cpm} = \sqrt{\frac{\sum (X_i - T)^2}{n-1}}$$

Average is at the Target Value



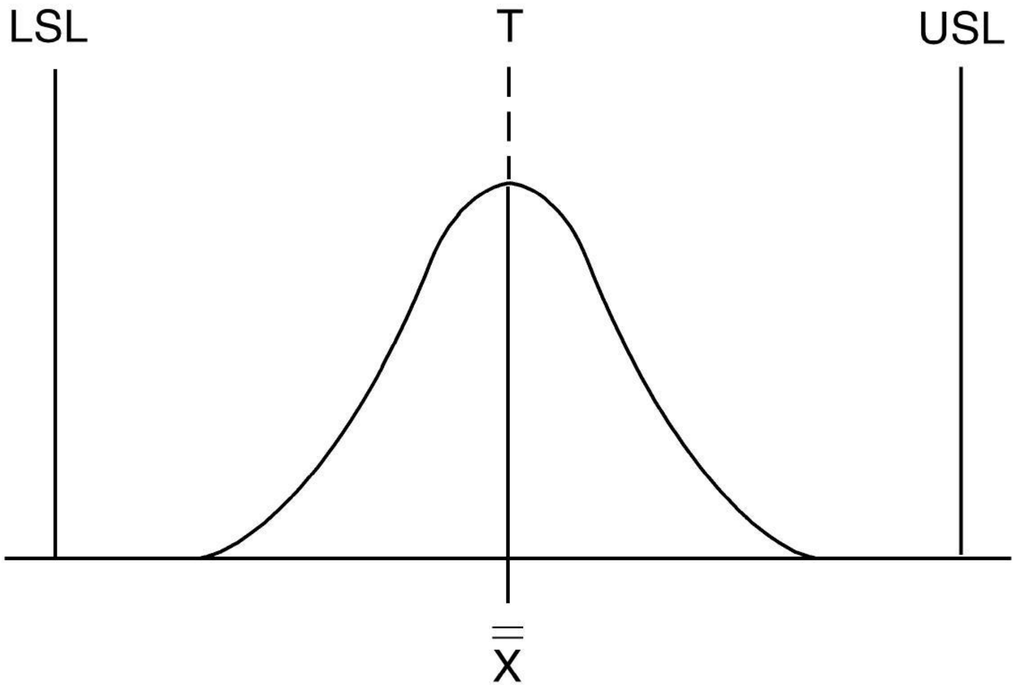
$C_p = 0.5$
$C_{pk} = 0.5$
$C_{pm} = 0.5$

Average is Off Target



$C_p = 2.0$
$C_{pk} = 1.0$
$C_{pm} = 0.65$

Average is at the Target Value



$C_p = 1.5$
$C_{pk} = 1.5$
$C_{pm} = 1.5$

Final Thoughts

- Control charts are designed to provide stability information
- Capability analysis allows you to compare different processes
- Capability analysis brings together the process limits (+/- 3 sigma) and specification limits

PQ Systems Software

SQC pack

GAGE pack

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