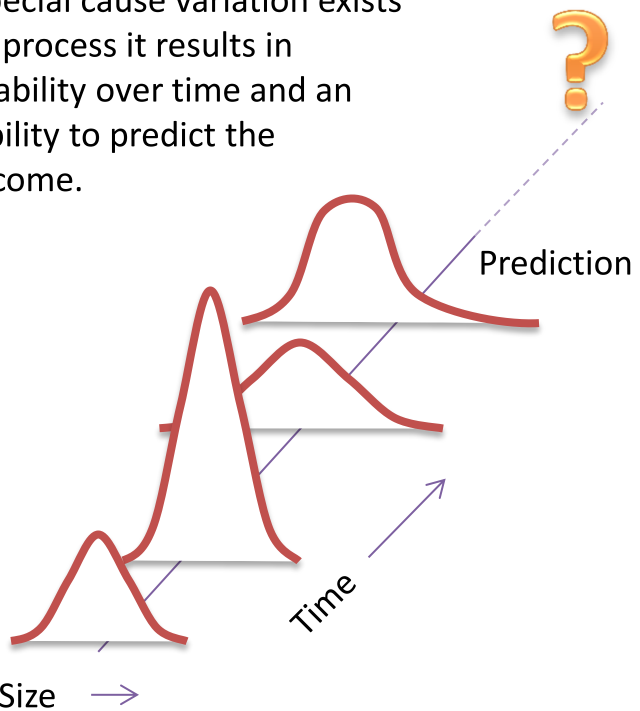
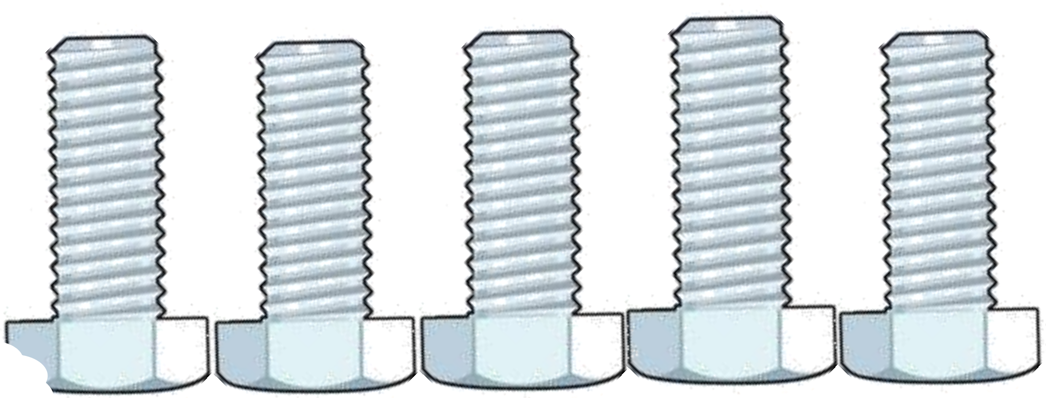
Special Cause Variation

If special cause variation exists in a process it results in instability over time and an inability to predict the outcome.





Special cause variation are due to out of the ordinary events. An example of this is the bolt with a broken head. Often these events are unpredictable and results in an unsatisfactory product

The Benefits of Process Control

- When a process is in control:
- You can predict the process outcome in terms of performance (location) and variation (spread)
- You can estimate the capability of the process in terms of the product specification
- It reduces process and production variation
- It reduces waste (scrap, customer satisfaction, etc.)
- It reduces process cost (downtime, adjustments, etc.)

CAUTION
When a process is not in control we cannot estimate capability or the ability to meet specification!

Process Control vs. Capability vs. Performance

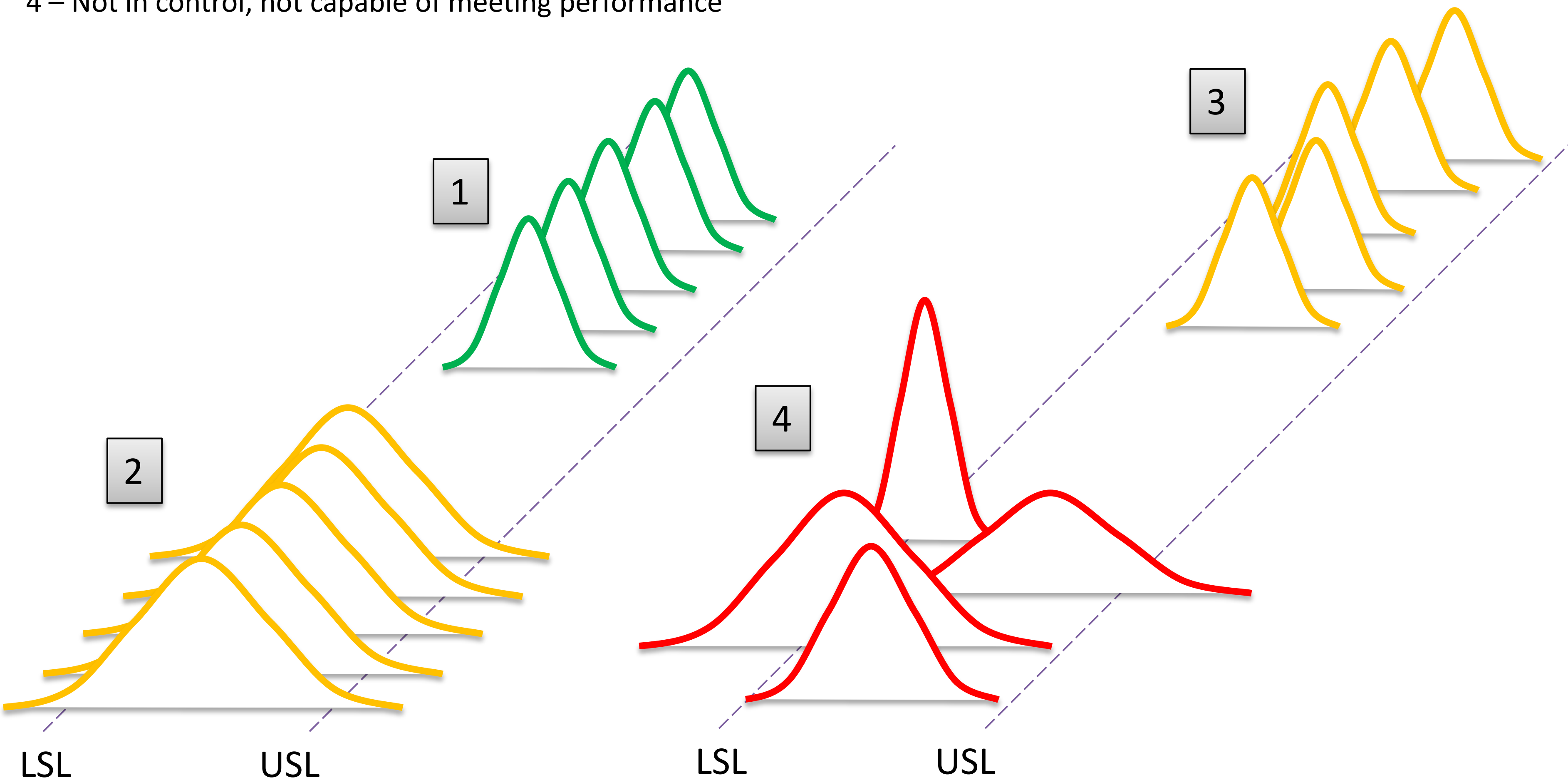
- Process Control:
- When a process is in control the only cause of variation present is due to common cause, regardless of product specification.
- Process Capability:
- When a process is in control (common cause variation). It generally represents the best performance of a stable process.
- Process Performance:
- The overall output of the process and how it relates to customer (internal and external) requirements, regardless of process variation within or between subgroups.

Process Control vs. Capability (Performance)

Capability (Performance)		Statistical Control: In-Control	Statistical Control: Out-of-Control
	Acceptable	Case 1 (Ideal state)	Case 3 (Brink of Chaos)
	Unacceptable	Case 2 (Threshold state)	Case 4 (State of Chaos)

The best condition is case 1, where the process is both in control and capable of meeting specification.
In case 2 the process is stable but has excessive common cause variation, which needs to be reduced.
In case 3 the process meets specification but is not stable due to special cause variation, which needs to be eliminated.
In case 4 the process is out of control and not capable of meeting specification. In this case common cause needs to be reduced and special causes eliminated.

1 – In control, capable of meeting performance
2 – In control, not capable of meeting performance
3 – Not in control, currently meeting specification
4 – Not in control, not capable of meeting performance



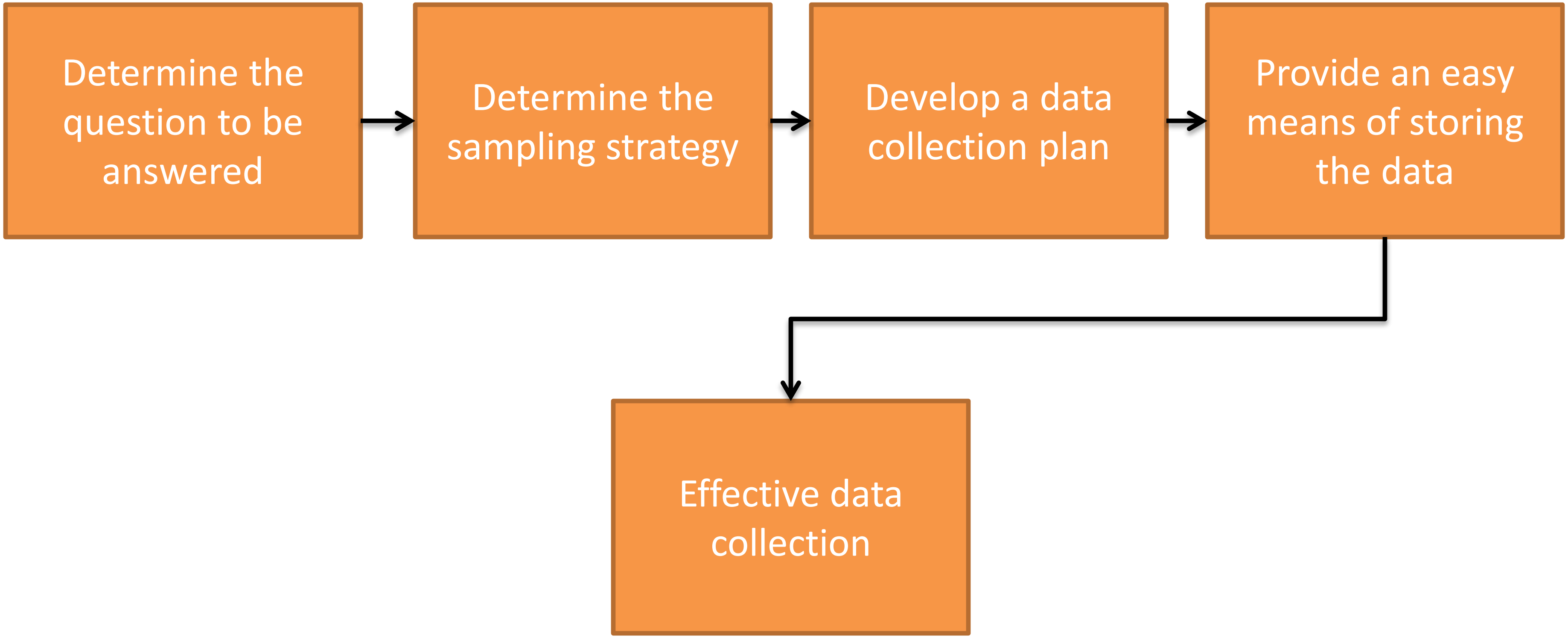
Review

- The end goal is to develop a process that is in control (stable) that has minimal variation.
- When reviewing data keep an eye out for special cause variation. If special cause variation is present in a process the team needs to identify root cause and implement corrective actions.

Control Charts

- Goal
  - Understand data collection
  - Develop a meaningful sampling plan
  - Understand common variable control charts
  - Understand common discrete control charts
  - Example manual control chart setup
  - Control charts in Minitab
  - Interpreting Results

Data Collection Flow



Why are you collecting data?

- When collecting data the following questions must be answered:
  - What is the intent of the data you plan to collect?
    - If process monitoring is important select process input that is key to success or a product characteristic that is directly impacted. Make sure the data is meaningful.
  - Will the data be representative of the population?
    - Measuring 15 parts before the injection molding tool warms up probably won't accurately reflect the product population.
  - Will the data collected be actionable?

Sampling Strategies

- Sampling Strategies
- Random sampling
  - Each member of the population has an equal chance of being included in the sample.
- Stratified sampling
  - The population is divided into subgroups and then randomly sampled
- Systematic sampling
  - Samples are taken at specific points in time or intervals.

Collection Plan

- When developing a data collection plan you must consider:
- What will be measured / collected?

  Product or process characteristic. Variable or attribute.
- How will it be measured / collected?

  Which measurement system?
- How much will be collected?

  Both frequency and sample size. Over what time period?
- Who (and where) will collect it?

  Operator or Engineer? Does the part need to normalize, be kept clean, etc.?

Sample Size / Frequency

- Overall goal is to choose a subgroup size and frequency that minimizes variation within subgroups and maximizes variation between subgroups.
- Any significant variation within subgroup should be immediately investigated.
- Subgroup size should be determined by process type, standard deviation of process, etc. Larger subgroup sizes makes small shifts in the process easier to detect.
- Collection frequency should be determined by the process requirements. Consider difference in operators, shifts, environmental impacts, tool life, etc.

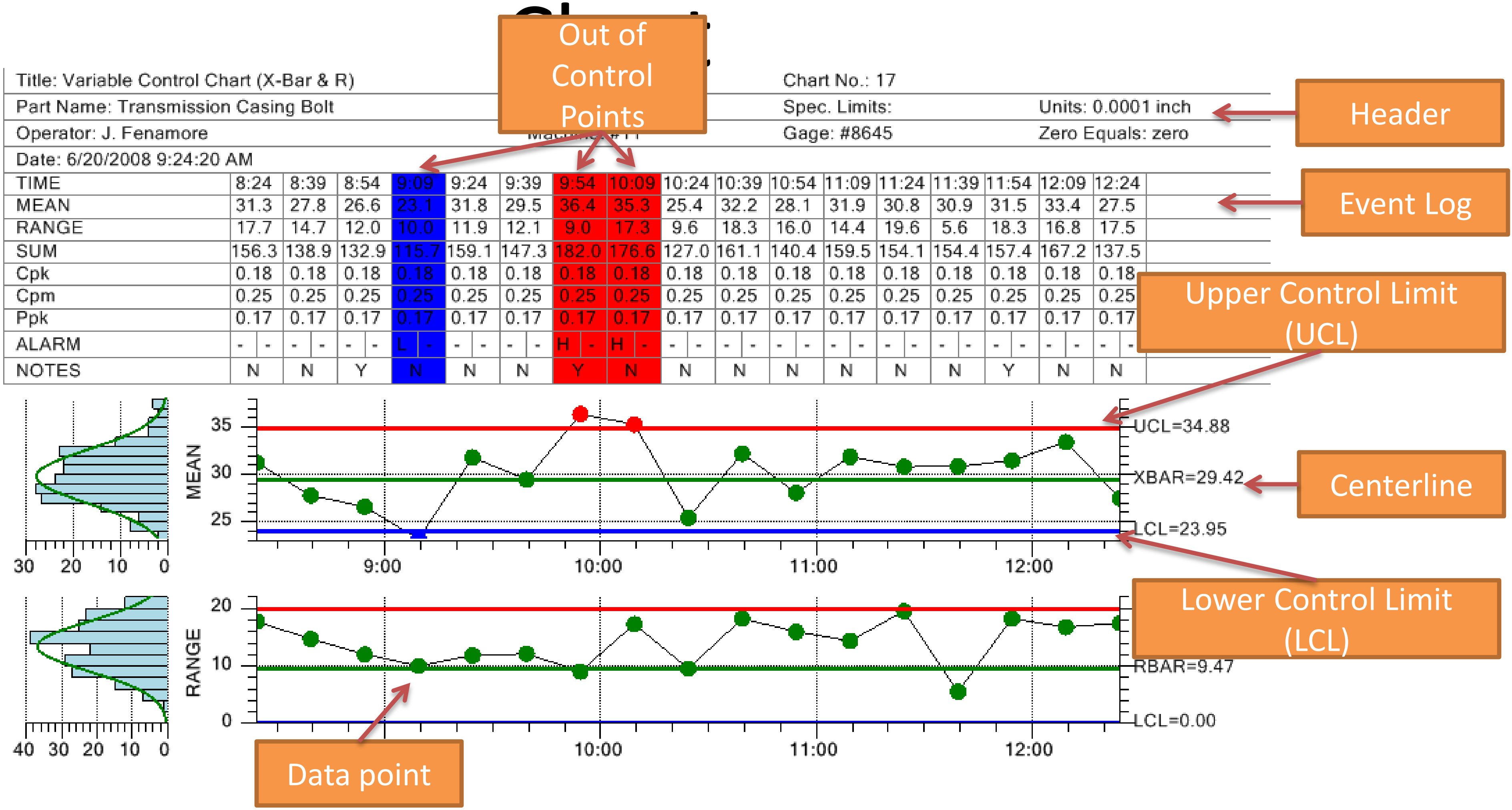
Sampling Size Starting Point

- Variable Data:
  - May be as small as 1 (IMR) or 3 (Xbar & R)
  - Smaller sample sizes at an increased frequency will identify process changes quicker (more susceptible to change)
- Attribute Data:
  - For U charts the sample size needs to be large (N≥100) so that the number of subgroups that have no nonconformities is very small
  - For p and NP charts, the sample size should be calculated as follows:
    - $n \geq \frac{5}{\bar{p}}$ where n is subgroup size and $\bar{p}$ is the proportion of nonconforming units

What are Control Charts?

- A time order graphical representation of a process characteristic
- They are used to:
  - Determine if a process has been operating in statistical control
  - Aid in maintaining statistical control
  - Determine the process location and spread (common cause variation)
  - Help identify special cause variation

Components of a Control Chart

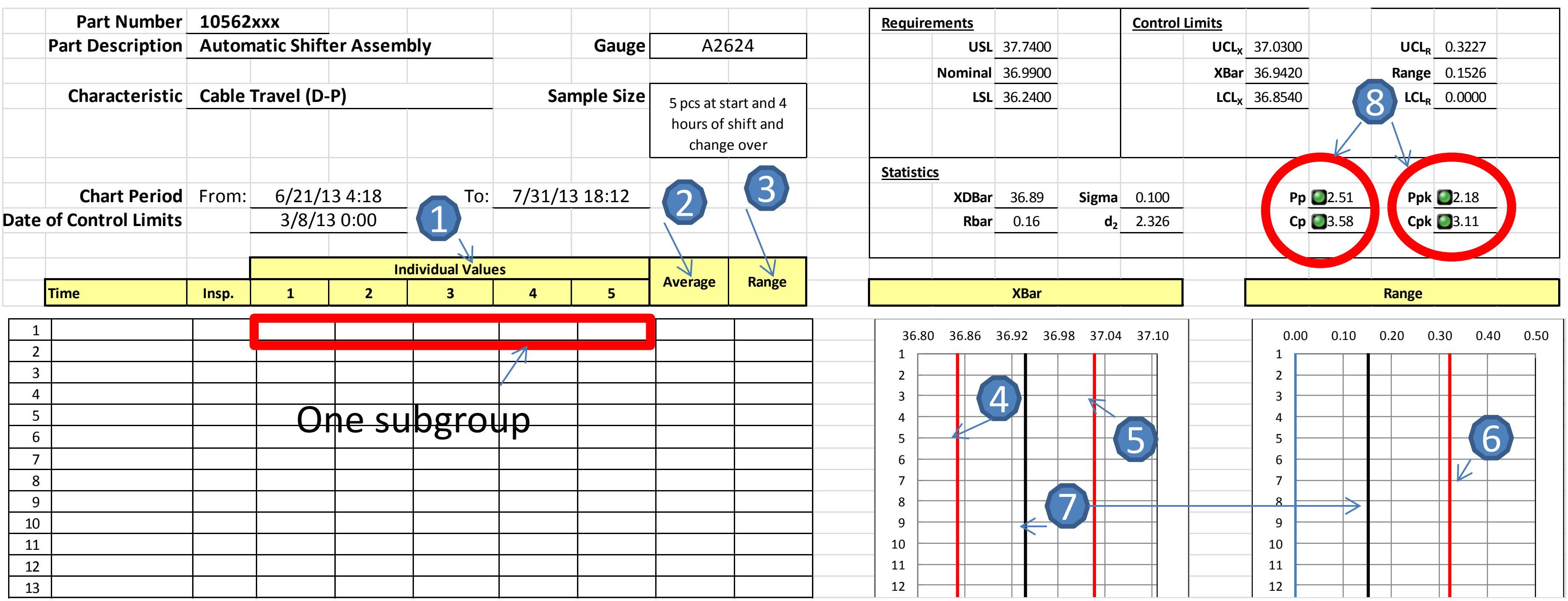


TIME	8:24	8:39	8:54	9:09	9:24	9:39	9:54	10:09	10:24	10:39	10:54	11:09	11:24	11:39	11:54	12:09	12:24
MEAN	31.3	27.8	26.6	23.1	31.8	29.5	36.4	35.3	25.4	32.2	28.1	31.9	30.8	30.9	31.5	33.4	27.5
RANGE	17.7	14.7	12.0	10.0	11.9	12.1	9.0	17.3	9.6	18.3	16.0	14.4	19.6	5.6	18.3	16.8	17.5
SUM	156.3	138.9	132.9	115.7	159.1	147.3	182.0	176.6	127.0	161.1	140.4	159.5	154.1	154.4	157.4	167.2	137.5
Cpk	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Cpm	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Ppk	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
ALARM	- -	- -	- -	L -	- -	- -	H -	H -	- -	- -	- -	- -	- -	- -	- -	- -	- -
NOTES	N	N	Y	N	N	N	Y	N	N	N	N	N	N	N	Y	N	N

Common Control Chart Types

- Variable Data
  - Average and Range - $\bar{X}$ & R Chart
    - This is the most common control chart type as it measures both process average ($\bar{X}$) and variation (R), though it may not be the best choice for all applications
  - Individual Moving Range - IMR Chart
- Attribute Data
  - p Chart / np Chart (Defective)
    - The np Chart requires a constant sample size, the p Chart does not
  - c Chart / u Chart (Number of defects)
    - The c Chart requires a constant sample size, the u Chart does not

GHSP Application of SPC



Item 1 is subgroup values- entered by inspector

Item 2 is subgroup average- calculated and plotted automatically

Item 3 is the Range biggest value minus smallest value in subgroup-calculated and plotted automatically

GHSP Application of SPC

Part Number	10562xxx			
Part Description	Automatic Shifter Assembly		Gauge	A2624
Characteristic	Cable Travel (D-P)		Sample Size	5 pcs at start of shift
Chart Period	From: 3/12/13 23:03	To: 3/14/13 15:28		
Date of Control Limits	3/8/13 0:00			

Requirements

USL	37.7400
Nominal	36.9900
LSL	36.2400

Control Limits

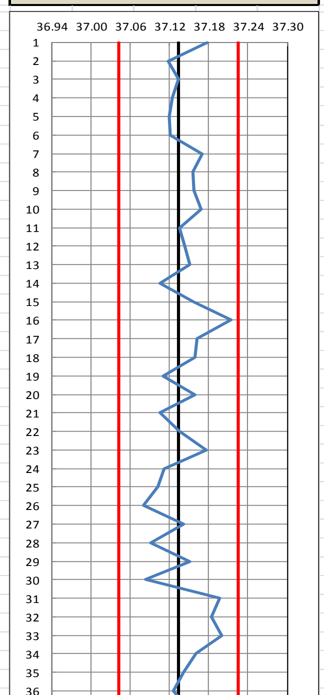
UCL_X	37.2250	UCL_R	0.3352
XBar	37.1336	Range	0.1585
LCL_X	37.0422	LCL_R	0.0000

Statistics

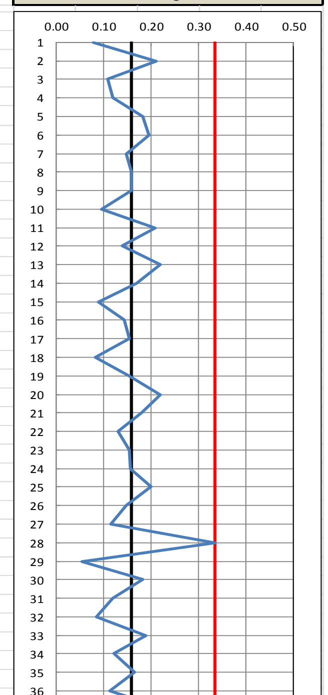
XDBar	37.13	Sigma	0.070	Pp	3.58	Ppk	2.91
Rbar	0.16	d_2	2.326	Cp	3.62	Cpk	2.94

	Time	Insp.	Data 1	2	3	4	5	Mean	Range
1	3/12/2013 23:03	DN	37.23	37.15	37.16	37.16	37.18	37.18	0.08
2	3/12/2013 23:25		37.02	37.08	37.07	37.23	37.20	37.12	0.21
3	3/12/2013 23:42		37.07	37.15	37.17	37.18	37.10	37.13	0.11
4	3/13/2013 0:05		37.15	37.16	37.13	37.14	37.04	37.12	0.12
5	3/13/2013 0:21		37.07	37.22	37.09	37.04	37.18	37.12	0.18
6	3/13/2013 0:37		37.15	37.13	37.00	37.13	37.20	37.12	0.20
7	3/13/2013 0:49		37.26	37.15	37.18	37.14	37.11	37.17	0.15
8	3/13/2013 1:07		37.20	37.23	37.19	37.09	37.07	37.16	0.16
9	3/13/2013 1:31		37.24	37.08	37.18	37.14	37.15	37.16	0.16
10	3/13/2013 1:51		37.18	37.14	37.17	37.23	37.13	37.17	0.10
11	3/13/2013 2:04		37.18	37.04	37.13	37.25	37.09	37.14	0.21
12	3/13/2013 2:19		37.06	37.15	37.19	37.20	37.12	37.14	0.14
13	3/13/2013 2:36		37.21	37.16	37.01	37.23	37.15	37.15	0.22
14	3/13/2013 2:53		37.12	37.15	37.19	37.02	37.06	37.11	0.17
15	3/13/2013 3:09		37.21	37.12	37.16	37.16	37.15	37.16	0.09
16	3/13/2013 3:44		37.22	37.19	37.31	37.16	37.19	37.21	0.14
17	3/13/2013 4:02		37.25	37.10	37.19	37.10	37.18	37.16	0.15
18	3/13/2013 4:14		37.12	37.17	37.21	37.18	37.12	37.16	0.08
19	3/13/2013 4:28		37.17	37.14	37.13	37.10	37.01	37.11	0.15
20	3/13/2013 4:43		37.21	37.25	37.16	37.15	37.03	37.16	0.22
21	3/13/2013 4:59		37.18	37.03	37.01	37.19	37.11	37.11	0.18
22	3/13/2013 5:30		37.14	37.13	37.21	37.08	37.11	37.14	0.13
23	3/13/2013 9:52	CF	37.08	37.18	37.22	37.23	37.17	37.18	0.15
24	3/13/2013 10:05		37.19	37.09	37.10	37.03	37.16	37.11	0.16
25	3/13/2013 10:21		37.21	37.12	37.05	37.11	37.01	37.10	0.20
26	3/13/2013 10:36		37.09	37.18	37.03	37.07	37.04	37.08	0.15
27	3/13/2013 10:52		37.10	37.11	37.21	37.12	37.18	37.14	0.12
28	3/13/2013 11:05		37.18	36.87	37.11	37.10	37.20	37.09	0.33
29	3/13/2013 11:17		37.15	37.17	37.15	37.12	37.17	37.15	0.05
30	3/13/2013 11:43		37.13	37.00	37.08	37.18	37.02	37.08	0.18
31	3/13/2013 12:19		37.14	37.21	37.18	37.22	37.26	37.20	0.12
32	3/13/2013 12:33		37.19	37.20	37.17	37.14	37.22	37.18	0.09
33	3/13/2013 12:46		37.11	37.19	37.18	37.21	37.30	37.20	0.19
34	3/13/2013 12:57		37.15	37.16	37.24	37.12	37.14	37.16	0.12
35	3/13/2013 13:12		37.14	37.07	37.24	37.12	37.13	37.14	0.16
36	3/13/2013 13:30		37.11	37.19	37.12	37.13	37.08	37.13	0.11
37	3/13/2013 13:44		37.19	37.18	37.02	37.10	37.26	37.15	0.24

XBar



Range



Example Control Chart

Goal: To create a sample Xbar and R chart for the data set below

Sample #1	0.0006	0.0008	0.0006	0.0002	0.0004	0.0004	
Sample #2	0.0007	0.0005	0.0006	0.0007	0.0004	0.0008	
Sample # 3	0.0001	0.0004	0.0000	0.0000	0.0006	0.0008	
Xbar	0.0005	0.0006	0.0004	0.0003	0.0005	0.002	
Range	0.0006	0.0004	.00006	0.0007	0.0002	0.0004	

Step 1: Calculate Xbar (average) for each observation

$\bar{X} = \frac{X^{n1} + Xn^{2} + Xn^{3} \cdots}{n}$ Where n = total number of samples and X^{nx} = individual sample

Step 2: Calculate the range for each observation

$R = x_{max} - x_{min}$

Sample #1	0.0006	0.0008	0.0006	0.0002	0.0004	0.0004	
Sample #2	0.0007	0.0005	0.0006	0.0007	0.0004	0.0008	
Sample # 3	0.0001	0.0004	0.0000	0.0000	0.0006	0.0008	
Xbar	0.0005	0.0006	0.0004	0.0003	0.0005	0.0020	$\bar{\bar{X}}$ = 0.0004
Range	0.0006	0.0004	0.0006	0.0007	0.0002	0.0006	$\bar{R}$ = 0.0005

Step 3: Calculate $\bar{\bar{X}} = \frac{\overline{X}_1 + \overline{X}_2 + \overline{X}_3 \ldots}{n}$

Step 4: Calculate $\bar{R} = \frac{R_1 + R_2 + R_3 \ldots}{n}$

Subgroup Size (n)	A2	D3	D4
2	1.880	0.000	3.267
3	1.023	0.000	2.574
4	0.729	0.000	2.282
5	0.577	0.000	2.114

NOTE: Control limits should be calculated once 20-25 subgroups are collected for normalization purposes

Sample #1	0.0006	0.0008	0.0006	0.0002	0.0004	0.0004	
Sample #2	0.0007	0.0005	0.0006	0.0007	0.0004	0.0008	
Sample # 3	0.0001	0.0004	0.0000	0.0000	0.0006	0.0008	
Xbar	0.0005	0.0006	0.0004	0.0003	0.0005	0.0020	$\bar{\bar{X}}$ = 0.000478
Range	0.0006	0.0004	0.0006	0.0007	0.0002	0.0006	$\bar{R}$ = 0.000480

Step 5: Calculate control limits

For the Xbar chart:

$UCL_{\bar{X}} = \bar{\bar{X}} + A_2\bar{R}$

$LCL_{\bar{X}} = \bar{\bar{X}} - A_2\bar{R}$

For the range chart:

$UCL_R = D_4\bar{R}$

$LCL_R = D_3\bar{R}$

For the Xbar chart:

$UCL_{\bar{X}} = 0.0004 + 1.023(0.0005) = 0.000969$

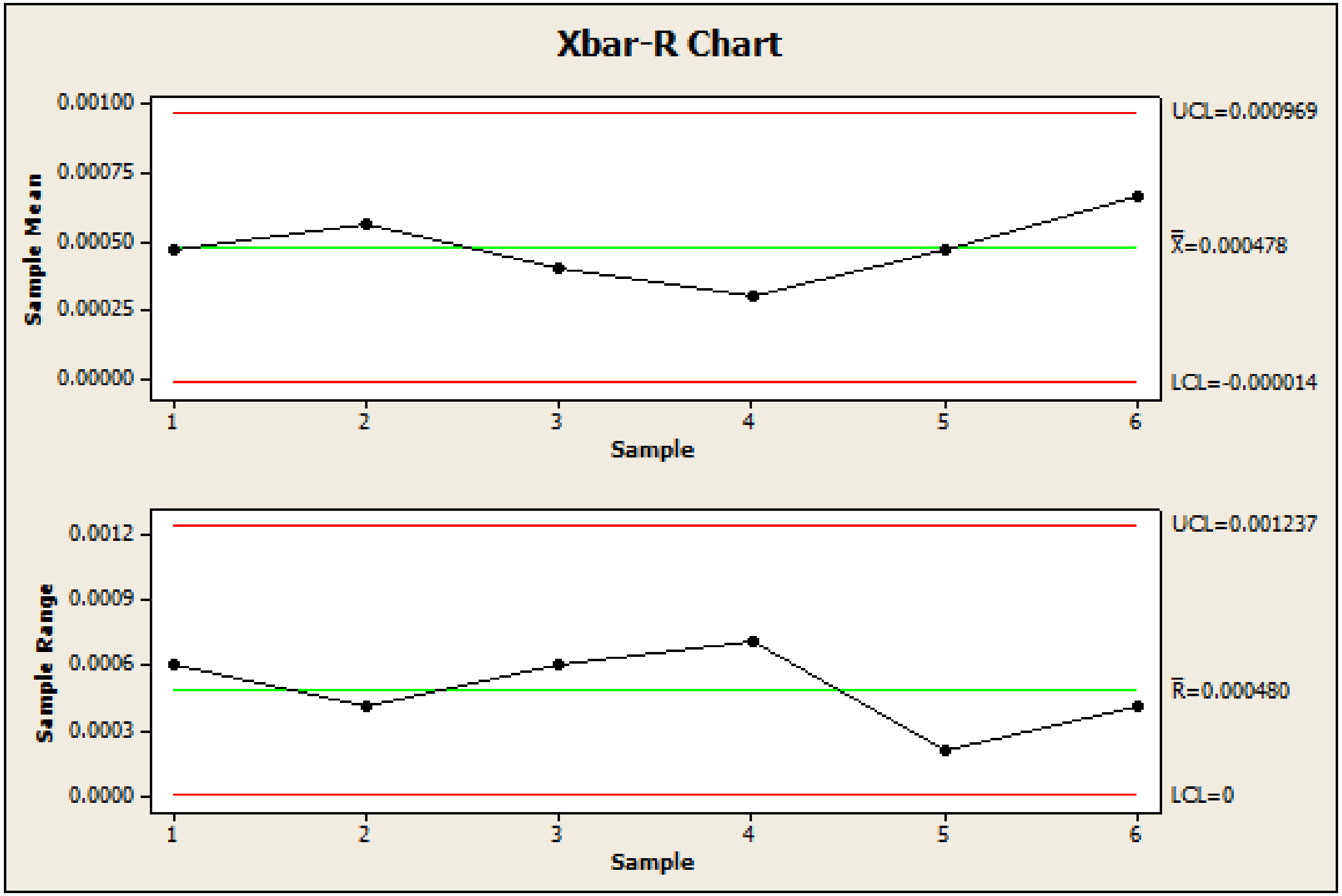
$LCL_{\bar{X}} = 0.0004 – 1.023(0.0005) = 0.000014$

For the range chart:

$UCL_R = 2.574(0.0005) = 0.001237$

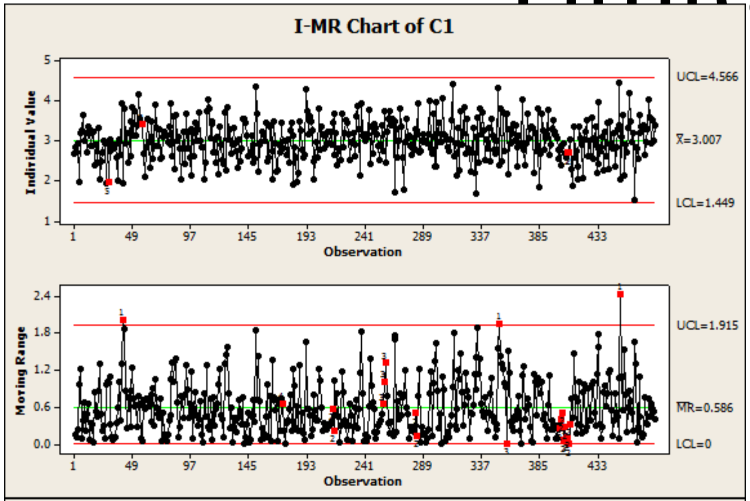
$LCL_R = 0(0.0005) = 0$

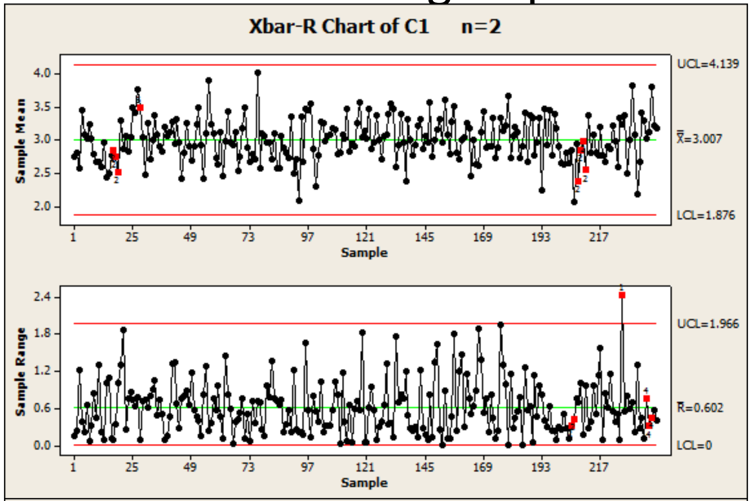
Step 6: Populate the Chart

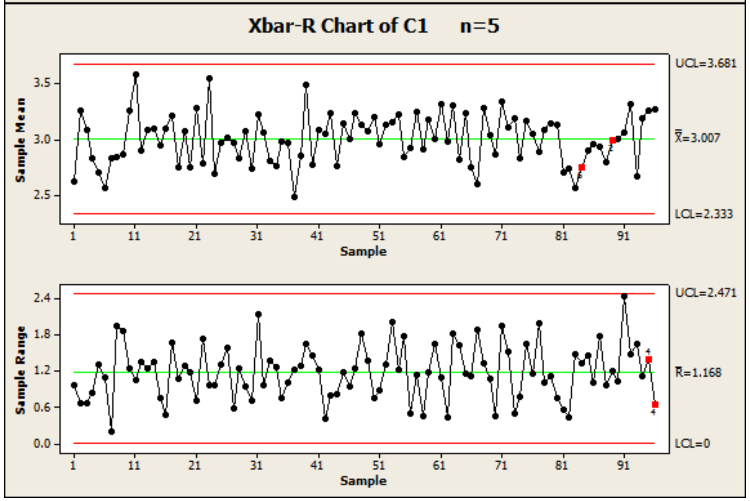


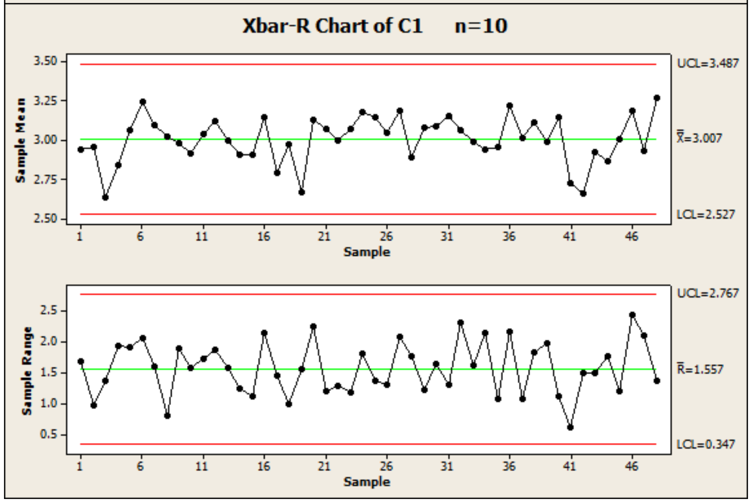
Quick Note about Control Limits

- Control limit calculation directly correlates with subgroup size.









Xbar and R Chart in Minitab

- Ensure all data is in time order
  - Data may be in row or column by subgroup
  - Data may all be in one column (simplest)
- Go to Stat > Control Charts > Variable Charts for Subgroups > Xbar – R
- Select the appropriate method the data is stored in
- Select the data
  - If all data is in one column select the appropriate subgroup size
- Add labels as desired and click OK

Interpreting Results

- Once your control chart is created continue collecting data as specified in your data collection plan
- If an out of control condition is identified take immediate action!
    - Determine root cause
    - Record root cause on the chart, in the log or via another method
    - Implement corrective actions to eliminate the root cause

Trends

- Note: There are out of control conditions that may be bad for one process, but good for another.
- An example of this is a run of 7 points above or below the centerline on a Xbar & R chart may indicate an out of control condition, whereas 7 points below the average on a p chart means less defects.
- All trends and runs must be understood and either corrected (bad) or retained (good)
- The goal is to use the fewest number of criteria to catch real signals, while avoiding false signals

Special Cause Criteria (AIAG / AT&T)

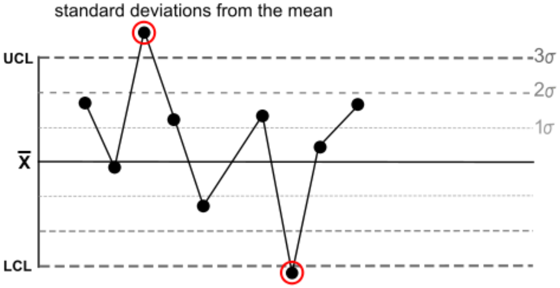
	Summary of Special Cause Criteria
1	1 point > 3 standard deviations from the centerline
2	7 consecutive points on the same side of the center line (either side)
3	6 points in a row, all increasing or decreasing
4	14 points alternating up and down
5	2 out of 3 points > 2 standard deviations from the centerline (same side)
6	4 out of 5 points > 1 standard deviations from the centerline (same side)
7	15 points in a row within 1 standard deviation of the centerline (either side)
8	8 consecutive points > 1 standard deviation from the centerline (either side)

Special Cause Criteria (Minitab / Nelson)

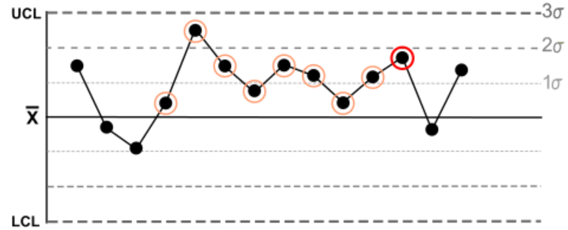
	Summary of Special Cause Criteria
1	1 point > 3 standard deviations from the centerline
2	9 consecutive points on the same side of the center line (either side)
3	6 points in a row, all increasing or decreasing
4	14 points alternating up and down
5	2 out of 3 points > 2 standard deviations from the centerline (same side)
6	4 out of 5 points > 1 standard deviations from the centerline (same side)
7	15 points in a row within 1 standard deviation of the centerline (either side)
8	8 consecutive points > 1 standard deviation from the centerline (either side)

Special Cause Criteria

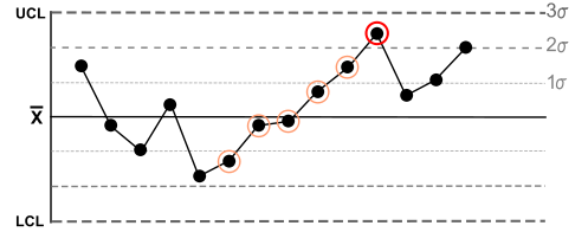
Rule 1: One point is more than 3 standard deviations from the mean



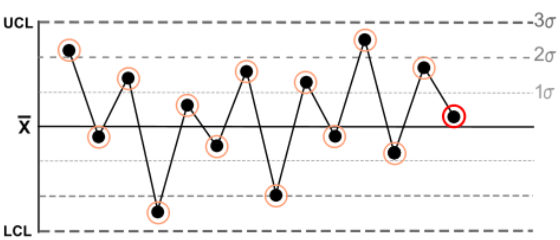
Rule 2: Nine (or more) points in a row are on the same side of the mean



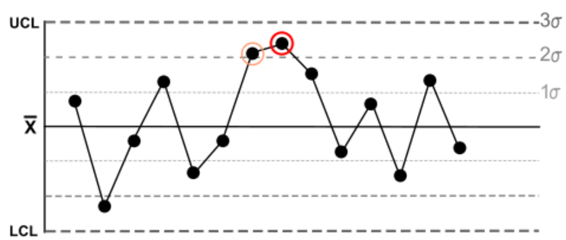
Rule 3: Six (or more) points in a row are continually increasing (or decreasing)



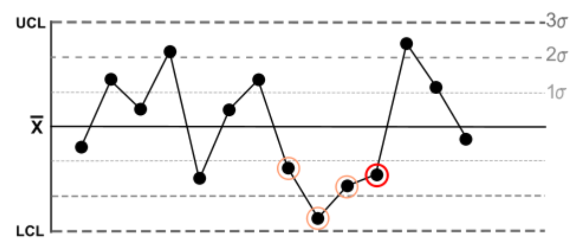
Rule 4: Fourteen (or more) points in a row alternate in direction, increasing then decreasing



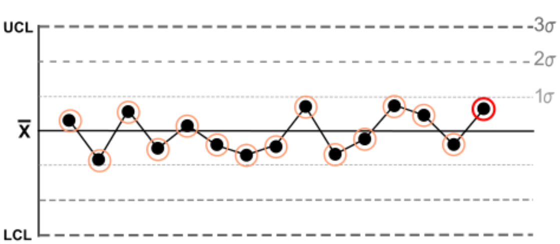
Rule 5: Two (or three) out of three points in a row are more than 2 standard deviations from the mean in the same direction



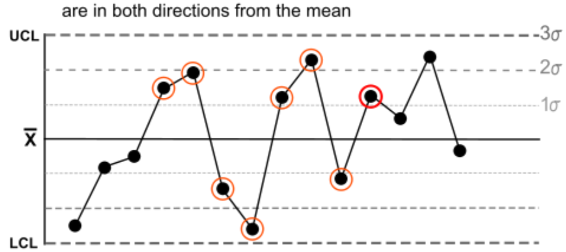
Rule 6: Four (or five) out of five points in a row are more than 1 standard deviation from the mean in the same direction



Rule 7: Fifteen points in a row are all within 1 standard deviation of the mean on either side of the mean



Rule 8: Eight points in a row exist with none within 1 standard deviation of the mean and the points are in both directions from the mean



What do these rules test for?

- Rule 1: Tests for stability. This is the strongest evidence of lack of control.
- Rule 2: Tests for stability. This can be used to supplement rule 1.
- Rule 3: Tests for a continuous trend up or down.
- Rule 4: Tests for a systematic variable. The pattern of variation should be random, but is predictable if failing rule 4.
- Rule 5: Tests for small shifts in the data.
- Rule 6: Tests for small shifts in the data.
- Rule 7: Tests for stratification, which can be misinterpreted as good process control.
- Rule 8: Tests for mixture, which is when the data avoids the center line and lies near the control limits.

Why the difference?

- There is debate about which rules best apply. The answer is… it depends on your process and how much risk of false positives you are willing to accept.

- The probability of a run of 7 points (AT&T) is $0.5^7 = 0.0078$
- The probability of a run of 9 points (Nelson) is $0.5^9 = 0.0020$

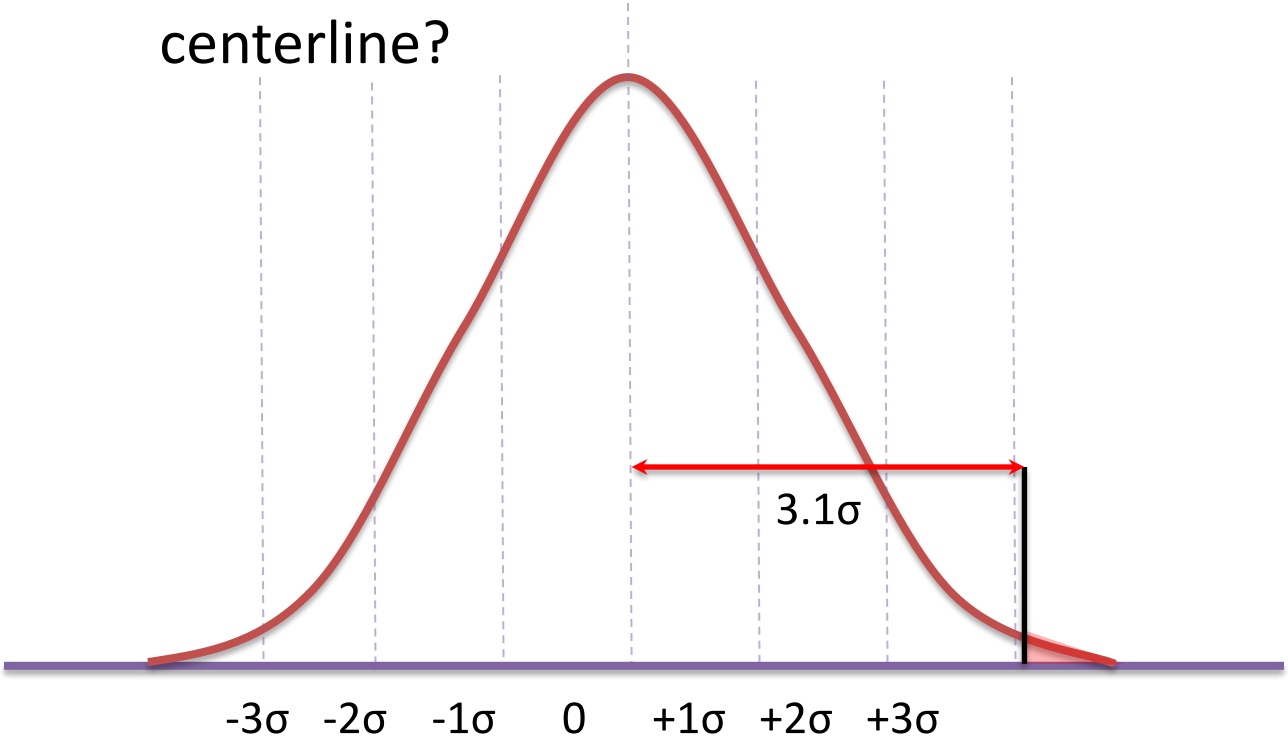
- The AT&T rules are much more stringent (relatively speaking) than Nelson's rules, but as we will see Nelson's rule better mimic the probability of rule #1…

How were these rules established?

- These rules look for unnatural trends in data assuming a normal distribution. Keep in mind that the more rules applied the greater the chance for a false signal.
- Let's take a look at an example…
- Rule #1 – "1 point > 3σ from the centerline"
- This rule is by far the most commonly used as it represents a true 'out of control' condition.

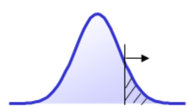
Rule #1

- A control chart of a normally distributed process shows a data point 3.1 standard deviations from the process mean. What is the probability of a point being outside of 3σ from the centerline?



Rule#1

Z Table



Z	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.50000	0.49601	0.49202	0.48803	0.48405	0.48006	0.47608	0.47210	0.46812	0.46414
0.1	0.46017	0.45620	0.45224	0.44828	0.44433	0.44038	0.43644	0.43251	0.42858	0.42465
0.2	0.42074	0.41683	0.41294	0.40905	0.40517	0.40129	0.39743	0.39358	0.38974	0.38591
0.3	0.38209	0.37828	0.37448	0.37070	0.36693	0.36317	0.35942	0.35569	0.35197	0.34827
0.4	0.34458	0.34090	0.33724	0.33360	0.32997	0.32636	0.32276	0.31918	0.31561	0.31207
0.5	0.30854	0.30503	0.30153	0.29806	0.29460	0.29116	0.28774	0.28434	0.28096	0.27760
0.6	0.27425	0.27093	0.26763	0.26435	0.26109	0.25785	0.25463	0.25143	0.24825	0.24510
0.7	0.24196	0.23885	0.23576	0.23270	0.22965	0.22663	0.22363	0.22065	0.21770	0.21476
0.8	0.21186	0.20897	0.20611	0.20327	0.20045	0.19766	0.19489	0.19215	0.18943	0.18673
0.9	0.18406	0.18141	0.17879	0.17619	0.17361	0.17106	0.16853	0.16602	0.16354	0.16109
1.0	0.15866	0.15625	0.15386	0.15151	0.14917	0.14686	0.14457	0.14231	0.14007	0.13786
1.1	0.13567	0.13350	0.13136	0.12924	0.12714	0.12507	0.12302	0.12100	0.11900	0.11702
1.2	0.11507	0.11314	0.11123	0.10935	0.10749	0.10565	0.10383	0.10204	0.10027	0.09853
1.3	0.09680	0.09510	0.09342	0.09176	0.09012	0.08851	0.08692	0.08534	0.08379	0.08226
1.4	0.08076	0.07927	0.07780	0.07636	0.07493	0.07353	0.07215	0.07078	0.06944	0.06811
1.5	0.06681	0.06552	0.06426	0.06301	0.06178	0.06057	0.05938	0.05821	0.05705	0.05592
1.6	0.05480	0.05370	0.05262	0.05155	0.05050	0.04947	0.04846	0.04746	0.04648	0.04551
1.7	0.04457	0.04363	0.04272	0.04182	0.04093	0.04006	0.03920	0.03836	0.03754	0.03673
1.8	0.03593	0.03515	0.03438	0.03362	0.03288	0.03216	0.03144	0.03074	0.03005	0.02938
1.9	0.02872	0.02807	0.02743	0.02680	0.02619	0.02559	0.02500	0.02442	0.02385	0.02330
2.0	0.02275	0.02222	0.02169	0.02118	0.02068	0.02018	0.01970	0.01923	0.01876	0.01831
2.1	0.01786	0.01743	0.01700	0.01659	0.01618	0.01578	0.01539	0.01500	0.01463	0.01426
2.2	0.01390	0.01355	0.01321	0.01287	0.01255	0.01222	0.01191	0.01160	0.01130	0.01101
2.3	0.01072	0.01044	0.01017	0.00990	0.00964	0.00939	0.00914	0.00889	0.00866	0.00842
2.4	0.00820	0.00798	0.00776	0.00755	0.00734	0.00714	0.00695	0.00676	0.00657	0.00639
2.5	0.00621	0.00604	0.00587	0.00570	0.00554	0.00539	0.00523	0.00508	0.00494	0.00480
2.6	0.00466	0.00453	0.00440	0.00427	0.00415	0.00402	0.00391	0.00379	0.00368	0.00357
2.7	0.00347	0.00336	0.00326	0.00317	0.00307	0.00298	0.00289	0.00280	0.00272	0.00264
2.8	0.00256	0.00248	0.00240	0.00233	0.00226	0.00219	0.00212	0.00205	0.00199	0.00193
2.9	0.00187	0.00181	0.00175	0.00169	0.00164	0.00159	0.00154	0.00149	0.00144	0.00139
3.0	0.00135	0.00131	0.00126	0.00122	0.00118	0.00114	0.00111	0.00107	0.00104	0.00100
3.1	0.00097	0.00094	0.00090	0.00087	0.00084	0.00082	0.00079	0.00076	0.00074	0.00071
3.2	0.00069	0.00066	0.00064	0.00062	0.00060	0.00058	0.00056	0.00054	0.00052	0.00050
3.3	0.00048	0.00047	0.00045	0.00043	0.00042	0.00040	0.00039	0.00038	0.00036	0.00035
3.4	0.00034	0.00032	0.00031	0.00030	0.00029	0.00028	0.00027	0.00026	0.00025	0.00024
3.5	0.00023	0.00022	0.00022	0.00021	0.00020	0.00019	0.00019	0.00018	0.00017	0.00017
3.6	0.00016	0.00015	0.00015	0.00014	0.00014	0.00013	0.00013	0.00012	0.00012	0.00011
3.7	0.00011	0.00010	0.00010	0.00010	0.00009	0.00009	0.00008	0.00008	0.00008	0.00008
3.8	0.00007	0.00007	0.00007	0.00006	0.00006	0.00006	0.00006	0.00005	0.00005	0.00005
3.9	0.00005	0.00005	0.00004	0.00004	0.00004	0.00004	0.00004	0.00004	0.00003	0.00003
4.0	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00002	0.00002	0.00002
4.1	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00002	0.00001
4.2	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
4.3	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
4.4	0.00001	0.00001	0.00001	0.00001	0.00001	0.00000	0.00000	0.00000	0.00000	0.00000
4.5	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4.6	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4.7	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4.8	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4.9	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

3.1	0.00097

Looking at the z-table there is a 0.097% chance for a part to be produced at or outside of 3.1σ from the centerline on one side of the centerline.

If a part is produced at this point we had better investigate!

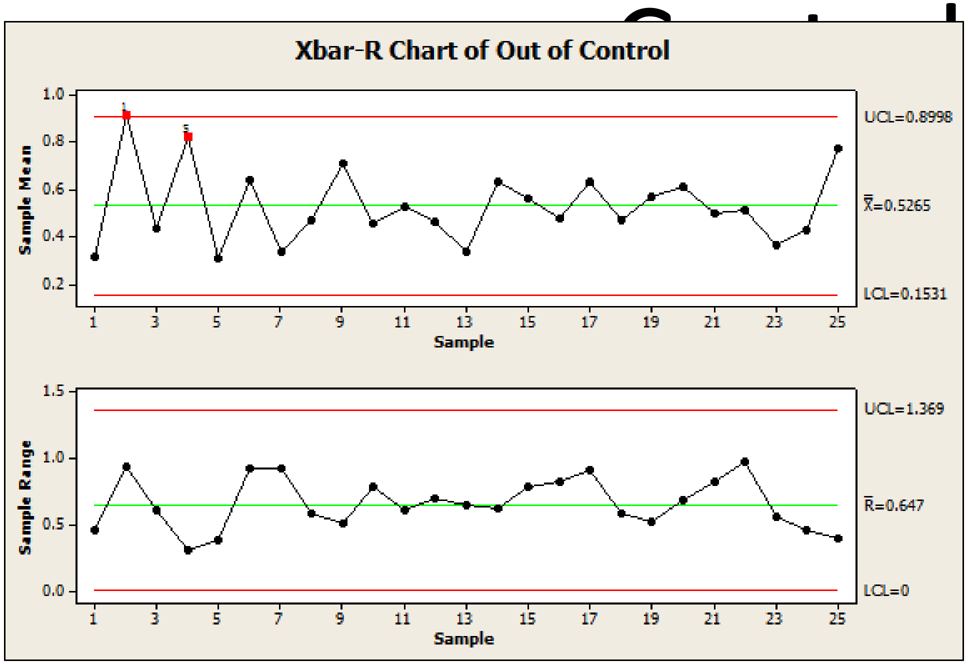
In general, for a normal process, the chance of a point falling outside of 3σ on either side of the center line is 0.27%.

The z-score for 3.0 is 0.00135

0.00135 x 2 = 0.0027

0.0027 x 100 = 0.27%

How to Determine Out of Control



Here we can see two points are highlighted.

Point #2 is outside of 3 standard deviations (test#1)

Point #4 shows 2 out of 3 points greater than 2σ from the mean (test#2)

Minitab will automatically highlight out of control points based on the 8 tests, as long as those tests are turned on when the control chart is created.

Rule Identification

- All eight rules previously listed have visual ques.
- Some of these rules are easily detected visually on a control chart, but others are not.
- How can you tell if 2 of 3 parts are greater than two standard deviations from the centerline?
- The answer is easy, set up a zone chart to help identify signals!

Zone Chart

- Zone charts, also known as sigma charts, are divided into six shaded areas corresponding with 1, 2, and 3 standard deviation intervals from the centerline.
- A value is then assigned for each zone. The typical values are as follows;

Zone	Score
$\bar{\bar{X}}$ to $\bar{\bar{X}}$+1σ	0 or +1
$\bar{\bar{X}}$ +1σ to $\bar{\bar{X}}$+2σ	+2
$\bar{\bar{X}}$ + 2σ to $\bar{\bar{X}}$+3σ	+4
$\bar{\bar{X}}$ + 3σ or greater	+8

OR

Zone	Score
$\bar{\bar{X}}$ to $\bar{\bar{X}}$+1σ	+1
$\bar{\bar{X}}$ +1σ to $\bar{\bar{X}}$+2σ	+2
$\bar{\bar{X}}$ + 2σ to $\bar{\bar{X}}$+3σ	+5
$\bar{\bar{X}}$ + 3σ or greater	+6

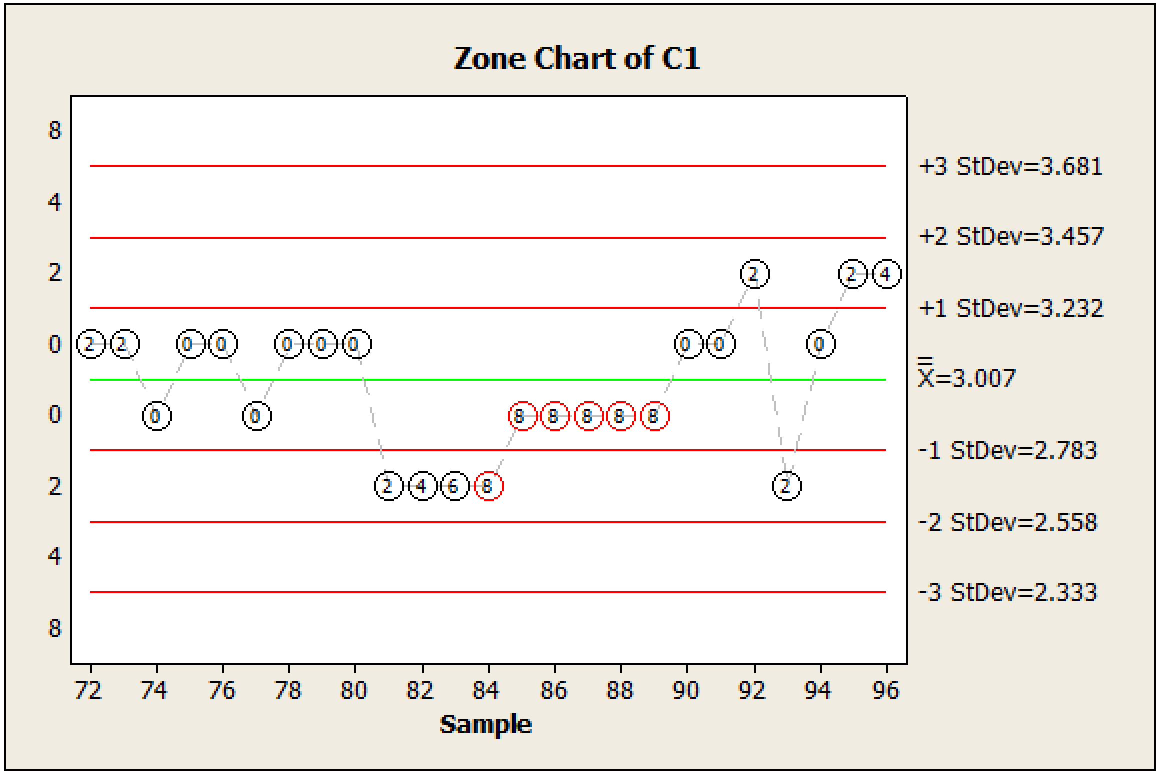
- Note: Standard deviation in this case refers to the standard deviation of sample averages, not the individual values.

Zone Chart

Each plotted point is scored based on the zone it lands in.

Each time a point crosses the centerline the score is reset to zero.

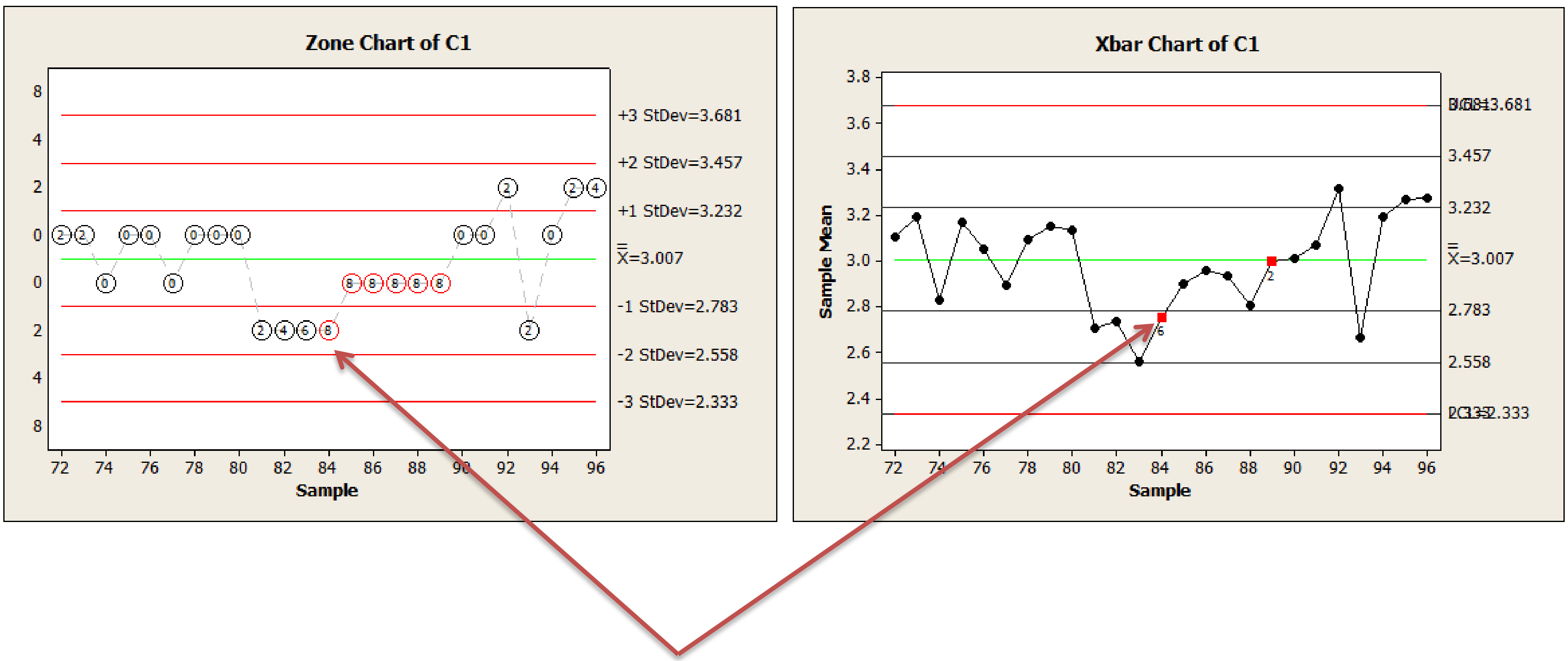
If the cumulative score reaches 8 it is considered out of control.



Zone vs. Xbar

- When using the 0,1,2,4,8 scoring method the zone chart is equivalent to the standard criteria 1,5 and 6 for a Xbar chart and is more stringent than criteria 8.
- When using the 1,2,5,6 scoring method the zone chart is equivalent to the standard criteria 1,5 and 6 for a Xbar cart and is more stringent than criteria 7 and 8.

Zone vs. Xbar



Notice the same data point is flagged on both the Zone Chart and Xbar chart

Out of Control

- There are varying degrees of out of control conditions (outliers, runs, trends, etc.) some of which include flags even if all points are within the control limits
- Early in a SPC program not all conditions may be understood by those completing the real-time analysis
- While each out of control condition should be understood it should also be noted that overreaction can also lead to waste

Possible Causes

- A point outside the control limits may be due to:
  1. The control limit or plotted point was miscalculated
  2. The observation to observation spread has increased, either at one point or as part of a trend
  3. The measurement system has changed (new operator, method, etc.)

Reacting to an Out of Control Condition

- There is an out of control condition! What do I do?

- Ford uses the format below to help determine next steps (SC/CC Items);

Control Chart Interpretation and Reaction

The Control Chart indicates that the process:	ACTIONS ON THE PROCESS OUTPUT Based on Process Capability (Ppk)	
	Less than 1.33	Equal to or Greater than 1.33
Is in control	100% inspect*	Accept product Continue to reduce product variation
Has gone out of control	**IDENTIFY SPECIAL CAUSE** 100% inspect* all product since the last in-control sample	

Reacting to an Out of Control Condition

- Some questions to ask:
  - Have control limits and plotted points been calculated correctly?
  - Is the measurement system working correctly?
    - Are there obvious signs of wear or damage?
    - Is there a different person taking the measurements?
  - Is the operator different? If so, have they been trained?
  - Has there been a process change?
  - Has there been a material / lot change?
  - Has the environment changed?
  - Is the production equipment adequate?
    - Is it damaged?
    - Is maintenance required? (Has maintenance recently been completed?)

Reacting to an Out of Control Condition

- Regardless of the action taken the primary focus for each out of control condition is to determine the root cause and ensure actions are implemented to eliminate the special cause variation

GHSP Application of SPC

Statistical Process Control chart conditions that require Shark attack:

1-Check if CPK=<2 and/or PPK=<1.67

2-Check to see that No yellow color or Red color cells in the Excel sheet cells for subgroup data.

-Yellow color means it is sample is about to be outside of tolerance

-Red means outside the sample is outside of tolerance

-If Range or Average of subgroup is red that means the value is outside control limits.

3-Is it the seventh subgroup average in a row above (to the right of) the chart Xbar line (center line) or the seventh subgroup average in a row below (to the left of) the chart Xbar line (center line).

4-Is it the seventh subgroup in a row increasing (moving to the right) or the seventh subgroup in a row decreasing (moving to the left).

Real World Examples

GHSP Example

Part Number 10562xxx

Part Description Automatic Shifter Assembly **Gauge** A2624

Characteristic Cable Travel (D-P) **Sample Size** 5 pcs at start of shift

Chart Period From: 4/14/13 23:41 To: 5/16/13 18:27

Date of Control Limits 3/8/13 0:00

Requirements

USL	37.7400
Nominal	36.9900
LSL	36.2400

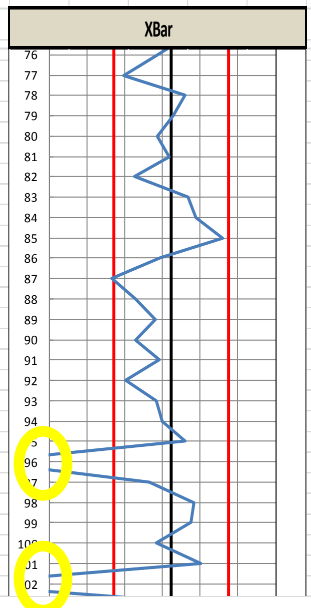
Control Limits

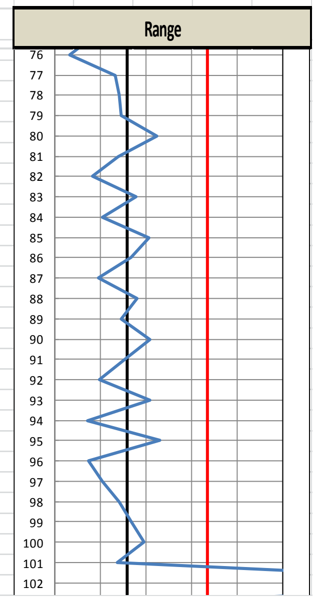
UCL_X	37.2250	UCL_R	0.3352
XBar	37.1336	Range	0.1585
LCL_X	37.0422	LCL_R	0.0000

Statistics

XDBar	37.12	Sigma	0.118	Pp	2.12	Ppk	1.74
Rbar	0.17	d_2	2.326	Cp	3.42	Cpk	2.82

	Time	Insp.	Data 1	2	3	4	5	Mean	Range
76	5/3/2013 18:48	AH	37.12	37.09	37.12	37.12	37.10	37.11	0.03
77	5/5/2013 23:42	DN	37.08	36.96	37.09	37.08	37.08	37.06	0.13
78	5/6/2013 7:27	wn	37.15	37.11	37.23	37.09	37.20	37.16	0.14
79	5/6/2013 12:17	wn	37.07	37.13	37.16	37.21	37.12	37.14	0.15
80	5/6/2013 14:16	AH	37.25	37.13	37.03	37.05	37.10	37.11	0.22
81	5/6/2013 20:48		37.19	37.10	37.12	37.05	37.19	37.13	0.14
82	5/7/2013 0:42	DN	37.07	37.09	37.03	37.07	37.11	37.07	0.08
83	5/7/2013 7:19	wn	37.22	37.09	37.07	37.16	37.25	37.16	0.18
84	5/7/2013 12:09	wn	37.18	37.11	37.21	37.16	37.21	37.17	0.10
85	5/7/2013 15:06	AH	37.27	37.09	37.17	37.25	37.30	37.22	0.21
86	5/7/2013 20:40		37.01	37.18	37.10	37.15	37.15	37.12	0.17
87	5/8/2013 0:34	DN	37.01	37.01	37.10	37.02	37.05	37.04	0.10
88	5/8/2013 8:11	wn	37.15	37.15	37.05	36.97	37.05	37.08	0.18
89	5/8/2013 13:00	wn	37.12	37.16	37.02	37.08	37.17	37.11	0.15
90	5/8/2013 15:30	AH	36.99	37.09	37.12	37.20	37.00	37.08	0.21
91	5/8/2013 19:20		37.07	37.02	37.18	37.15	37.15	37.11	0.16
92	5/9/2013 1:59	DN	37.06	37.01	37.08	37.06	37.10	37.06	0.10
93	5/9/2013 7:09	wn	37.10	37.22	37.01	37.11	37.11	37.11	0.21
94	5/9/2013 15:16	AH	37.12	37.11	37.08	37.15	37.14	37.12	0.07
95	5/9/2013 19:04		37.12	37.00	37.20	37.23	37.22	37.16	0.23
96	5/10/2013 4:15	JR	36.80	36.81	36.88	36.85	36.83	36.83	0.07
97	5/10/2013 7:25	wn	37.12	37.11	37.04	37.08	37.14	37.10	0.11
98	5/10/2013 16:55	AH	37.11	37.19	37.25	37.19	37.11	37.17	0.14
99	5/10/2013 18:33		37.09	37.20	37.25	37.15	37.14	37.17	0.17
100	5/11/2013 4:28	wn	37.23	37.03	37.19	37.06	37.05	37.11	0.20
101	5/11/2013 9:31	AH	37.17	37.15	37.22	37.11	37.25	37.18	0.14
102	5/13/2013 3:28	JR	36.60	36.56	36.52	37.62	36.64	36.79	1.10





Part Number 10562xxx

Part Description Automatic Shifter Assembly

Gauge A2624

Characteristic Cable Travel

Sample Size 5 pcs at start of shift and 4 hours and each change over

For out of control conditions actions must be listed in the action tab as shown below.

Sub Group	Date	Feature out of control			Condition(s)	Action Taken	Resp Person
		D-P	D-N	D-L			
87	5/8/2013	x			average data is out of control limits	see Shark attack dated 5-8-13 0:34	Drew S.
96	5/10/2013	x			average data is out of control limits	see Shark attack dated 5-10-13 4:15	Arron H.
102	5/13/2013	x			average and range are data is out control limits	see Shark attack dated 5-13-13 3:28	Arron H.

Shark Attack Commitment Form

Date:	5/13/2013 (subgroup 102)	Time: 3:28
Product & Part Number:	10562114	
Problem Description:	Out of of control limits for mean and range	
Work Area:	C520- WC 516 station #3	
Team Members:	Sid, Mike R., Mike C.	

Problem Solving:

What is the problem? loose locator plate screrws

Man: no issue found

Method: Screws were not tightened- screws comes loose from machine vibration.

Material: no issue found

Machine: no issue found with machines sttings.

*Write what you know is fact, NA for not applicable.

Root Cause:

Do we know Root cause at this point: (Y) N If Yes, write below. If No, follow-up via Review/Long Term.

Root Cause: Loose screws

Review / Long Term:

All completed Shark Attack forms to be handed in to the Quality Facilitator, VSM team, Molding Shark Attack team, etc.

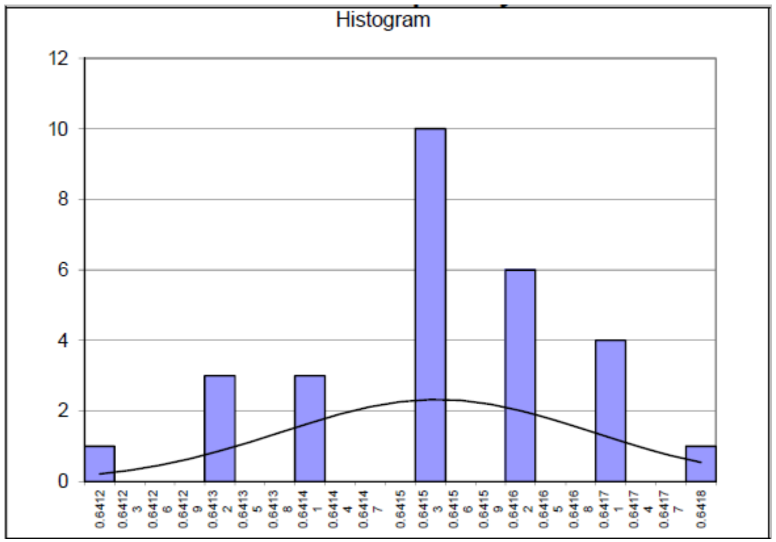
Action Items:

Task or Assignment To Be Completed	Promise Date	Sign and Date
Add locking washer to setup.	5/13/2013	Dan Appel

Yes	N/A	Action Checklist
	x	1) Containment in-house
	x	2) Issue Quality alert
	x	3) Create Sort/Rework (QA 502)
	x	4) Create PTR
	x	5) Create PCR

Shark Attack Leader: Arron Hart

Example 2



Process Data	
USL	0.643
LSL	0.64
# of Samples	30
# of Sub Groups	30
Sub Group Size (n)	1
Max Value	0.6418
Min Value	0.6412
Range	0.0006
X Bar	0.6415367
R Bar	0.00
St. Dev. (Within)	0.0001312
St. Dev. (Overall)	0.0001542
UCL X	0.6419303
LCL X	0.641143
UCL R	0.0004844
Normality	Normal

Pre-Control Limits	
Upper PC line	Not Stable
Lower PC line	Not Stable

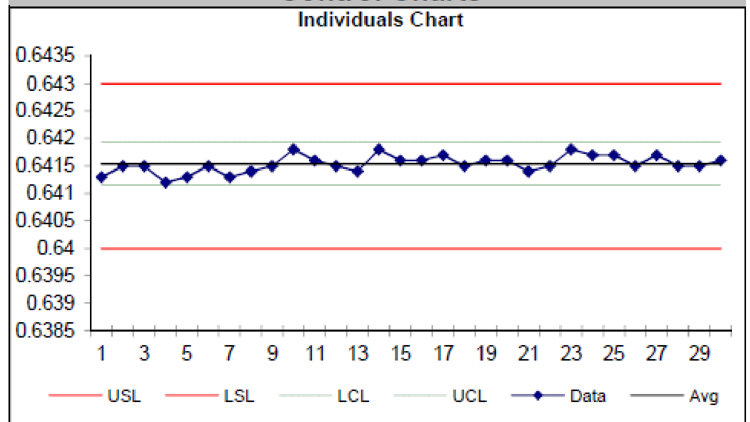
Potential (within) Capability	
Cp	3.81
CpU	3.72
CpL	3.90
Cpk	3.72

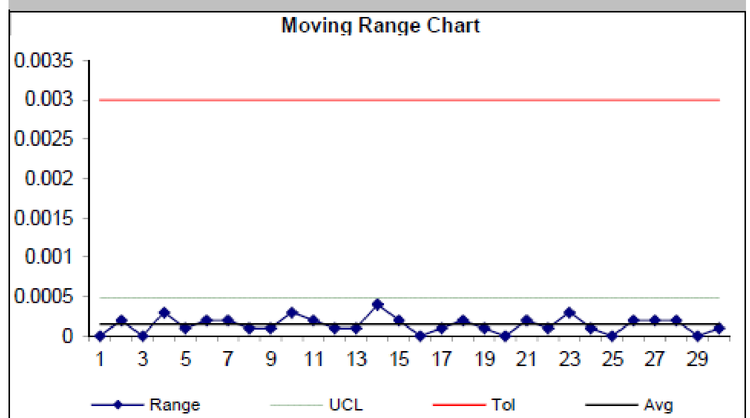
Potential (overall) Capability	
Pp	3.24
PpU	3.16
PpL	3.32
Ppk	3.16

I MR Chart Limits	
UCL X	0.64189365
LCL X	0.64110635
UCL R	0.00048442

X Median Chart Limits	
UCL X	Use IMR
LCL X	Use IMR
UCL R	Use IMR

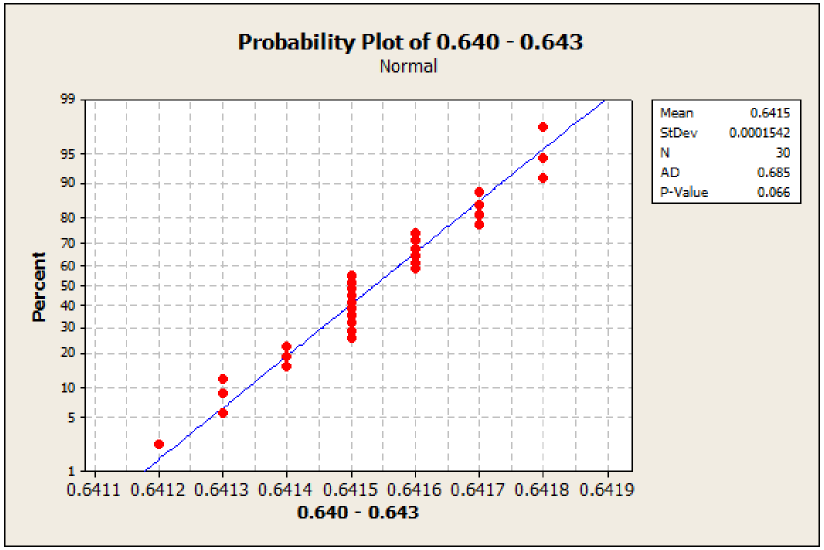
Control Charts

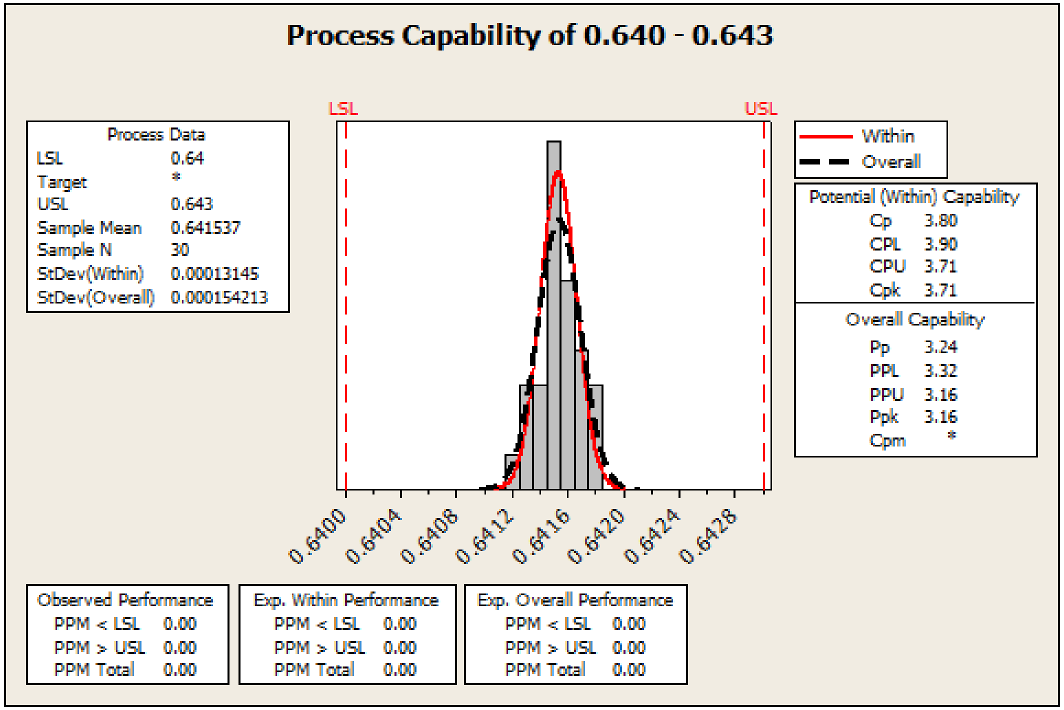


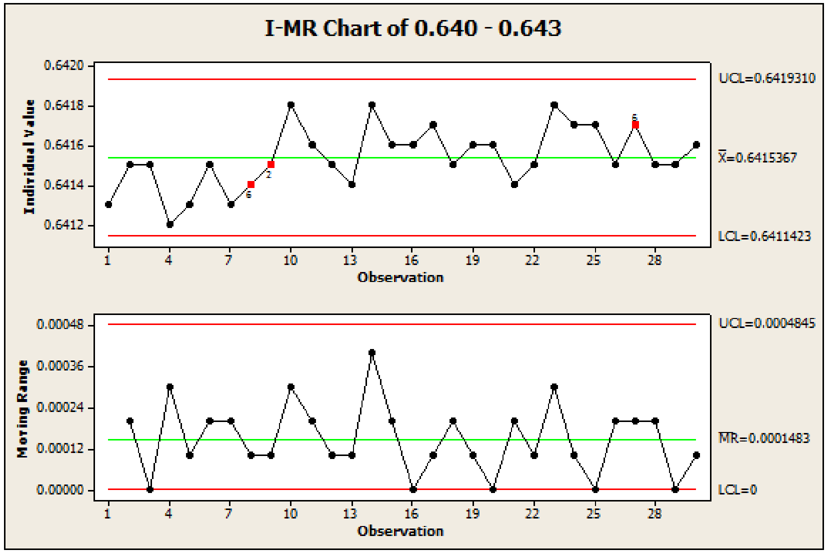


One or more points are outside the control limits	Pass
More than 9 points in a row on one side of the avg	Fail
Six points in a row increasing or decreasing	Pass
14 points in a row alternating up and down	Pass
More than 2/3rd of pts outside 2 sigma	Pass
More than 1/3rd of pts outside 1 sigma	Pass
15 pts in a row within 1 sigma of centerline	Pass
8 pts in a row more than 1 sigma from centerline	Pass

Example 2





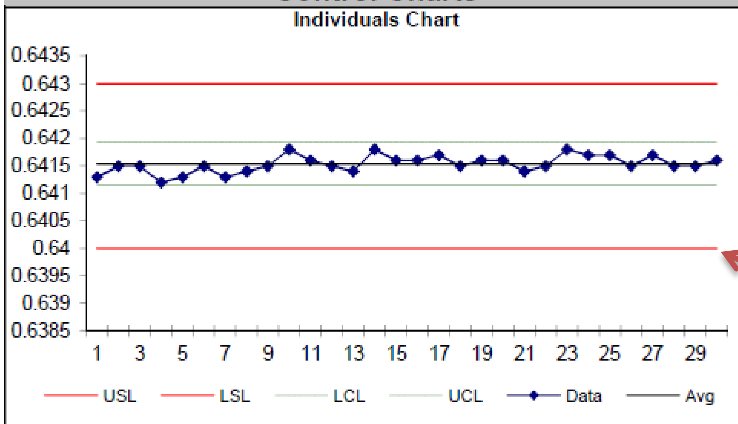


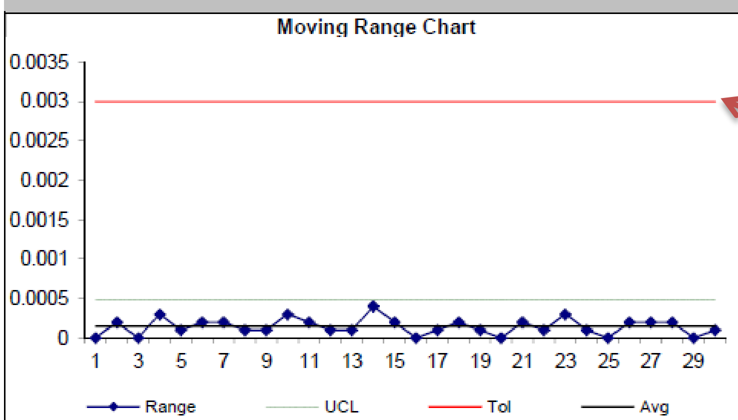
Test Results for I Chart of 0.640 - 0.643

```
TEST 2. 9 points in a row on same side of center line.
Test Failed at points:  9

TEST 6. 4 out of 5 points more than 1 standard deviation from center line (on
     one side of CL).
Test Failed at points:  8, 27
```

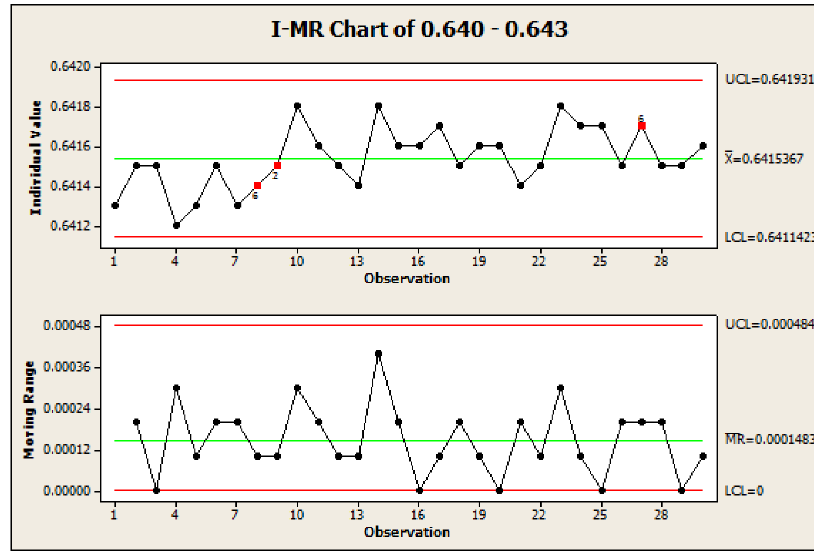
Example 2 Comparison

Control Charts





One or more points are outside the control limits	Pass
More than 9 points in a row on one side of the avg	Fail
Six points in a row increasing or decreasing	Pass
14 points in a row alternating up and down	Pass
More than 2/3rd of pts outside 2 sigma	Pass
More than 1/3rd of pts outside 1 sigma	Pass
15 pts in a row within 1 sigma of centerline	Pass
8 pts in a row more than 1 sigma from centerline	Pass

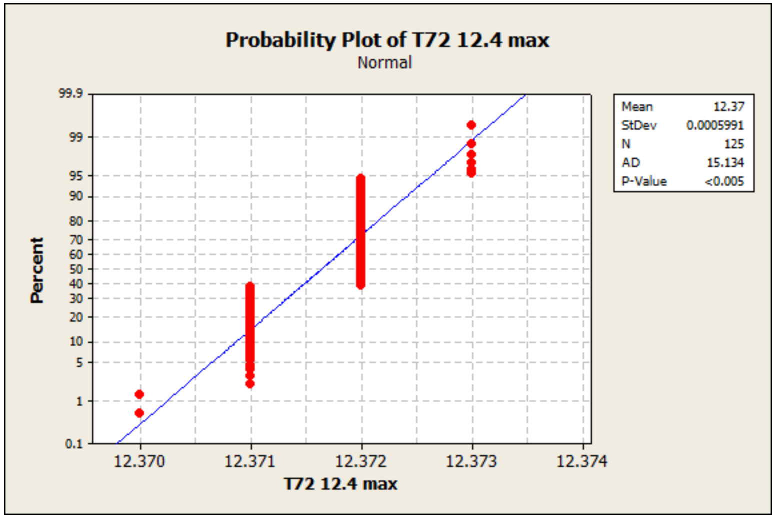


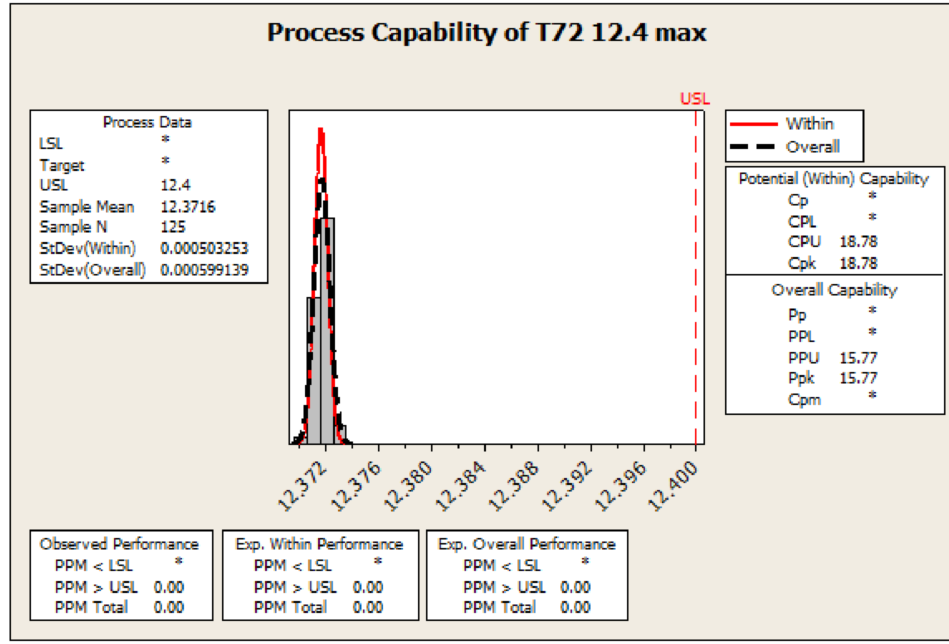
Test Results for I Chart of 0.640 - 0.643

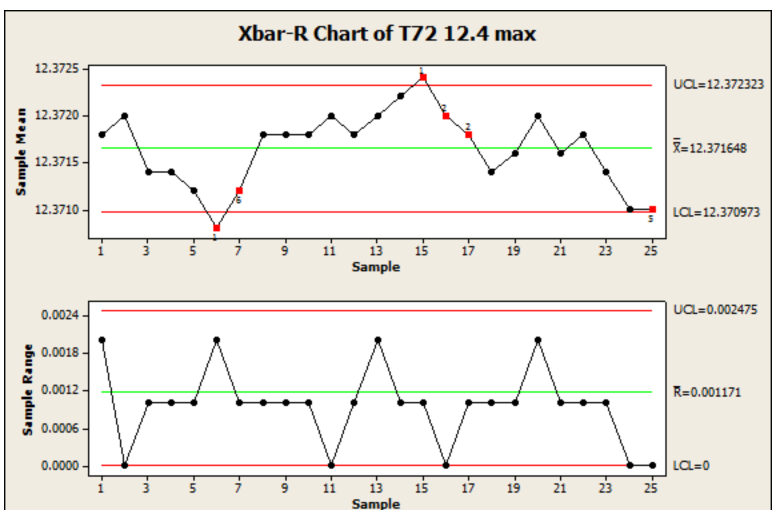
```
TEST 2. 9 points in a row on same side of center line.
Test Failed at points:  9

TEST 6. 4 out of 5 points more than 1 standard deviation from center line (on
     one side of CL).
Test Failed at points:  8, 27
```

What conclusion would you make about this capability study?

Example 3



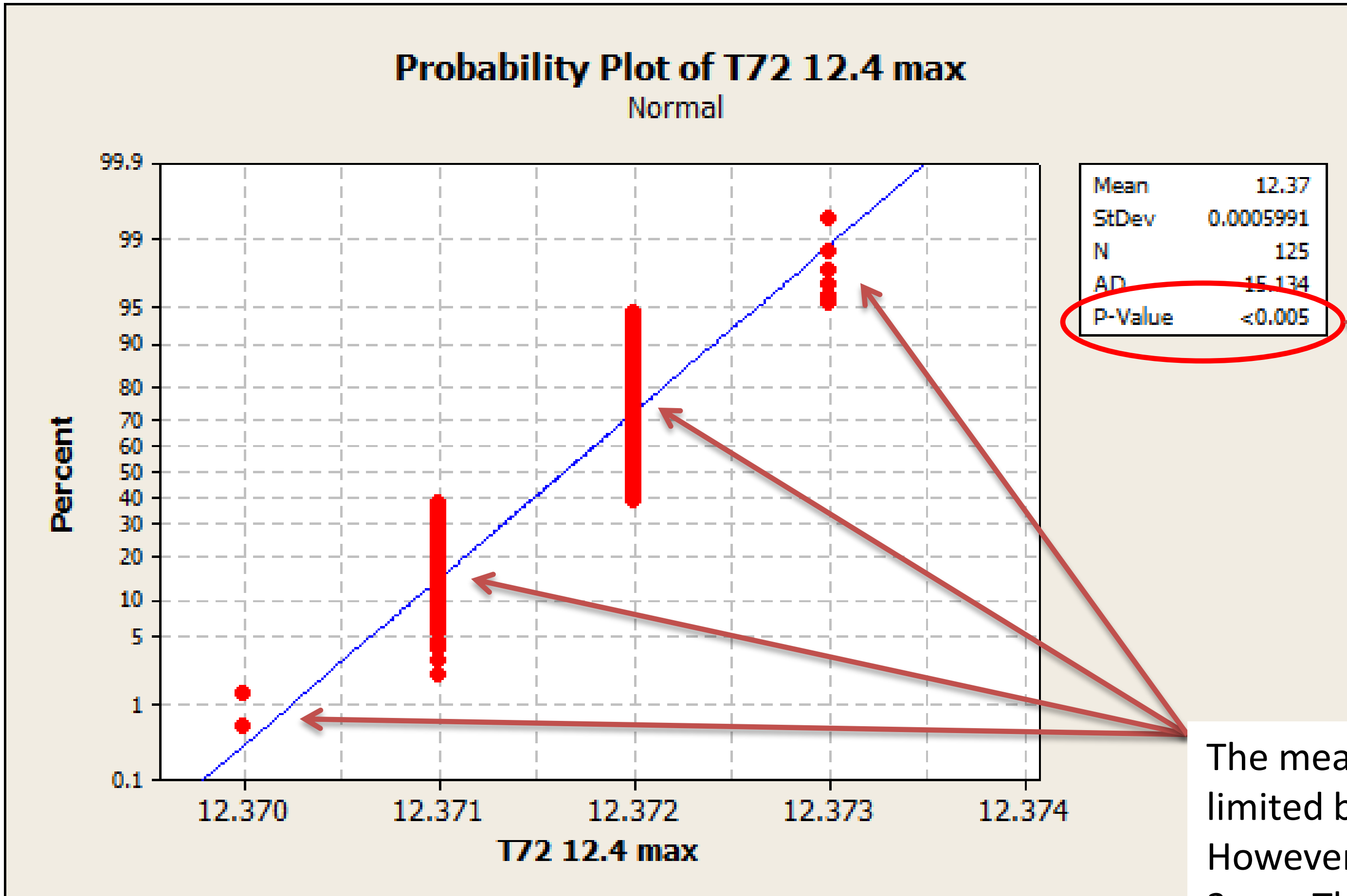




Test Results for Xbar Chart of T72 12.4 max

```
TEST 1. One point more than 3.00 standard deviations from center line.
Test Failed at points:  6, 15

TEST 2. 9 points in a row on same side of center line.
Test Failed at points:  16, 17

TEST 5. 2 out of 3 points more than 2 standard deviations from center line (on
     one side of CL).
Test Failed at points:  15, 25

TEST 6. 4 out of 5 points more than 1 standard deviation from center line (on
     one side of CL).
Test Failed at points:  6, 7, 15, 16
```

Example 3

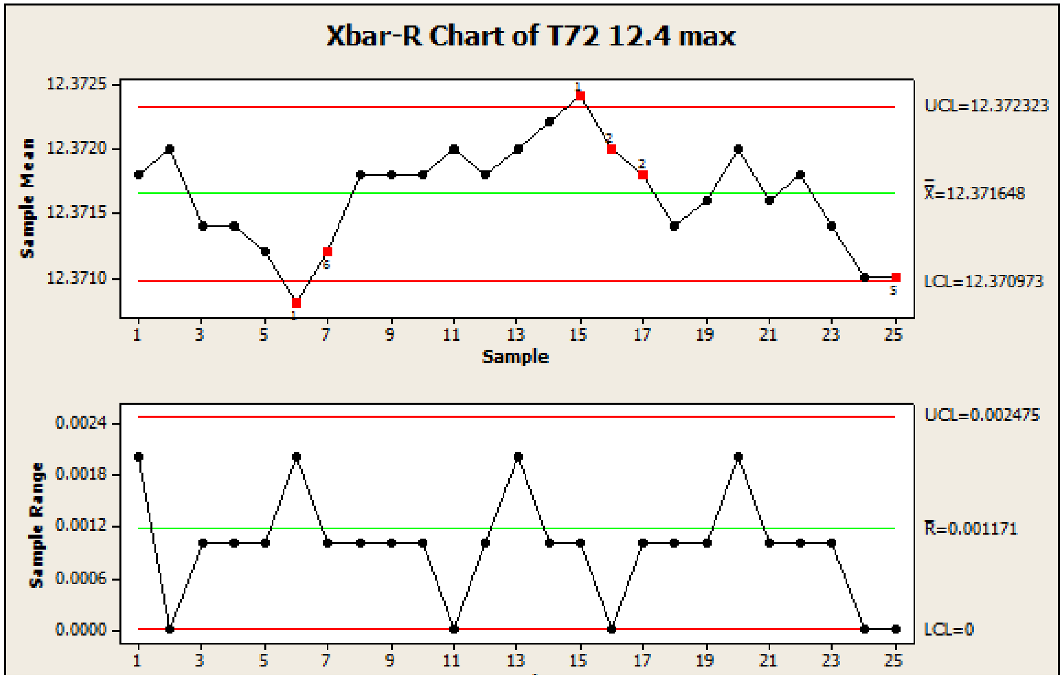


A P-value of greater than 0.05 shows normality.
This process is not normal. Why?

The measurement system is limited by resolution.
However, the total variation is 3µm. This is more than sufficient.

Is this normality study acceptable? Yes!

Example 3



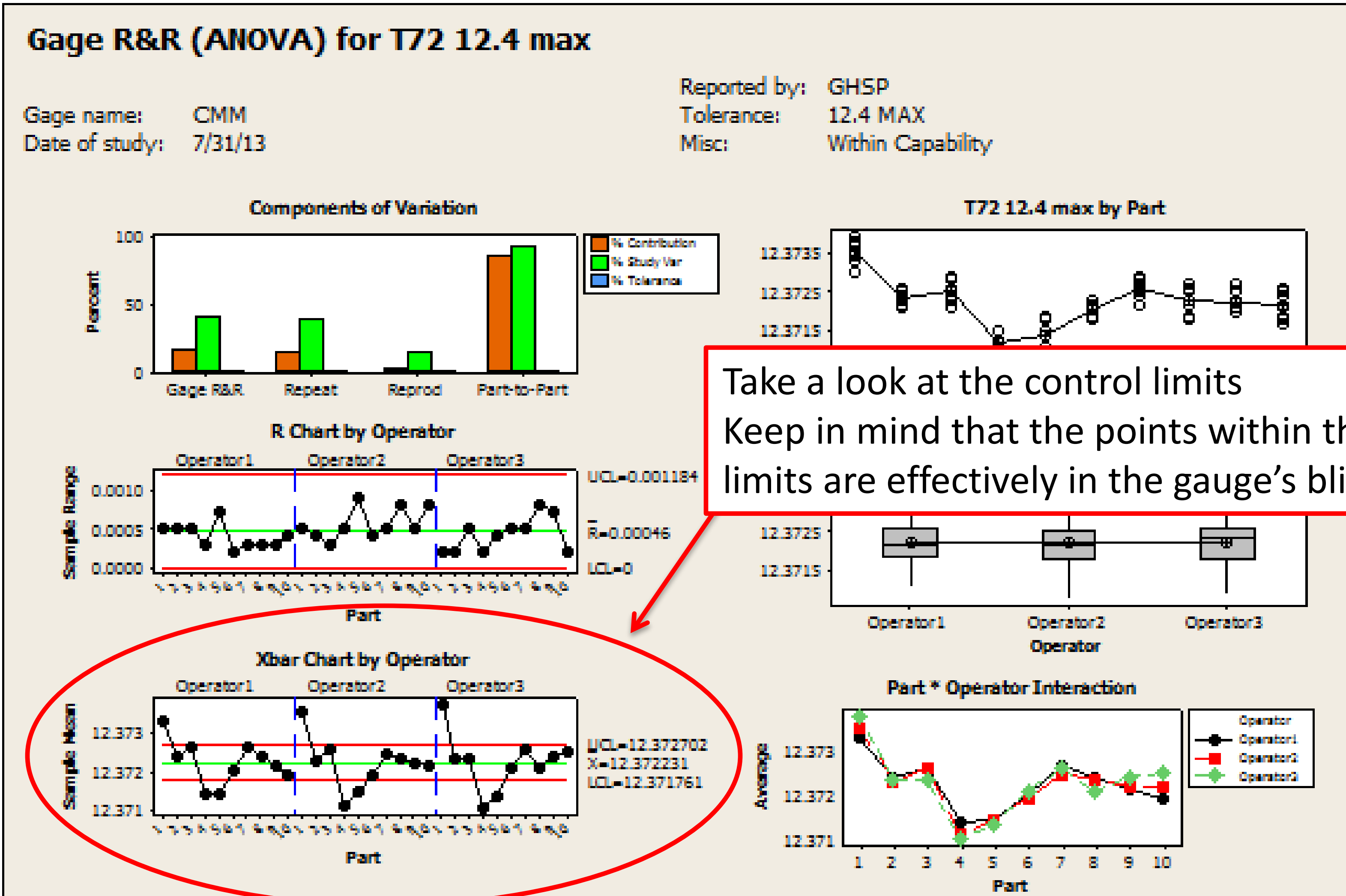
Is this control chart acceptable?

Let's take a look at the gage R&R…

Test Results for Xbar Chart of T72 12.4 max

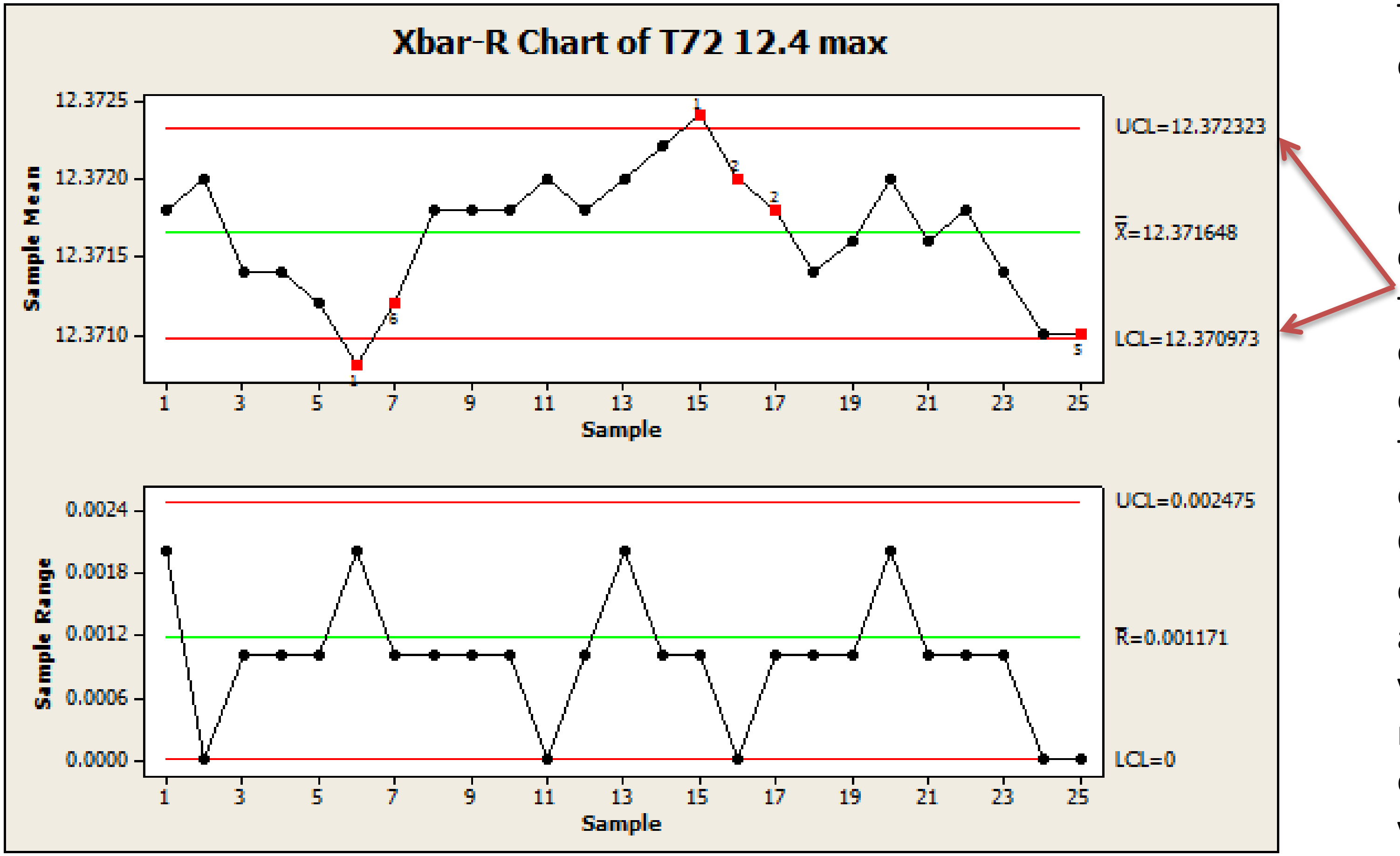
```
TEST 1. One point more than 3.00 standard deviations from center line.
Test Failed at points:  6, 15

TEST 2. 9 points in a row on same side of center line.
Test Failed at points:  16, 17

TEST 5. 2 out of 3 points more than 2 standard deviations from center line (on
     one side of CL).
Test Failed at points:  15, 25

TEST 6. 4 out of 5 points more than 1 standard deviation from center line (on
     one side of CL).
Test Failed at points:  6, 7, 15, 16
```

Example 3



Take a look at the control limits
Keep in mind that the points within the control limits are effectively in the gauge's blind spot

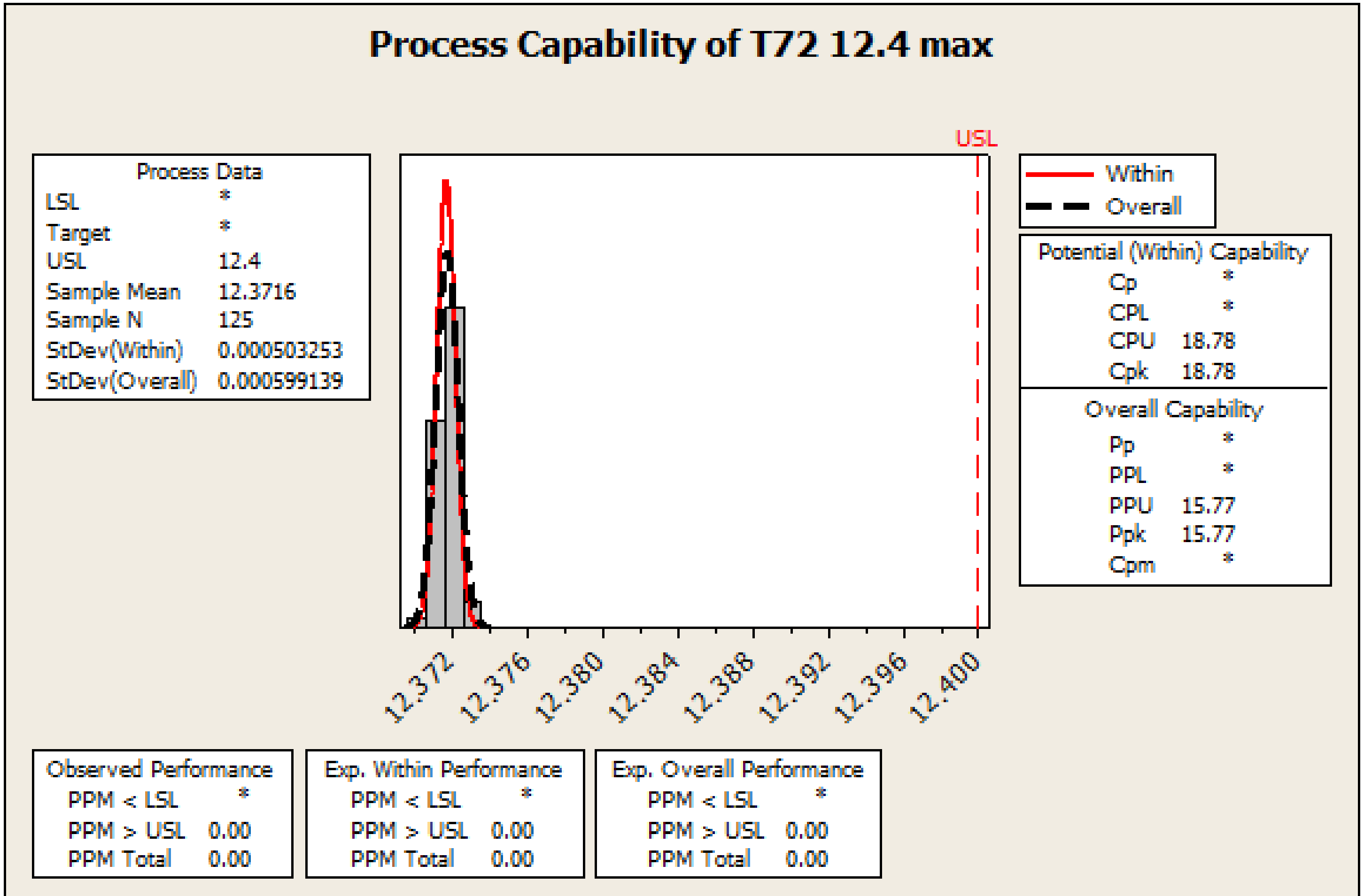
Example 3



The GRR control chart limits were 12.3727 / 12.3717

Comparing this to the control limits here the gauge used can't effectively differentiate most of these parts from each other. Considering this the control chart is acceptable as the variation seen here may be due to gauge error and the variation is minimal.

Example 3 Final Analysis



Is this capability study acceptable?

The data used for this study is not normal. However, it is limited by resolution (1µm)

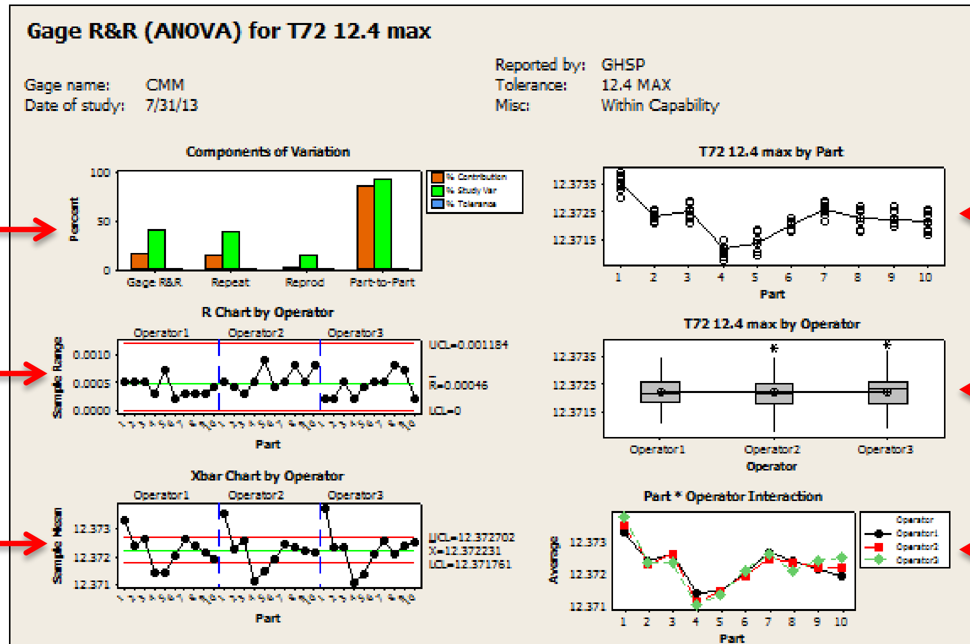
The data used for this study was not in control. However, the variation was due mostly to gauge error.

The process is extremely capable.

This study is acceptable!

Example 3 Final Analysis

So we accept the initial process study, but talk about gauge variation.
Does this mean we need a better gauge?



Acceptable (Components of Variation)

Acceptable (R Chart by Operator)

Not normally acceptable, but expected given the low part to part variation (high process capability) (Xbar Chart by Operator)

Acceptable (T72 12.4 max by Part)

Acceptable (T72 12.4 max by Operator)

Acceptable (Part * Operator Interaction)

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.0002783	0.0016701	40.16	0.01
Repeatability	0.0002627	0.0015761	37.90	0.01
Reproducibility	0.0000921	0.0005524	13.29	0.00
Operator	0.0000000	0.0000000	0.00	0.00
Operator*Part	0.0000921	0.0005524	13.29	0.00
Part-To-Part	0.0006347	0.0038082	91.58	0.03
Total Variation	0.0006930	0.0041583	100.00	0.03

Acceptable (%Tolerance)

Acceptable considering the high process capability (%Study Var)

Number of Distinct Categories = 3

Acceptable (Number of Distinct Categories)

QUESTIONS?