

Supplier Quality Management

Continuous Improvement Training

Statistical Process Control (SPC)
Part 1 - Introduction
Advanced Quality Team



Agenda

Part 1

- Training Timeline
- Statistical Process Control Background
- Training Objectives
- APQP Relationship
- Terminology (Process Variation: Common & Special Causes)

Part 2

- Interpreting a Control Chart
- Control Chart Tests for Special Cause Variation
 - *Potential causes for each test*
- Confusing Common and Special Cause Variation
- Control Chart examples (Minitab and Excel)
- Appendix B – Additional Control Chart Analysis and Interpretation



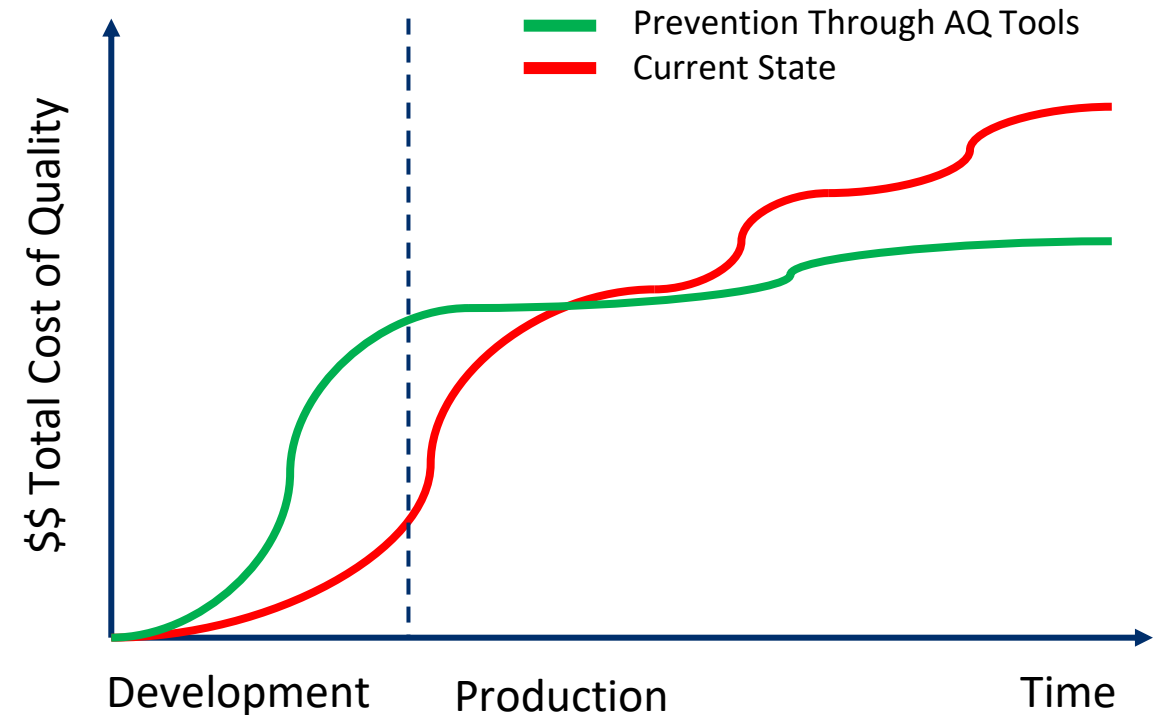
Training Objectives

Include:

- Understanding the benefits and application of SPC methodology
- Recognizing variation in manufacturing processes
- Differentiating between common and special causes of variation
- Learning about data collection and control charts
- Understanding the importance of reducing variation
- Implementing control charting to assess process stability
- Selecting, applying, and interpreting basic SPC tools for process analysis

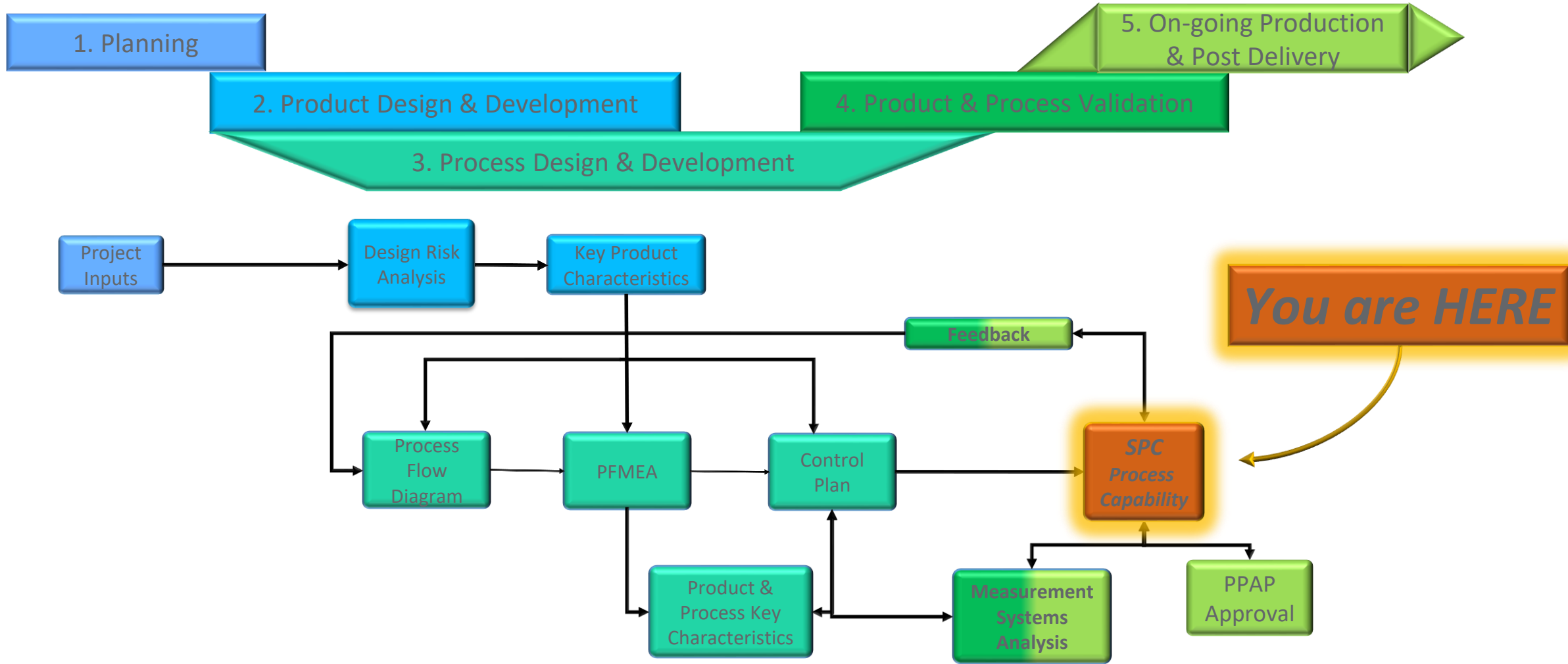


Background



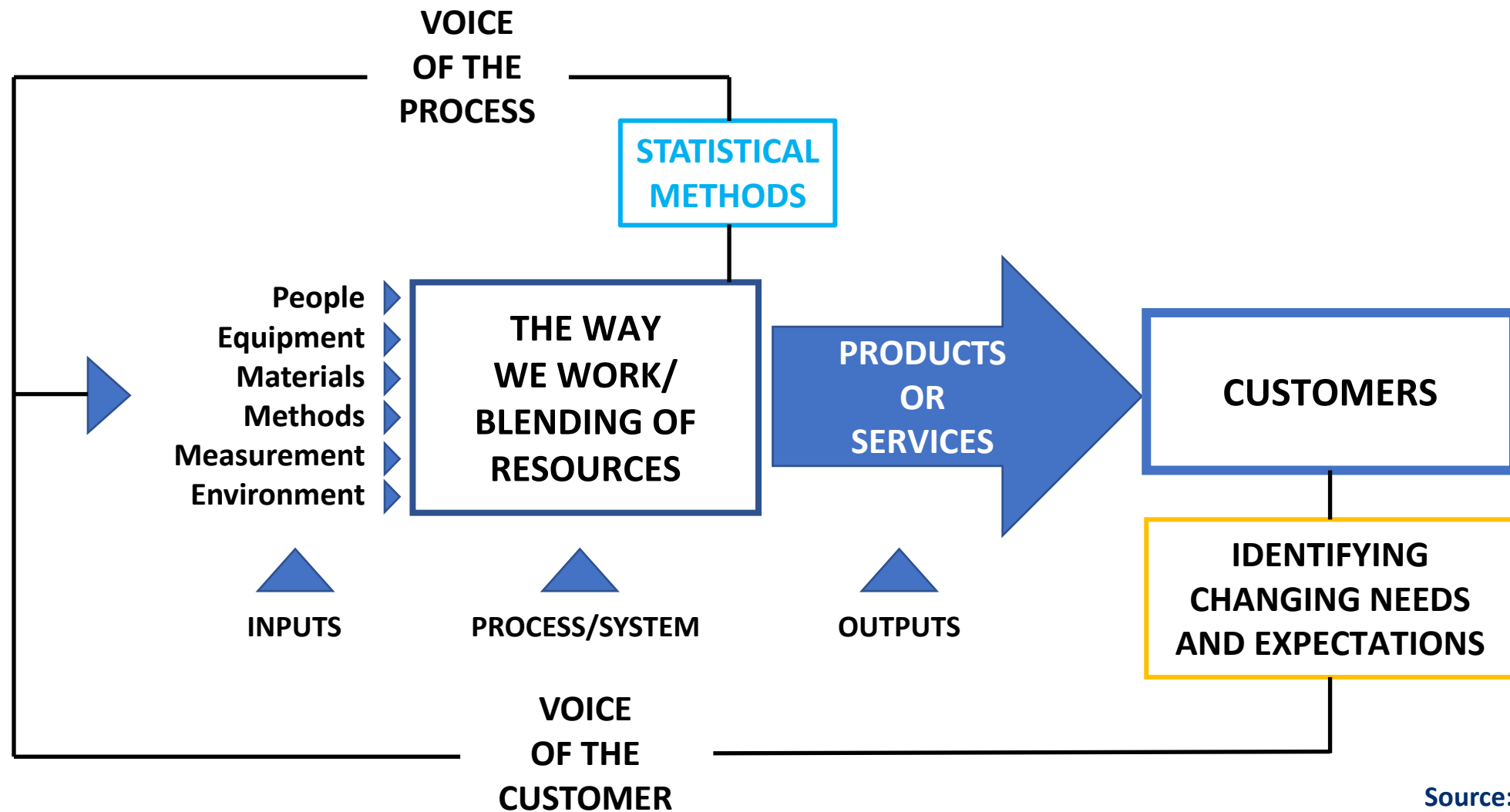
Value Proposition
Invest more in upfront planning to significantly reduce cost later in the product lifecycle!

APQP Relationship



* Reference AS9145 Table 2 – Production part approval process

Process Control System Model with Feedback



Source: SPC Manual
AIAG, 2nd Ed.

What is Statistical Process Control (SPC)?

Statistical process control (SPC) is defined as the use of statistical techniques to control a process or production method. SPC tools and procedures can help you monitor process behavior, discover issues in internal systems, and find solutions for production issues. (Source: ASQ)

History of Statistical Process Control (SPC)

- Initially developed by Dr. Walter Shewhart in the 1920's
- Expanded by Dr. W. Edwards Deming after WWII
- Dr. Shewhart identified two sources of process variation:
 - *Chance variation – inherent in process, and stable over time.*
 - *Assignable variation – which is unstable over time, the result of specific events outside the system*
- Dr. Deming relabeled chance variation as Common Cause variation, and assignable variation as Special Cause variation.

Quiz: Special vs Common Cause

- cc** Poor working conditions
- sc** Out of date drawings
- cc** Normal wear and tear of tooling
- sc** Poor batch material
- sc** Tool damage
- cc** Poor maintenance of machines
- sc** Maintenance check overlooked
- cc** Ambient temperature / humidity
- sc** Machine breakdown

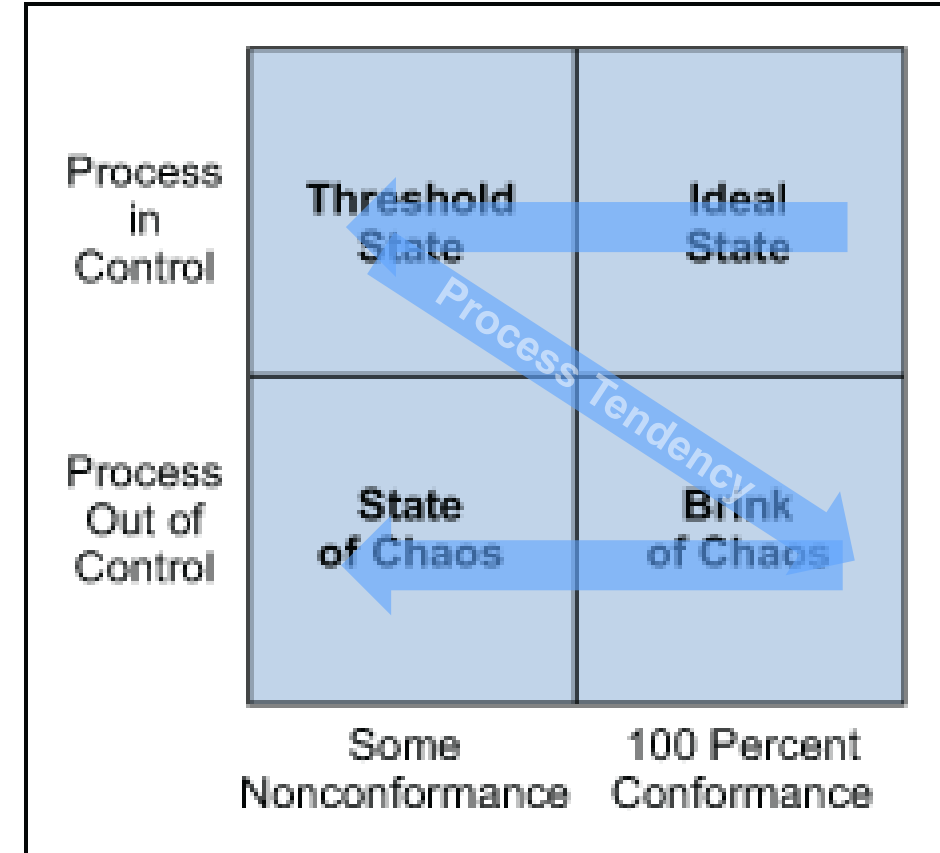
SC = Special Cause
CC = Common Cause



Statistical Process Control (SPC)

- The four Process States:

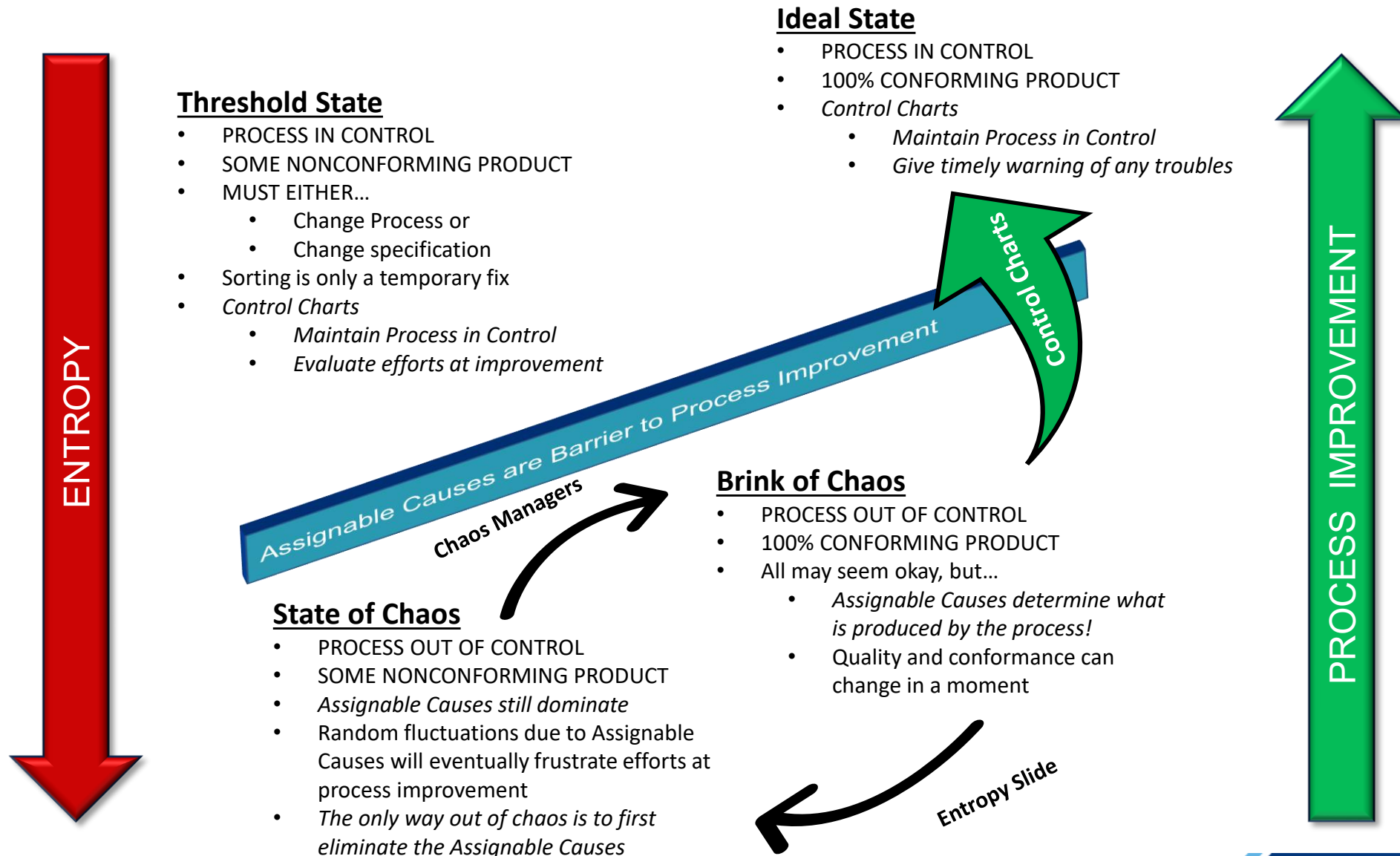
- Ideal State
- Threshold State
- Brink of Chaos
- State of Chaos



Four Process States

Source: *Understanding Statistical Process Control*. Donald J. Wheeler

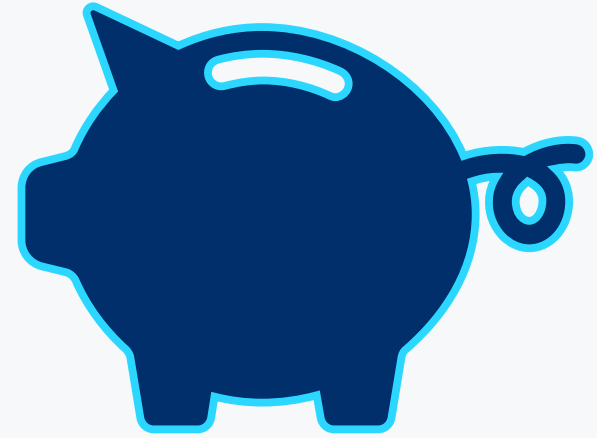
Statistical Process Control (SPC)



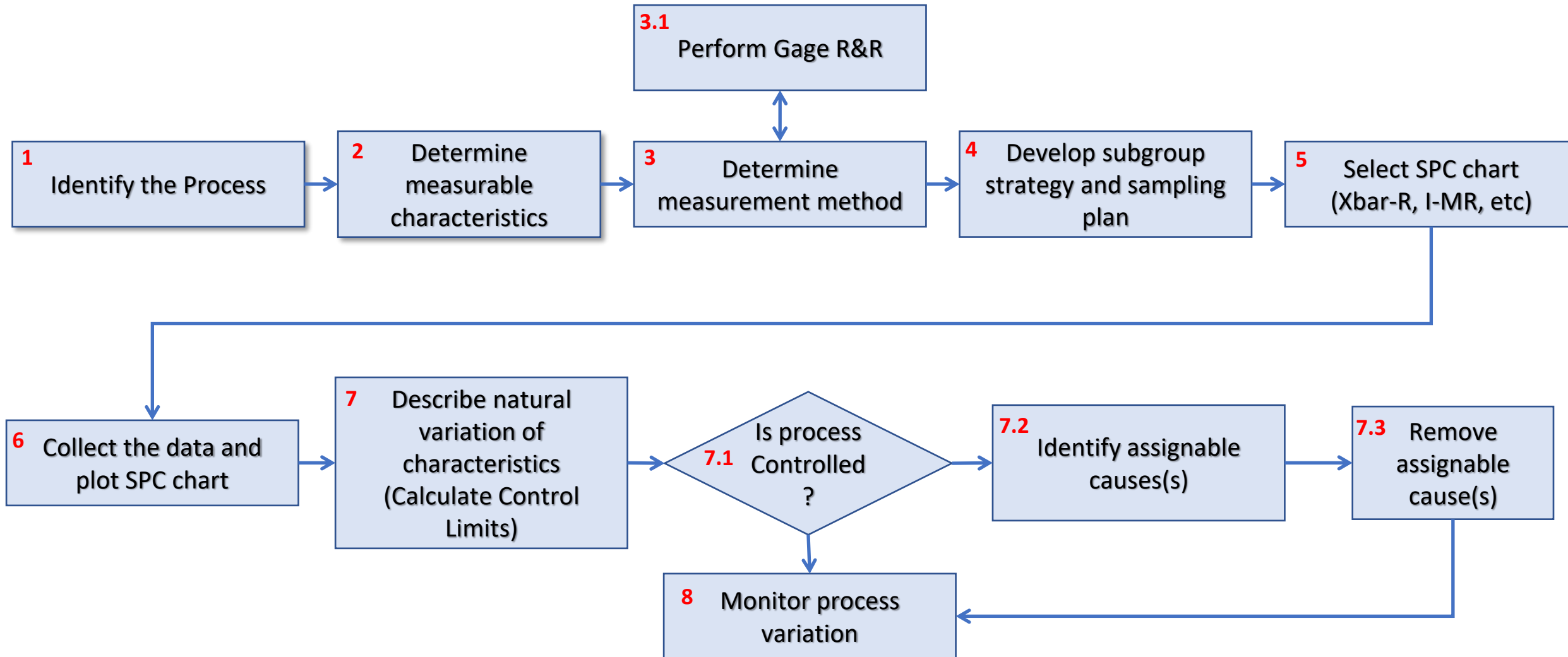
Source:
*Understanding
Statistical
Process Control.*
Donald J. Wheeler

SPC Benefits

- ✓ Reduce scrap and rework
- ✓ Increase productivity
- ✓ Improve overall quality
- ✓ Match process capability to product requirement
- ✓ Continuously monitor process to maintaining control
- ✓ Provide data to support decision making
- ✓ Streamline the process
- ✓ Increase in product reliability
- ✓ Opportunity for company-wide improvements



How to Perform SPC



What is a Control Chart?

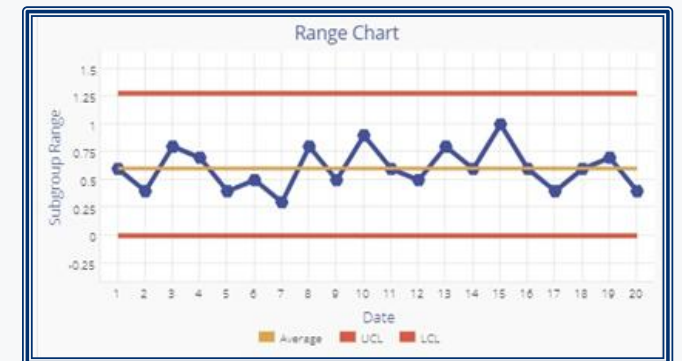
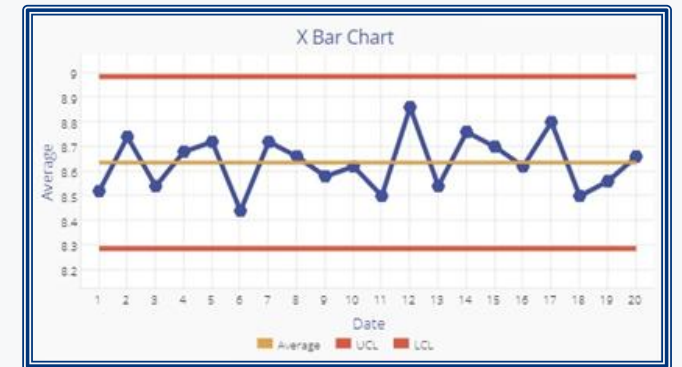
The **Control chart** is a graph used to study how a process changes over time.

Data are plotted in time order. A **control chart** always has:

- a **central line** for the **average**
- an **upper line** for the **upper control limit**
- a **lower line** for the **lower control limit**.

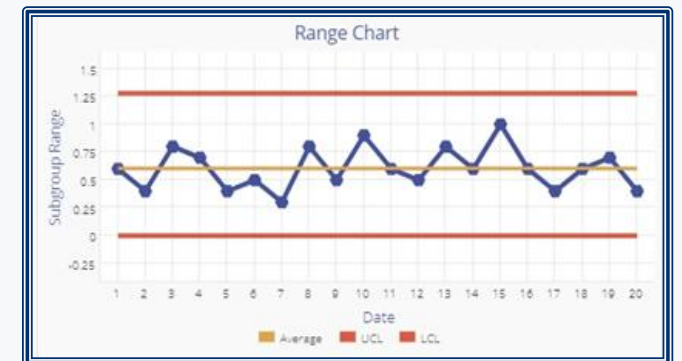
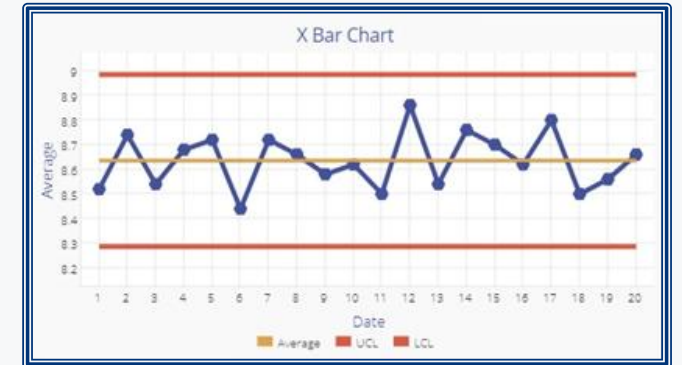
These lines are determined from historical data.

Source: <http://asq.org/learn-about-quality/data-collection-analysis-tools/overview/control-chart.html>



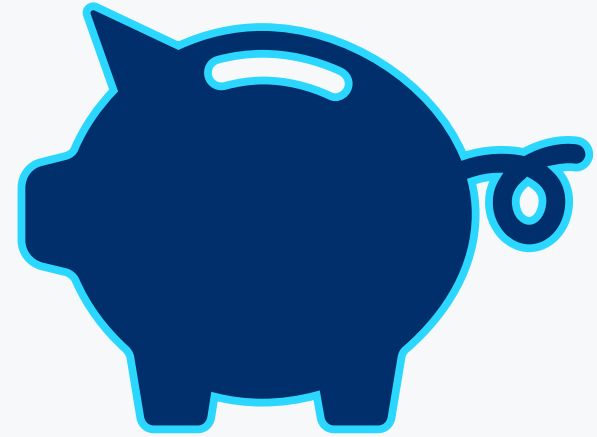
Purpose of a Control Chart

- Control Chart information can be used to **determine the natural range of the process** and compare it with the specified tolerance range.
- Control Charts are used as **predictive tools** to indicate requirements for process changes to prevent production of non-conforming material.
- Using Control Charts **significantly reduces the amount of defective products.**

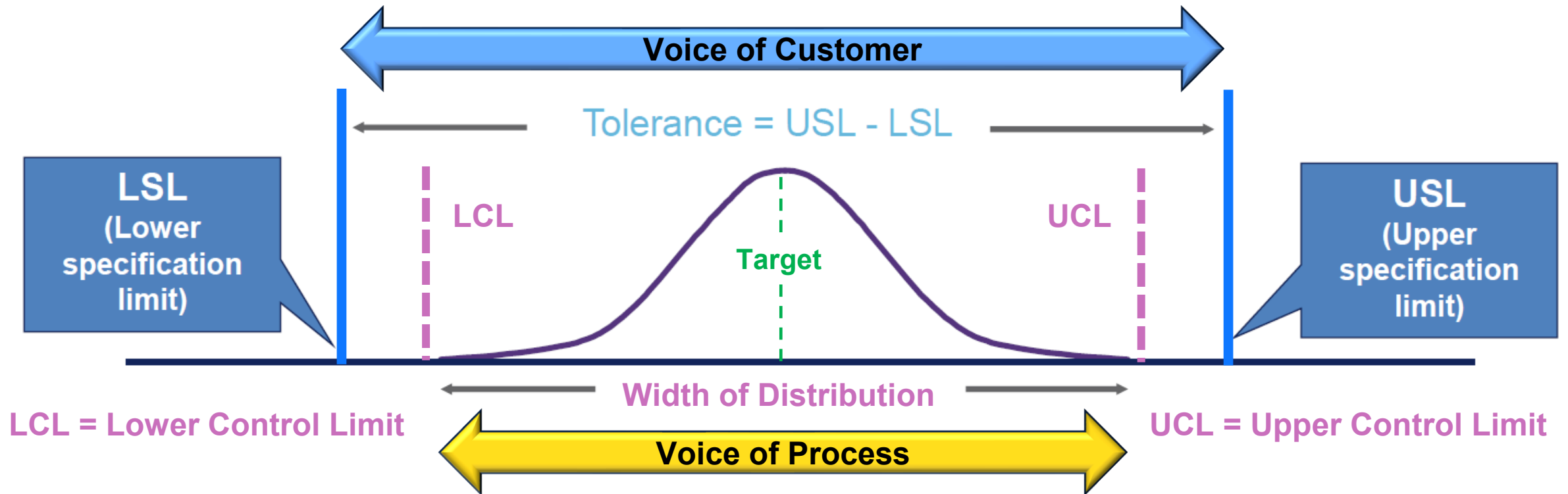


Control Charts Benefits

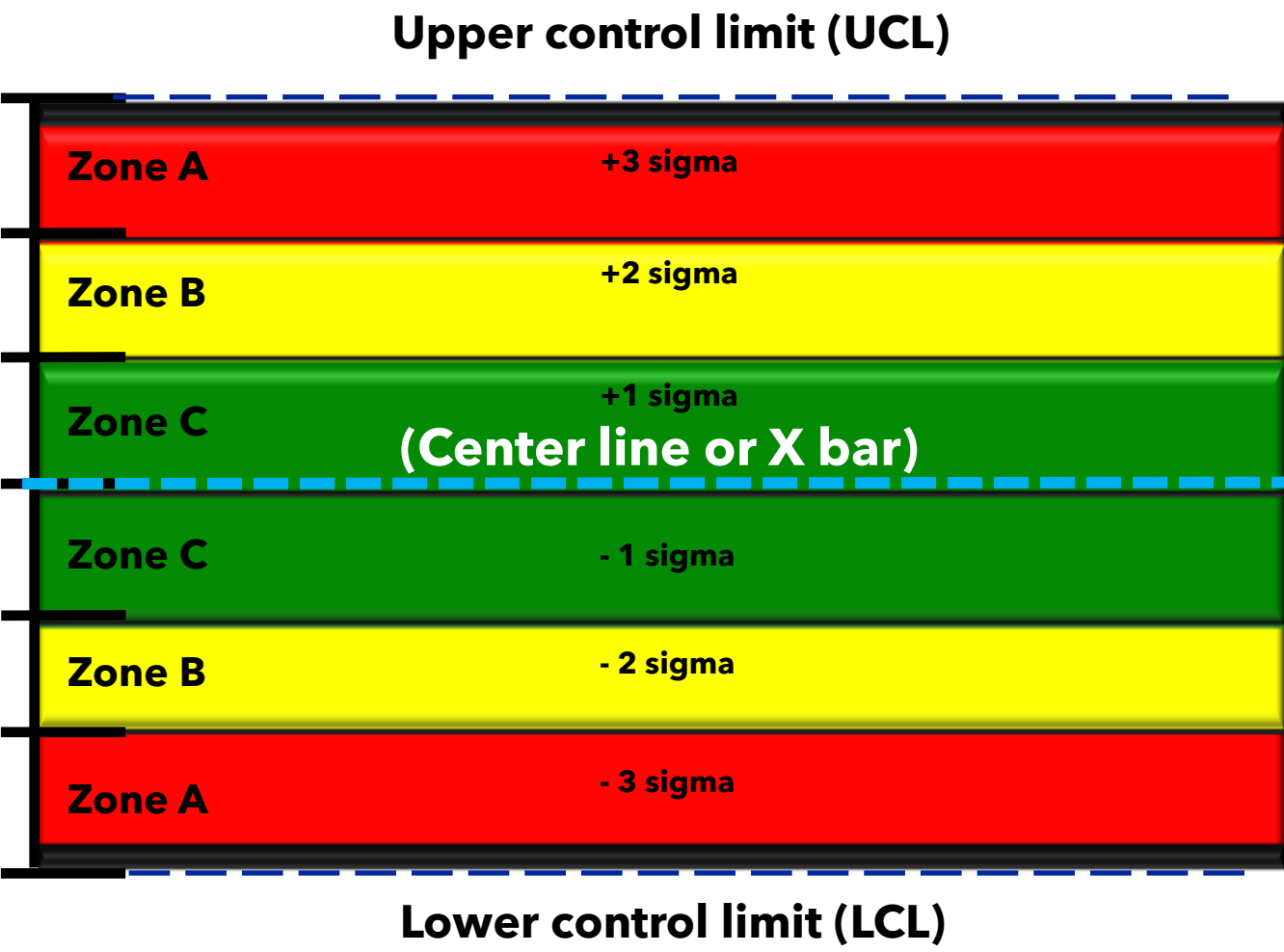
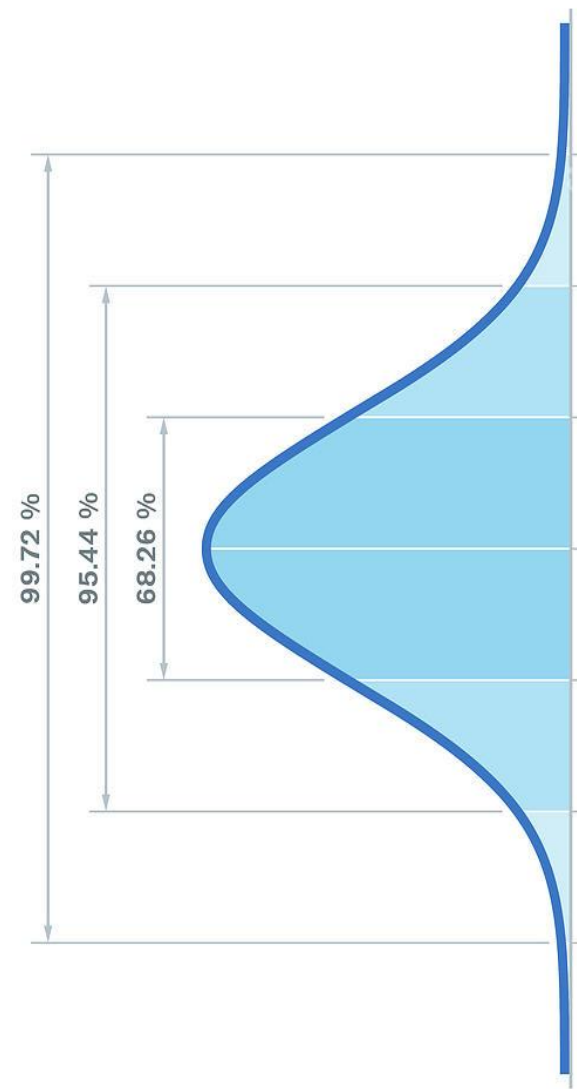
- ✓ Detect variation
- ✓ Monitor/measure process performance and variation over time
- ✓ Differentiate between special & common cause variation
- ✓ Assess the effectiveness of changes to improve a process
- ✓ Establish if a process is in control
- ✓ Reduced inspection can be considered once stability is achieved through control chart analyses
- ✓ Decide when action is appropriate
- ✓ Establish preventative measures



Process limits versus Specification limits



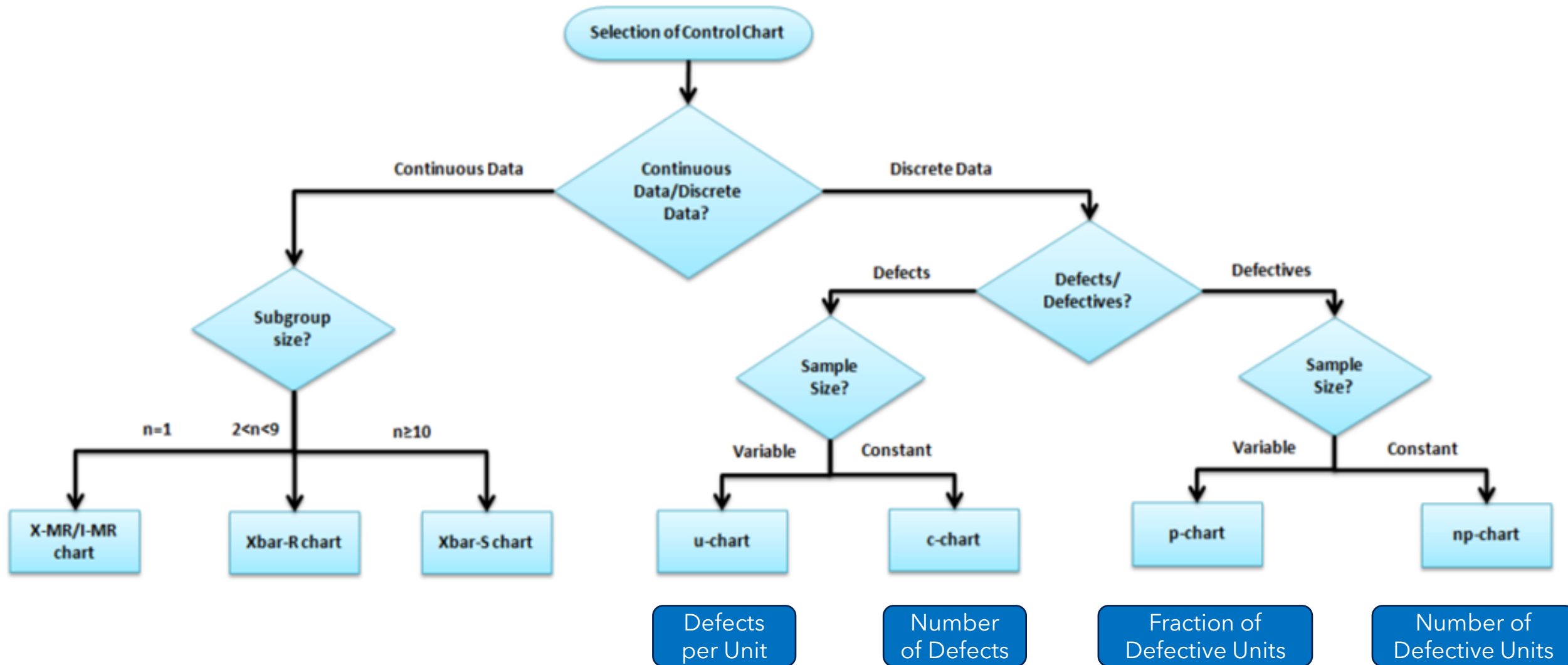
Control Limits



Call the AVG.
the center line
or X bar.

Extend
the + or - 3 sigma
lines, call them
control limits.

Selection of Control Charts



How to Calculate Control Limits

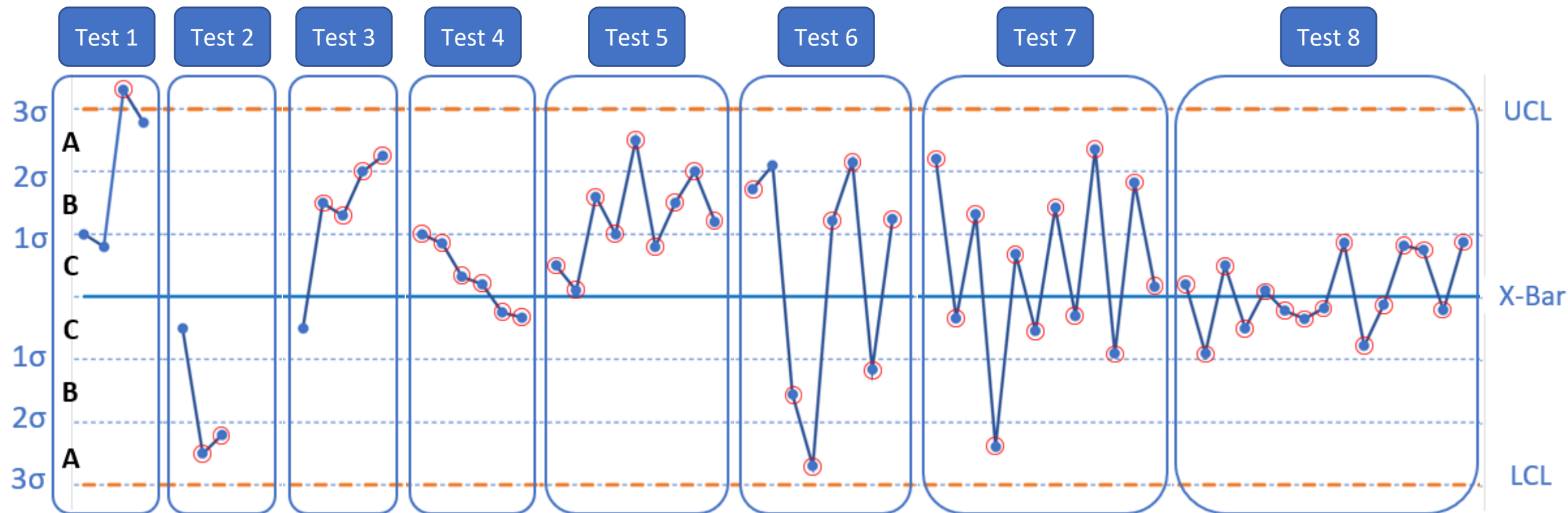
Calculate Control Limits [After 20-25 Subgroups]

Variable Data Chart Formulas		
Chart Type	Subgroup Size	Control Limits
$\bar{X}$ and R Average and Range Chart	< 10 (usually 3-5)	$\bar{X}$ Central Line: $\bar{\bar{X}} = \frac{(\bar{X}_1 + \bar{X}_2 + \dots + \bar{X}_k)}{k}$
		$\bar{X}$ UCL = $\bar{\bar{X}} + A_2 \bar{R}$
		$\bar{X}$ LCL = $\bar{\bar{X}} - A_2 \bar{R}$
		R Central Line: $\bar{\bar{R}} = \frac{(R_1 + R_2 + \dots + R_k)}{k}$
		R UCL = $D_4 \bar{R}$
		R LCL = $D_3 \bar{R}$
X and mR Individuals and Moving Range Chart	1	X Central Line: $\bar{\bar{X}} = \frac{(X_1 + X_2 + \dots + X_k)}{k}$
		X UCL = $\bar{\bar{X}} + (3.14 \times \widetilde{mR})$
		X LCL = $\bar{\bar{X}} - (3.14 \times \widetilde{mR})$
		mR Central Line: Median Moving Range
		mR UCL = $(3.87 \times \widetilde{mR})$
		Note: $\widetilde{mR}$ = Median Moving Range

X̄ & R Chart			
Subgroup Size (n)	A ₂	D ₃	D ₄
2	1.880	0	3.267
3	1.023	0	2.574
4	0.729	0	2.282
5	0.577	0	2.114
6	0.483	0	2.004
7	0.419	0.076	1.924
8	0.373	0.136	1.864
9	0.337	0.184	1.816
10	0.308	0.223	1.777

Assess Statistical Control Tests for Special Cause Variation

Tests/Rules for Special Cause Variation



Source: AS13006 App. D

Recap

- Two sources of process variation: common and special cause variation
- Four process states: Ideal, Threshold, Brink of Chaos, State of Chaos
- Voice of the customer (Specification Limits)
- Voice of the Process (Control Limits)
- Control limits at ± 3 sigma (zones A, B, C)
- Eight tests for special cause variation (AS13006)

Resources

- AS13006 Process Controls Methods

- SPC (2nd Ed.) AIAG

- SPC for Excel

<https://www.spcforexcel.com/spc-for-excel-publications-category>

- Process Capability and Control

IAQG – Supply Chain Management Handbook (SCMH),

https://www.sae.org/servlets/registration?PORTAL_CODE=IAQG&OBJECT_PKG=iaqg.businessClasses&OBJECT_TYPE=SCMHGeneral&PAGE=getSCMHBOOK

- Minitab 20 Support

<https://support.minitab.com/en-us/minitab/20/help-and-how-to/quality-and-process-improvement/>

- Understanding Variation – The Key to Managing Chaos, Donald J. Wheeler

- Short Run SPC, Donald J. Wheeler



Statistical Process Control (SPC) & Process Control Charts

Monitoring Process Stability and Driving Continuous Improvement



1 WHAT IS SPC?



DATA COLLECTION

9.95	10.02	10.01
9.98	9.97	10.00
10.03	9.96	9.99
...	...	...

DATA ANALYSIS



- Uses statistical methods to monitor and control manufacturing processes.
- Detects variation before defects occur.
- Improves capability, consistency, and product quality.

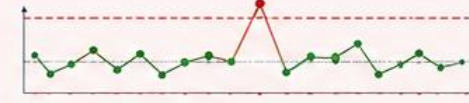
2 TYPES OF VARIATION

COMMON CAUSE VARIATION



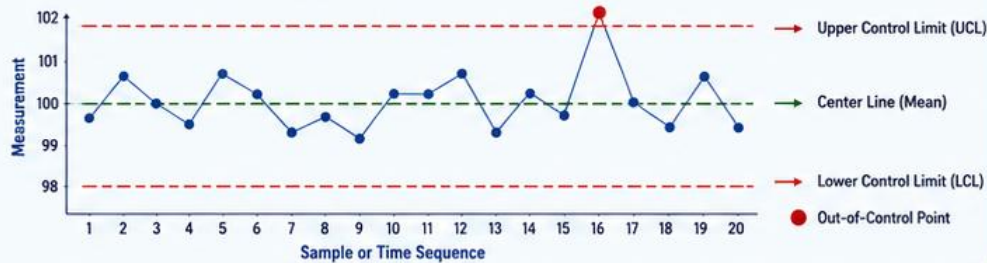
- ✓ Natural process variation
- ✓ Stable and predictable
- ✓ Requires process improvement

SPECIAL CAUSE VARIATION



- ! Unexpected events
- ! Equipment failures, operator error, material changes
- ! Requires investigation and corrective action

3 CONTROL CHART ANATOMY

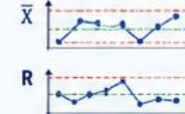


5 RULES FOR OUT-OF-CONTROL SIGNALS



4 COMMON SPC CHARTS

1 $\bar{X}$ -R CHART



- Variable data
- Monitors process mean and range
- Small subgroup sizes (2-10)

2 $\bar{X}$ -S CHART



- Variable data
- Mean and standard deviation
- Larger subgroup sizes (> 10)

3 INDIVIDUALS-MOVING RANGE (I-MR) CHART



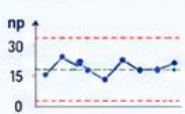
- Individual measurements
- Low production volume

4 p CHART



- Fraction defective
- Variable sample size

5 np CHART



- Number of defectives
- Constant sample size

6 c CHART



- Number of defects per unit
- Constant inspection area

7 u CHART



- Number of defects per unit
- Variable sample size



BENEFITS OF SPC



REDUCED VARIATION
More consistent process performance



HIGHER QUALITY
Fewer defects and better products



LOWER SCRAP AND REWORK
Reduce waste and save costs



PREDICTABLE PERFORMANCE
Stable processes you can rely on

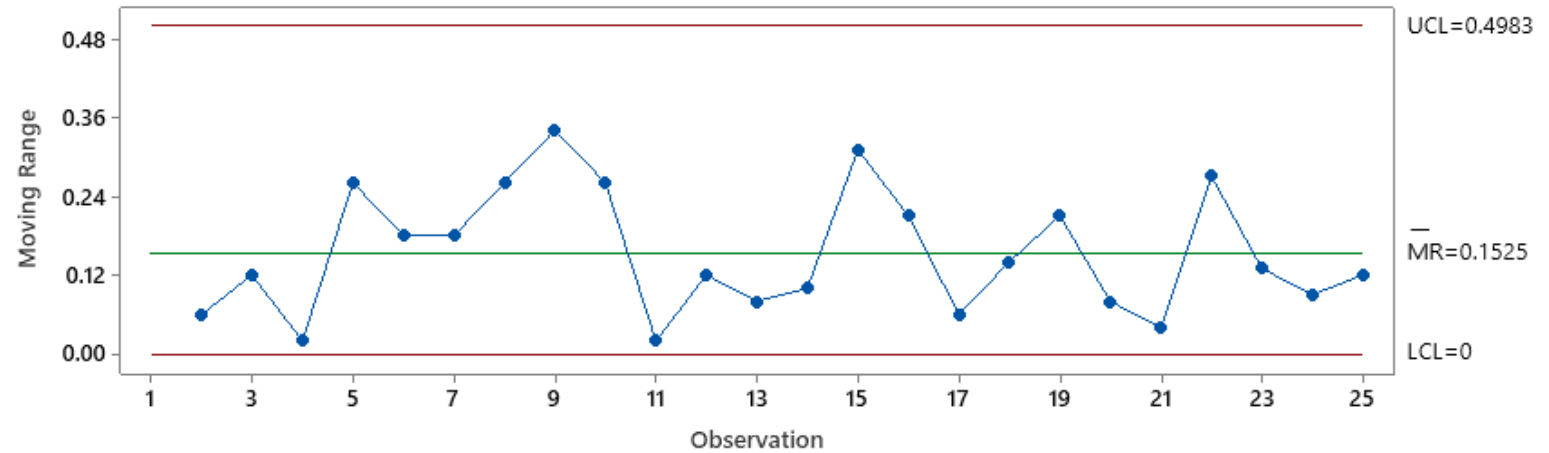
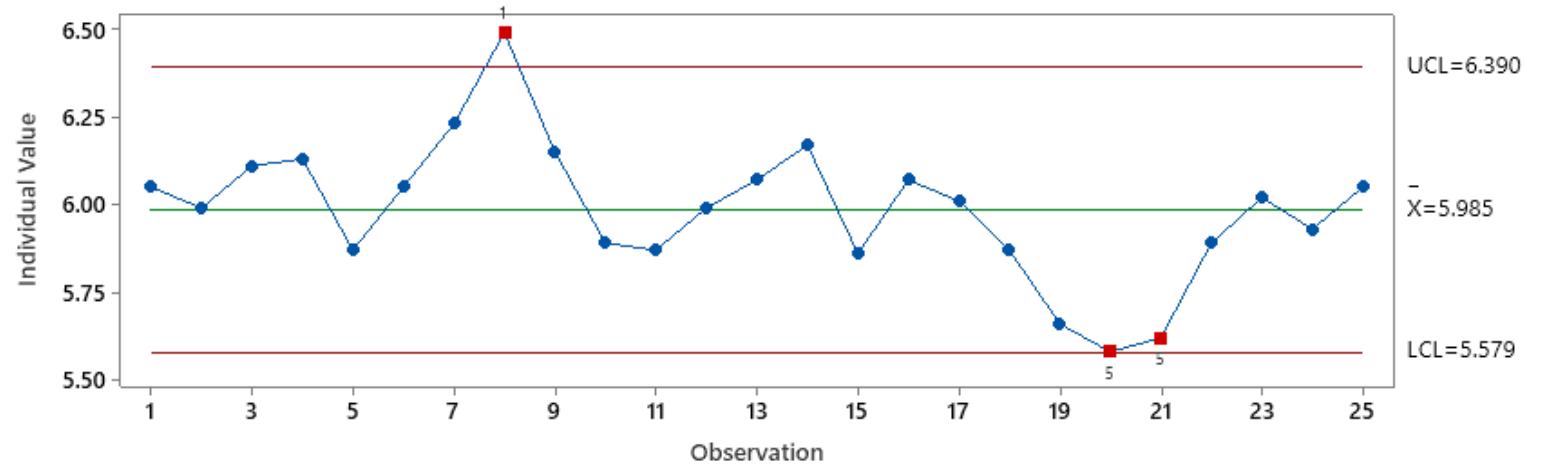
LOCKHEED MARTIN 

Appendix A

Control Charts Types Continuous Data

I-MR Chart

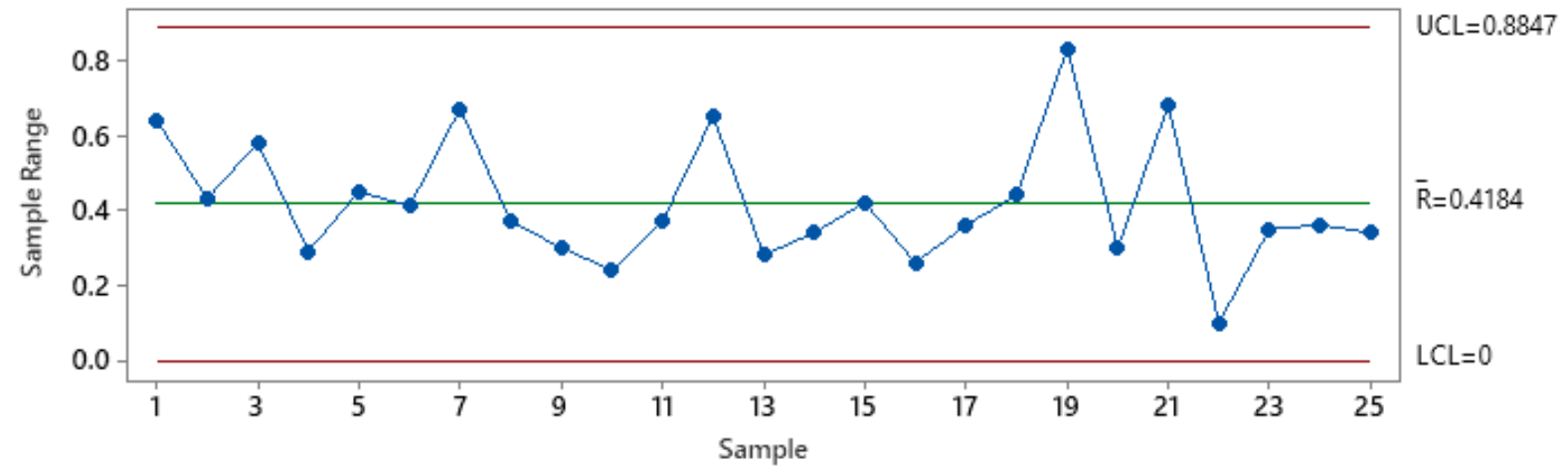
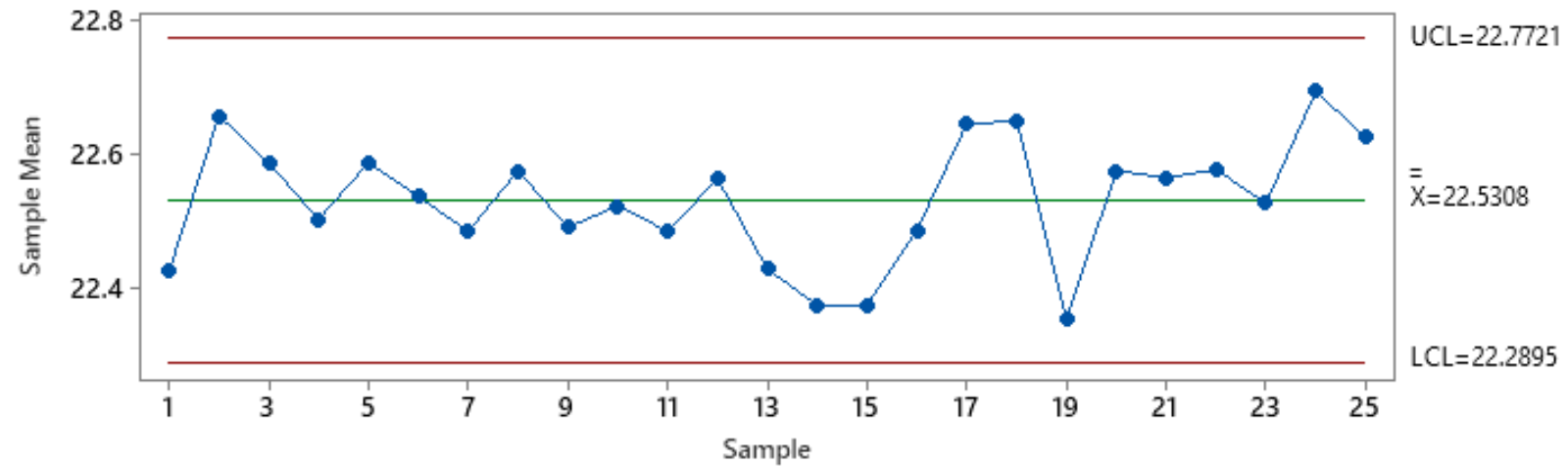
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Note: $\widetilde{mR}$ = Median Moving Range		



X-Bar and R Chart

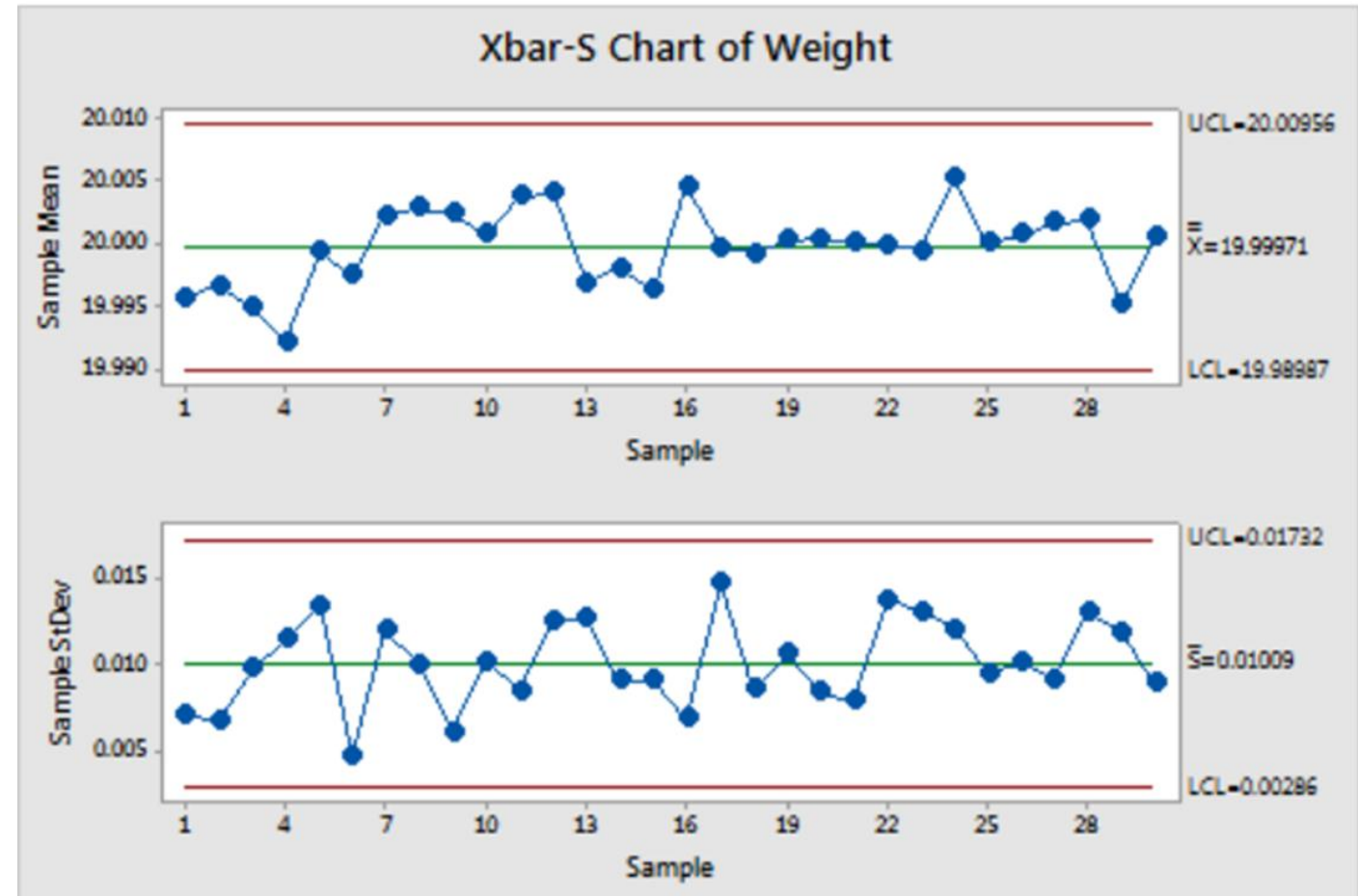
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		R Central Line: $\bar{\bar{R}} = \frac{(R_1 + R_2 + \dots + R_k)}{k}$
		R UCL = $D_4 \bar{R}$
		R LCL = $D_3 \bar{R}$



X-Bar and S Chart

Variable Data Chart Formulas		
Chart Type	Subgroup Size	Control Limits
$\bar{X}$ and S Average and Standard Deviation Chart	≥ 9	$\bar{X}$ Central Line: $\bar{\bar{X}} = \frac{(\bar{X}_1 + \bar{X}_2 + \dots + \bar{X}_k)}{k}$ $\bar{X}$ UCL = $\bar{\bar{X}} + A_3 \bar{S}$ $\bar{X}$ LCL = $\bar{\bar{X}} - A_3 \bar{S}$ S chart : $UCL_{\bar{S}} = B_4 \bar{S}$ $LCL_{\bar{S}} = B_3 \bar{S}$

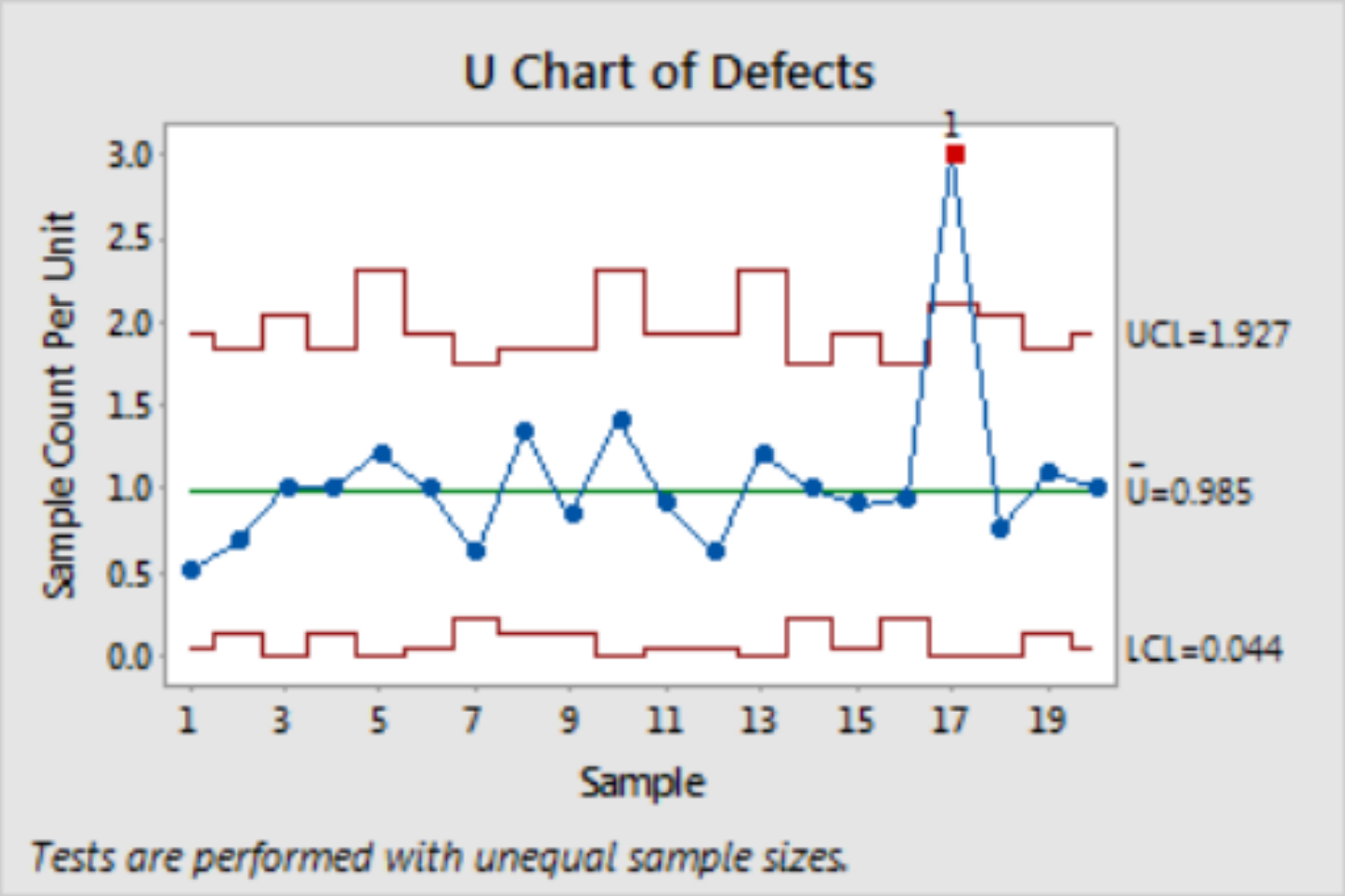


Control Charts Types

Discrete Data

U Chart of Number of Defect per Unit

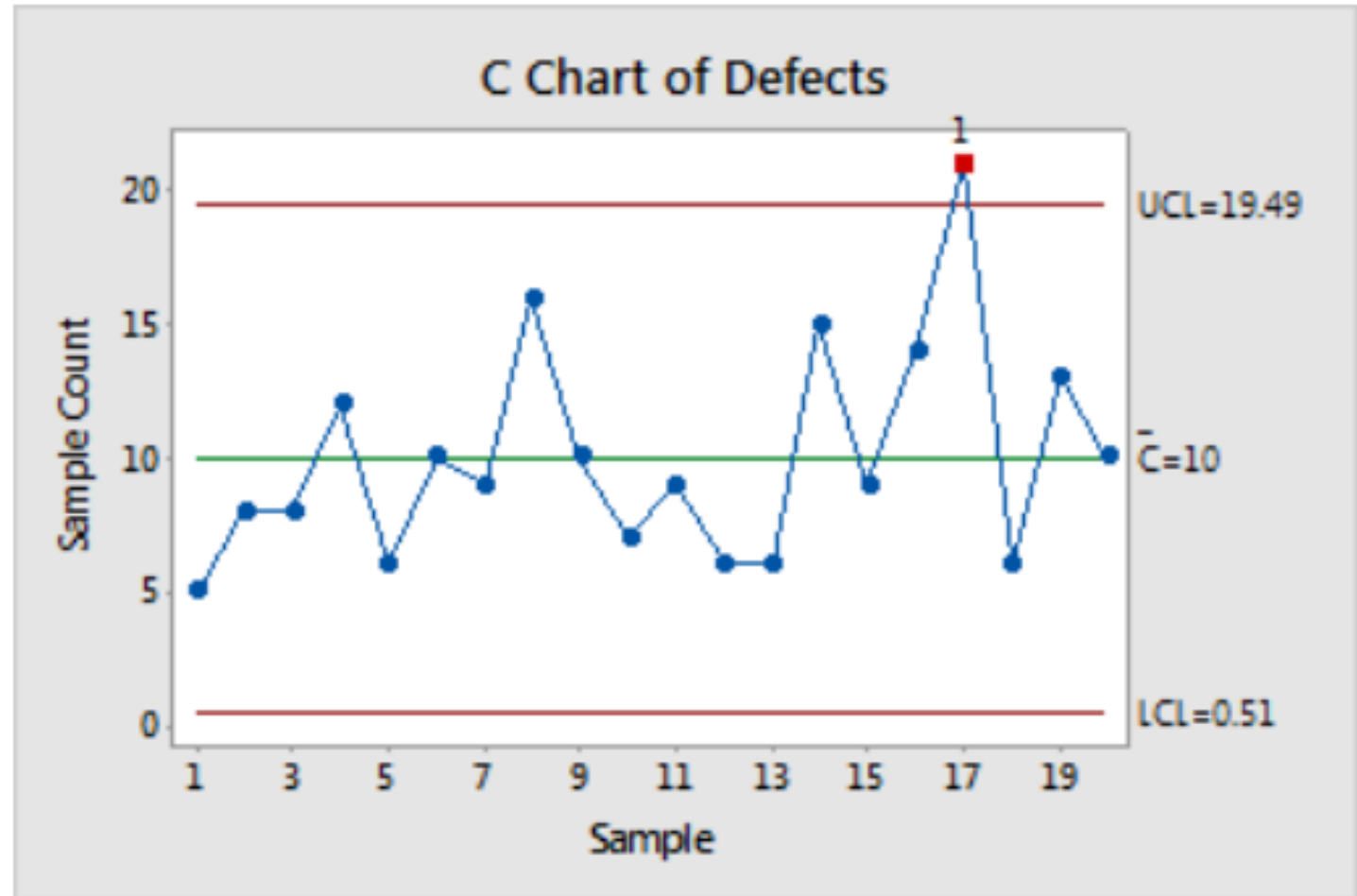
Attribute Data Chart Formulas		
Chart Type	Subgroup Size	Control Limits
u Chart Number of Defects per Unit	Variable or Constant	Central Line: $\bar{u} = \sum c / \sum n$ UCL = $\bar{u} + 3\sqrt{\bar{u}/n}$ LCL = $\bar{u} - 3\sqrt{\bar{u}/n}$



C Chart - Number of Defects

Attribute Data Chart Formulas

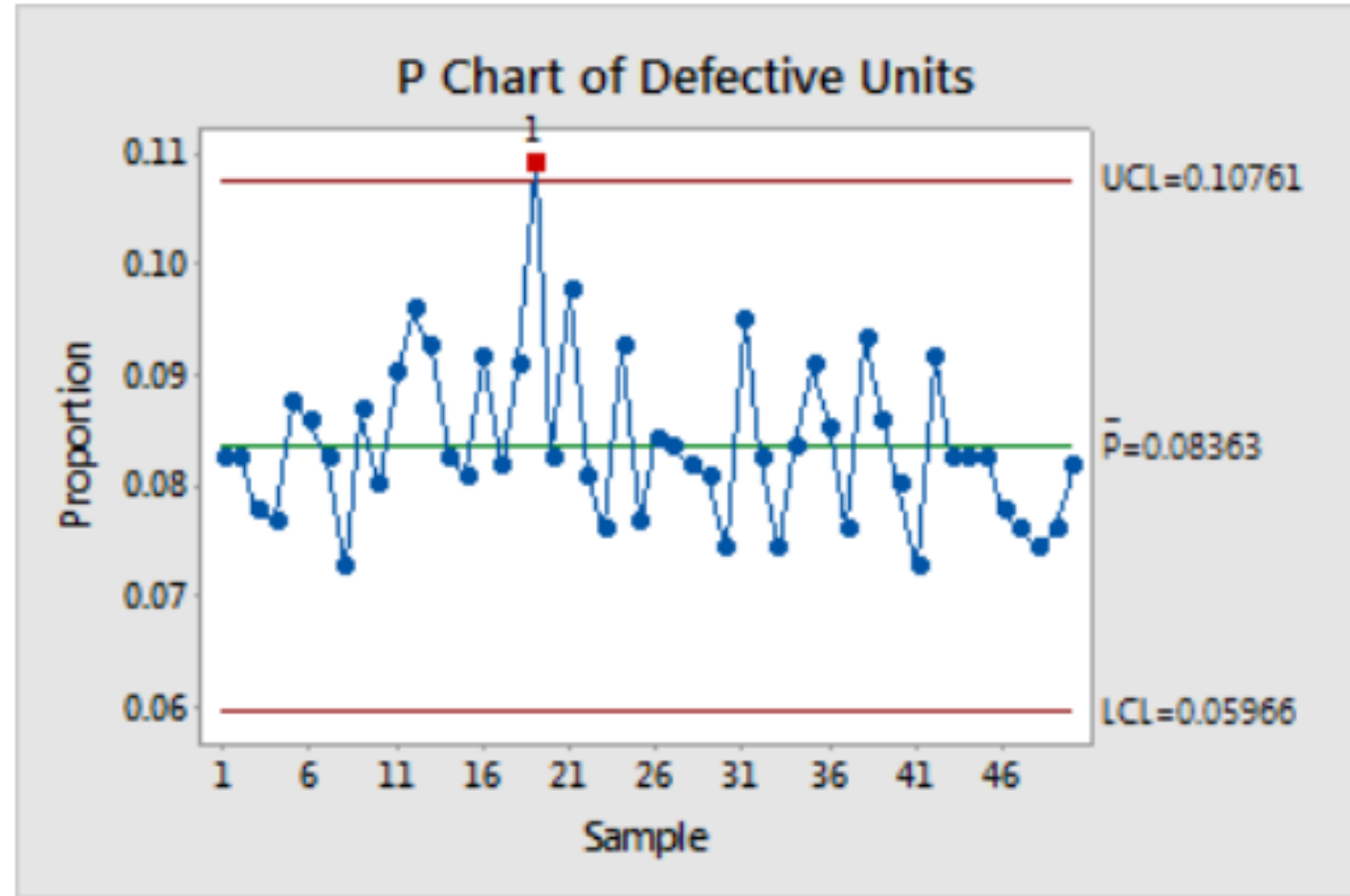
Chart Type	Subgroup Size	Control Limits
c Chart Number of Defects	Constant	Central Line: $\bar{c} = \sum c / k$ UCL = $\bar{c} + 3\sqrt{\bar{c}}$ LCL = $\bar{c} - 3\sqrt{\bar{c}}$



P Chart – Fraction Defective

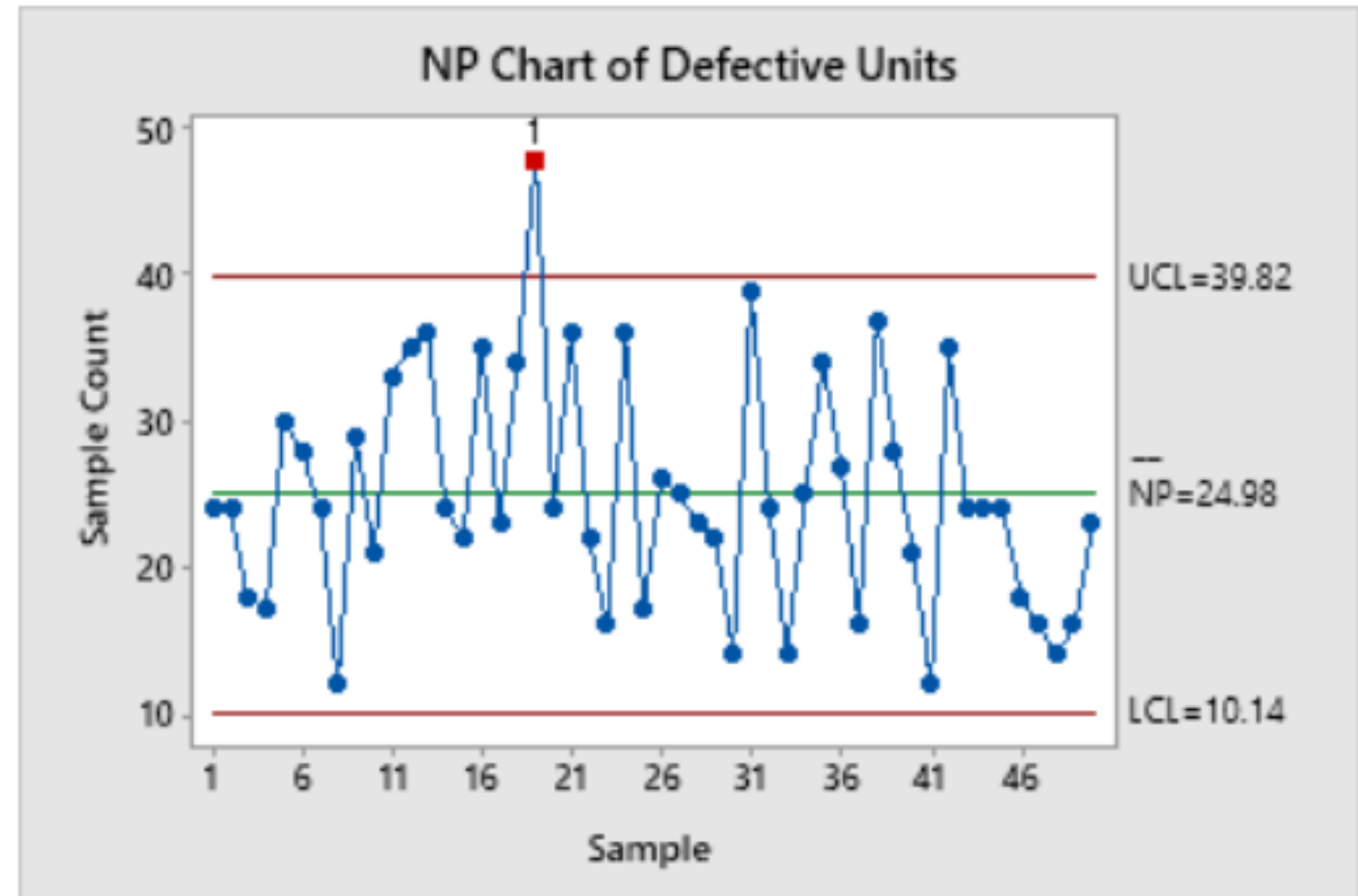
Attribute Data Chart Formulas

Chart Type	Subgroup Size	Control Limits
p Chart Fraction Defective	Variable or Constant	Central Line: $\bar{p} = \sum np / \sum n$ UCL = $\bar{p} + 3\sqrt{(\bar{p}(1-\bar{p}))/n}$ LCL = $\bar{p} - 3\sqrt{(\bar{p}(1-\bar{p}))/n}$



NP Chart – Number Defectives

Attribute Data Chart Formulas		
Chart Type	Subgroup Size	Control Limits
np Chart Number Defective	Constant	Central Line: $\bar{np} = \sum np / k$
		UCL = $\bar{np} + 3\sqrt{\bar{np}(1-\bar{p})}$
		LCL = $\bar{np} - 3\sqrt{\bar{np}(1-\bar{p})}$



Calculate Control Limits [After 20-25 Subgroups]

Attribute Data Chart Formulas		
Chart Type	Subgroup Size	Control Limits
p Chart Fraction Defective	Variable or Constant	Central Line: $\bar{p} = \sum np / \sum n$ UCL = $\bar{p} + 3\sqrt{\bar{p}(1-\bar{p})/n}$ LCL = $\bar{p} - 3\sqrt{\bar{p}(1-\bar{p})/n}$
np Chart Number Defective	Constant	Central Line: $\bar{np} = \sum np / k$ UCL = $\bar{np} + 3\sqrt{\bar{np}(1-\bar{p})}$ LCL = $\bar{np} - 3\sqrt{\bar{np}(1-\bar{p})}$
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u Chart Number of Defects per Unit	Variable or Constant	Central Line: $\bar{u} = \sum c / \sum n$ UCL = $\bar{u} + 3\sqrt{\bar{u}/n}$ LCL = $\bar{u} - 3\sqrt{\bar{u}/n}$

Supplier Quality Management

Continuous Improvement Training

Statistical Process Control (SPC)
Part 2 - Application
Advanced Quality Team



GROUND RULES



Silence cell phones



**Mute your
microphone**



No Multitasking



**All Questions are
welcome**

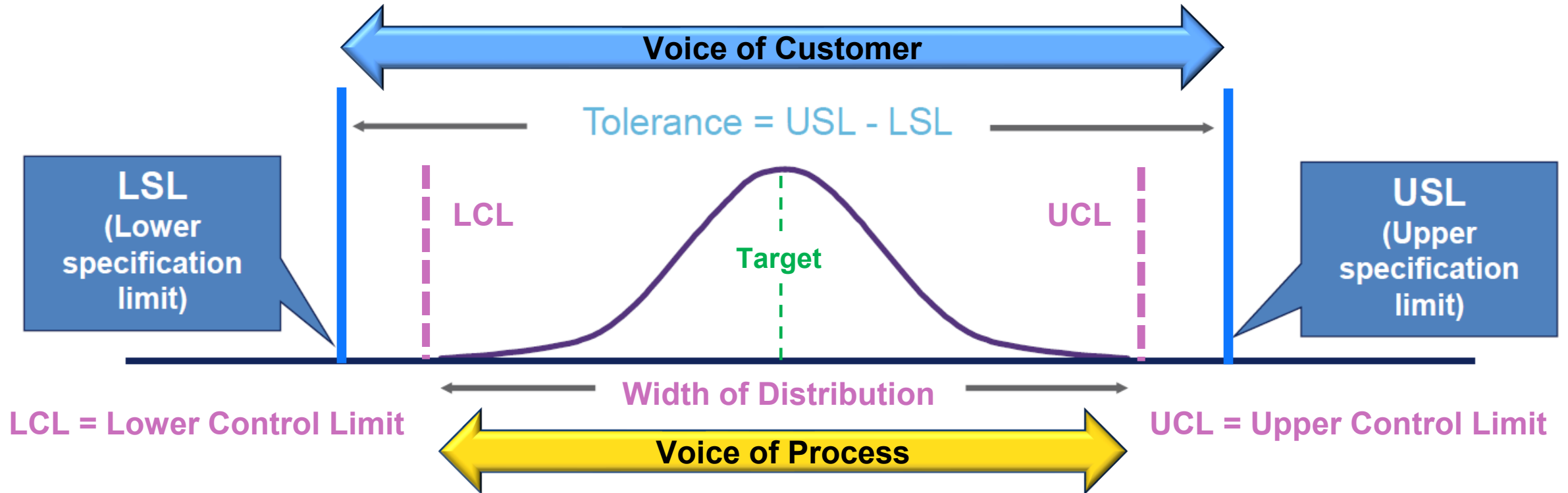
Agenda

Part 2

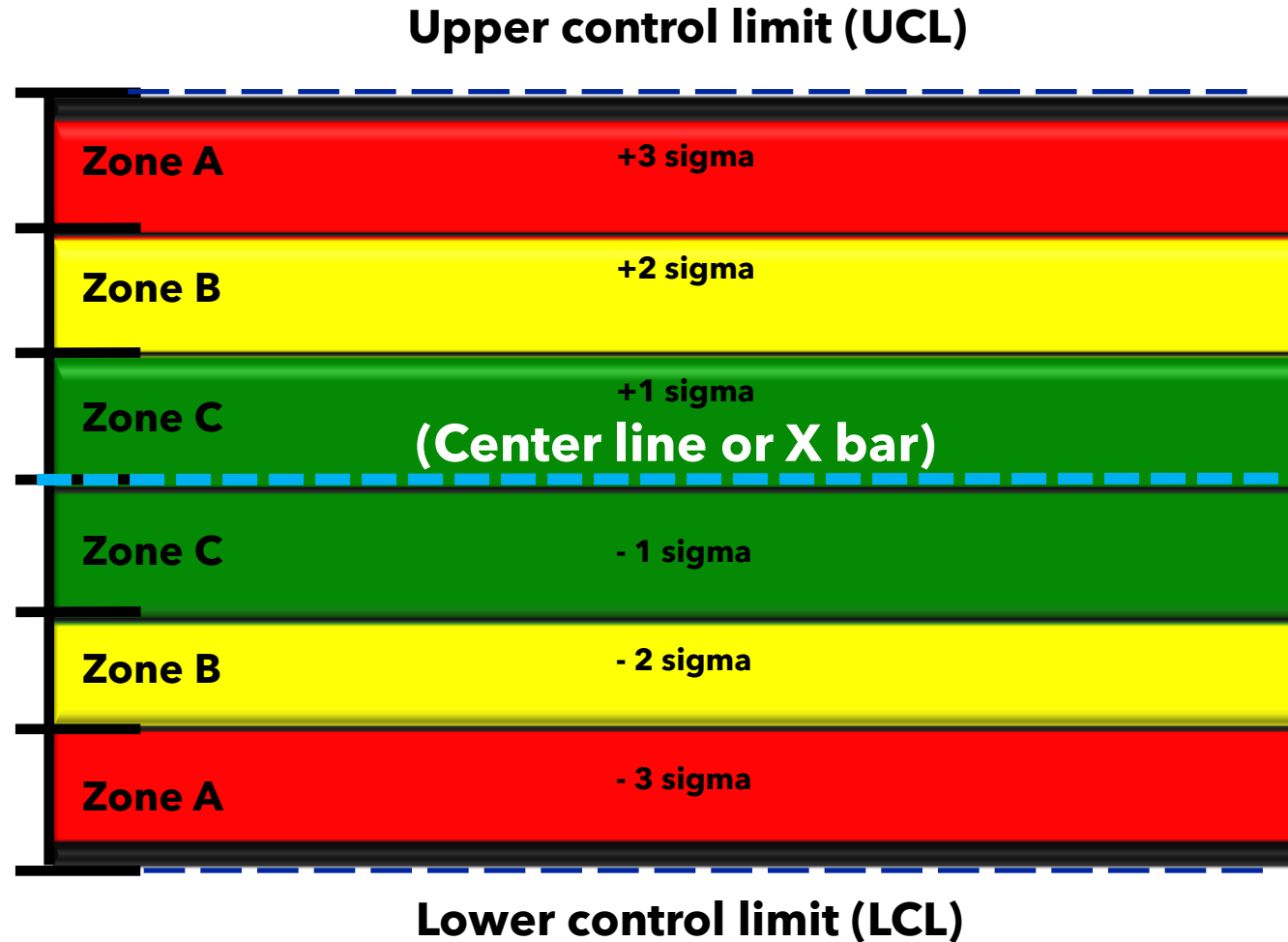
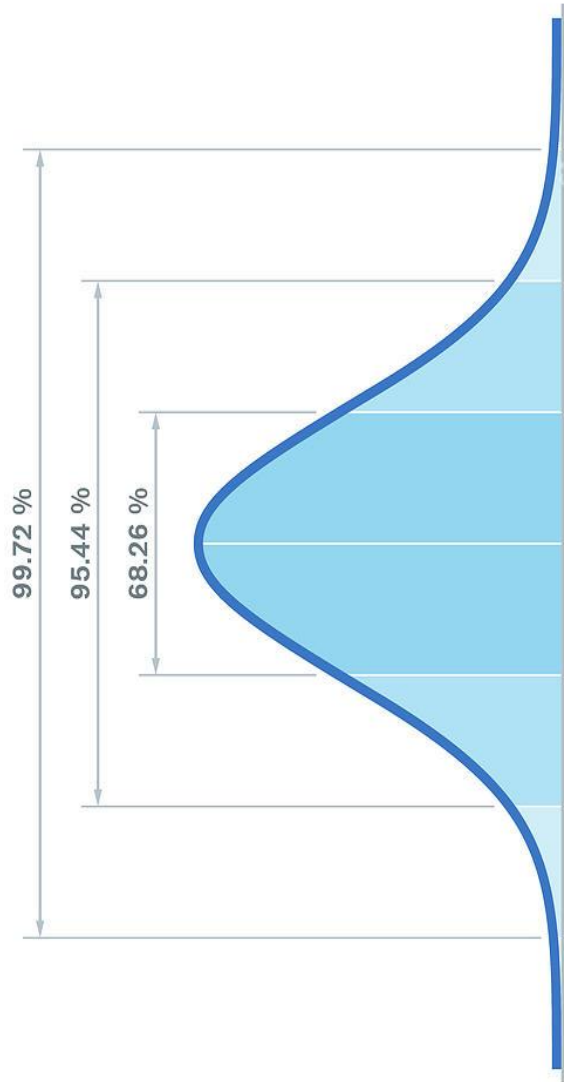
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Process limits versus Specification limits



Control Limits



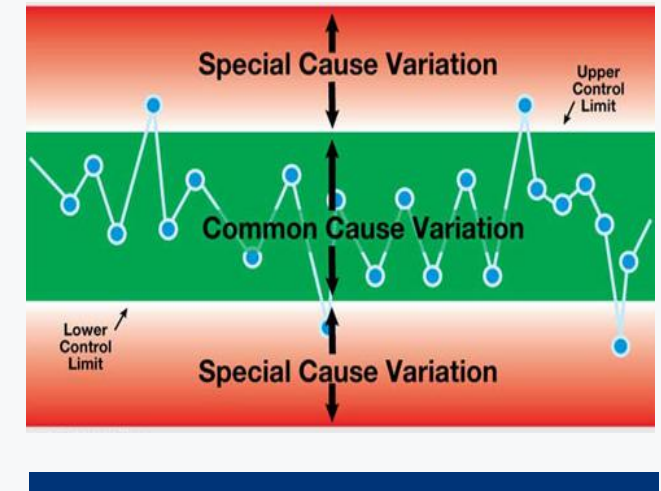
Call the AVG.
the center line
or X bar.

Extend
the + or - 3 sigma
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control limits.

Interpreting a Control Chart

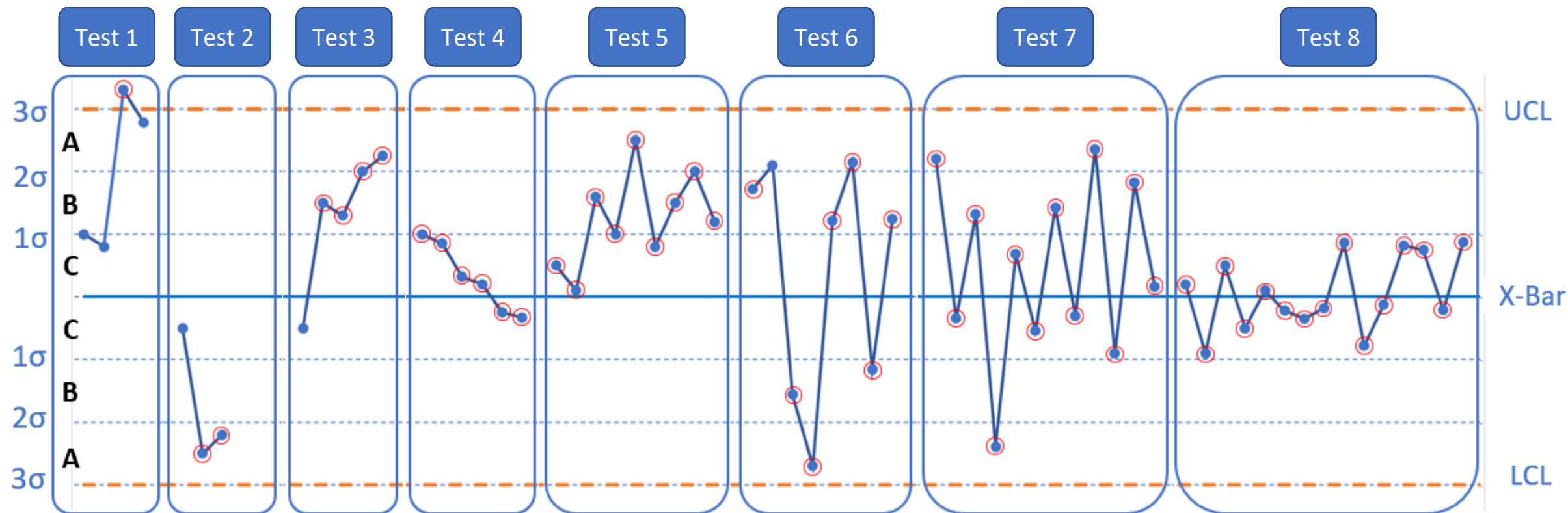
Identify the following conditions:

- **Instability:** All over the map
- **Systematic Variation:** Up-Down, Up-Down
- **Trends:** Long series of points that are moving in one direction
- **Sudden Change:** Major change in data/process
- **Cycles:** Roller coaster curve



Assess Statistical Control Tests for Special Cause Variation

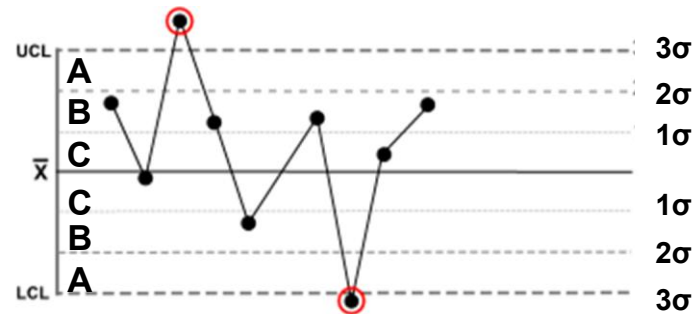
Tests/Rules for Special Cause Variation



Source: AS13006 App. D

Potential Causes for Each Test

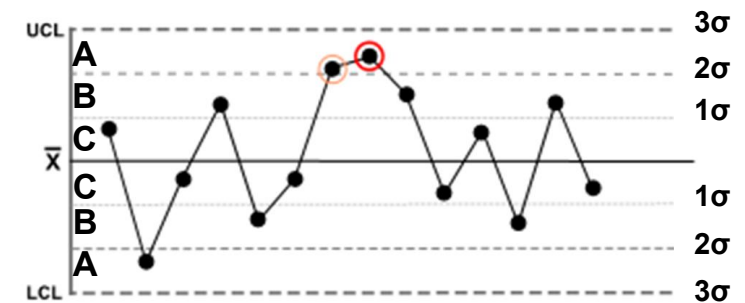
TEST 1: Single point is outside the control limits. (Instability)



What are the Possible Causes?

- New person doing the job
- A machine breakdown
- Wrong setup
- Process Step not completed
- Power failure
- A piece of bad material
- Process step skipped

TEST 2: Two out of three points more than 2 standard deviations from the centerline or mean (Zone A).



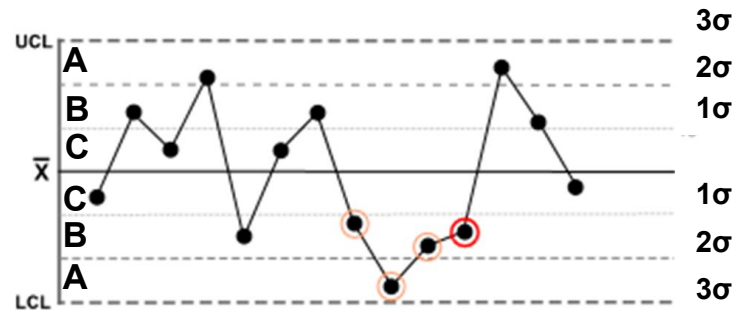
Some prolonged bias exists.

What are the Possible Causes?

- New person doing the job
- A machine breakdown
- Wrong setup
- Process Step not completed
- Power failure
- A piece of bad material
- Process step skipped

Potential Causes for Each Test

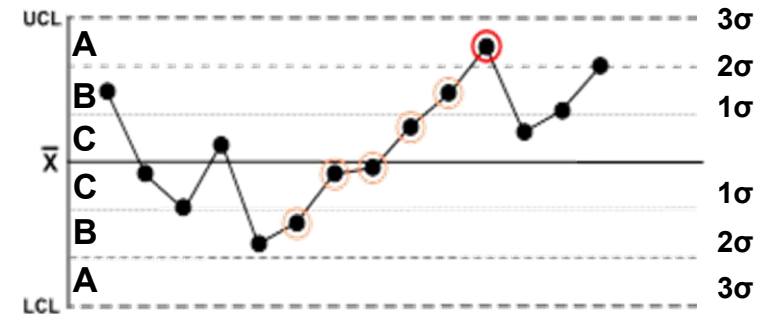
TEST 3: Four out of five points more than 1 standard deviation from the centerline or mean (Zone A or B).



What are the Possible Causes?

- Raw material change
- Change in work instruction
- Different measurement device/calibration
- Different shift
- Person gains greater skills in doing the job
- Change in maintenance program
- Change in setup procedure

TEST 4: Six points in a row increasing or decreasing.

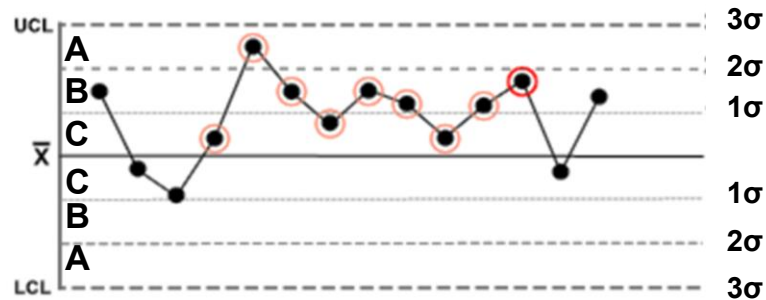


What are the Possible Causes?

- Tooling wear
- Operator fatigue
- Changes in raw material
- Shifts in environmental conditions: (cooling, heating)

Potential Causes for Each Test

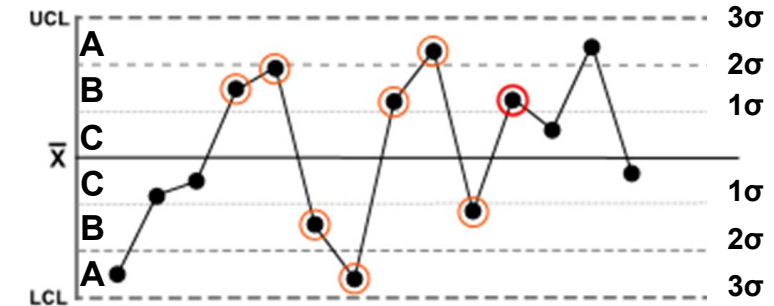
TEST 5: A run of eight points on the same side of the centerline.



What are the Possible Causes?

- Raw material change
- Change in work instruction
- Different measurement device/calibration
- Different shift
- Person gains greater skills in doing the job
- Change in maintenance program
- Change in setup procedure

TEST 6: Eight points in a row greater than 1 standard deviation from the centerline or mean (Zone A or B).

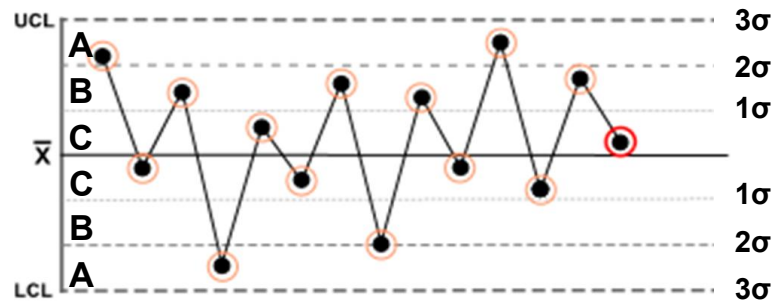


What are the Possible Causes?

- More than one process present (e.g. shifts, machines, raw material.)

Potential Causes for Each Test

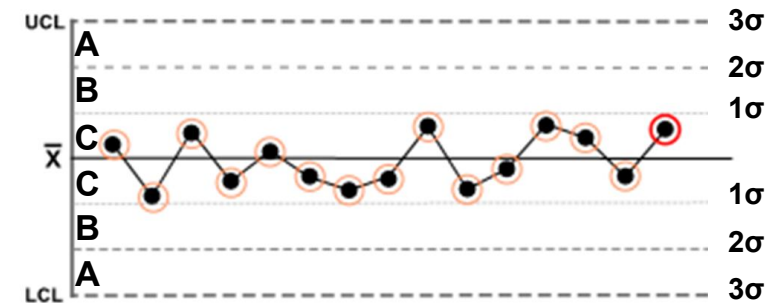
TEST 7: Fourteen points in a row alternating up and down.
Over-control



What are the Possible Causes?

- Tampering by operator
- Alternating raw materials
- Two different processes occurring simultaneously
- Two different machines
- Two different operators

TEST 8: Fifteen points in a row hugging the centerline (all within Zone C). Stratification

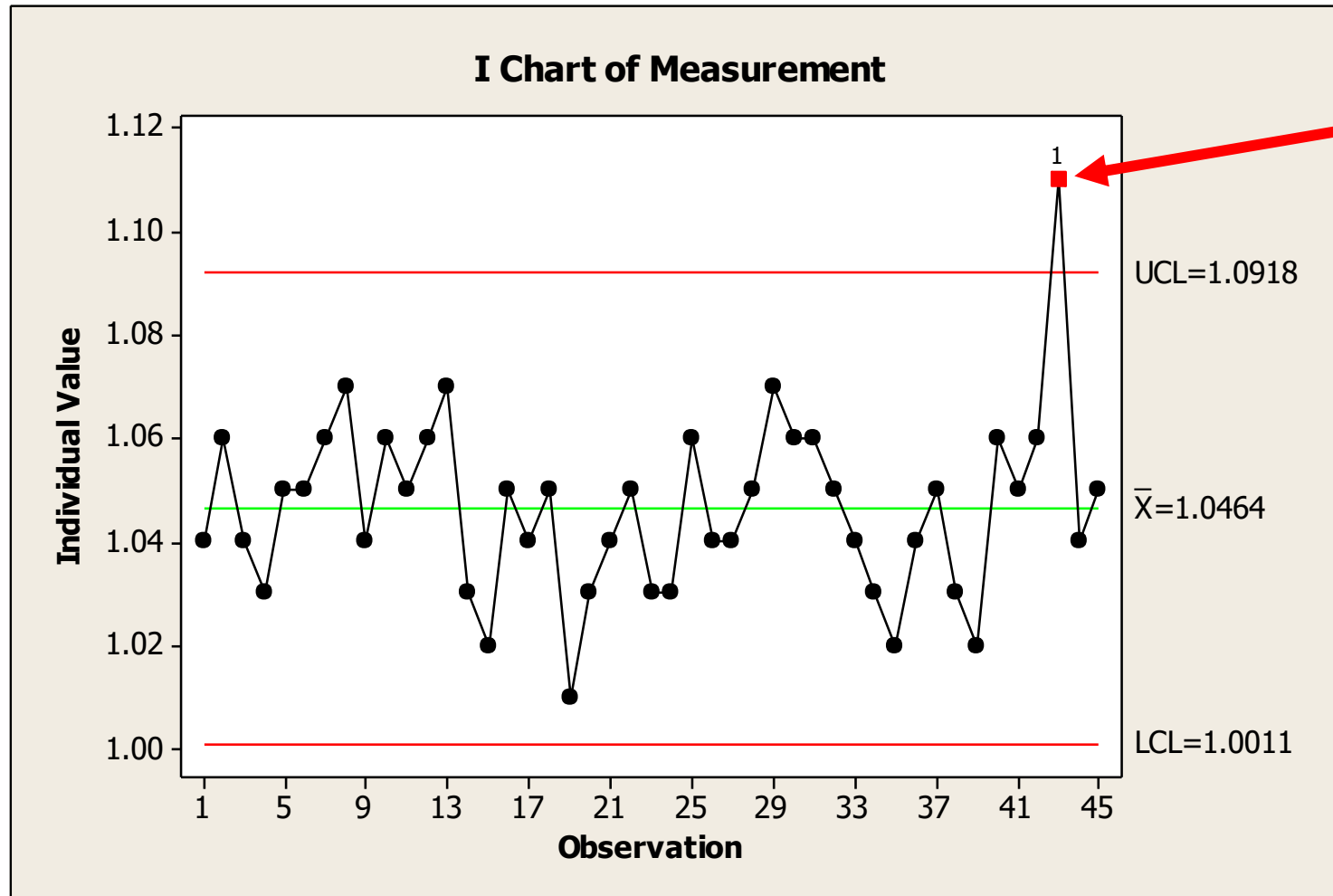


What are the Possible Causes?

- More than one process present (e.g. shifts, machines, raw materials)
- Improper sampling techniques
- An operator trying to make the data appear too good
- A change in process variability not properly accounted for in the control limits.

Confusing Common and Special Cause Variation Examples

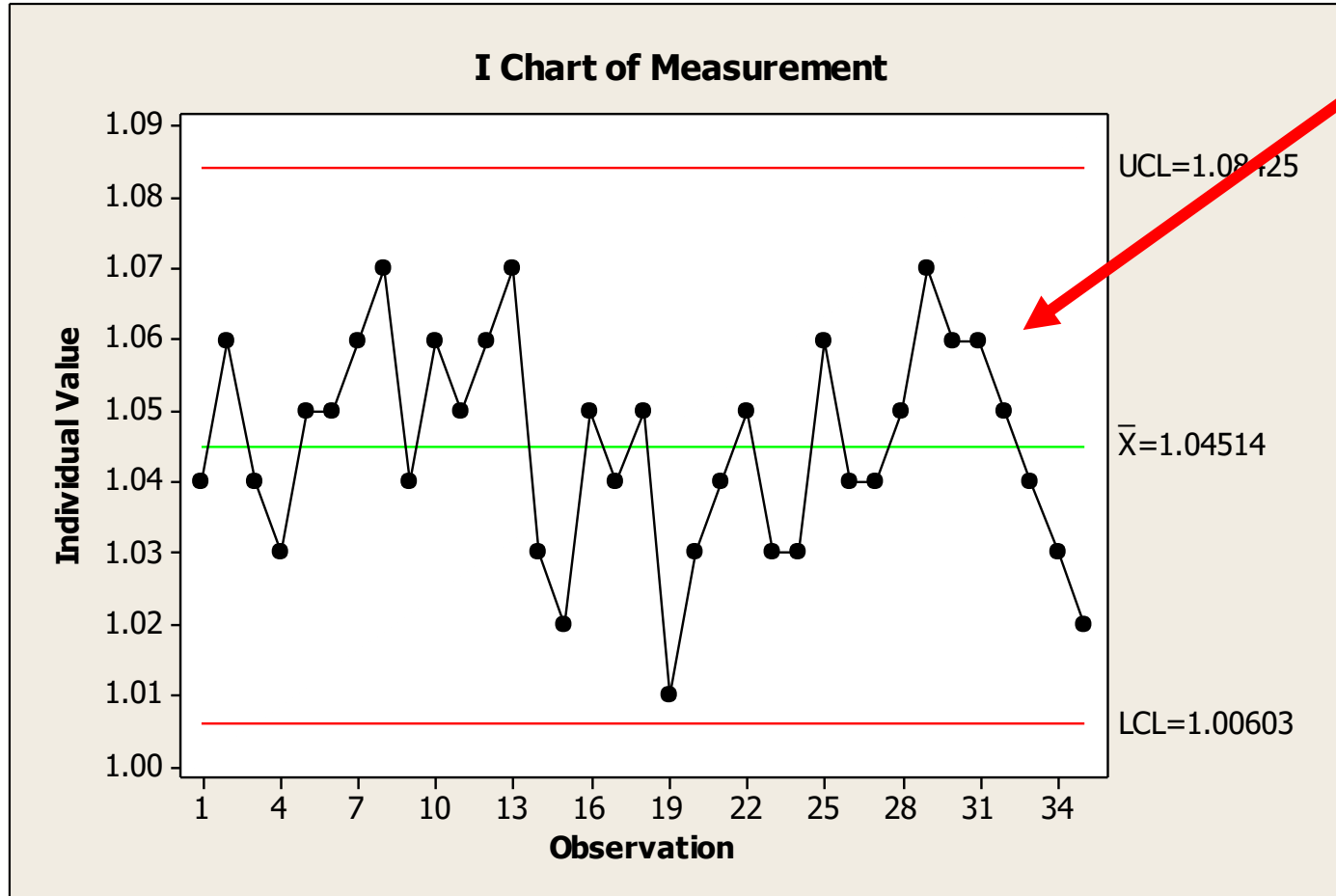
Example #1



Special Cause
Variation
Requires
Immediate Action!

A process that is NOT in control is NOT PREDICTABLE!

Example #2



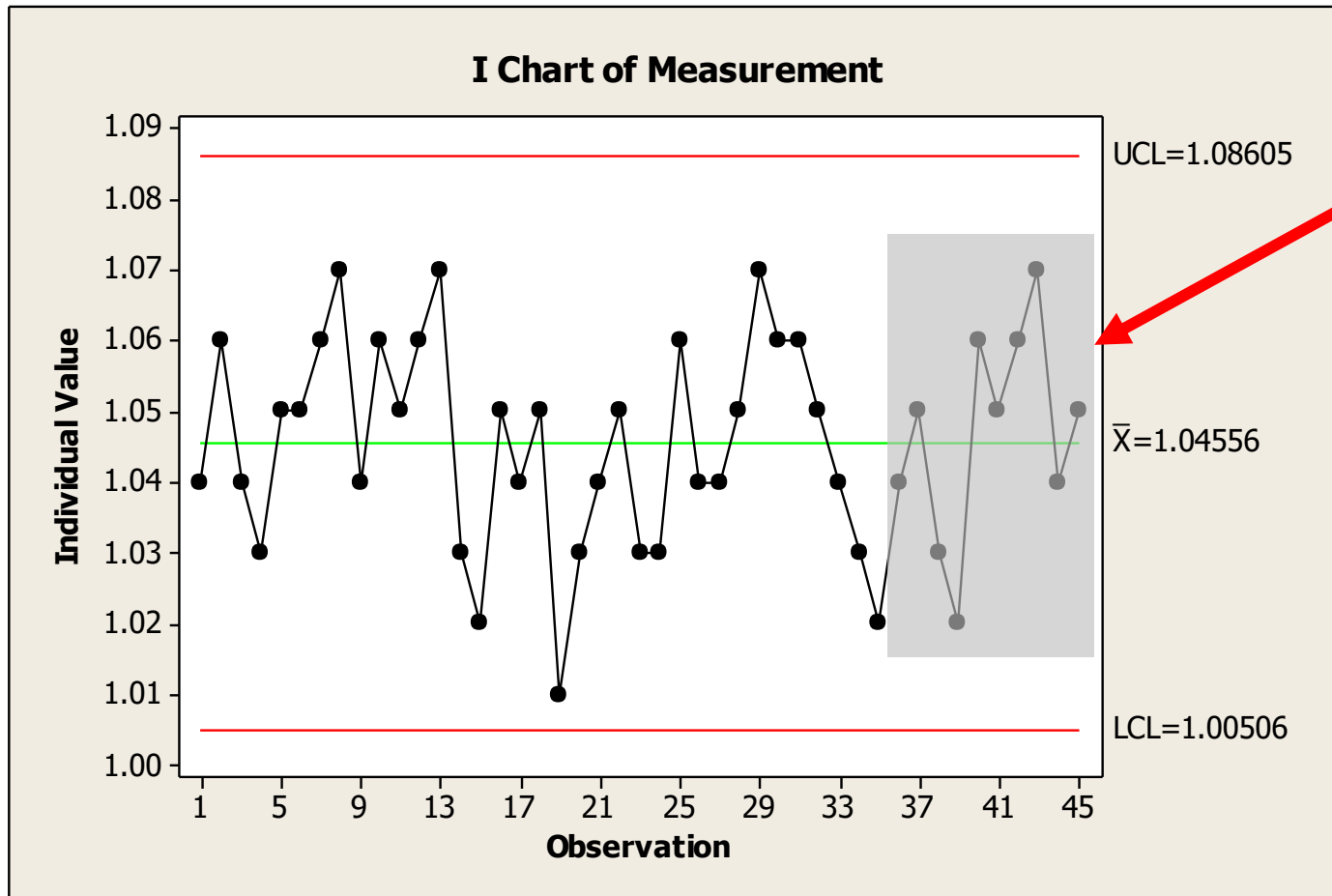
Typical Reaction:

The process is going bad! Action must be taken or it's going to get worse...i.e. this is obviously an "early warning indicator."

Appears to be downward trend, but (as it stands) it is part of inherent process variation – no action should be taken (yet) because of downward trend. Taking action means tampering with the process and it can actually make things worse!

No special cause variation present...yet

Example #3



Same chart as previous slide, but with "New" data points added

If no action was taken, you would probably see something like this.

A process that is in control is PREDICTABLE.

Control Chart Excel Examples

Xbar-R (Hole Diameter)

A Quality Engineer monitors the diameter of a hole and wants to assess whether the process is in control. The engineer takes a sample of 125 individual values collected using a subgroup size of five. Hence 25 subgroups.

Control Chart Data

22.531	Xbar/IMR Chart Avg	22.61	Xbar one sigma Upper Limit	0.574	Rbar one sigma Upper Limit
0.4184	Range Chart Avg	22.69	Xbar two sigma Upper Limit	0.729	Rbar two sigma Upper Limit
0.17988	Rbar/d ₂	22.77	Xbar three sigma Upper Limit	0.885	Rbar three sigma Upper Limit
125	Number of samples	22.45	Xbar one sigma Lower Limit	0.263	Rbar one sigma Lower Limit
5	Subgroup size	22.37	Xbar two sigma Lower Limit	0.107	Rbar two sigma Lower Limit
25	Number of subgroups	22.29	Xbar three sigma Lower Limit	n/a	Rbar three sigma Lower Limit

Quality Tools

Control Charts

Description

This template illustrates a Statistical Process Control (SPC) chart. A detailed discussion of SPC charts can be found at www.ASQ.org

[Learn About Statistical Process Control](#)

Instructions

- Select the correct subgroup size. When in doubt, select a subgroup size of one. Partial subgroups are not displayed.

☐ One ☒ Two ☐ Three
☐ Four ☐ Five ☐ Six

- Enter up to 200 data points in the cells provided. Do not enter values in the subgroup column. These cells update automatically to show the subgroup in which the data point is included.

- Identify any out of control conditions. Four tests are performed. Use the legend to identify the points corresponding to a particular test.
- If a test looks for a proportion of points, only the offending point will be identified. For example, if eight points in a row are on one side of the centerline only the eighth point will be identified.

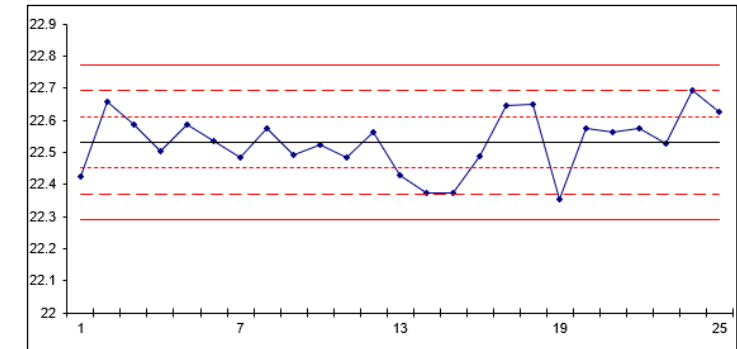
Learn More

To learn more about other quality tools, visit the ASQ [Learn About Quality](#) web site.

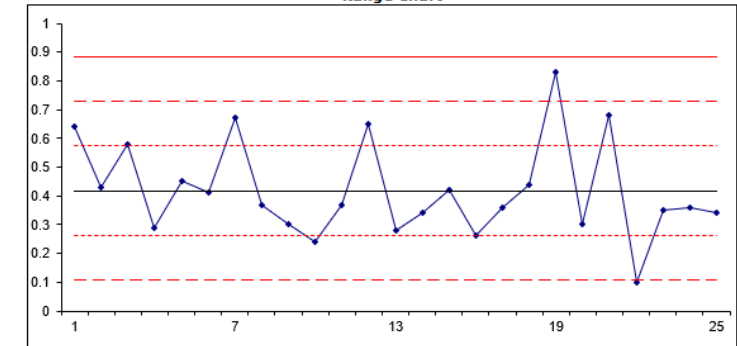
[Learn About Quality](#)



X Bar Chart



Range Chart



- Three Sigma Limit
- Two Sigma Limit
- One Sigma Limit
- Average
- A single point outside the control limits
- Two of three pts outside the two sigma limit
- Four of Five pts outside the one sigma limit
- Eight in a row on the same side of centerline

I-MR (Detergent pH)

A quality engineer monitors the manufacture of liquid detergent and wants to assess whether the process is in control. The engineer measures the pH of 25 consecutive batches of detergent.

Because the data are not collected in subgroups, you can use this data to demonstrate **I-MR Chart**.

Sample Size = 25

Control Chart Data

5.9848	Xbar/IMR Chart Avg	6.12	Xbar one sigma Upper Limit	0.268	Rbar one sigma Upper Limit
0.1525	Range Chart Avg	6.255	Xbar two sigma Upper Limit	0.383	Rbar two sigma Upper Limit
0.135195	Rbar/d ₂	6.391	Xbar three sigma Upper Limit	0.499	Rbar three sigma Upper Limit
25	Number of samples	5.85	Xbar one sigma Lower Limit	0.037	Rbar one sigma Lower Limit
1	Subgroup size	5.714	Xbar two sigma Lower Limit	n/a	Rbar two sigma Lower Limit
25	Number of subgroups	5.579	Xbar three sigma Lower Limit	n/a	Rbar three sigma Lower Limit

Sub Group	Data	Sub Group	Data	Sub Group	Data	Sub Group	Data	Sub Group	Data	Sub Group	Data	Sub Group	Data	Sub Group	Data
1	6.05	26		51		76		101		126		151		176	
2	5.99	27		52		77		102		127		152		177	
3	6.11	28		53		78		103		128		153		178	
4	6.13	29		54		79		104		129		154		179	
5	5.87	30		55		80		105		130		155		180	
6	6.05	31		56		81		106		131		156		181	
7	6.23	32		57		82		107		132		157		182	
8	6.49	33		58		83		108		133		158		183	
9	6.15	34		59		84		109		134		159		184	
10	5.89	35		60		85		110		135		160		185	
11	5.87	36		61		86		111		136		161		186	
12	5.99	37		62		87		112		137		162		187	
13	6.07	38		63		88		113		138		163		188	
14	6.17	39		64		89		114		139		164		189	
15	5.86	40		65		90		115		140		165		190	
16	6.07	41		66		91		116		141		166		191	
17	6.01	42		67		92		117		142		167		192	
18	5.87	43		68		93		118		143		168		193	
19	5.66	44		69		94		119		144		169		194	
20	5.58	45		70		95		120		145		170		195	
21	5.62	46		71		96		121		146		171		196	
22	5.89	47		72		97		122		147		172		197	
23	6.02	48		73		98		123		148		173		198	
24	5.93	49		74		99		124		149		174		199	
25	6.05	50		75		100		125		150		175		200	

Quality Tools

Control Charts

Description

This template illustrates a Statistical Process Control (SPC) chart. A detailed discussion of SPC charts can be found at www.ASQ.org

[Learn About Statistical Process Control](#)

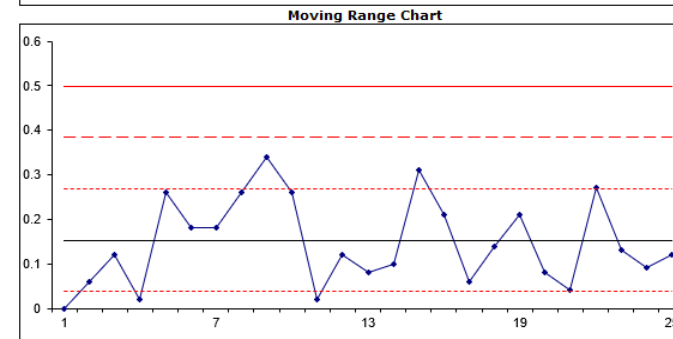
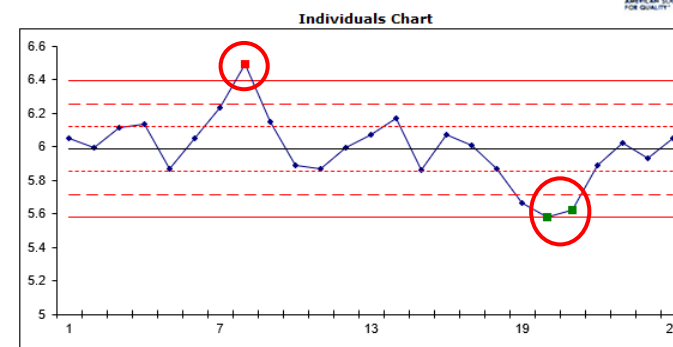
Instructions

- Select the correct subgroup size. When in doubt, select a subgroup size of one. Partial subgroups are not displayed.
 - ☒ One ☐ Two ☐ Three
 - ☐ Four ☐ Five ☐ Six
- Enter up to 200 data points in the cells provided. Do not enter values in the subgroup column. These cells update automatically to show the subgroup in which the data point is included.
- Identify any out of control conditions. Four tests are performed. Use the legend to identify the points corresponding to a particular test.
- If a test looks for a proportion of points, only the offending point will be identified. For example, if eight points in a row are on one side of the centerline only the eighth point will be identified.

Learn More

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[Learn About Quality](#)



- Three Sigma Limit
- Two Sigma Limit
- One Sigma Limit
- Average
- A single point outside the control limits
- Two of three pts outside the two sigma limit
- Four of five pts outside the one sigma limit
- Eight in a row on the same side of centerline

Control Chart Minitab Examples

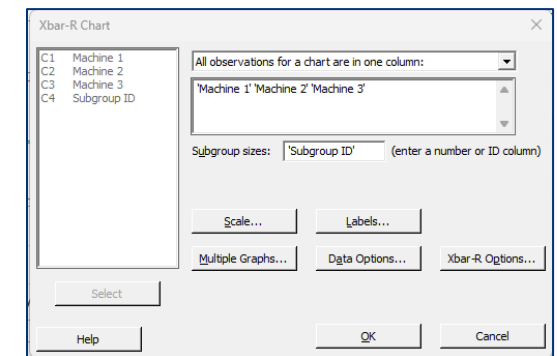
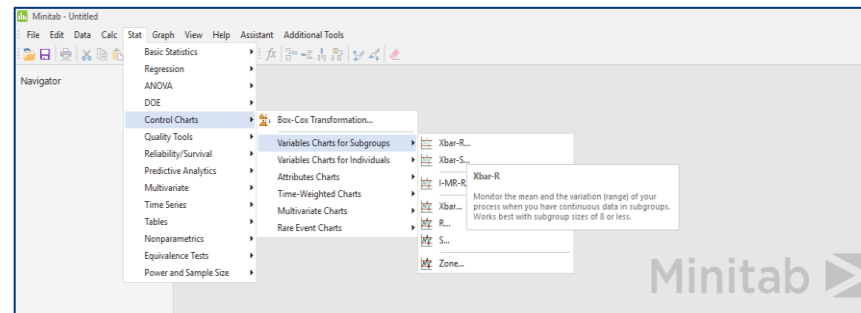
EXAMPLE

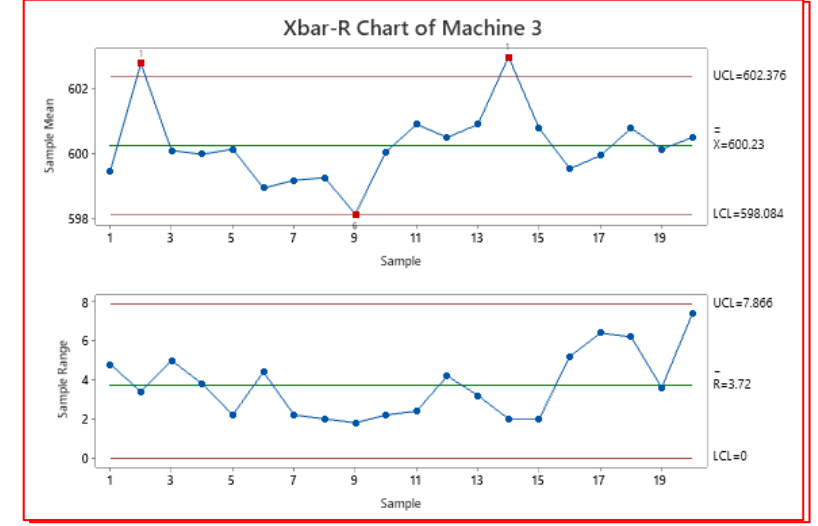
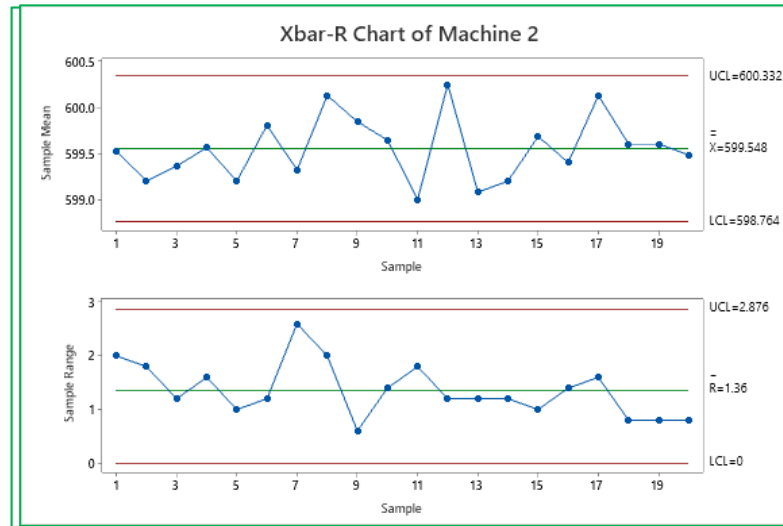
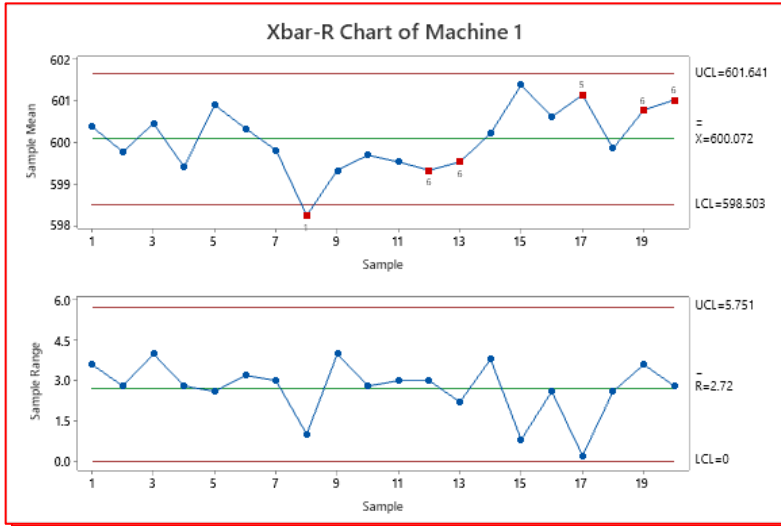
The quality engineer creates an Xbar-R chart for each machine to monitor the camshaft lengths.

- Entered the data in four columns, labeled Machine 1, Machine 2, Machine 3 and Subgroup ID. Choose **Stat > Control Charts > Variables Charts for Subgroups > Xbar-R**.
- From the drop-down list, select **All observations for a chart are in one column** and enter *Machine 1 Machine 2 Machine 3*.
- In **Subgroup sizes**, enter *Subgroup ID*.

↓	C1	C2	C3	C4
	Machine 1	Machine 2	Machine 3	Subgroup ID
1	601.4	598.0	601.6	1
2	601.6	599.8	600.4	1
3	598.0	600.0	598.4	1
4	601.4	599.8	600.0	1
5	599.4	600.0	596.8	1
6	600.0	600.0	602.8	2
7	600.2	598.8	600.8	2
8	601.2	598.2	603.6	2
9	598.4	599.4	604.2	2
10	599.0	599.6	602.4	2
11	601.2	599.4	598.4	3
12	601.0	599.4	599.6	3
13	600.8	600.0	603.4	3
14	597.6	598.8	600.6	3
15	601.6	599.2	598.4	3

↓	C1	C2	C3	C4
	Machine 1	Machine 2	Machine 3	Subgroup ID
86	601.4	600.0	602.4	18
87	601.4	599.4	602.2	18
88	598.8	599.8	600.6	18
89	598.8	599.2	596.2	18
90	598.8	599.6	602.4	18
91	598.2	599.4	601.4	19
92	601.8	600.0	599.2	19
93	601.0	600.0	601.6	19
94	601.4	599.2	600.4	19
95	601.4	599.4	598.0	19
96	599.0	599.6	601.2	20
97	601.4	599.8	604.2	20
98	601.8	599.0	600.2	20
99	601.6	599.6	600.0	20
100	601.2	599.4	596.8	20





Test Results for Xbar Chart of Machine 1

TEST 1. One point more than 3.00 standard deviations from center line.

Test Failed at points: 8

TEST 5. 2 out of 3 points more than 2 standard deviations from center line (on one side of CL).

Test Failed at points: 17

TEST 6. 4 out of 5 points more than 1 standard deviation from center line (on one side of CL).

Test Failed at points: 12, 13, 19, 20

Test Results for Xbar Chart of Machine 3

TEST 1. One point more than 3.00 standard deviations from center line.

Test Failed at points: 2, 14

TEST 6. 4 out of 5 points more than 1 standard deviation from center line (on one side of CL).

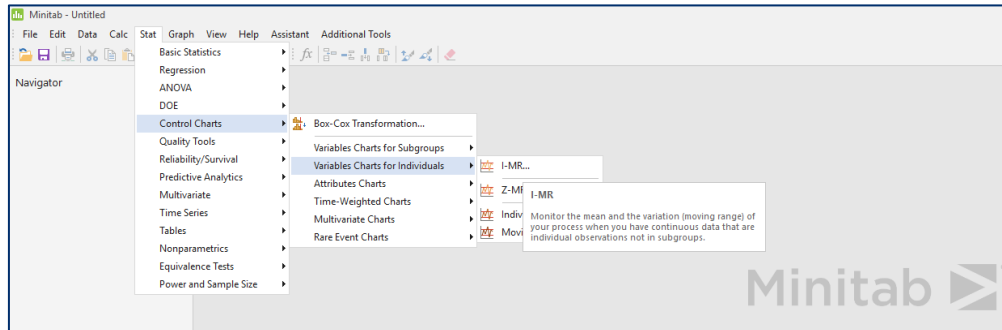
Test Failed at points: 9

I-MR (Detergent pH)

A quality engineer monitors the manufacture of liquid detergent and wants to assess whether the process is in control. The engineer measures the pH of 25 consecutive batches of detergent.

Because the data are not collected in subgroups, you can use this data to demonstrate **I-MR Chart**.

Sample Size = 25



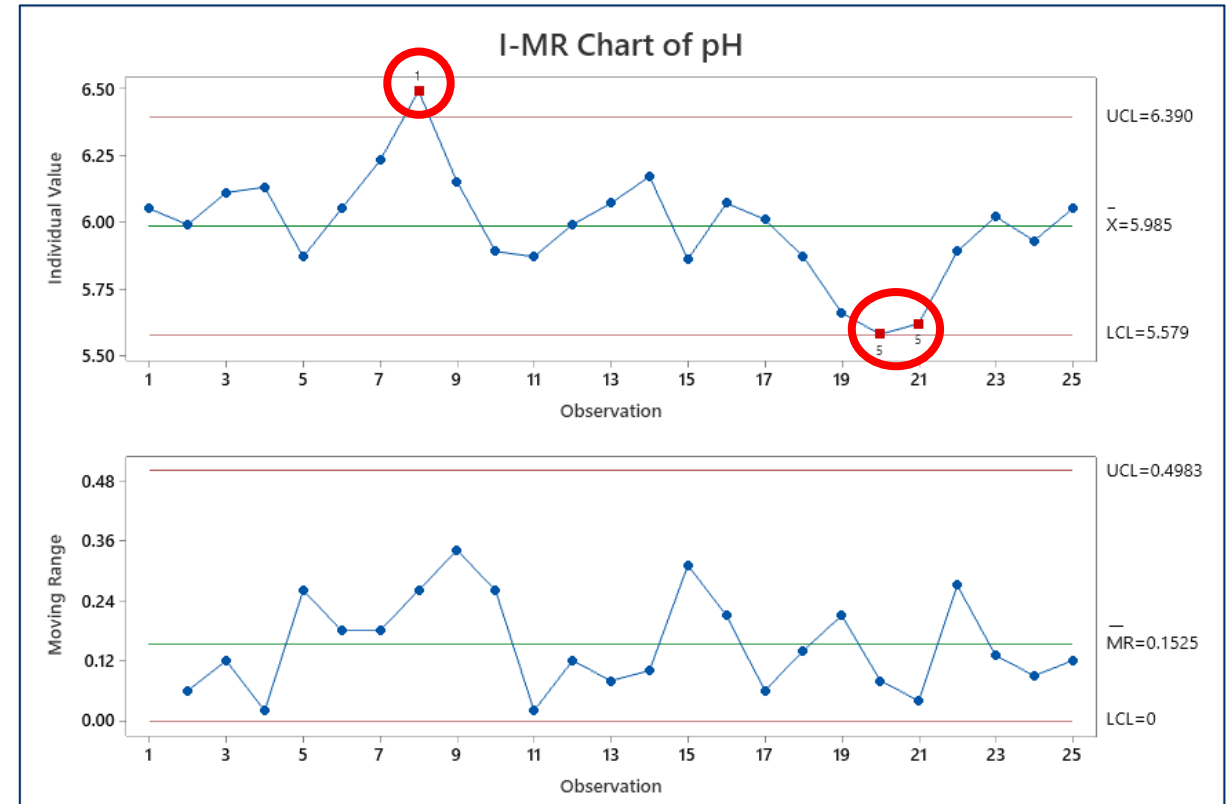
Test Results for I Chart of pH

TEST 1. One point more than 3.00 standard deviations from center line.

Test Failed at points: 8

TEST 5. 2 out of 3 points more than 2 standard deviations from center line (on one side of CL).

Test Failed at points: 20, 21



p Chart (Defective Records data)

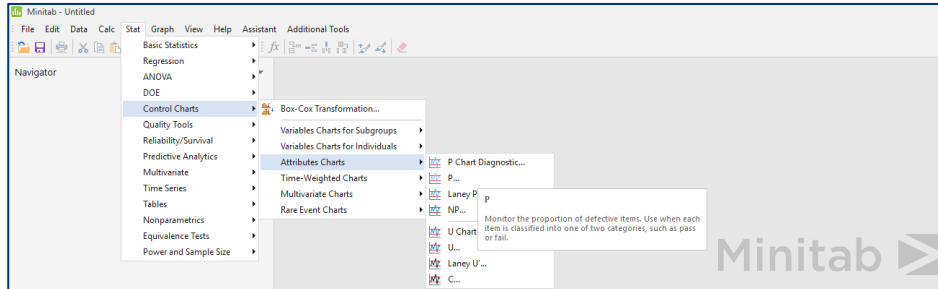
A supervisor at a small hospital wants to ensure that the number of errors in the hospital's medical records remains in control. The supervisor records the total number of medical records that are filed each day and the number of records that are incomplete or inaccurate (defectives).

Because the data are counts of defectives, you can use this data to demonstrate **P Chart**

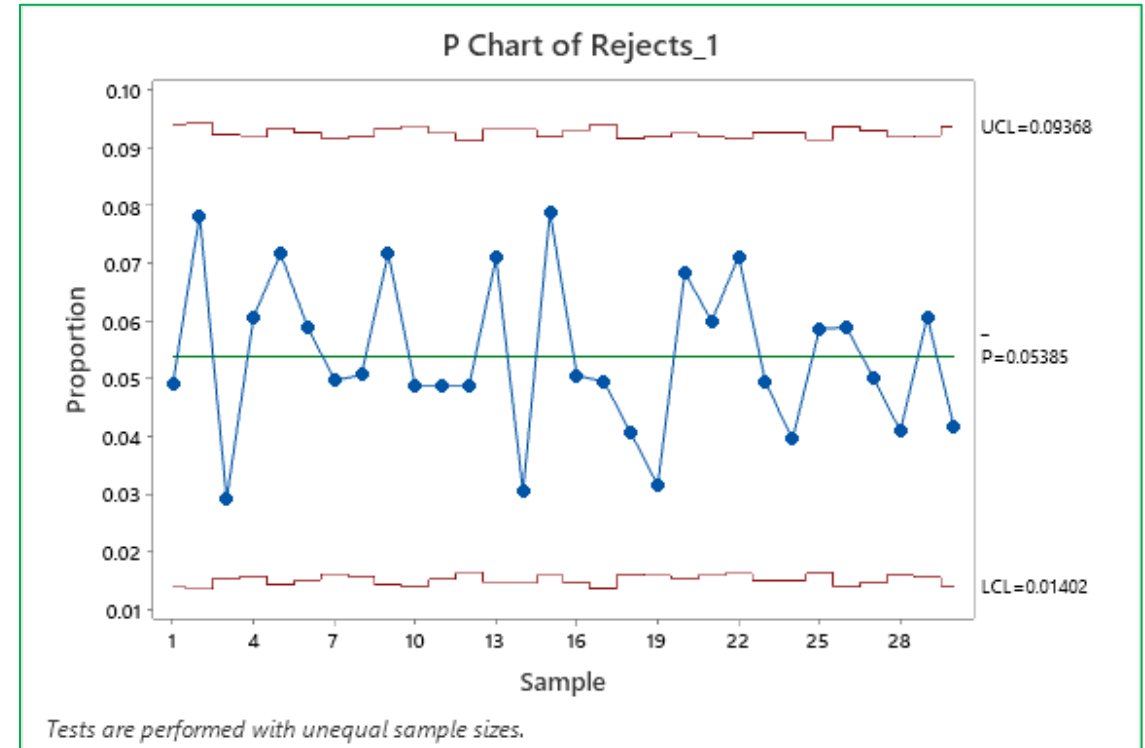
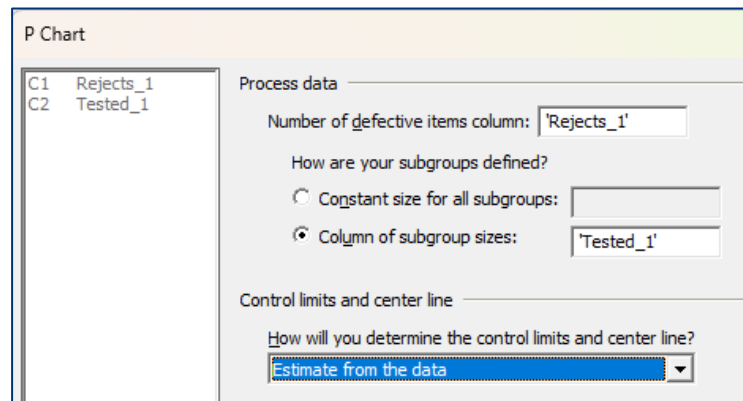
Defectives. The number of incomplete and inaccurate records that are filed each day.

Total Records. The total number of records that are filed each day. This column contains the subgroup sizes.

	C1	C2
	Rejects_1	Tested_1
1	14	286
2	22	281
3	9	310
4	19	313
5	21	293
6	18	305
7	16	322
8	16	316
9	21	293
10	14	287
11	15	307
12	16	328
13	21	296
14	9	296
15	25	317



	C1	C2
	Rejects_1	Tested_1
16	15	297
17	14	283
18	13	321
19	10	317
20	21	307
21	19	317
22	23	323
23	15	304
24	12	304
25	19	324
26	17	289
27	15	299
28	13	318
29	19	313
30	12	289



Short Run Charts

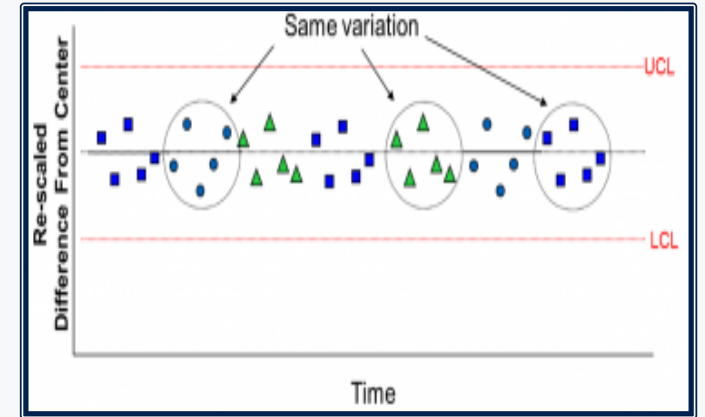
"We are pretty much a job shop!

"Our production runs are short!

"We are always changing over to
a different product!"

"Each job is different.

We can't use SPC here."



Short Run Charts

$$\text{Zed Value} = \frac{X - \text{Nominal}}{\text{Sigma (X)}}$$

X = Observation

$$\text{Sigma (X)} = \frac{R}{d_2}$$

$$d_2 = 1.128$$

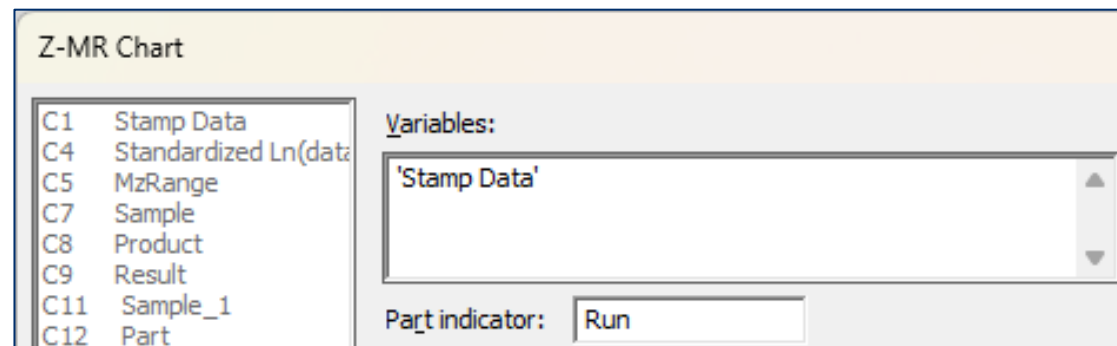
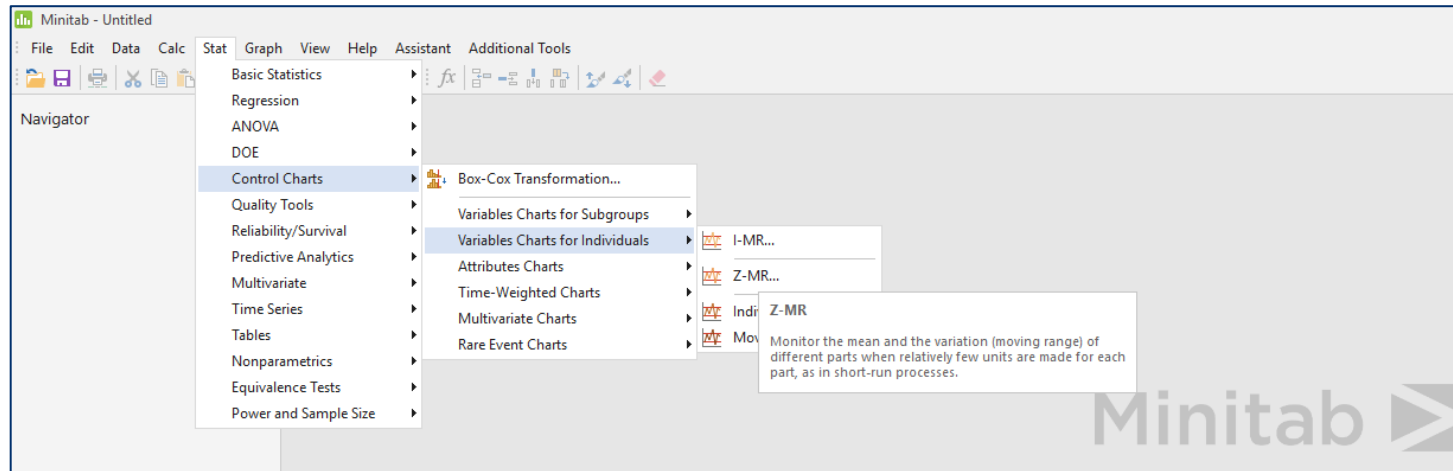
$$UCL_w = \bar{X} + 3d_3$$

X = Data point

Minitab Example Z-MR Chart

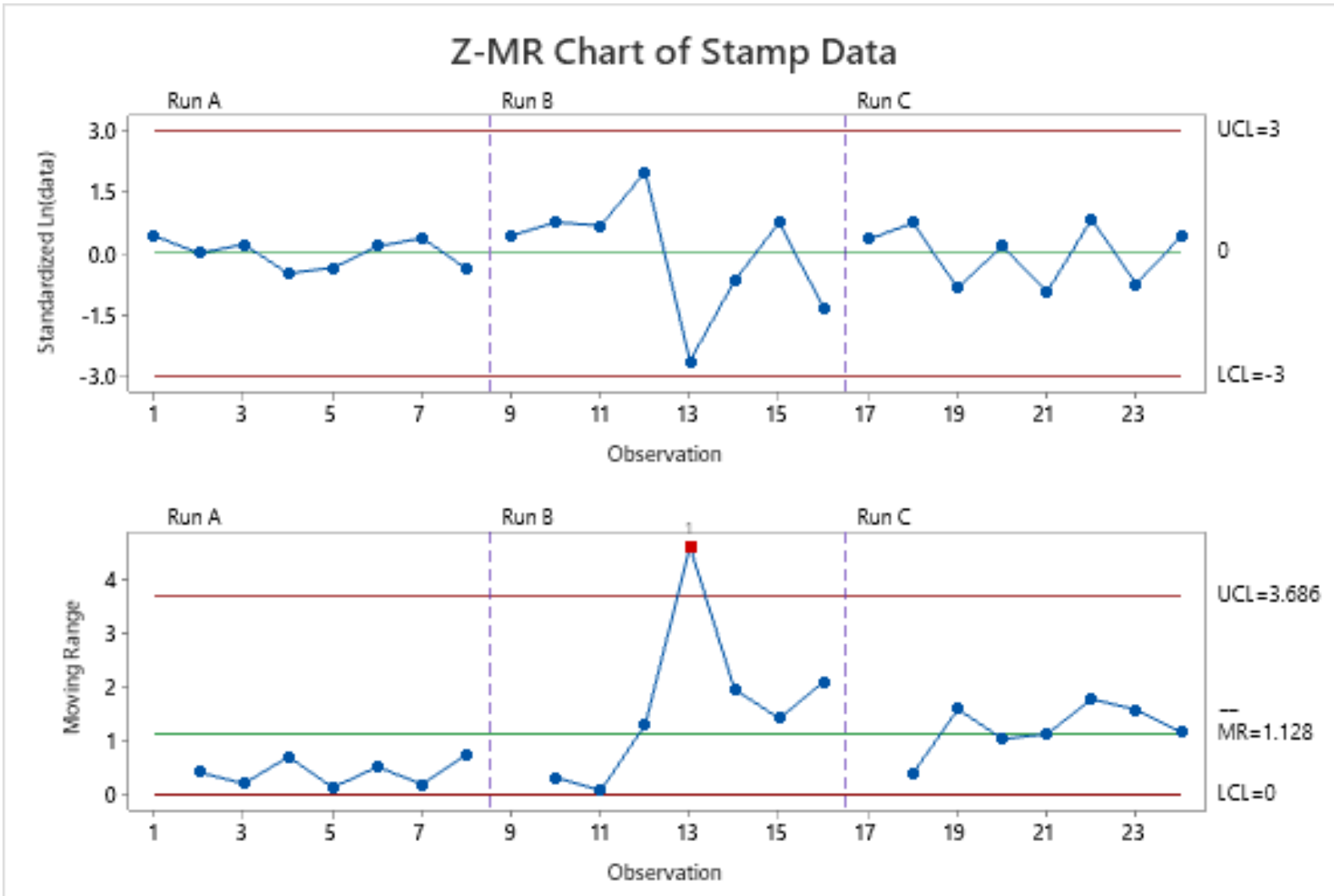
A manufacturer uses short runs to create small batches of metal parts. The quality manager measures parts from three runs to assess the stability of the stamping process. The manager creates a Z-MR chart to monitor the stamping process.

- Choose **Stat > Control Charts > Variables Charts for Individuals > Z-MR**.
- In **Variables**, enter *Stamp Data*.
- In **Part indicator**, enter *Run*.



↓	C1	C2-T	C3	C4	C5
	Stamp Data	Run		Standardized Ln(data)	MzRange
1	302.634	Run A		0.427	*
2	300.558	Run A		0.008	0.419
3	301.604	Run A		0.220	0.212
4	298.130	Run A		-0.486	0.706
5	298.824	Run A		-0.345	0.142
6	301.384	Run A		0.175	0.520
7	302.373	Run A		0.375	0.200
8	298.685	Run A		-0.373	0.748
9	504.188	Run B		0.437	*
10	506.879	Run B		0.762	0.324
11	506.189	Run B		0.678	0.083
12	517.210	Run B		1.991	1.313
13	479.511	Run B		-2.621	4.612
14	495.170	Run B		-0.663	1.958
15	506.851	Run B		0.758	1.421
16	489.671	Run B		-1.343	2.101
17	400.548	Run C		0.343	*
18	403.193	Run C		0.744	0.401
19	392.790	Run C		-0.848	1.593
20	399.538	Run C		0.189	1.038
21	392.192	Run C		-0.941	1.131
22	403.812	Run C		0.838	1.779
23	393.457	Run C		-0.745	1.583
24	401.051	Run C		0.420	1.165

Short Run Charts



Test Results for MR Chart of Stamp Data

TEST 1. One point more than 3.00 standard deviations from center line.

Test Failed at points: 13

Interpret the results

Point 13 is above the upper control limit on the Moving Range chart. Also, Run A appears to have less variation in the moving ranges, than either Run B or Run C. You can see that variation across runs in the Z chart as well.

Based on these results, special causes may currently influence the process.

QUIZ



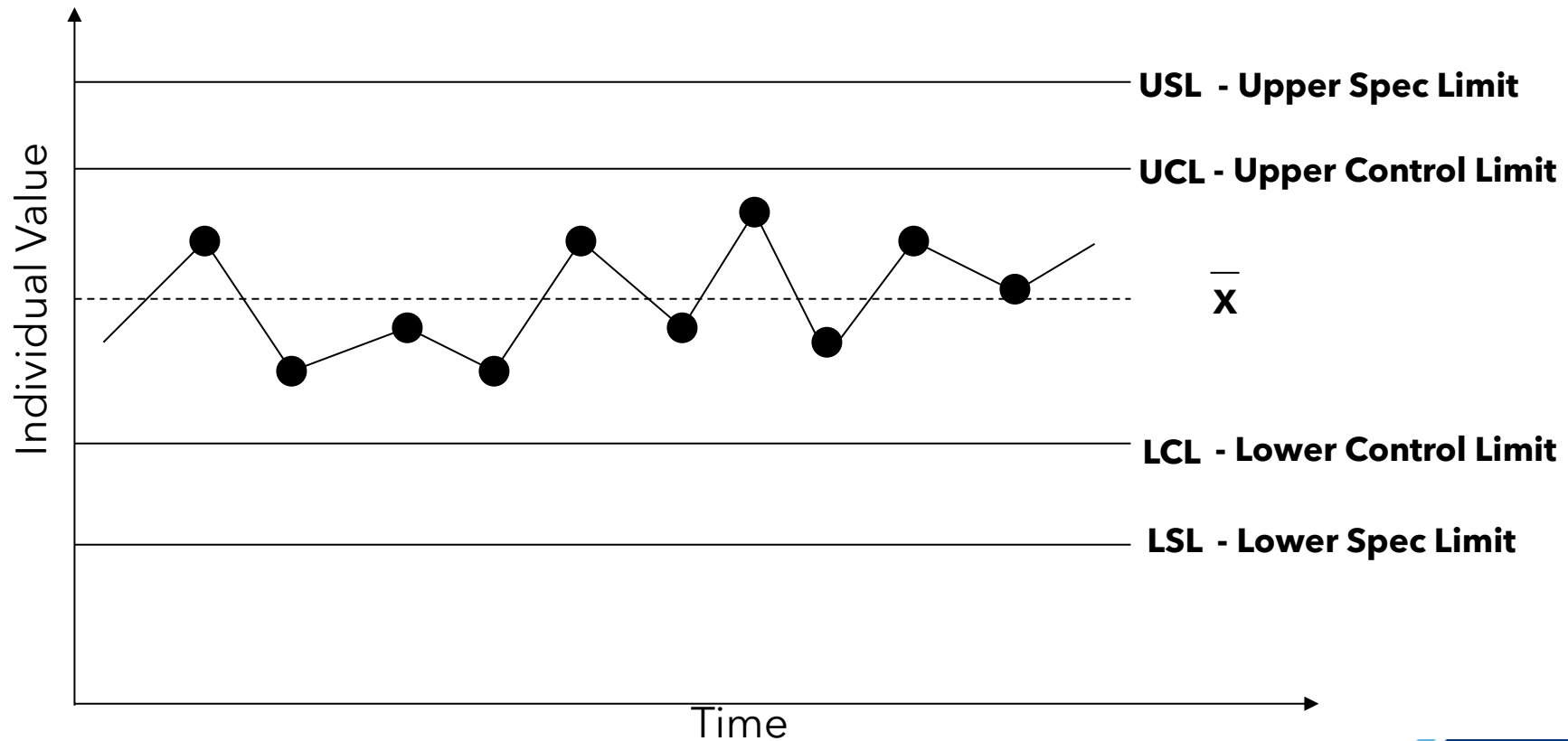
Quiz

Example (I-MR)

Q. Is this process capable? **Yes!**

Q. Do all processes have inherent variation? **Yes!**

Q. How are Spec Limits and Control Limits related? **Independent**

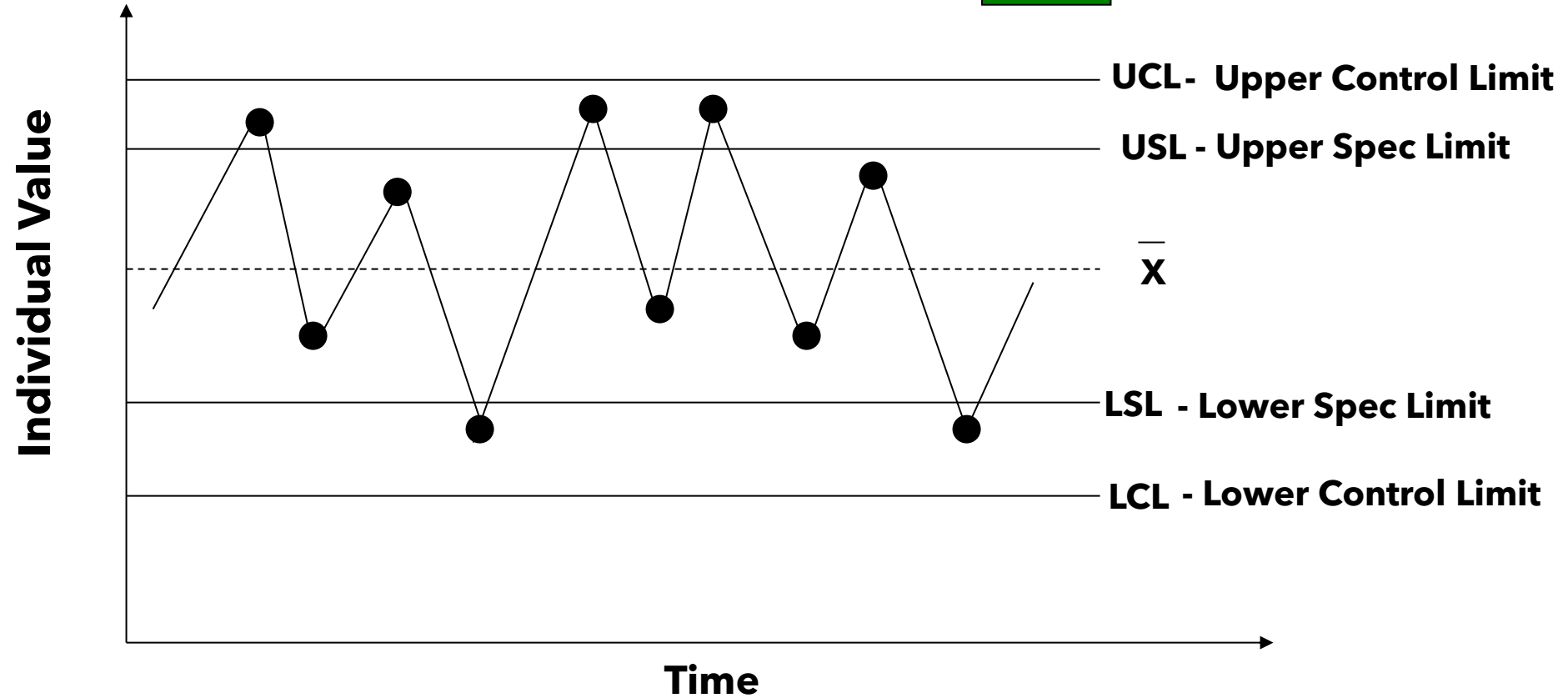


Quiz

Example (I-MR)

Q. Is this process capable? **No!**

Q. Is the process in control? **Yes!**



Caution: There is such a thing as having good control of a bad process!

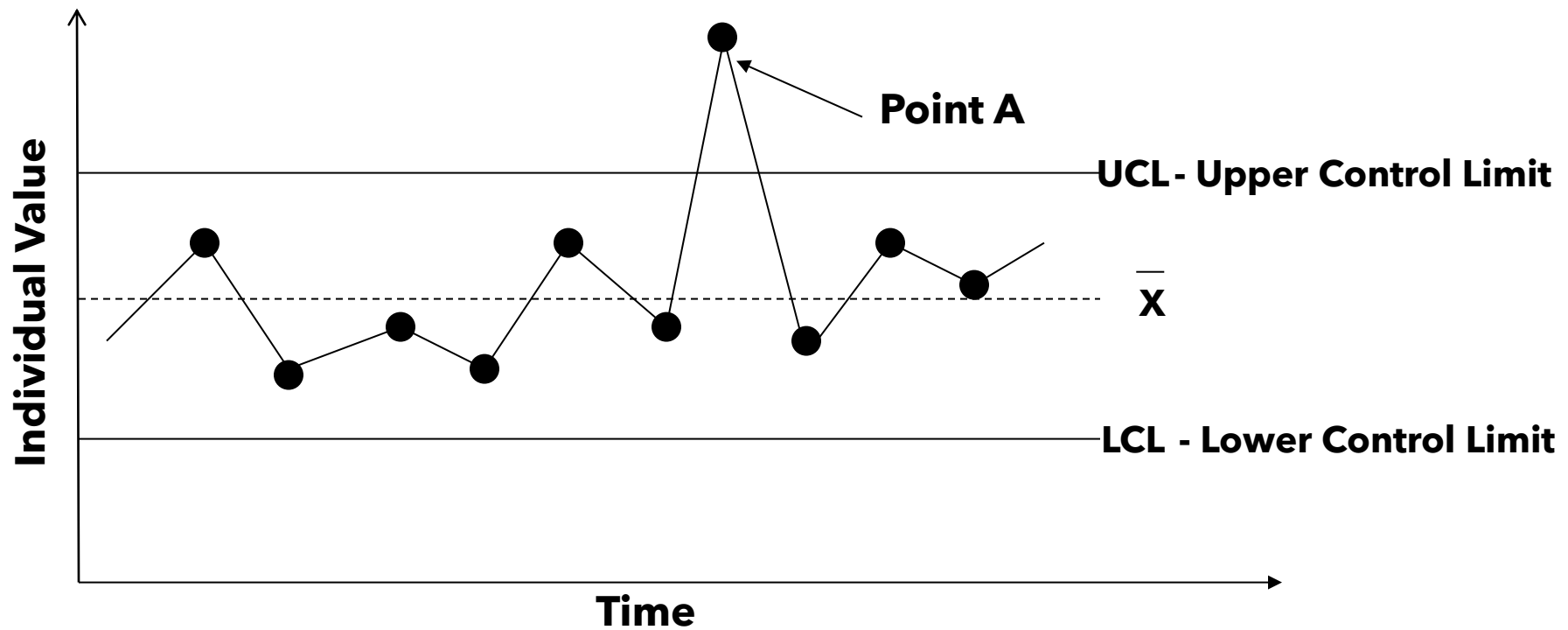
Quiz

Q. What are the 2 types of process variation?

Special & Common Cause

Q. What type of variation does Point A represent?

Special Cause



One main purpose for using control charts is to identify special cause variation.

Control Chart Tips

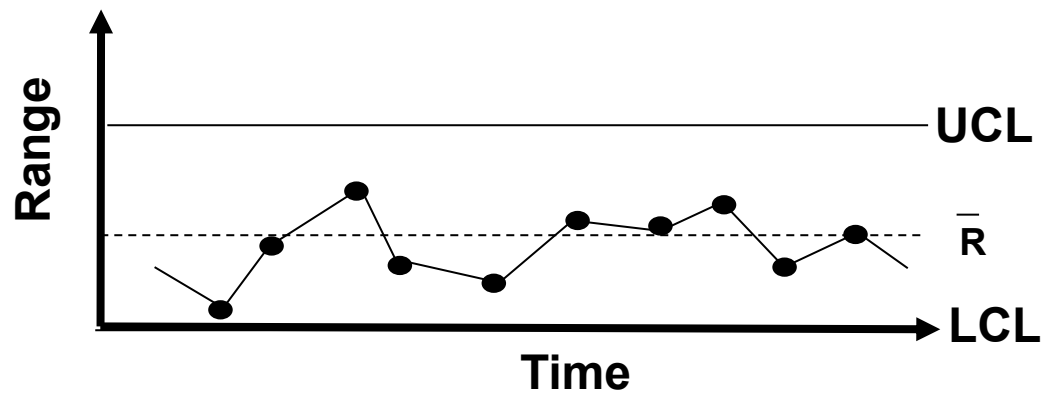
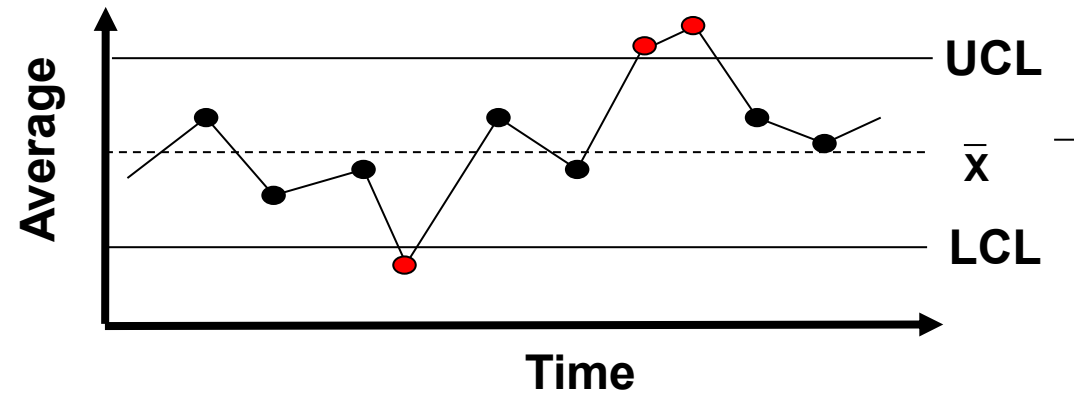
- Tip 1** “In Control” doesn’t necessarily mean that the product or service will meet the customer needs.
- Tip 2** Do not remove any out-of-control data from the calculations unless you know the special cause of the instability and have eliminated it.
- Tip 3** When a control chart has been initiated and all special causes removed, continue to plot new data on a new chart, but DO NOT recalculate the control limits.
- Tip 4** Nothing will change just because a chart was created!

Additional Control Chart Analysis and Interpretation

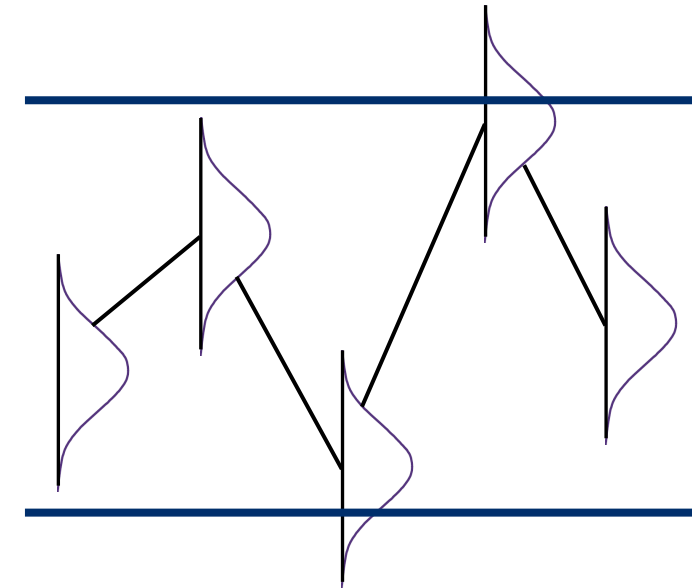
Source:
CSSBB Primer; Quality Council of Indiana

Control Chart Analysis

1. Process Average Out-of-Control

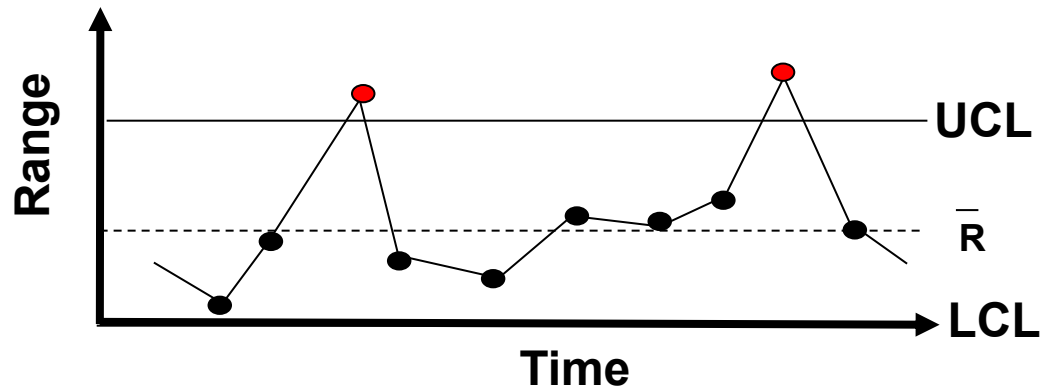
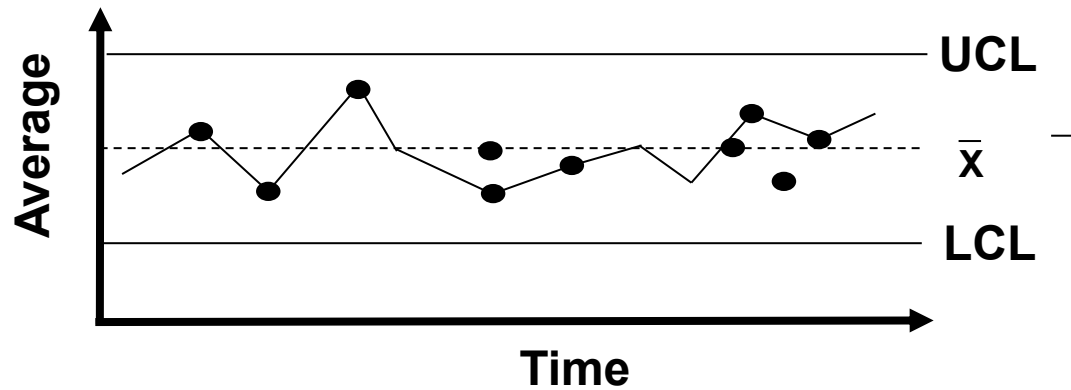


Average Shifting
Variation Stable

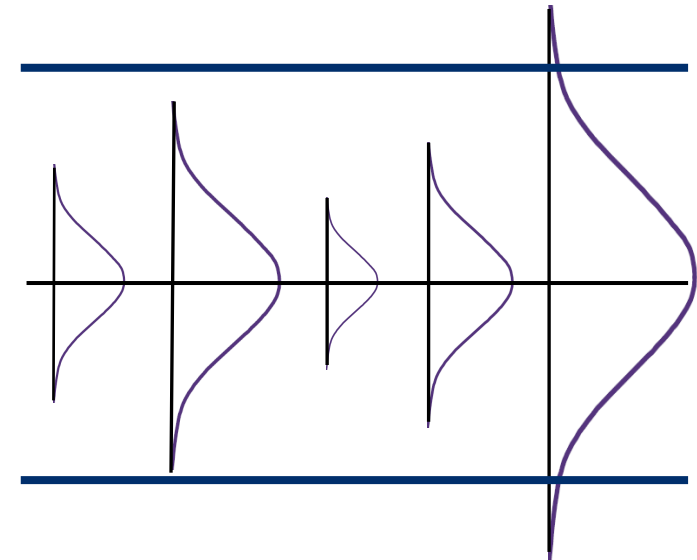


Control Chart Analysis

2. Process Variation Out-of-Control

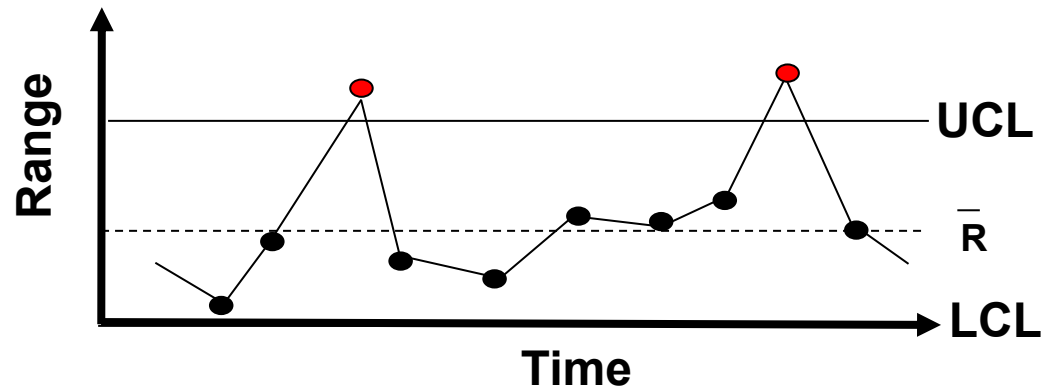
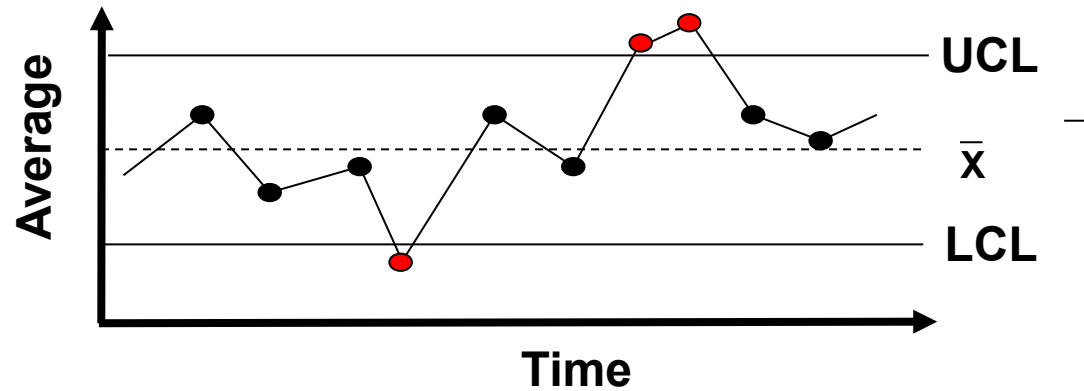


Average Stable
Variation Changing

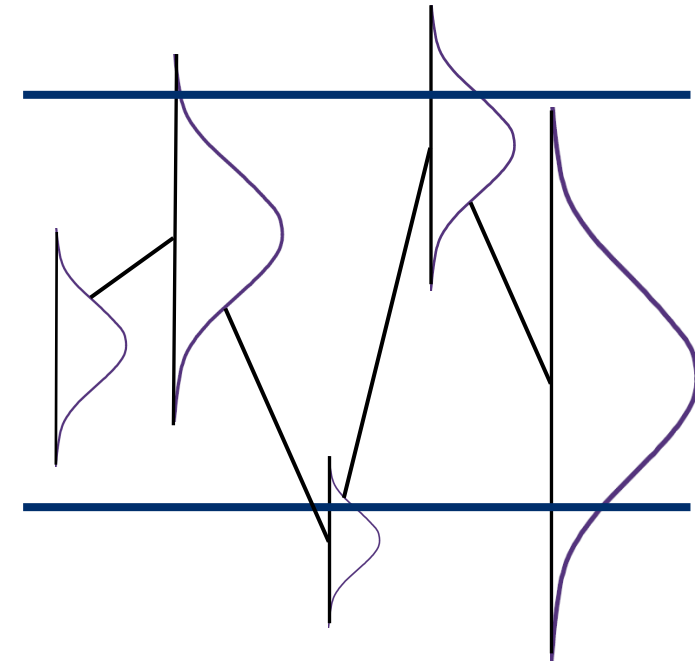


Control Chart Analysis

3. Process Average and Variation Out-of-Control

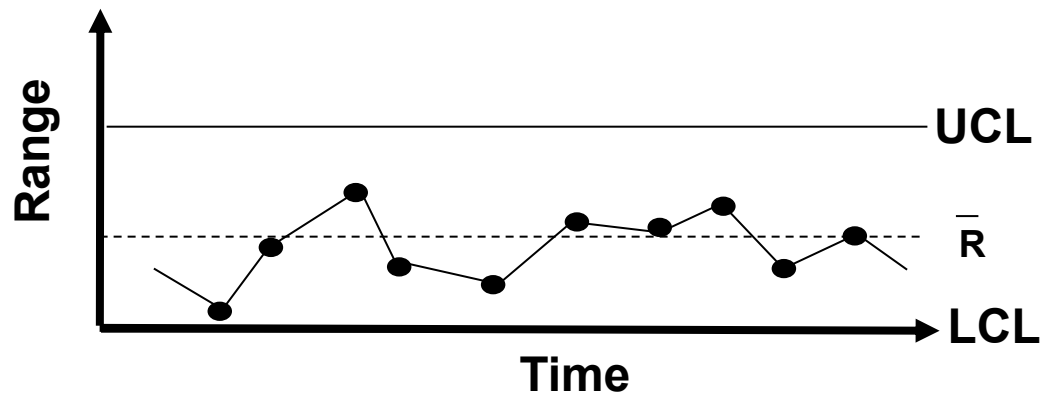
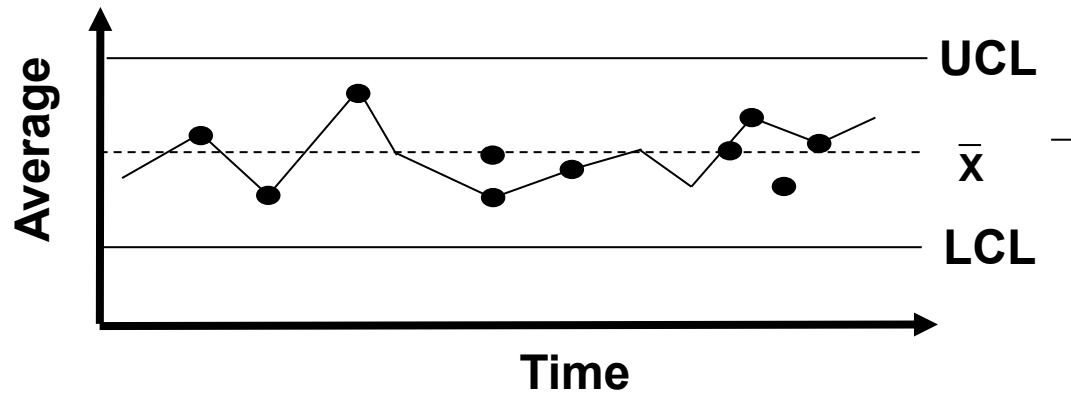


Average Shifting
Variation Changing

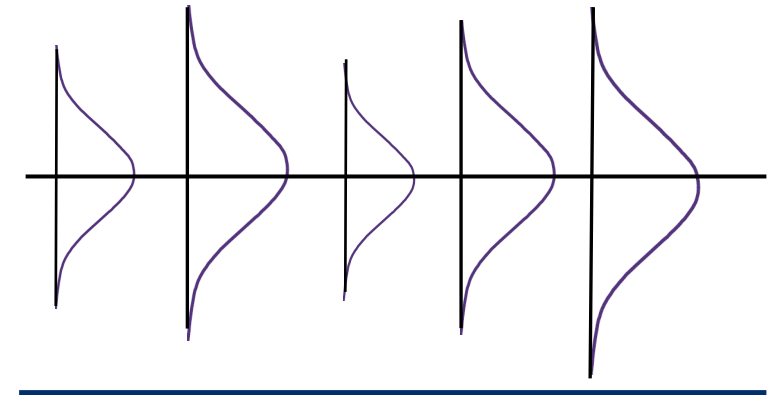


Control Chart Analysis

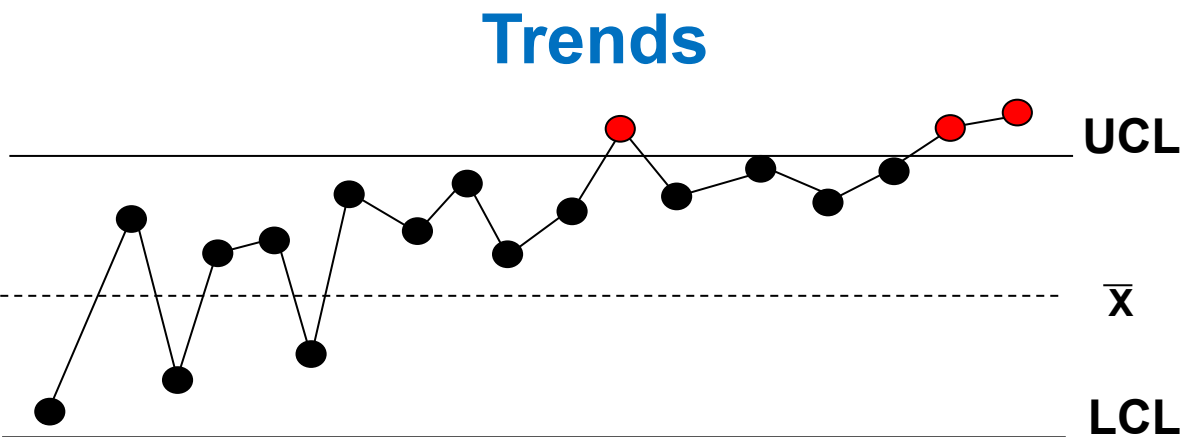
4. Process In-Control



Average Stable
Variation Stable



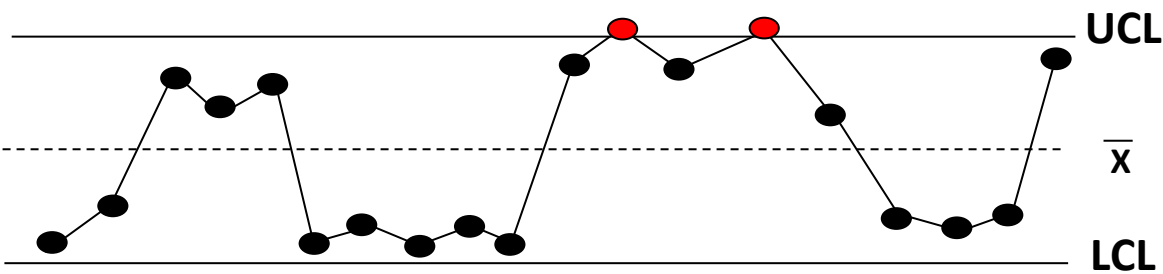
Control Chart Interpretation



$\bar{X}$ CHART CAUSES	R CHART CAUSES
• Deterioration of machine • Tired operator • Tool wear	• Improvement or deterioration of operator skill • Tired operator • Change in incoming material quality
CORRECTIVE ACTION	
• Repair or use alternate machine if available • Discuss operation with operator to find cause • Rotate operator • Change, repair, or sharpen tool • Investigate material	

Control Chart Interpretation

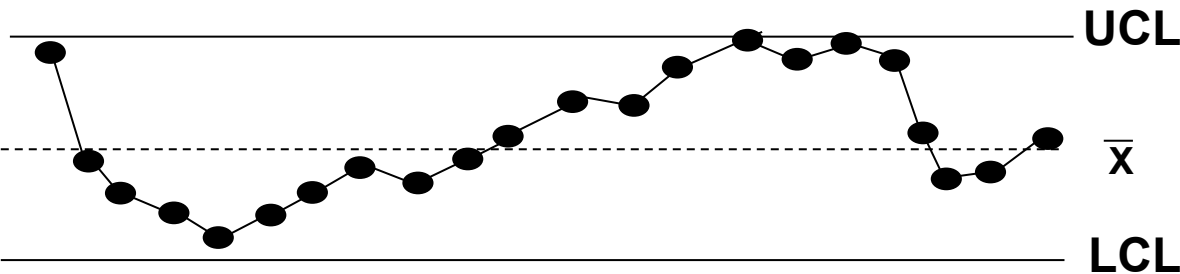
Jumps in Process Level



$\bar{x}$ CHART CAUSES	R CHART CAUSES
- Changes in proportions of material coming from different sources - New operator or machine - Modification of production method or process - Change in inspection device or method	- Change in material - Change in method - Change in operator - Change in inspection
CORRECTIVE ACTION	
- Keep material supply consistent - Investigate source of material - Check out machine capability - Examine operator methods and instruction - Check calibration of measurement device	

Control Chart Interpretation

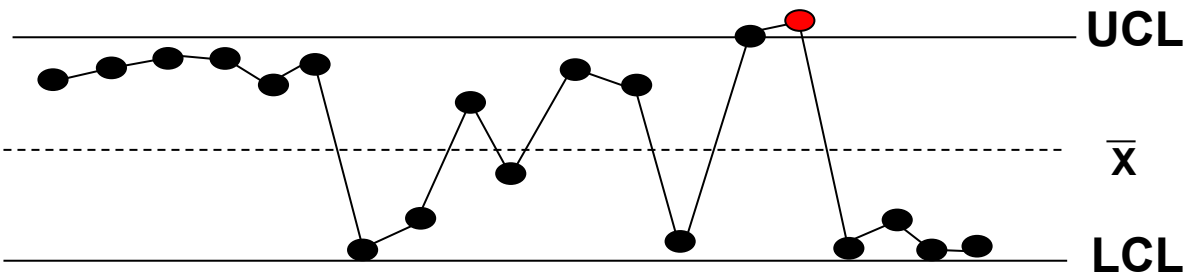
Recurring Cycles



$\bar{X}$ CHART CAUSES	R CHART CAUSES
- Physical environment - Temperature - Humidity - Tired operator - Regular rotation of machine or operator	- Scheduled maintenance - Tired operator - Tool wear
CORRECTIVE ACTION	
- If environment is controllable, adjust it - Service equipment - Rotate operators - Evaluate machine maintenance - Replace, sharpen, or repair tool	

Control Chart Interpretation

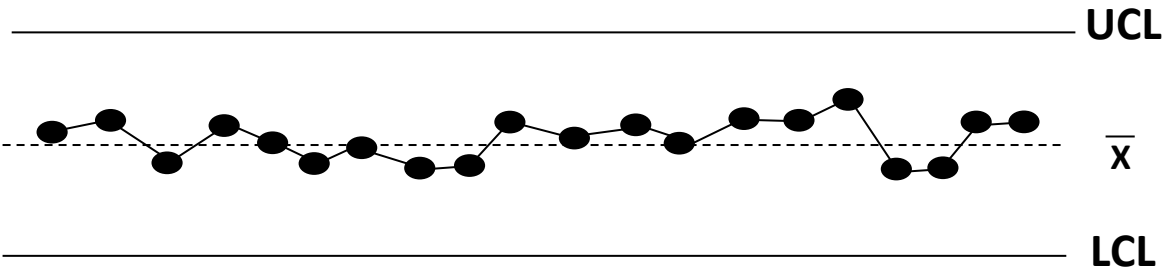
Points Near or Outside Limits



$\bar{X}$ CHART CAUSES	R CHART CAUSES
• Over control • Large systematic difference in material quality • Large systematic differences on test methods or equipment	• Mixture of material of distinctly different quality
CORRECTIVE ACTION	
• Check control limits • Investigate material variation • Evaluate test procedures • Evaluate inspection frequency or methods • Eliminate operator overadjustment of the process	

Control Chart Interpretation

Lack of Variability



$\bar{x}$ CHART CAUSES	R CHART CAUSES
• Incorrect calculation of control limits • Improvement in process since limits were calculated • Employee may not be making checks	• Collecting in each sample a number of measurements from widely different lots • Improvement in process since limits were calculated
CORRECTIVE ACTION	
• Check control limits • Validate rational sample subgroupings • Verify checking procedure, gages, etc. • Verify proper employee measurement • Congratulate someone for improvement	

Take Aways

- Process stability or instability is reflected in Control Charts
- If a process is stable, there is a *very slim chance* a point will fall outside the control limits.
- If a point falls outside the control limits, it is usually treated as a “special cause” of variation.
- Special cause variation can still exist within control limits, resulting in a lack of statistical control.
- Control Charts are based ideally on control limits which are +/- 3 standard deviations (3 sigma) away from the centerline (average).



Statistical Process Control (SPC) & Process Control Charts

Monitoring Process Stability and Driving Continuous Improvement



1 WHAT IS SPC?



DATA COLLECTION

9.95	10.02	10.01
9.98	9.97	10.00
10.03	9.96	9.99
...	...	...

DATA ANALYSIS



- Uses statistical methods to monitor and control manufacturing processes.
- Detects variation before defects occur.
- Improves capability, consistency, and product quality.

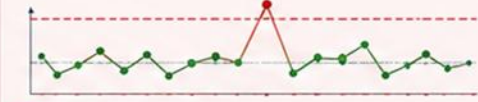
2 TYPES OF VARIATION

COMMON CAUSE VARIATION



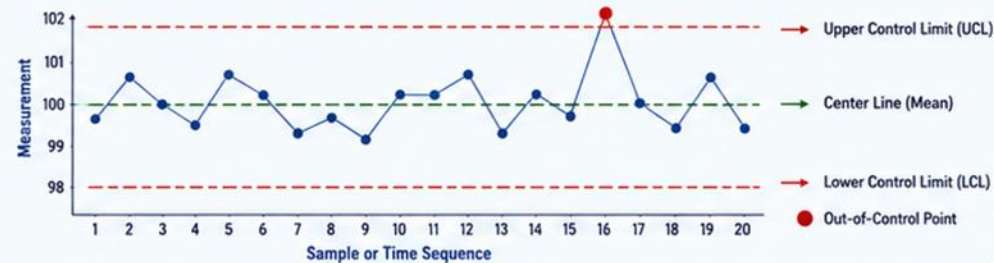
- ✓ Natural process variation
- ✓ Stable and predictable
- ✓ Requires process improvement

SPECIAL CAUSE VARIATION



- ❗ Unexpected events
- ❗ Equipment failures, operator error, material changes
- ❗ Requires investigation and corrective action

3 CONTROL CHART ANATOMY



5 RULES FOR OUT-OF-CONTROL SIGNALS



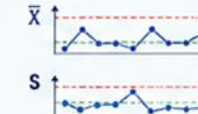
4 COMMON SPC CHARTS

1 $\bar{X}$ -R CHART



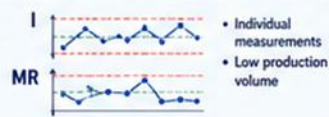
- Variable data
- Monitors process mean and range
- Small subgroup sizes (2-10)

2 $\bar{X}$ -S CHART



- Variable data
- Mean and standard deviation
- Larger subgroup sizes (> 10)

3 INDIVIDUALS-MOVING RANGE (I-MR) CHART



- Individual measurements
- Low production volume

4 p CHART



- Fraction defective
- Variable sample size

5 np CHART



- Number of defectives
- Constant sample size

6 c CHART



- Number of defects per unit
- Constant inspection area

7 u CHART



- Number of defects
- Variable sample size



BENEFITS OF SPC



REDUCED VARIATION
More consistent process performance



HIGHER QUALITY
Fewer defects and better products



LOWER SCRAP AND REWORK
Reduce waste and save costs



PREDICTABLE PERFORMANCE
Stable processes you can rely on

LOCKHEED MARTIN 