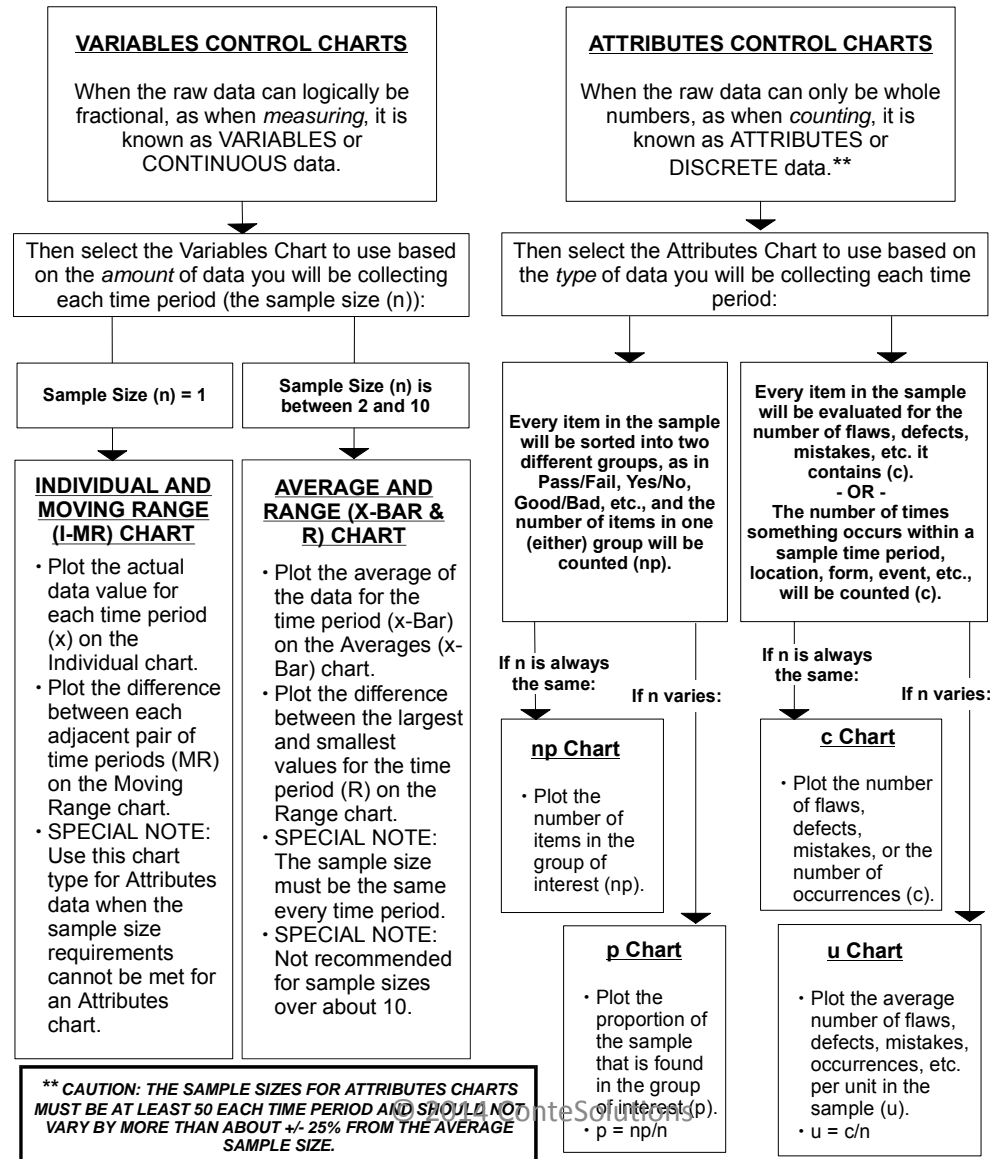


SUMMARY OF STATISTICAL PROCESS CONTROL (SPC) CHARTS

First select the family of control charts to use based on the type of raw data you are collecting:



(This file is posted on the message board.)

Control Chart Formulas

Variables Control Charts

Chart Type	Centerline	Control Limits	Estimate of Sigma
\bar{X} and R	$\bar{\bar{X}} = \frac{\sum \bar{X}}{k}$ $\bar{R} = \frac{\sum R}{k}$	$UCL_{\bar{X}} = \bar{\bar{X}} + A_2 \bar{R}$ $LCL_{\bar{X}} = \bar{\bar{X}} - A_2 \bar{R}$ $UCL_R = D_4 \bar{R}$ $LCL_R = D_3 \bar{R}$	\bar{R}/d_2
$\bar{I}\bar{X}$ and MR	$\bar{I}\bar{X} = \frac{\sum I\bar{X}}{k}$ $\overline{MR} = \frac{\sum MR}{k-1}$	$UCL_{I\bar{X}} = \bar{I}\bar{X} + A_2 \overline{MR}$ $LCL_{I\bar{X}} = \bar{I}\bar{X} - A_2 \overline{MR}$ $UCL_{MR} = D_4 \overline{MR}$ $LCL_{MR} = 0$	\overline{MR}/d_2
\bar{X} and s	$\bar{\bar{X}} = \frac{\sum \bar{X}}{k}$ $\bar{s} = \frac{\sum s}{k}$	$UCL_{\bar{X}} = \bar{\bar{X}} + A_3 \bar{s}$ $LCL_{\bar{X}} = \bar{\bar{X}} - A_3 \bar{s}$ $UCL_s = B_4 \bar{s}$ $LCL_s = B_3 \bar{s}$	\bar{s}/c_4

Control Chart Constants

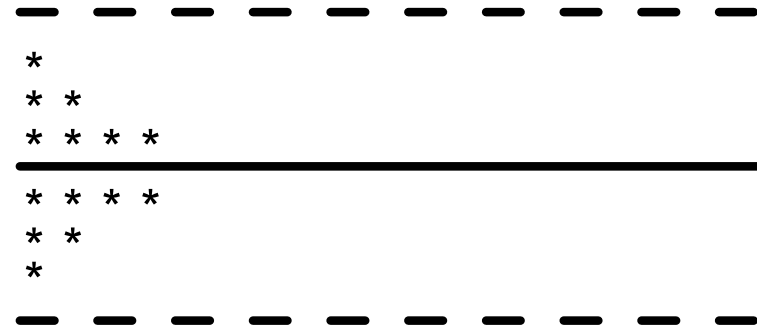
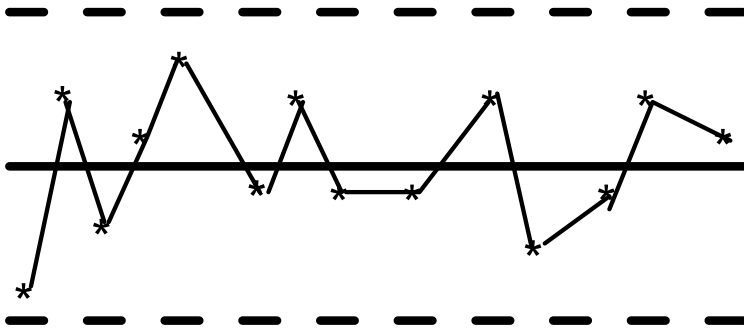
\bar{X} and R Control Charts

n	A ₂	D ₃	D ₄	d ₂
1	2.660	—	—	—
2	1.880	0	3.267	1.128
3	1.023	0	2.574	1.693
4	0.729	0	2.282	2.059
5	0.577	0	2.114	2.326
6	0.483	0	2.004	2.534
7	0.419	0.076	1.924	2.704
8	0.373	0.136	1.864	2.847
9	0.337	0.184	1.816	2.970
10	0.308	0.223	1.777	3.078
11	0.285	0.256	1.744	3.173
12	0.266	0.283	1.717	3.258

\bar{X} and S Control Charts

n	A ₃	B ₃	B ₄	C ₄
10	0.975	0.284	1.716	0.9727
11	0.927	0.321	1.679	0.9754
12	0.886	0.354	1.646	0.9776
13	0.850	0.382	1.618	0.9794
14	0.817	0.406	1.594	0.9810
15	0.789	0.428	1.572	0.9823
16	0.763	0.448	1.552	0.9835
17	0.739	0.466	1.534	0.9845
18	0.718	0.482	1.518	0.9854
19	0.698	0.497	1.503	0.9862
20	0.680	0.510	1.490	0.9869
21	0.663	0.523	1.477	0.9876
22	0.647	0.534	1.466	0.9882
23	0.633	0.545	1.455	0.9887
24	0.619	0.555	1.445	0.9892
25	0.606	0.565	1.435	0.9896

Control Chart Interpretation



+ 3 sigma Zone A

+ 2 sigma Zone B

+ 1 sigma Zone C

- 1 sigma Zone C

- 2 sigma Zone B

- 3 sigma Zone A



+ 3 sigma

+ 2 sigma

≈ 13 - 14%

+ 1 sigma

≈ 34%

- 1 sigma

≈ 34%

- 2 sigma

≈ 13 - 14%

- 3 sigma

+ 3 sigma

≈ 2 - 3%

+ 2 sigma

≈ 13 - 14%

+ 1 sigma

≈ 34%

- 1 sigma

≈ 34%

- 2 sigma

≈ 13 - 14%

- 3 sigma

≈ 2 - 3%

B-6.2 Characteristics of an unnatural pattern

Unnatural patterns tend to fluctuate too widely, or else they fail to balance themselves around the centerline. A pattern may also be unnatural because it does not fluctuate widely enough. Unnatural patterns always involve the absence of one or more of the characteristics of a natural pattern. For example:

- (1) Absence of points near the centerline produces an unnatural pattern known as "Mixture."
- (2) Absence of points near the control limits

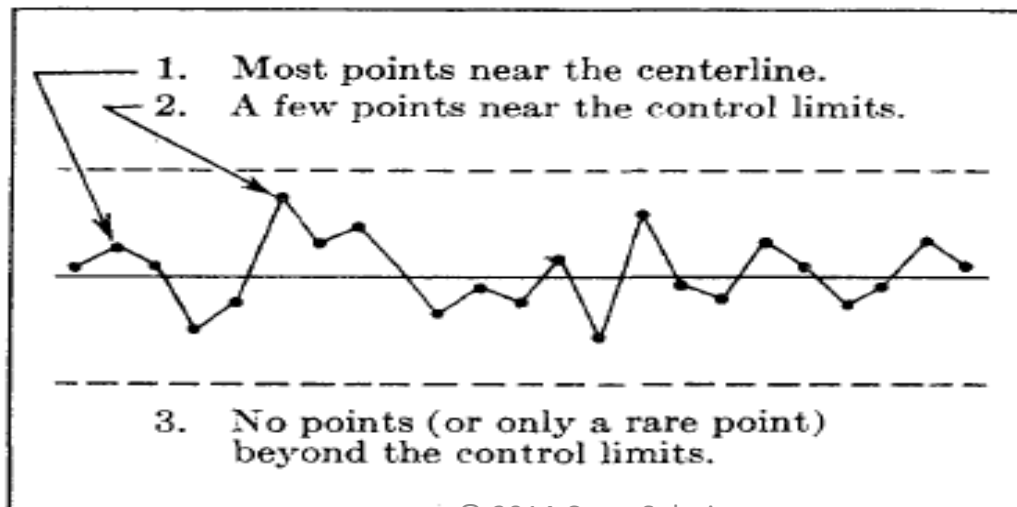


Fig. 32. Three characteristics of a natural pattern.

WECO "Test 1"

Test 1. A single point falls outside of the 3 sigma limit (beyond Zone A). See Figure 34.

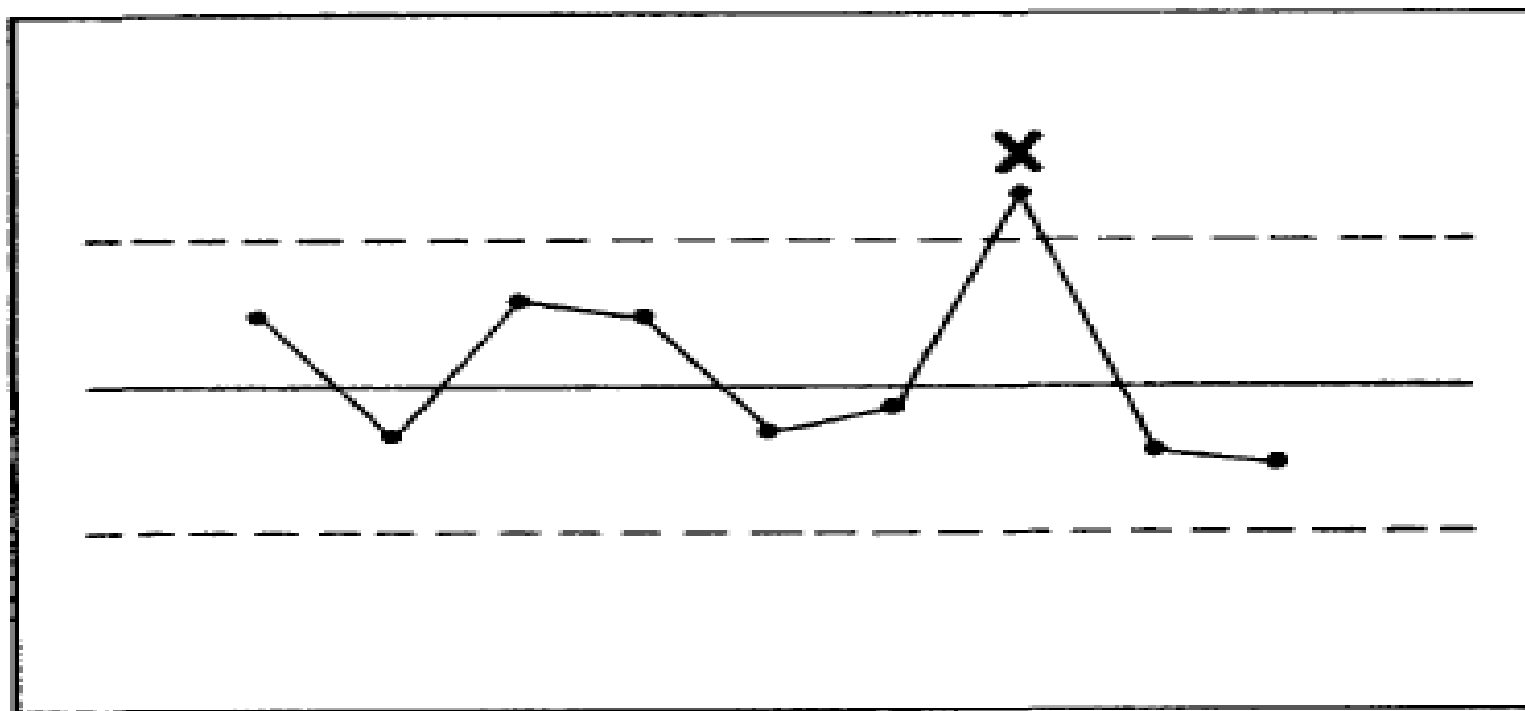


Fig. 34. First test for unnaturalness: a single point outside of 3 sigma.

WECO "Test 2"

Test 2. Two out of three successive points fall in Zone A or beyond.

(Note: The odd point may be anywhere. Only the two points count.) See Figure 35.

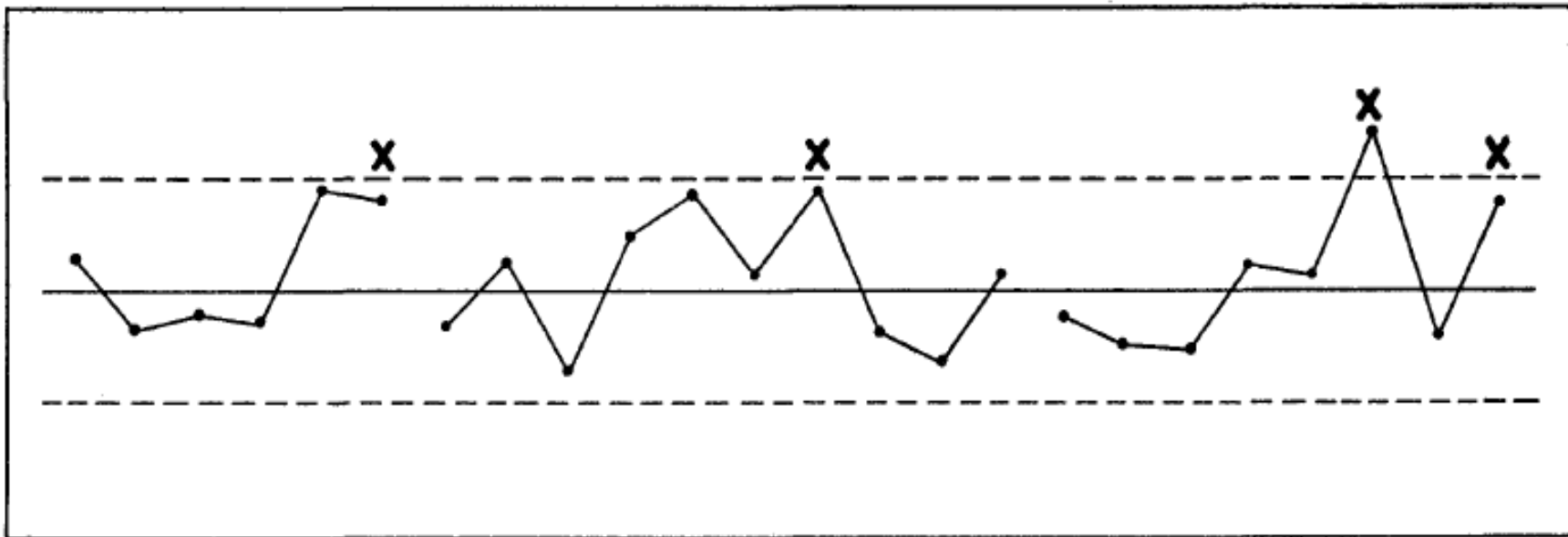


Fig. 35. Second test for unnaturalness: Two out of three successive points outside of 2 sigma.

Mark only the second of the two points with an "x," since the second point is necessary to produce a reaction to the test. In the last example above, the point which is third from the end is marked because it reacted to Test 1, and not because it was part of the test for "2 out of 3."

WECO "Test 3"

Test 3. Four out of five successive points fall in Zone B or beyond.

(Note: The odd point may be anywhere. Only the four points count.) See Figure 36.

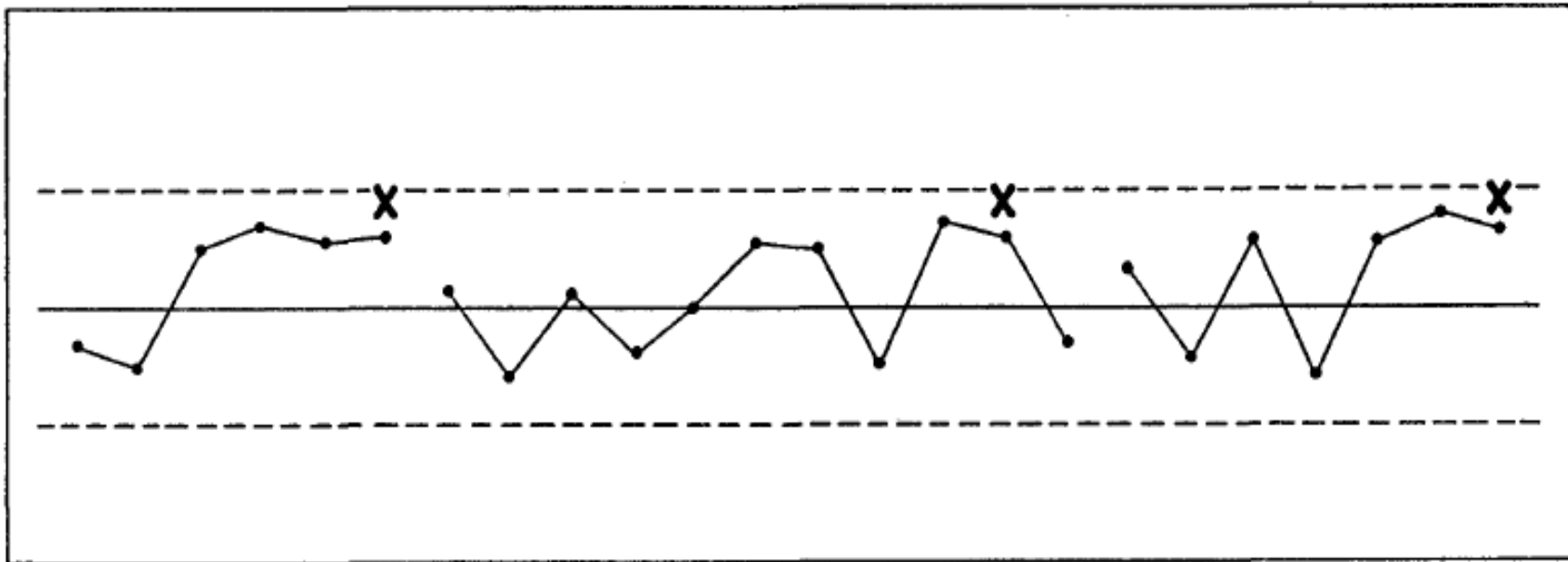


Fig. 36. Third test for unnaturalness: Four out of five successive points outside of 1 sigma.

Mark only the last of the four points with an "x," since there is no reaction to the test until the fourth point.

WECo "Test 4"

Test 4. Eight successive points fall in Zone C or beyond.

(This is sometimes expressed as "eight points in a row on one side of the centerline.") See Figure 37.

Mark only the eighth point with an "x," since all eight points are necessary to produce a reaction to the test.

26

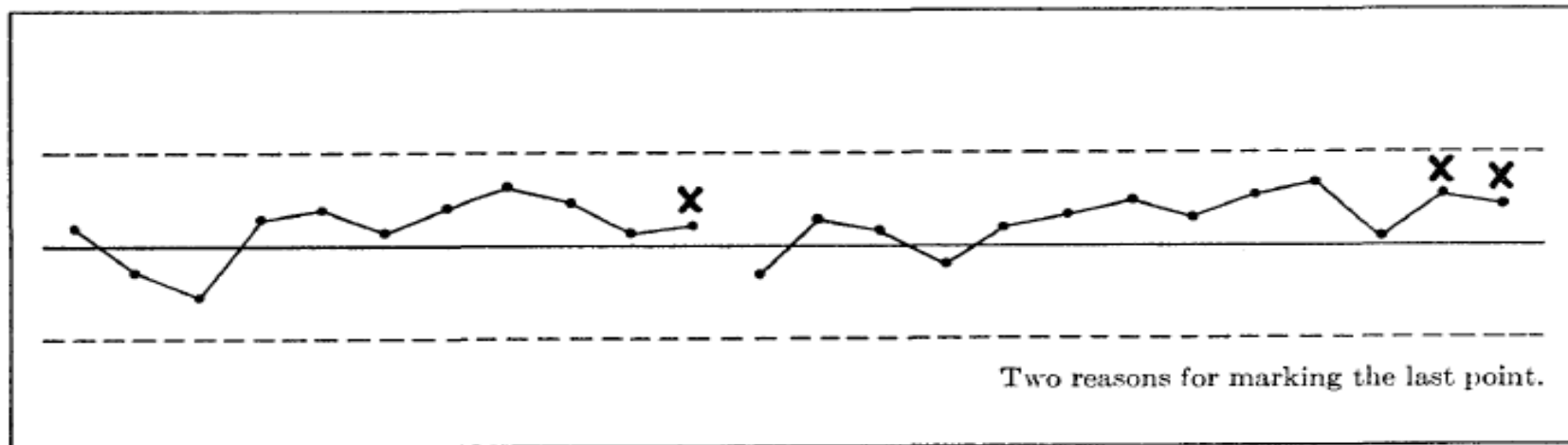


Fig. 37. Fourth test for unnaturalness: Eight successive points on one side of the centerline.

WECO Summary of Run Tests

<i>Upper Half</i>	<i>Lower Half</i>

A 2 out of 3 in Zone A or above	
B 4 out of 5 in Zone B or above	
C 8 in a row in Zone C or above	

	C 8 in a row in Zone C or below
	B 4 out of 5 in Zone B or below
	A 2 out of 3 in Zone A or below

	Single point out

Fig. 38. Summary of tests for unnatural patterns.

NOTE ON RUN TESTS:

the run tests are not used with Moving Range or Range charts because the control limits are not symmetrical about the centerline

B-8 OTHER UNNATURAL PATTERNS

The following patterns should be watched for in addition to patterns of instability. The ability to recognize these patterns can greatly increase the usefulness of the control chart, by permitting a fuller interpretation of its meaning. These patterns are different from the patterns of instability in that *both halves of the control chart are considered together in looking for the patterns shown below.*

These patterns are marked with *circled x's*

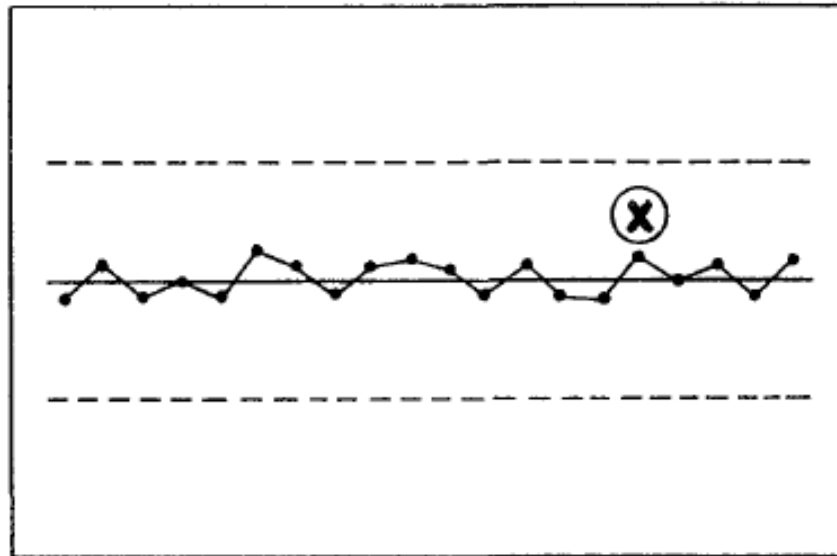


Fig. 40. Pattern of stratification.

(2) Mixture

If the pattern shows a tendency to avoid the centerline, with too many points near the control limits, this is an indication of mixture. See pages 169–170, 171, and 179–180.

Consider that mixture exists when the chart shows 8 consecutive points on both sides of the centerline with none of the points falling in Zone C.

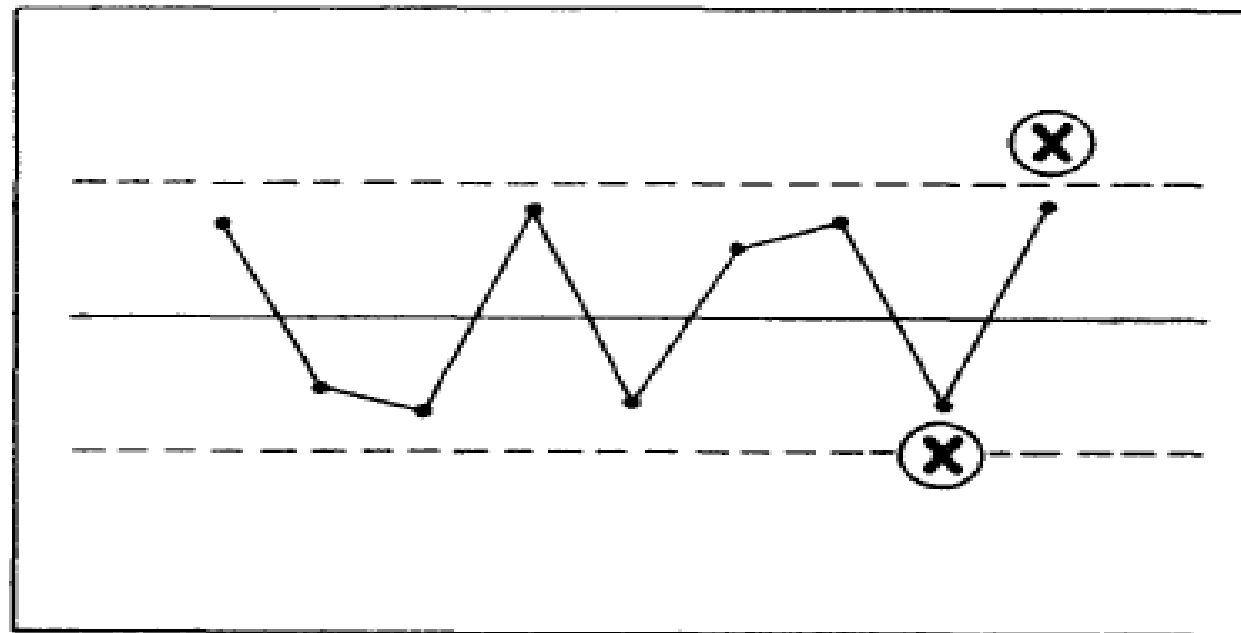
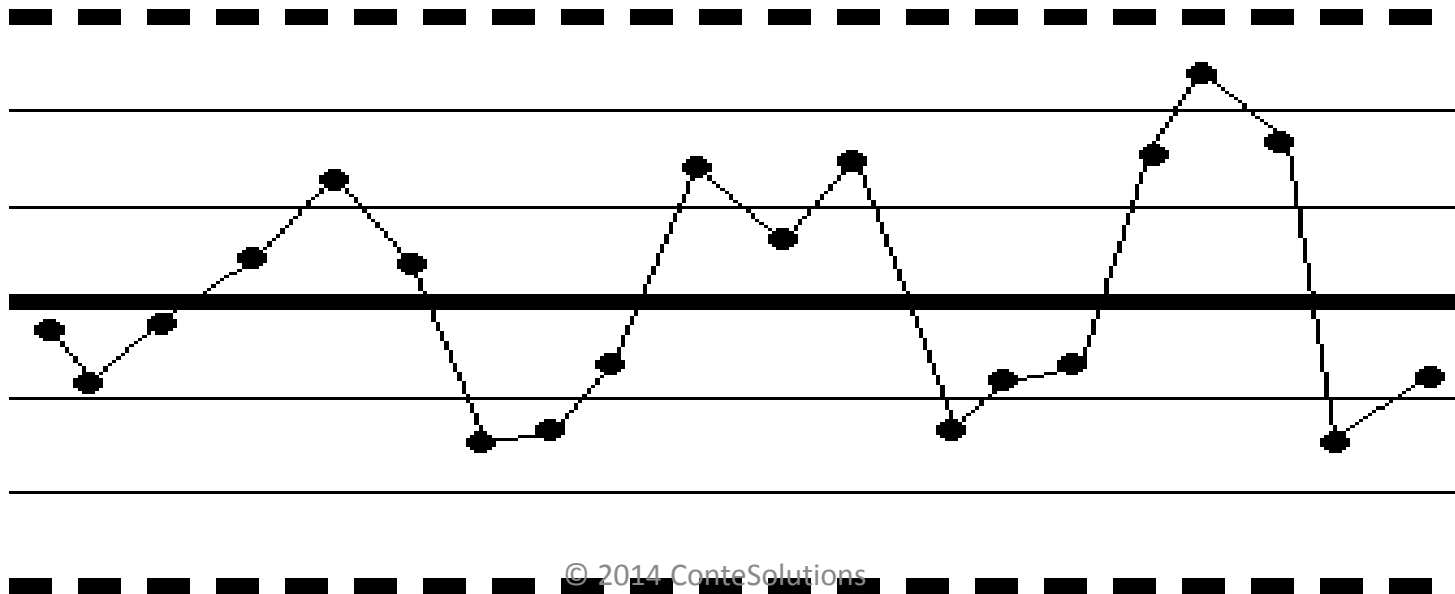


Fig. 41. Pattern of mixture.

Test for Cycles / Repeating Patterns

A chart cycles when the plotted points form a repeating pattern.

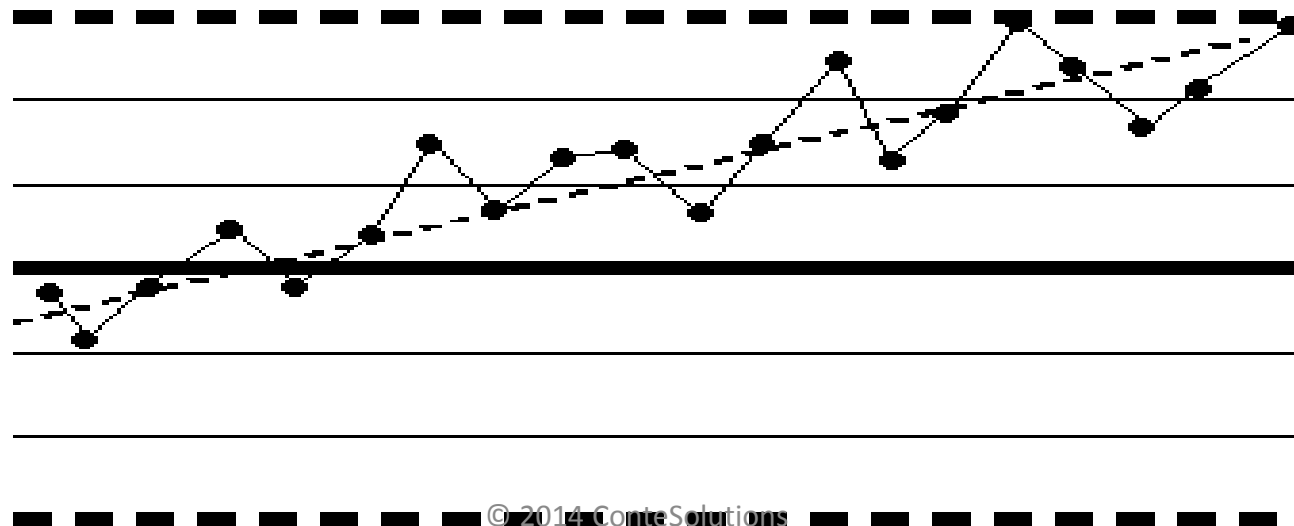
WHY? Normal distributions occur when there are no assignable causes of variation that will result in patterns or cycles in the data; only common cause (random) variation is present. CYCLES are short trends in the data that occur in repeated patterns. A Cycle is clearly a sign of an unnatural condition since a random process distribution does not repeat predictably.



Test for Trends / Gradual Changes in Level

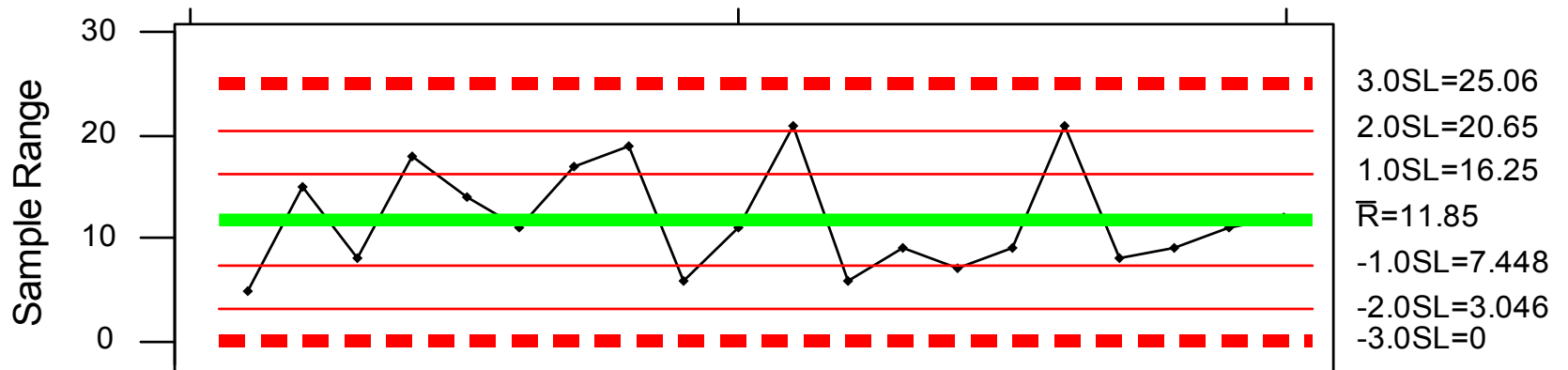
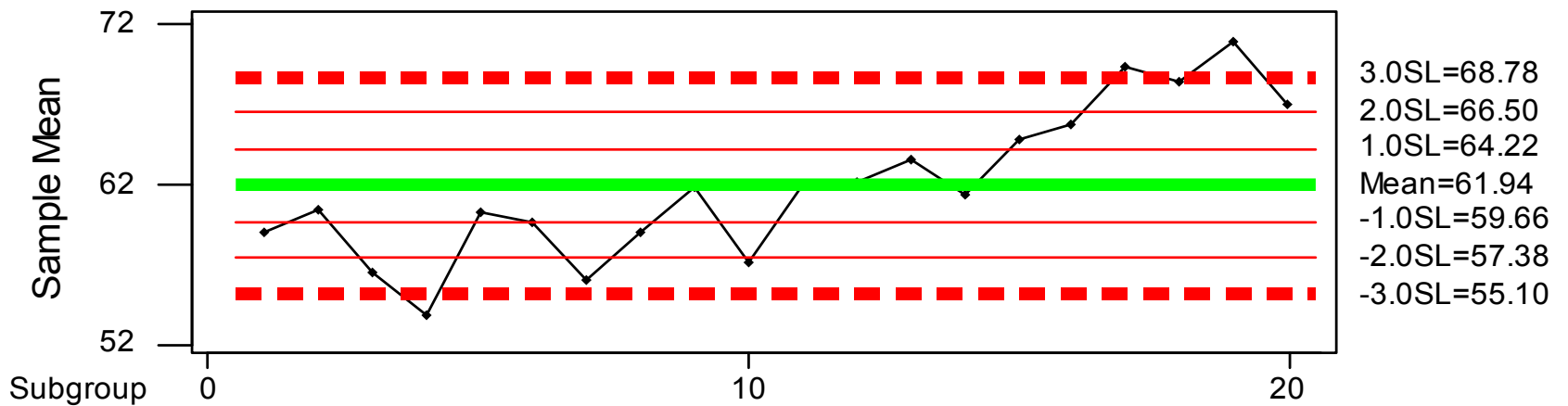
A chart shows a trend if a long series of plotted points gradually move toward either control limit, or there is a long series of data points without a change in direction.

WHY? A trend indicates the process average is increasing or decreasing and no longer at the centerline of the control chart. Stable processes will display data that are “horizontal” over time – the average will not be changing.



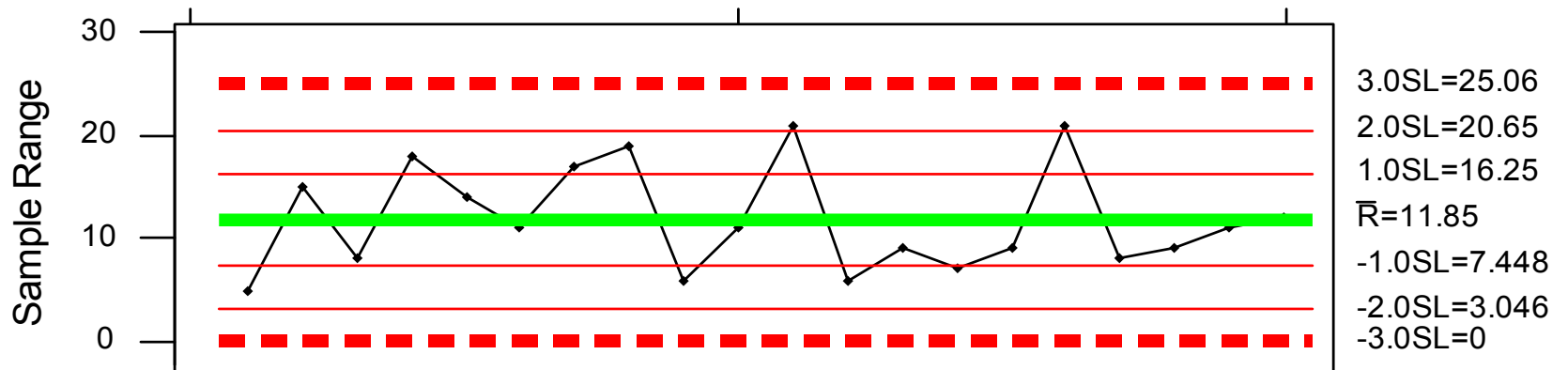
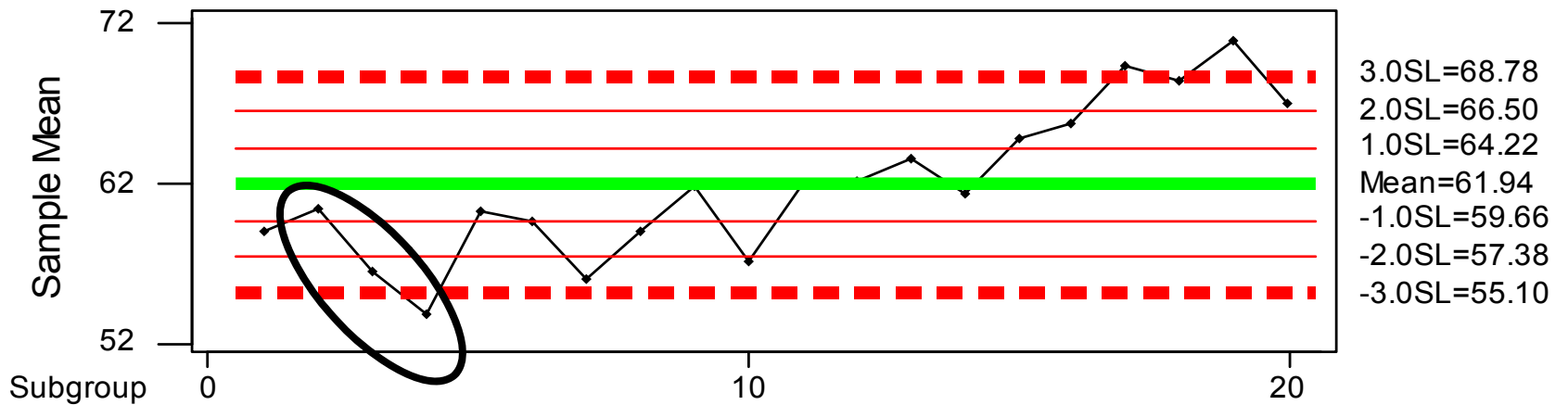
Is this x-bar chart stable?

Xbar/R Chart

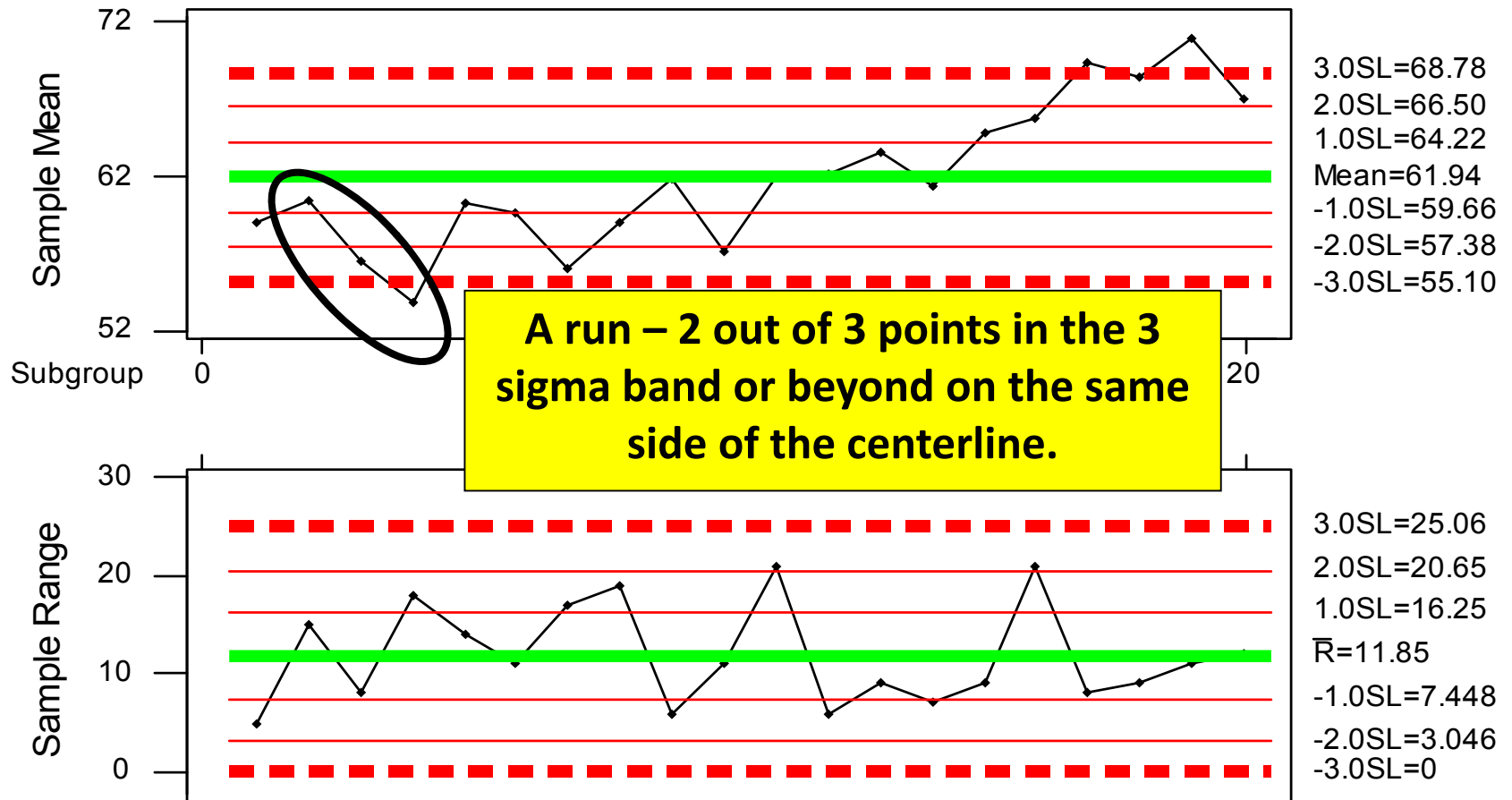


What is this failure mode called?

Xbar/R Chart

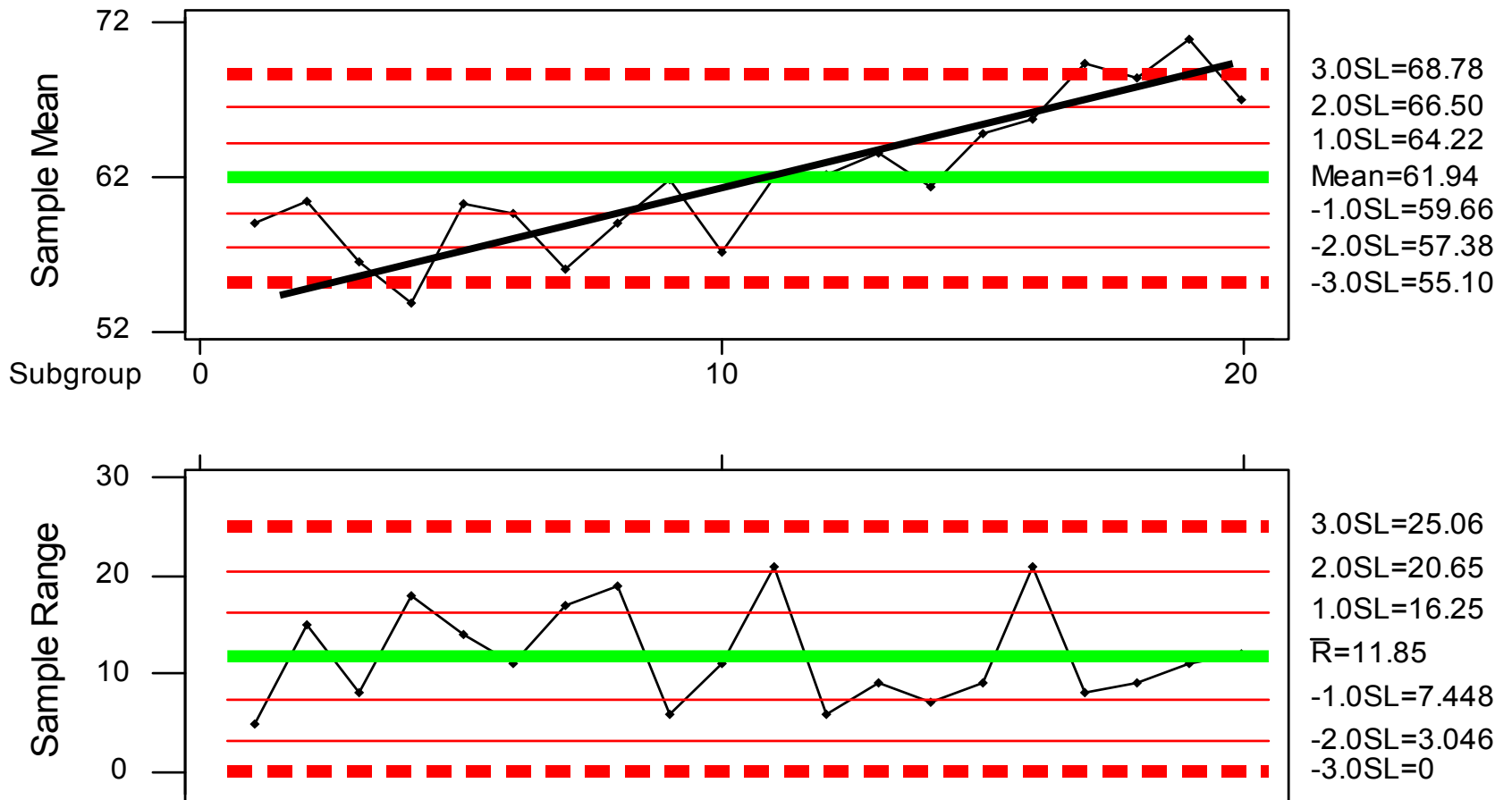


Xbar/R Chart

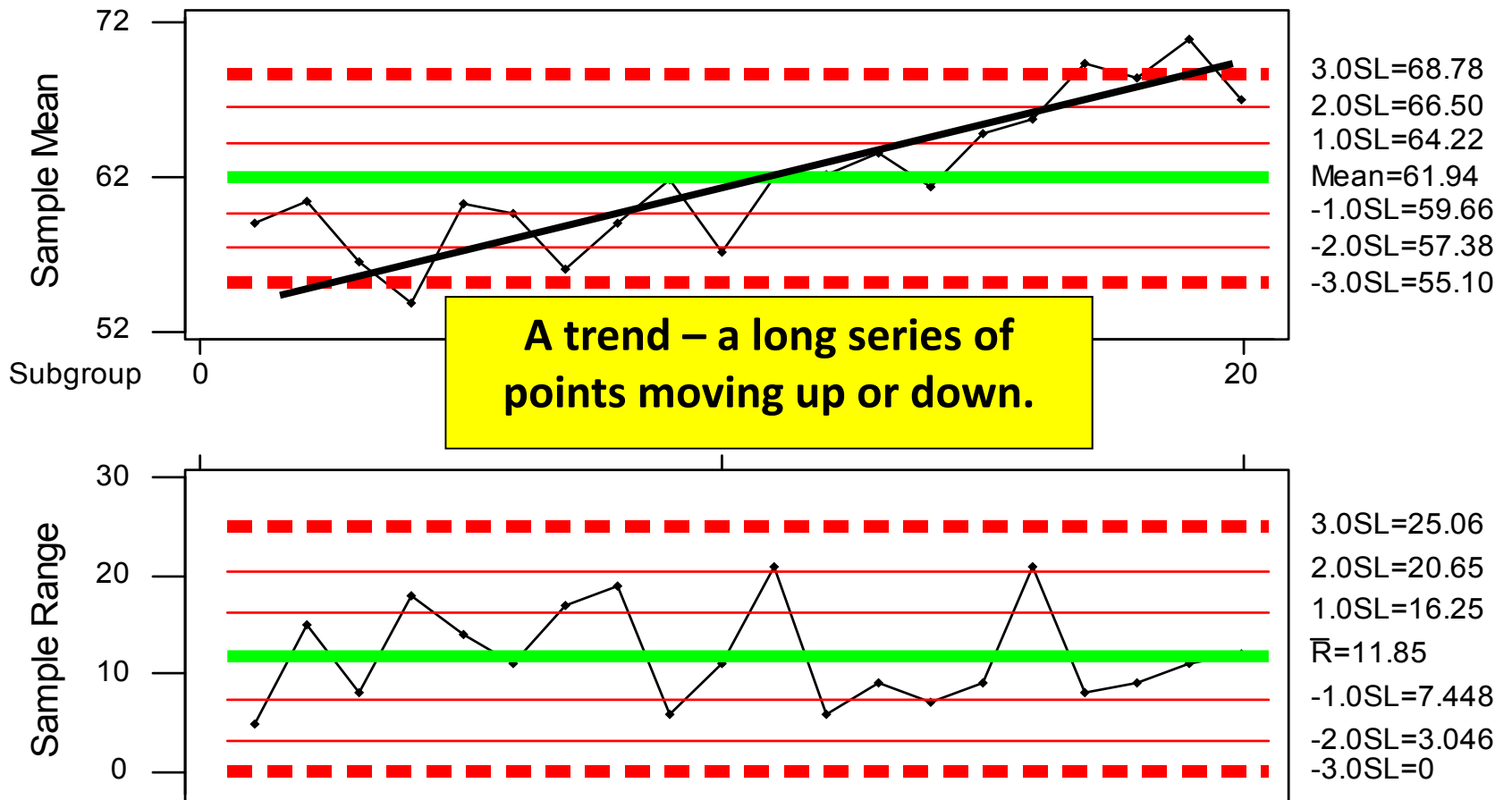


What is this failure mode called?

Xbar/R Chart



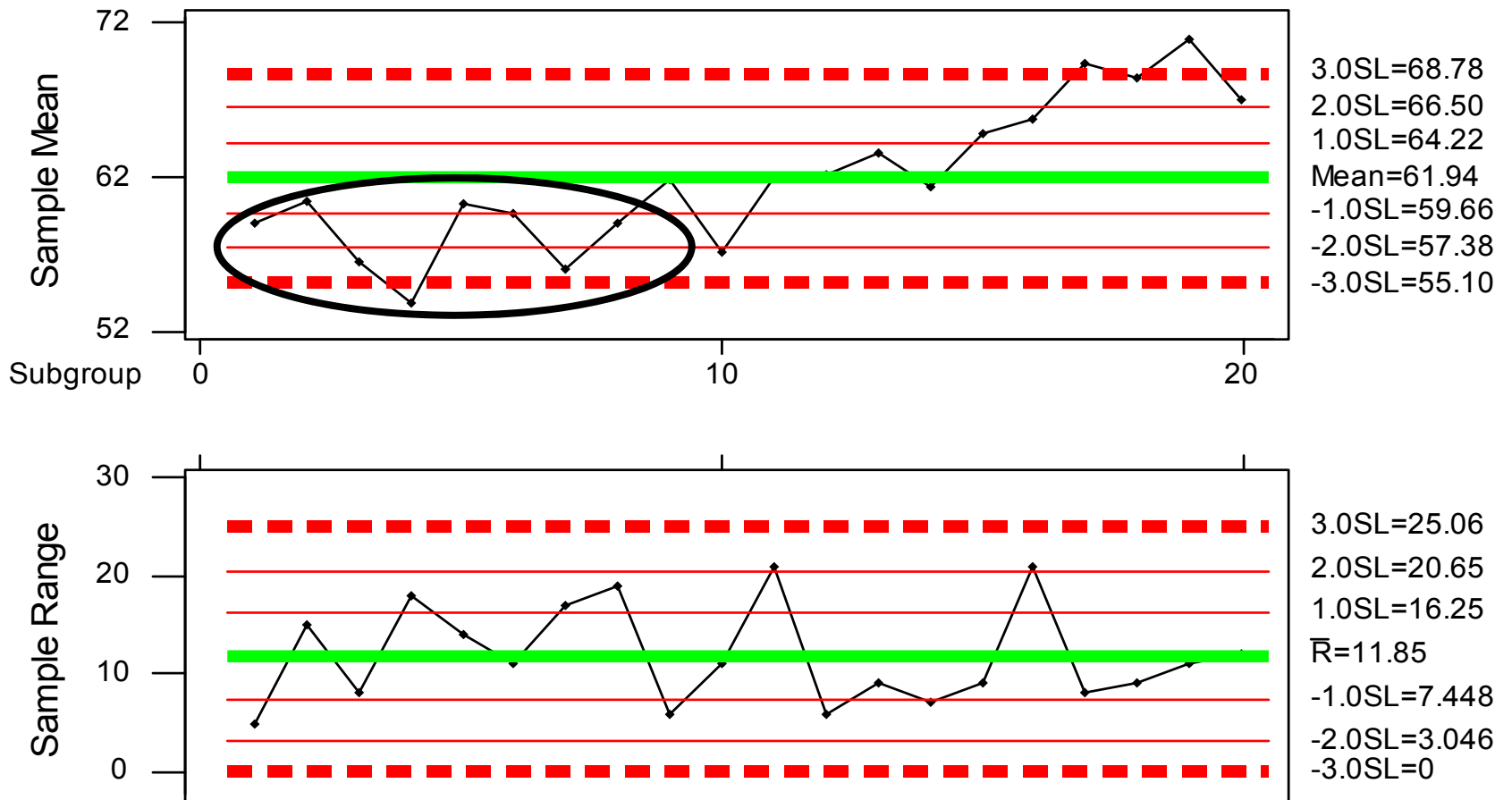
Xbar/R Chart



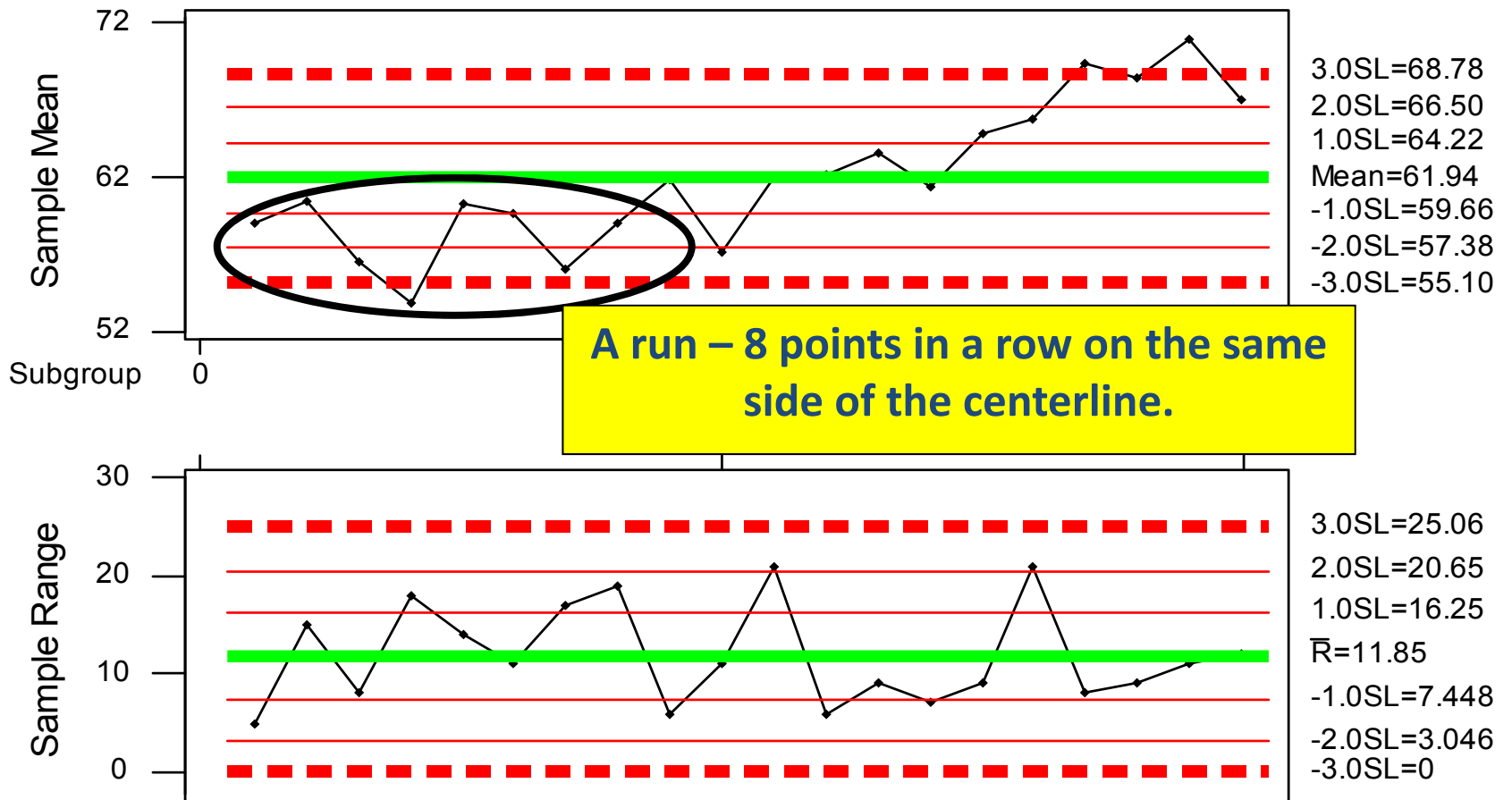
A trend – a long series of points moving up or down.

What is this failure mode called?

Xbar/R Chart

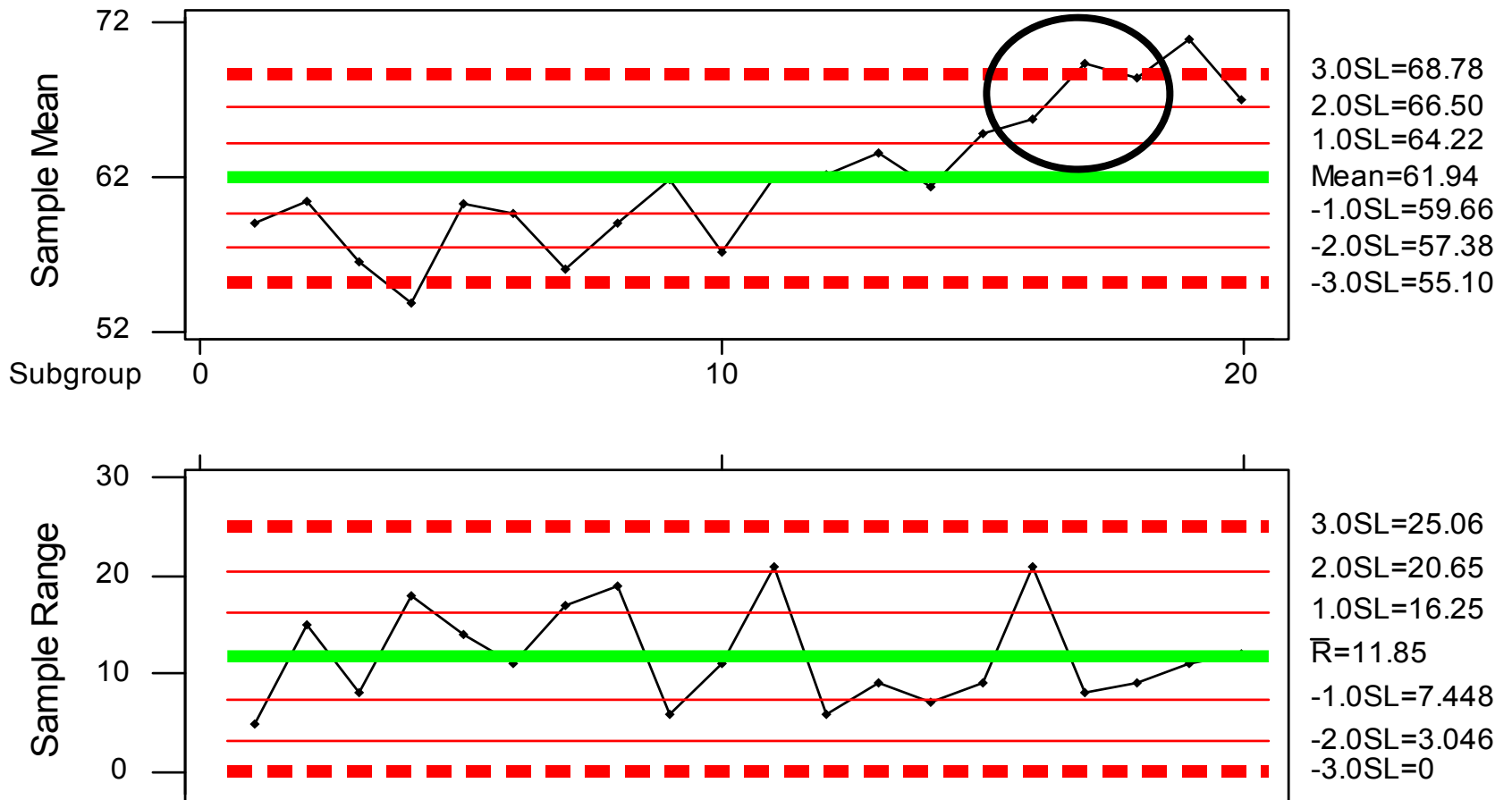


Xbar/R Chart

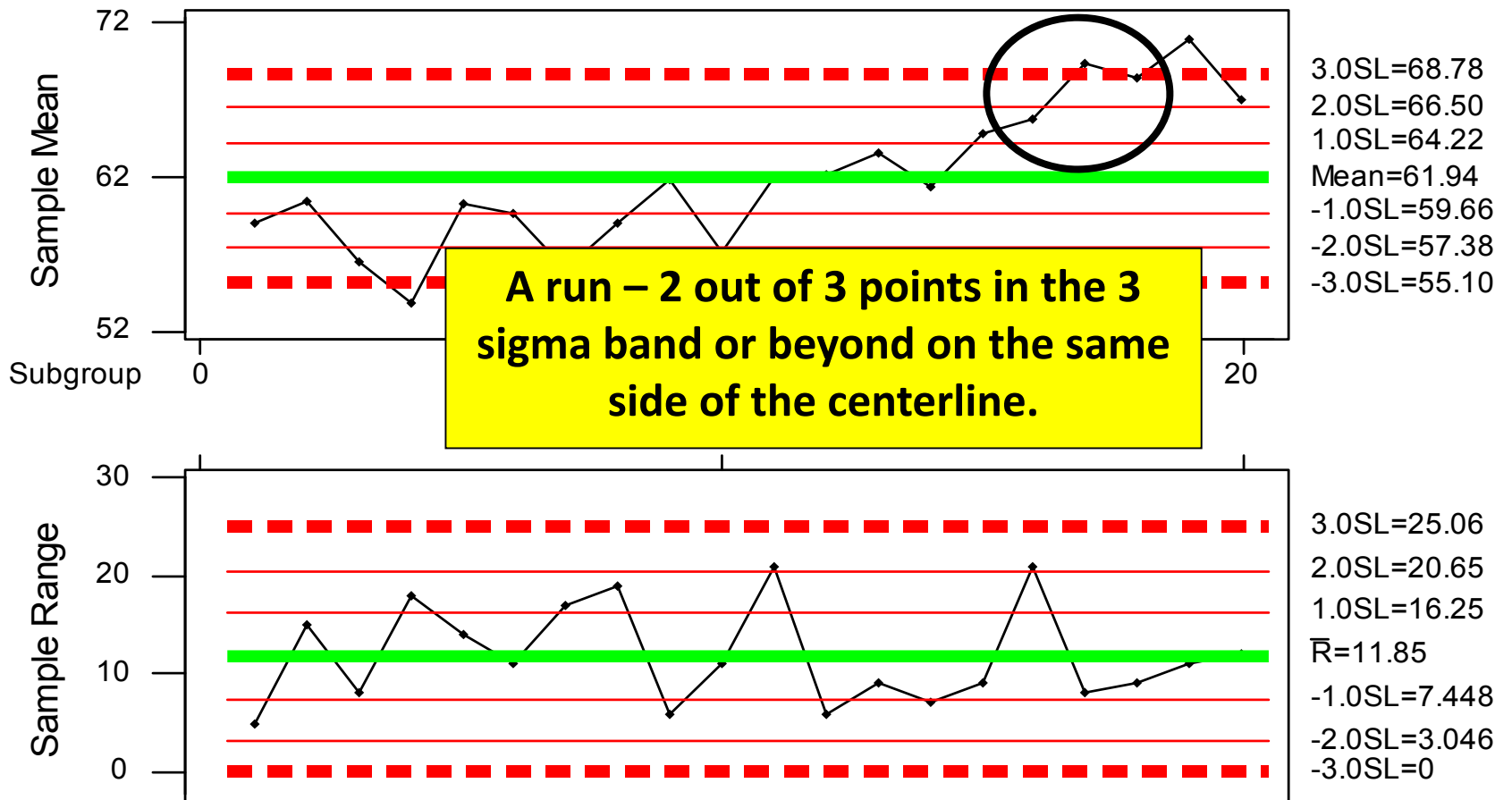


What is this failure mode called?

Xbar/R Chart

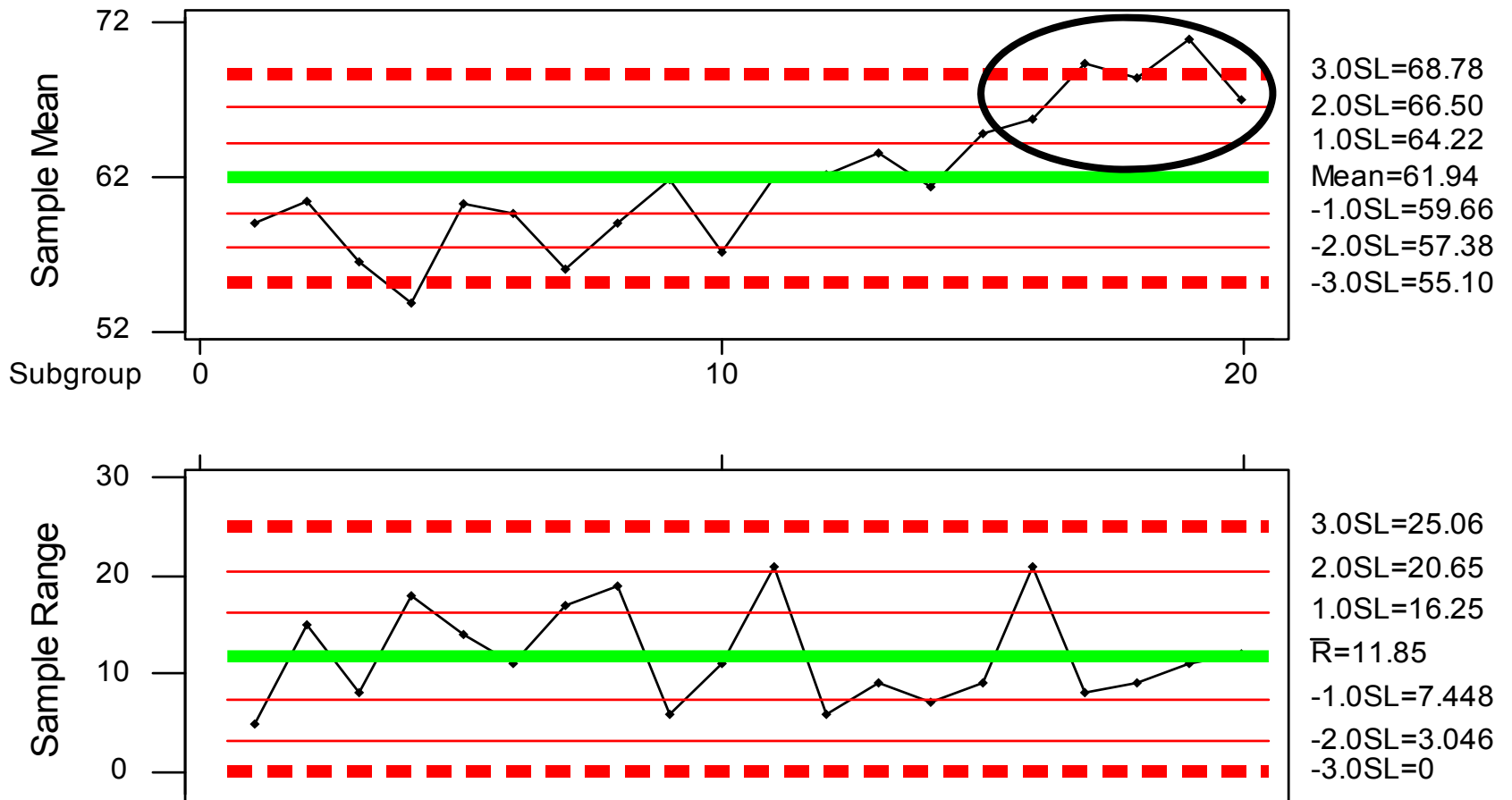


Xbar/R Chart

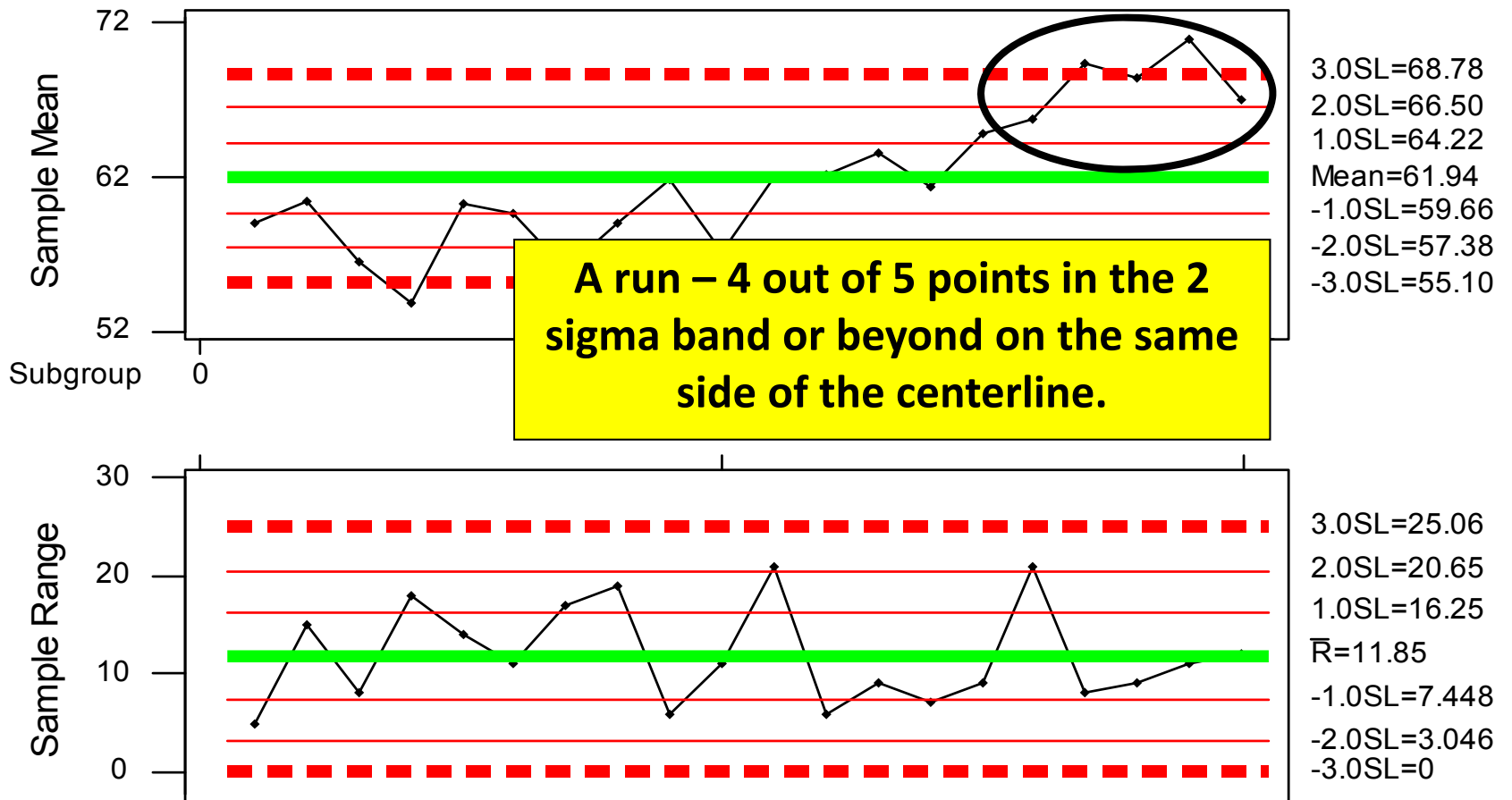


What is this failure mode called?

Xbar/R Chart

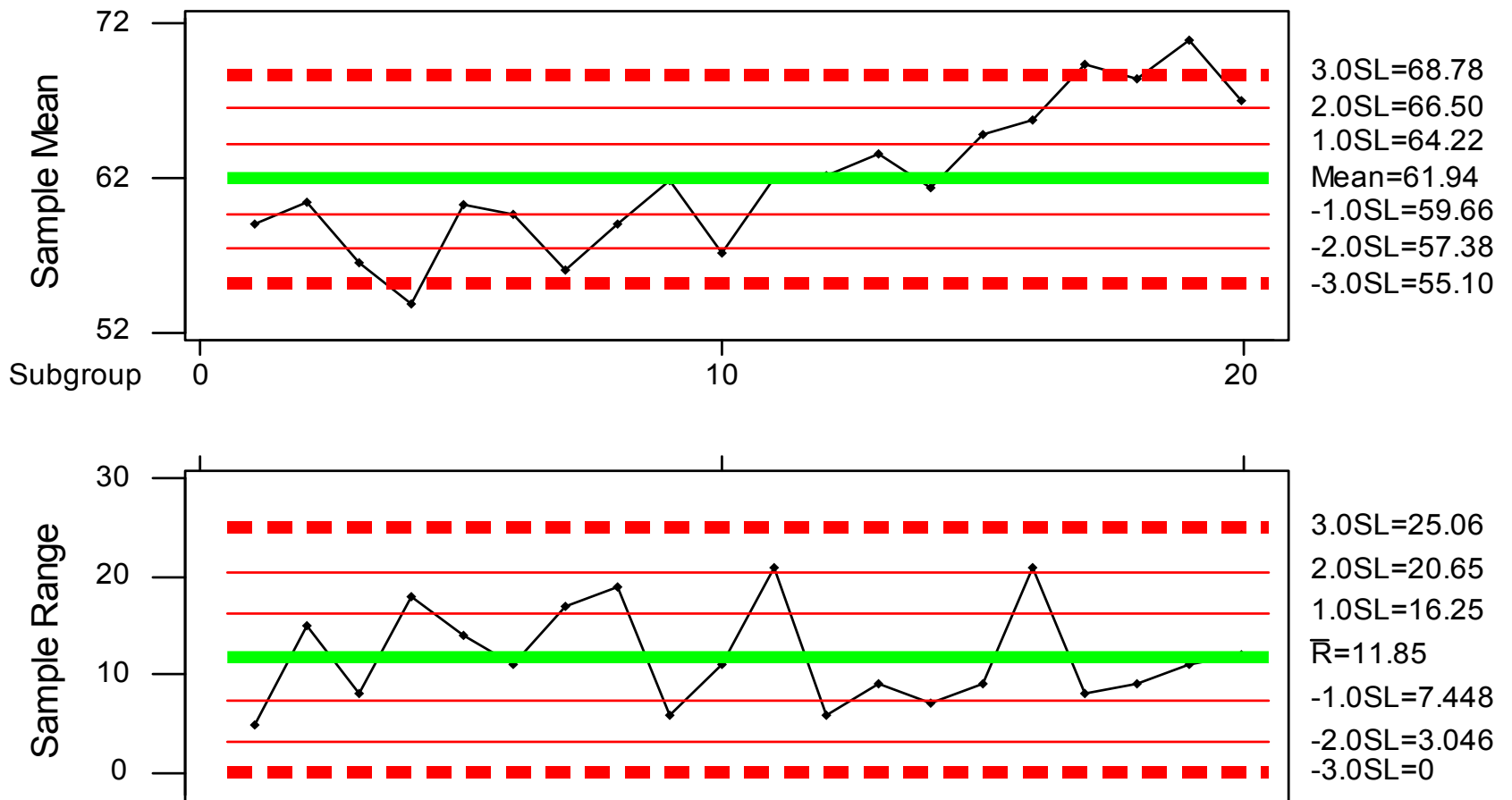


Xbar/R Chart

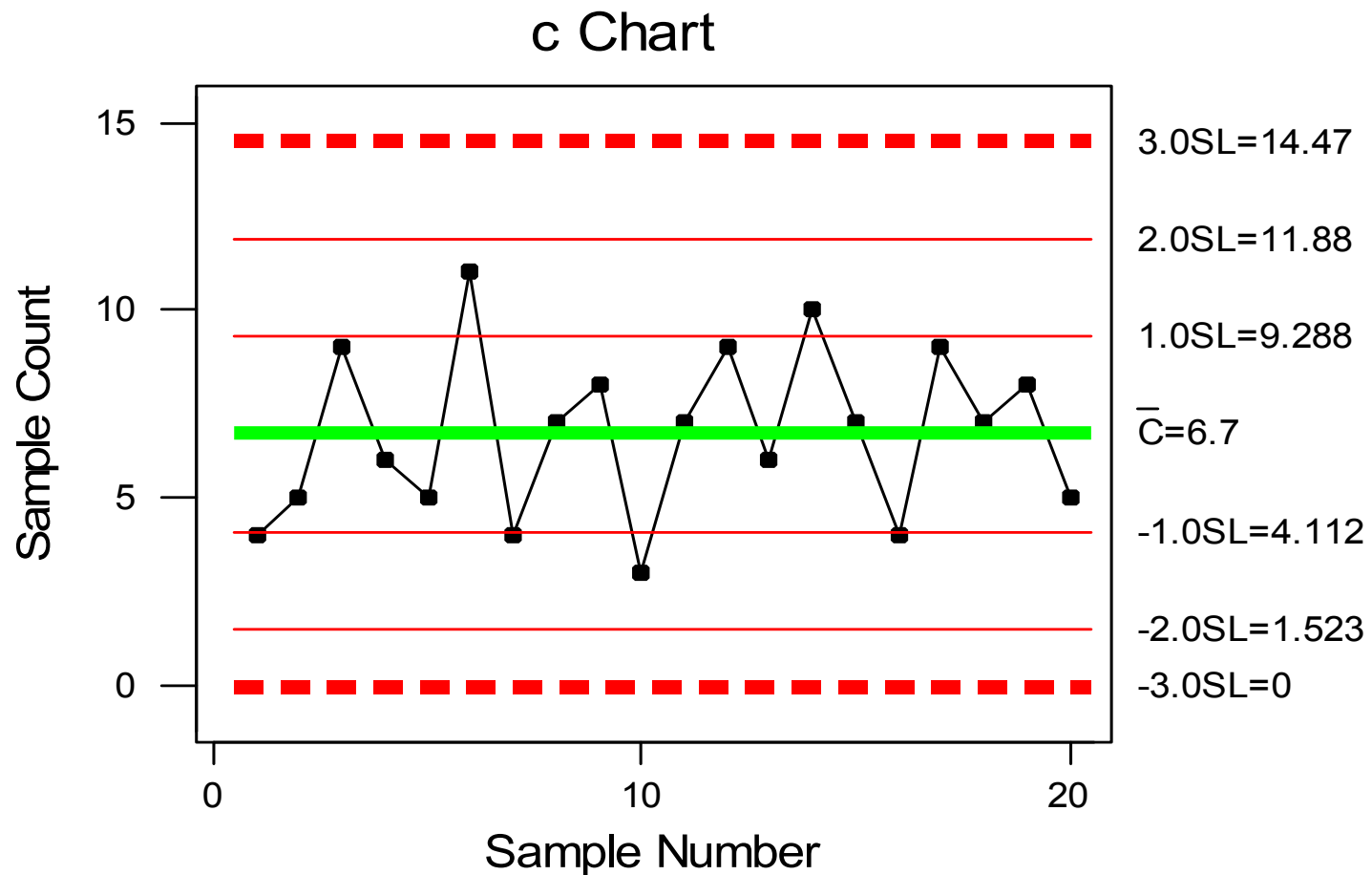


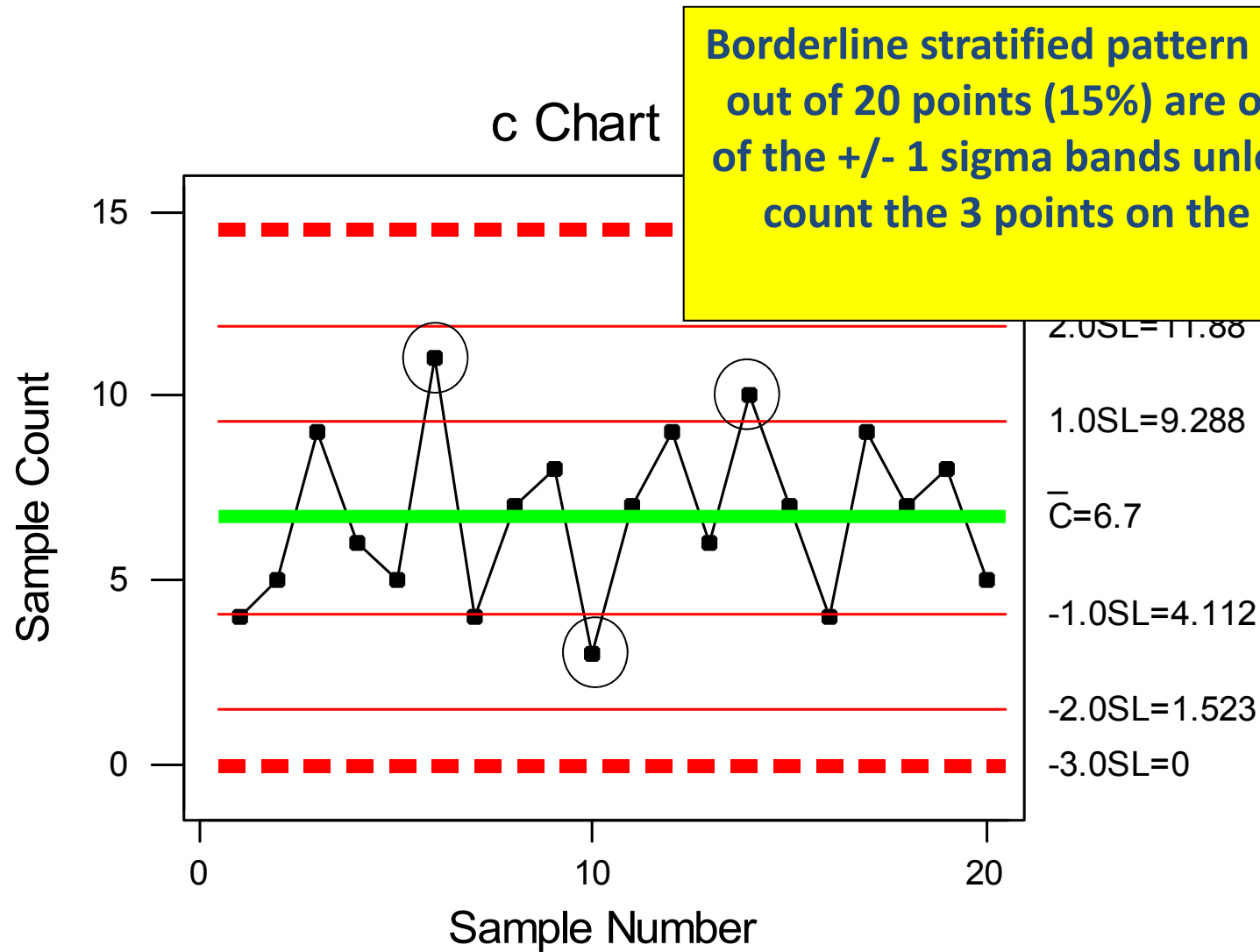
Is this Range chart stable?

Xbar/R Chart



Is this process stable?



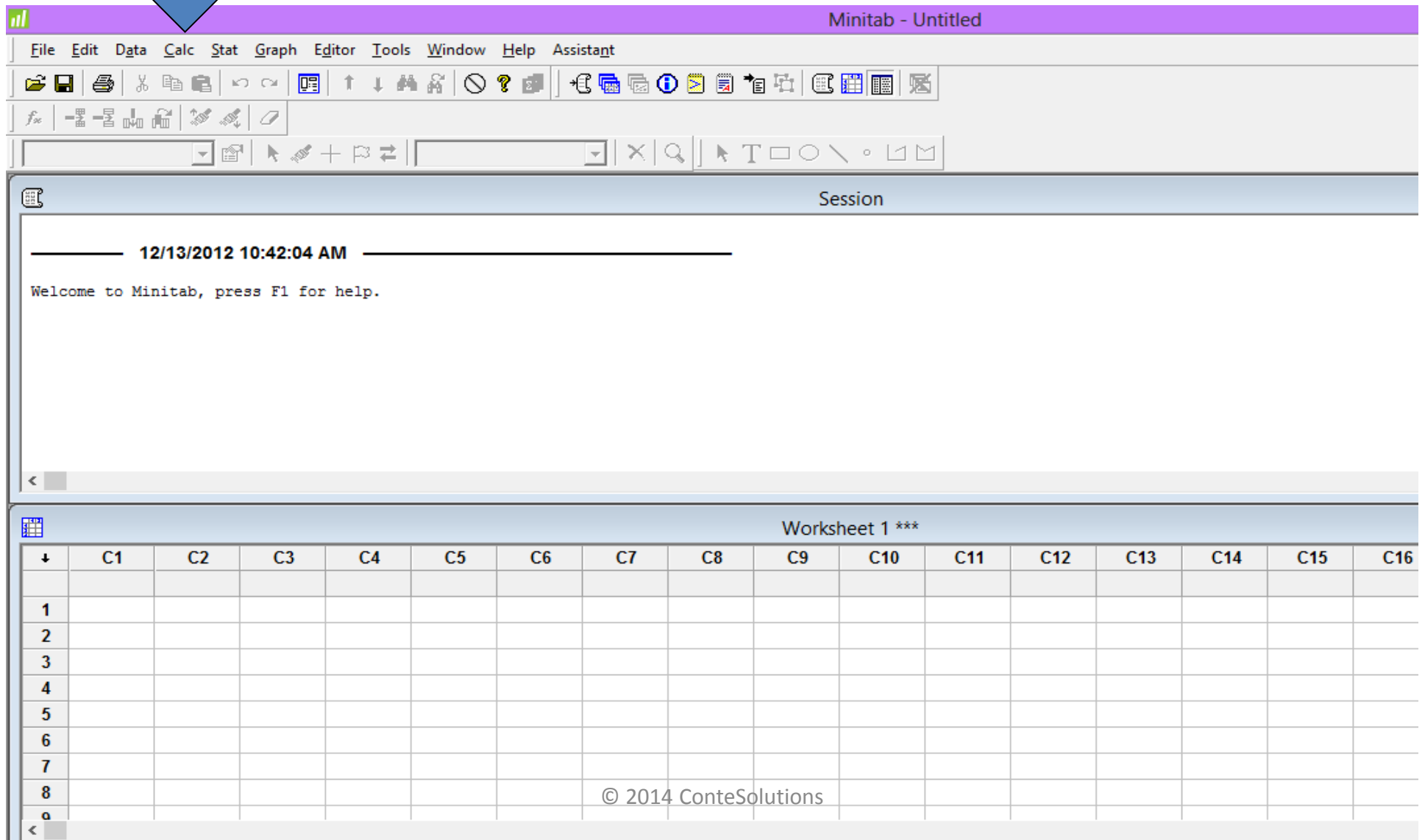


Borderline stratified pattern - only 3 out of 20 points (15%) are outside of the +/- 1 sigma bands unless you count the 3 points on the line.

Minitab SPC Test

- Escape Whiteboard to JAC Desktop
- Bring up Minitab
- Worksheet has 1000 data values in C1
- Create an x-bar and R chart
- Check for tests
- Note control limits when process has mean of 10 and std dev of 1.0

Default screen in Minitab



The screenshot displays the Minitab software interface. At the top, a purple title bar reads "Minitab - Untitled". Below it is a menu bar with options: File, Edit, Data, Calc, Stat, Graph, Editor, Tools, Window, Help, Assistant. A toolbar with various icons follows, including file operations, editing, and statistical functions. Below the toolbar is a Session window with a light blue header and a white body containing the text: "12/13/2012 10:42:04 AM" and "Welcome to Minitab, press F1 for help." Below the Session window is a Worksheet window with a light blue header and a white grid. The grid has 16 columns labeled C1 through C16 and 9 rows labeled 1 through 9. A copyright notice "© 2014 ConteSolutions" is visible in the bottom right corner of the grid.

Minitab - Untitled

File Edit Data Calc Stat Graph Editor Tools Window Help Assistant

12/13/2012 10:42:04 AM

Welcome to Minitab, press F1 for help.

Worksheet 1 ***

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
1																
2																
3																
4																
5																
6																
7																
8																
9																

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Calc/Random Data/Normal

The image shows a screenshot of a spreadsheet application window titled "Session". A "Normal Distribution" dialog box is open, allowing the user to generate random data. The dialog box has a purple title bar and a red close button. It contains the following fields and controls:

- Number of rows of data to generate:** A text box containing the value "1000".
- Store in column(s):** A list box containing the value "c1".
- Mean:** A text box containing the value "10".
- Standard deviation:** A text box containing the value "1.0".
- Buttons:** "Select", "Help", "OK", and "Cancel".

The background shows a spreadsheet grid with column headers "C6", "C14", and "C15" visible.

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Data in column C1

The screenshot displays the Minitab software interface. At the top, the title bar reads "Minitab - Untitled". Below it is a menu bar with options: File, Edit, Data, Calc, Stat, Graph, Editor, Tools, Window, Help, Assistant. A toolbar with various icons is positioned below the menu bar. The main workspace is divided into two panes. The top pane, titled "Session", shows a timestamp "12/13/2012 10:42:04 AM" and the text "Welcome to Minitab, press F1 for help." The bottom pane, titled "Worksheet 1 ***", contains a data table with 15 columns (C1 to C15) and 9 rows. The data in column C1 is as follows:

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
1	11.3890														
2	8.8126														
3	11.9496														
4	9.8861														
5	9.2737														
6	9.4698														
7	9.2667														
8	10.7180														
9	9.1987														

Session

Xbar-R Chart [X]

C1

All observations for a chart are in one column: [v]

c1

Subgroup sizes: [5] (enter a number or ID column)

Scale... Labels...

Multiple Graphs... Data Options... Xbar-R Options...

Select

Help OK Cancel

Xbar-R Chart of C1

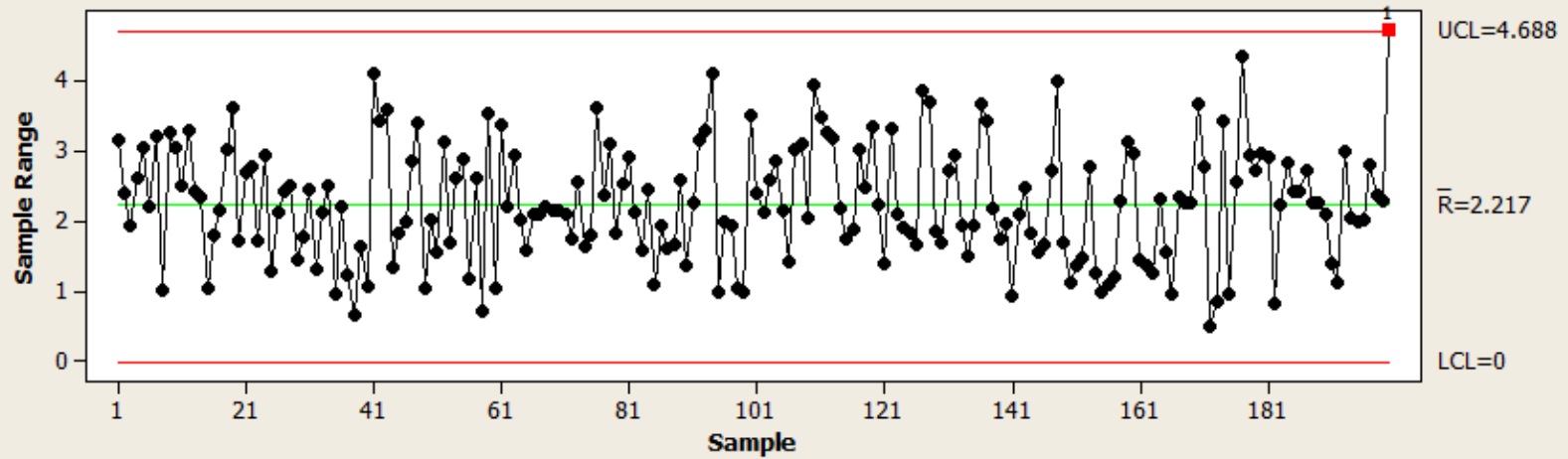
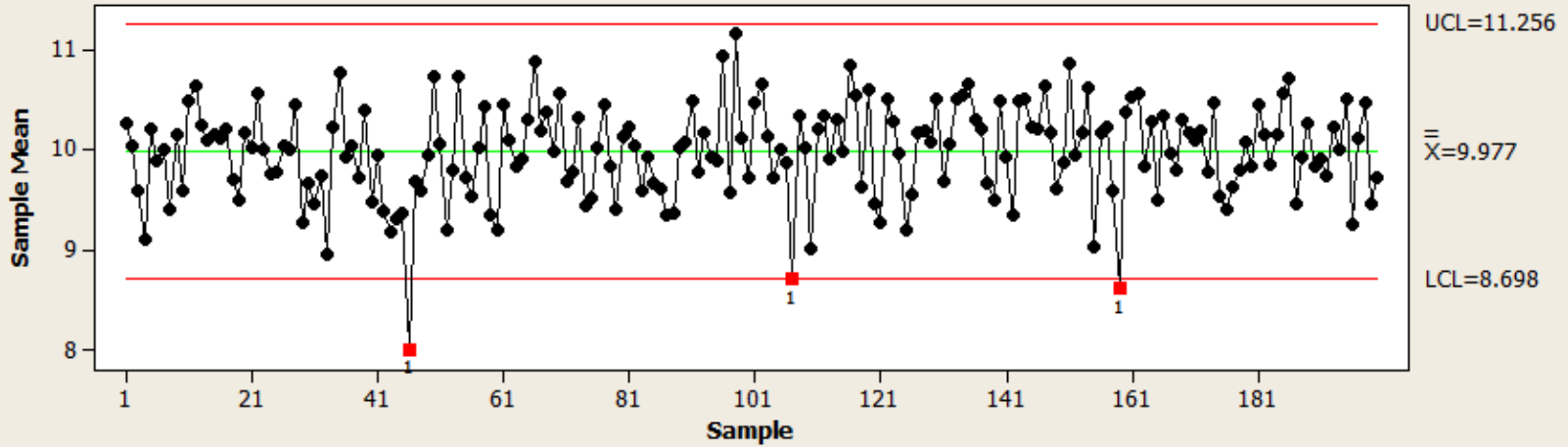


Chart of CI

1
P

Xbar-R Chart - Options

Parameters | Estimate | S Limits | Tests | Stages | Box-Cox | Display | Storage

To specify the values for one or both parameters, enter them here. Minitab uses these values instead of estimating them from the data.

Mean:

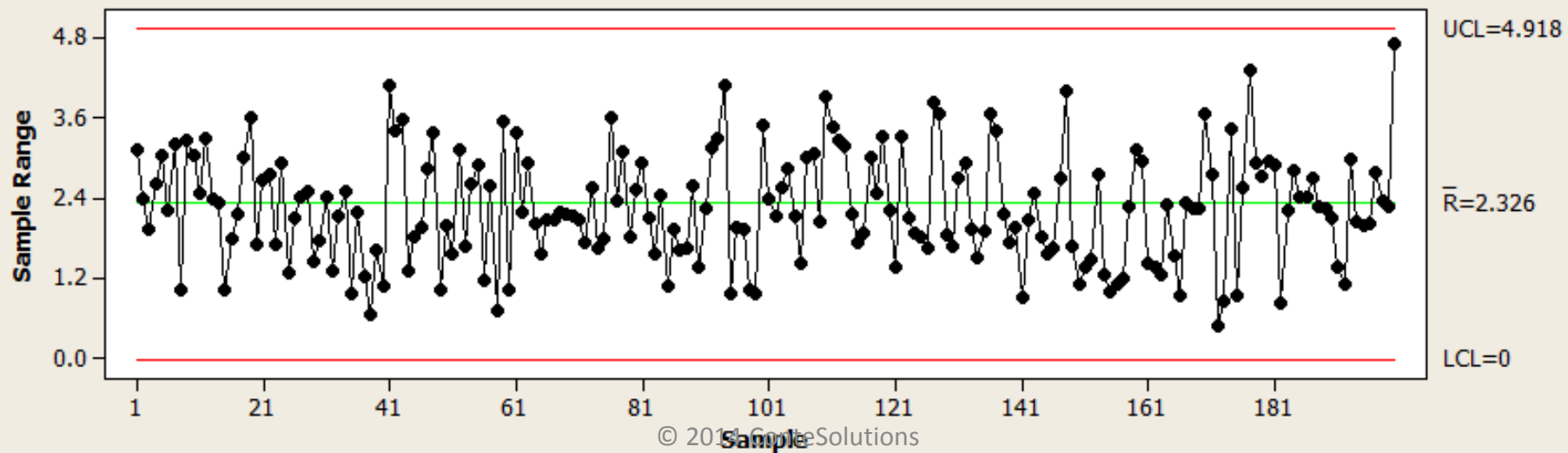
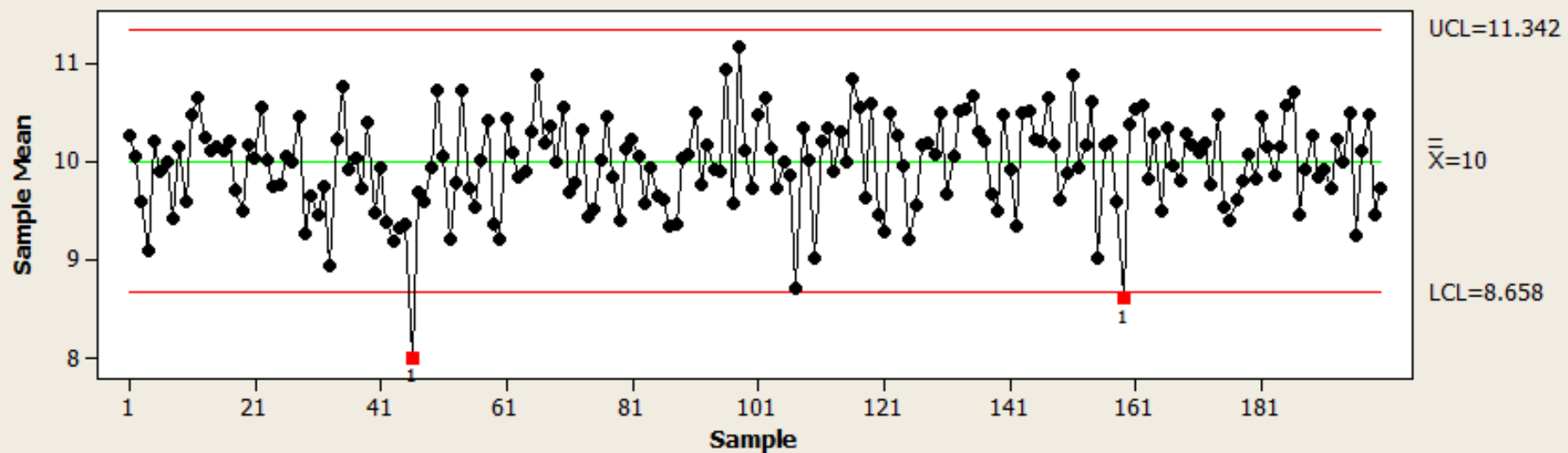
Standard deviation:

Help OK Cancel

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R=2.217

Xbar-R Chart of C1



Xbar-R Chart - Options



Parameters

Estimate

S Limits

Tests

Stages

Box-Cox

Display

Storage

Perform selected tests for special causes

K

- | | | |
|-------------------------------------|--|---------------------------------|
| <input checked="" type="checkbox"/> | 1 point $>$ K standard deviations from center line | <input type="text" value="3"/> |
| <input type="checkbox"/> | K points in a row on same side of center line | <input type="text" value="9"/> |
| <input type="checkbox"/> | K points in a row, all increasing or all decreasing | <input type="text" value="6"/> |
| <input type="checkbox"/> | K points in a row, alternating up and down | <input type="text" value="14"/> |
| <input type="checkbox"/> | K out of K+1 points $>$ 2 standard deviations from center line (same side) | <input type="text" value="2"/> |
| <input type="checkbox"/> | K out of K+1 points $>$ 1 standard deviation from center line (same side) | <input type="text" value="4"/> |
| <input type="checkbox"/> | K points in a row within 1 standard deviation of center line (either side) | <input type="text" value="15"/> |
| <input type="checkbox"/> | K points in a row $>$ 1 standard deviation from center line (either side) | <input type="text" value="8"/> |

Help

OK

Cancel