NHS
Institute for Innovation and Improvement

A guide to creating and interpreting run and control charts

Turning Data into Information for Improvement

Using this guide

The NHS Institute has developed this guide as a reminder to commissioners how to create and analyse time-series data as part of their improvement work.

It should help you ask the right questions and to better assess whether a change has led to an improvement.
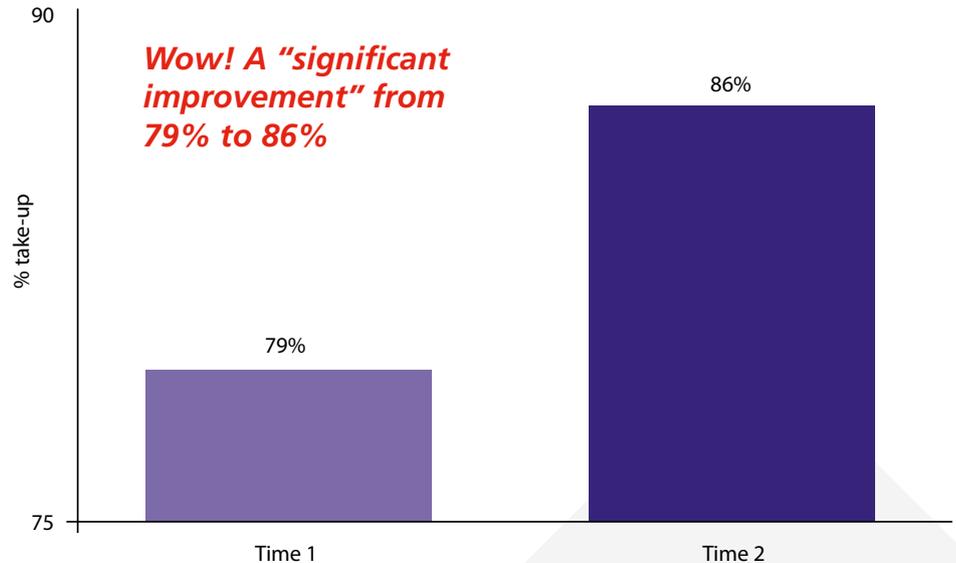
Contents

The importance of time-based measurements

Improving immunisation rates

Before and after the implementation of a new recall system

This example shows yearly figures for immunisation rates before and after a new system was introduced. The aggregated data seems to indicate the change was a success.
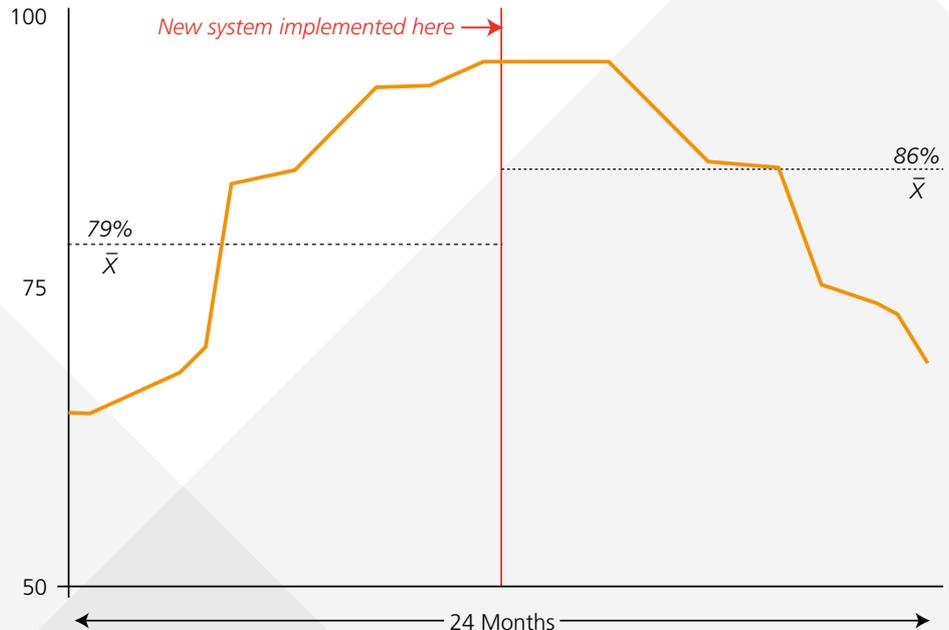
Wow! A "significant improvement" from 79% to 86%

% take-up

90

86%

79%

75

Time 1 | Time 2

Conclusion - The change was a success!

Improving immunisation rates

Before and after the implementation of a new recall system

However, viewing how the rates have changed within the two periods tells a very different story. Here we see that immunisation rates were actually improving until the new system was introduced. They then became worse.

Seeing this more detailed time based picture prompts a different response.
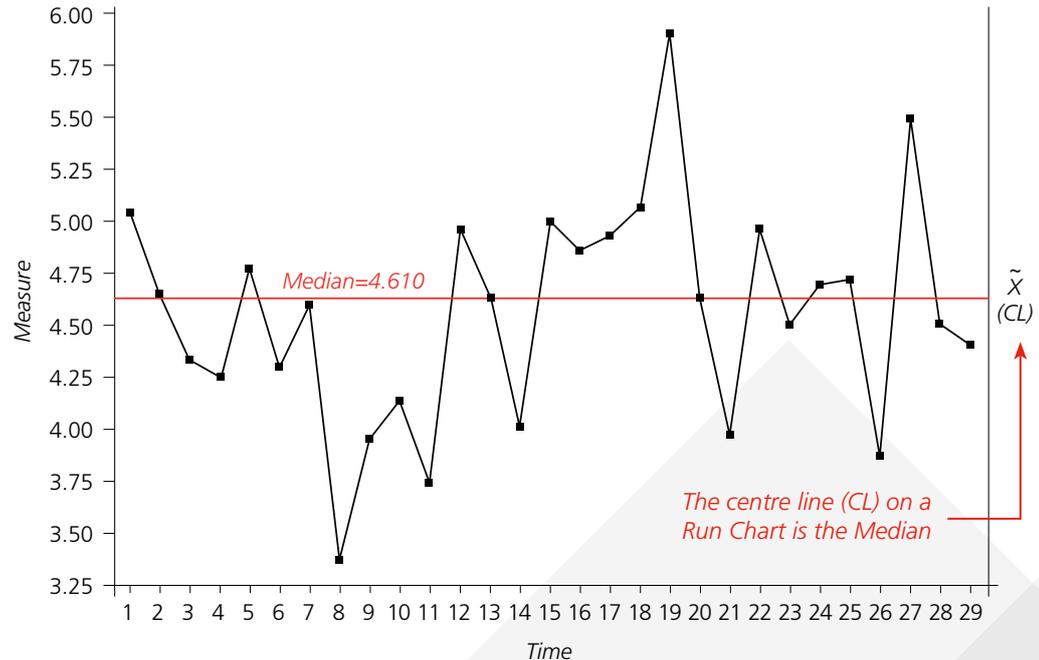
Now what do you conclude about the impact of the new system?

New system implemented here →

79%
$\bar{X}$

86%
$\bar{X}$

100

75

50

24 Months

Run Charts

Elements of a run chart

A run chart shows a measurement on the y-axis plotted over time (on the x-axis). A centre line (CL) is drawn at the median. The median is simply the 50th percentile measurement (ie, the middle data point when all the measurements are arranged in value order). The median is often written as $\tilde{X}$.

Median=4.610

$\tilde{X}$
(CL)

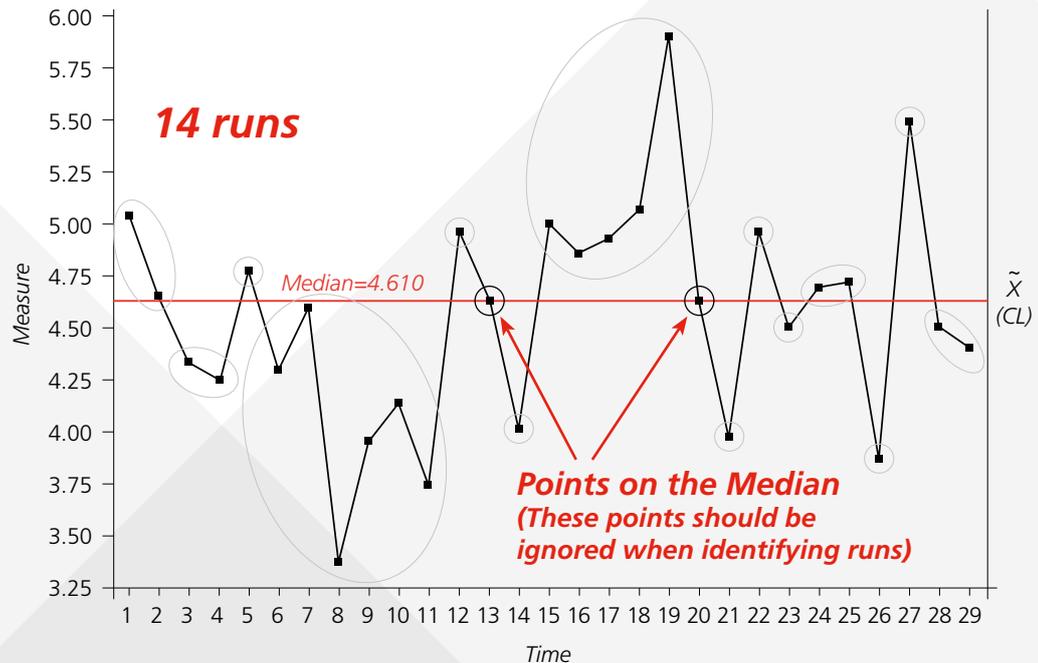*The centre line (CL) on a Run Chart is the Median*

Measure

Time

What is a run?

A run is defined as one or more consecutive data points on the same side of the median. We do not include data points that fall on the median.

Two methods exist for counting the number of runs:

- Draw a circle around each run and count the number of circles you have drawn

- Count the number of times the sequence of data points crosses the median and add "1"

How many runs are on this chart?

14 runs

Median=4.610

Measure

Points on the Median
(These points should be ignored when identifying runs)

$\tilde{X}$
(CL)

Time

Types of variation

Two types of variation may be present in data that is plotted over time. These are **common cause** and **special cause** variation.

Common cause variation

- is inherent in the design of the process
- is due to regular, natural or ordinary causes
- affects all the outcomes of a process
- results in a "stable" process that is predictable
- also known as random or unassignable variation

Special cause variation

- is due to irregular or unnatural causes that are not inherent in the design of the process
- affect some, but not necessarily all aspects of the process
- results in an "unstable" process that is not predictable
- also known as non-random or assignable variation

Rules to identify special cause patterns on a run chart

These non-random patterns indicate special cause variation on a run chart.

Rule 1
- A shift in the process or too many data points in a run (6 or more consecutive points above or below the median)

Rule 2
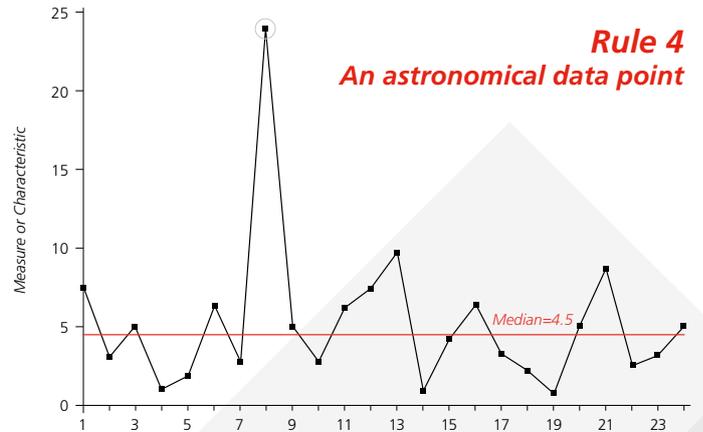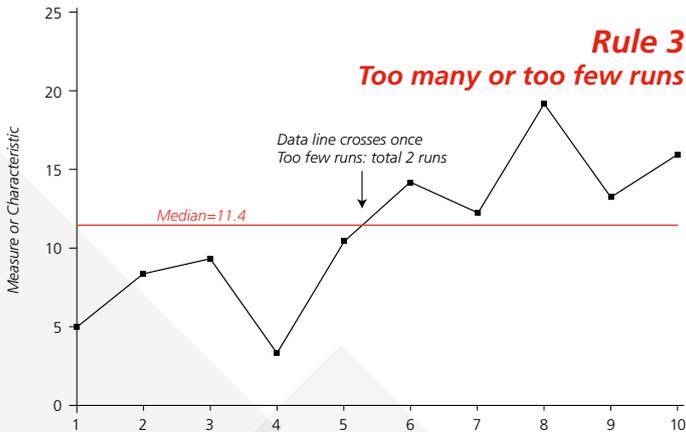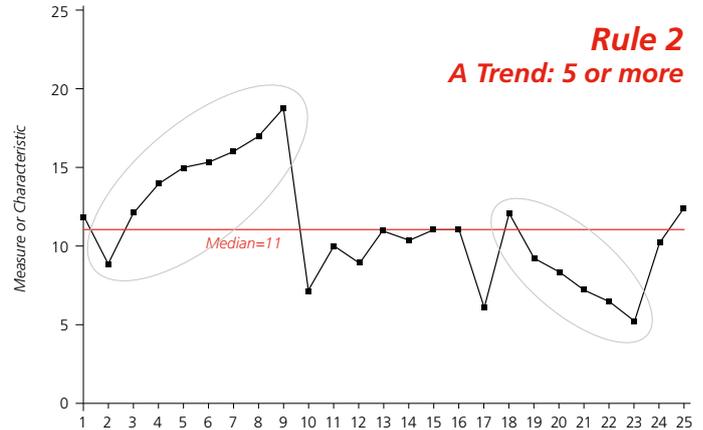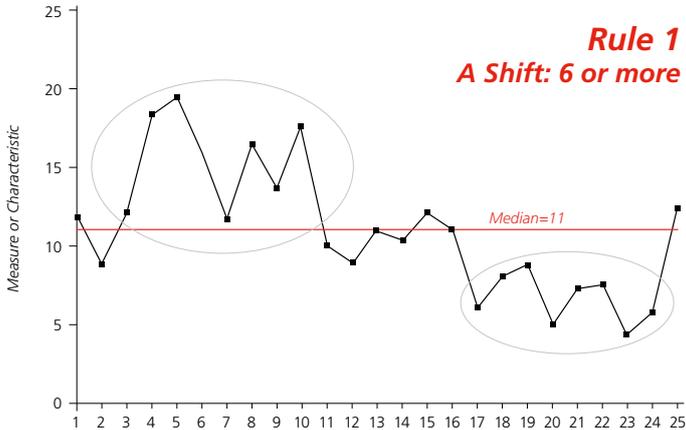- A trend (5 or more consecutive points all increasing or decreasing)

Rule 3
- Too many or too few runs (A table is used in conjunction with this rule and is shown on page 11)

Rule 4
- An "astronomical" data point (Note that this is based upon judgment rather than specific rules)

Non-random rules for run charts

Source: The Data Guide by L. Provost and S. Murray, Austin, Texas. February 2007: p3-10

Using Rule 3 (too few or too many runs)

Use this table to identify the lower and upper limit for the number of runs. First, calculate the number of useful observations in your data set. This is done by subtracting the number of data points on the median from the total number of data points.

Then, read across to establish the lower and upper limits.

If the number of runs in your data falls below the lower limit or above the upper limit then this is a signal of a special cause.

On the earlier example of a run chart on page 7 we had 29 data points with 2 lying on the median. This gives us 27 useful observations. Using this table for 27 useful observations we expect between 9 and 19 runs. We in fact found 14 so we do not have a special cause according to Rule 3.

Useful Observations	Lower Limit for Number of Runs	Upper Limit for Number of Runs
10	3	8
11	3	9
12	3	10
13	4	10
14	4	11
15	4	12
16	5	12
17	5	13
18	6	13
19	6	14
20	6	15
21	7	15
22	7	16
23	8	16
24	8	17
25	9	17
26	9	18
27	9	19
28	10	19
29	10	20
30	11	20
31	11	21
32	11	22
33	11	22
34	12	23
35	13	23
36	13	24
37	13	25
38	14	25
39	14	26
40	15	26
41	16	26
42	16	27
43	17	27
44	17	28
45	17	29
46	17	30
47	18	30
48	18	31
49	19	31
50	19	32
60	24	37
70	28	43
80	33	48
90	37	54
100	42	59
110	46	65
120	51	70

Source: Quality Improvement: Practical Applications for Medical Group Practice. D Balestracci and J L Barlow
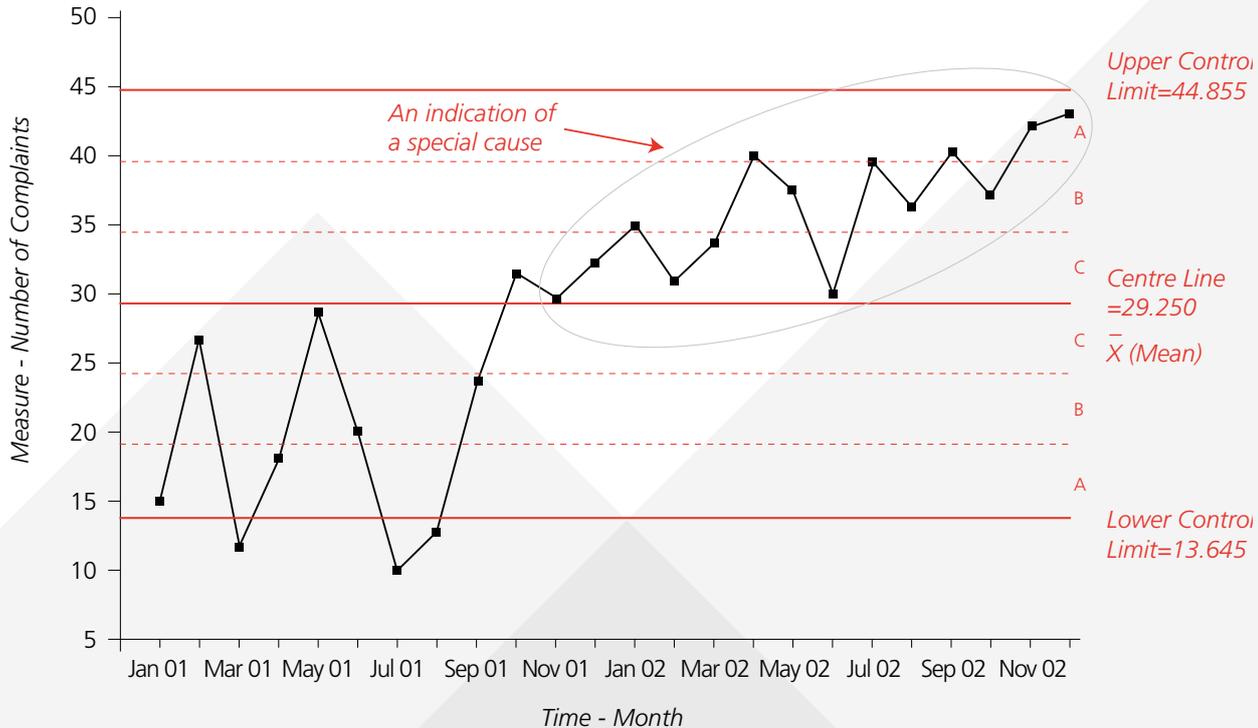
Control Charts

Elements of a control chart

A **control chart** is similar to a run chart in so far as it plots a measurement over time. However, control charts are based upon a more in-depth statistical analysis of the data and thus have some different features from a run chart.

- The central line on a control chart is the **mean** of the measurements (instead of the median which is used in a run chart). The mean is calculated by adding up all the measurement points and then dividing by the total number of measurement points.

- A control chart has **upper and lower control limits** shown as horizontal lines across the chart. These lines are used when identifying special causes. In some types of control chart these lines can have a stepped appearance (as shown later for a p-chart).

- Control charts have their own set of **rules** for identifying special causes which are generally different from the rules applied to run charts.

Elements of a control chart

A variety of methods exist to create control charts. The type of chart is determined by the type of data being analysed – **variable or attribute**.

Measure - Number of Complaints (y-axis)

Time - Month (x-axis)

An indication of a special cause

Upper Control Limit=44.855

Centre Line =29.250

$\bar{X}$ (Mean)

Lower Control Limit=13.645

Attribute and variable data

Variable data:

Is also known as "**measurement**" data. It can be measured along a continuous scale (like the scale of a ruler).

Attribute data:

Is also known as "**discrete**" or "**count**" data. This type of data relates to attributes that can be classified into categories. For example, a patient is alive or dead, pregnant or not pregnant.

Attribute data can be further classified into **defectives** or **defects**. The difference between these two is subtle but important. For **defectives** it is possible to count up when a defective event occurred (such as a death) as well as count up the total number of opportunities for the event to occur (such as the total number of patients who had a particular risky procedure). Thus for **defectives** you can calculate a percentage (such as the percentage of deaths). For **defects** on the other hand it is possible to know when a defect event occurred (such as a fall) but you do not know the number of non-defects (such as the number of non-falls). Instead for **defects** you tend to know the opportunity for a non-defect (such as the total number of patient days in hospital). Thus for **defects** you tend to calculate a rate (such as falls per patient day).

Examples of attribute data

Defects:
- Needle-stick injuries per week
- Falls per admitted patient day
- Number of medication errors per week
- Complaints per patient (which is different from the defective measure since a patient may complain more than once)
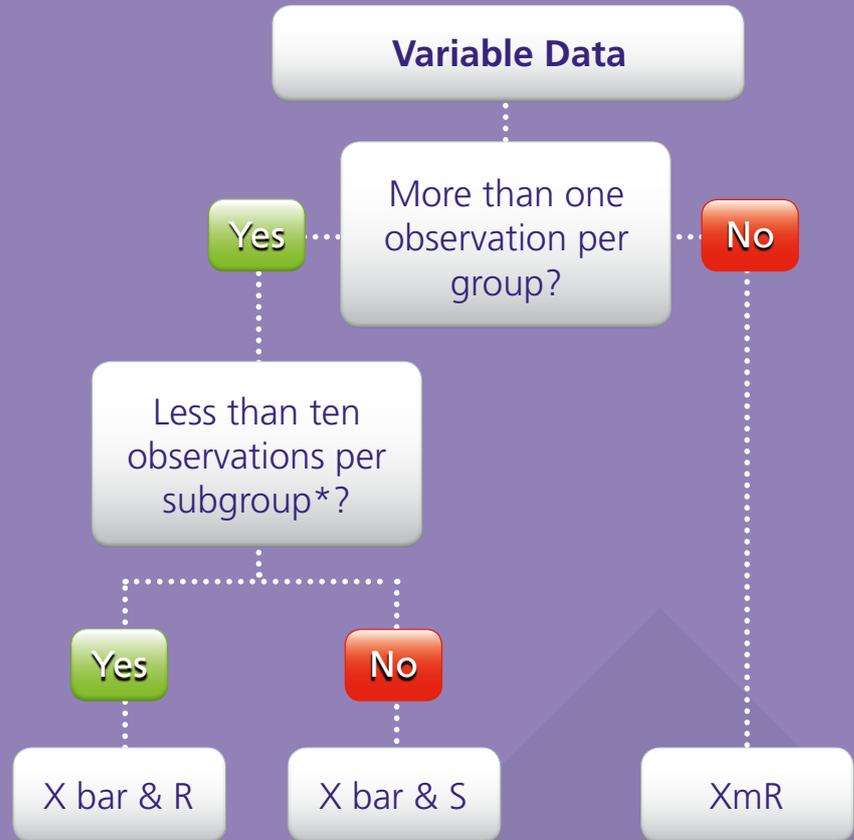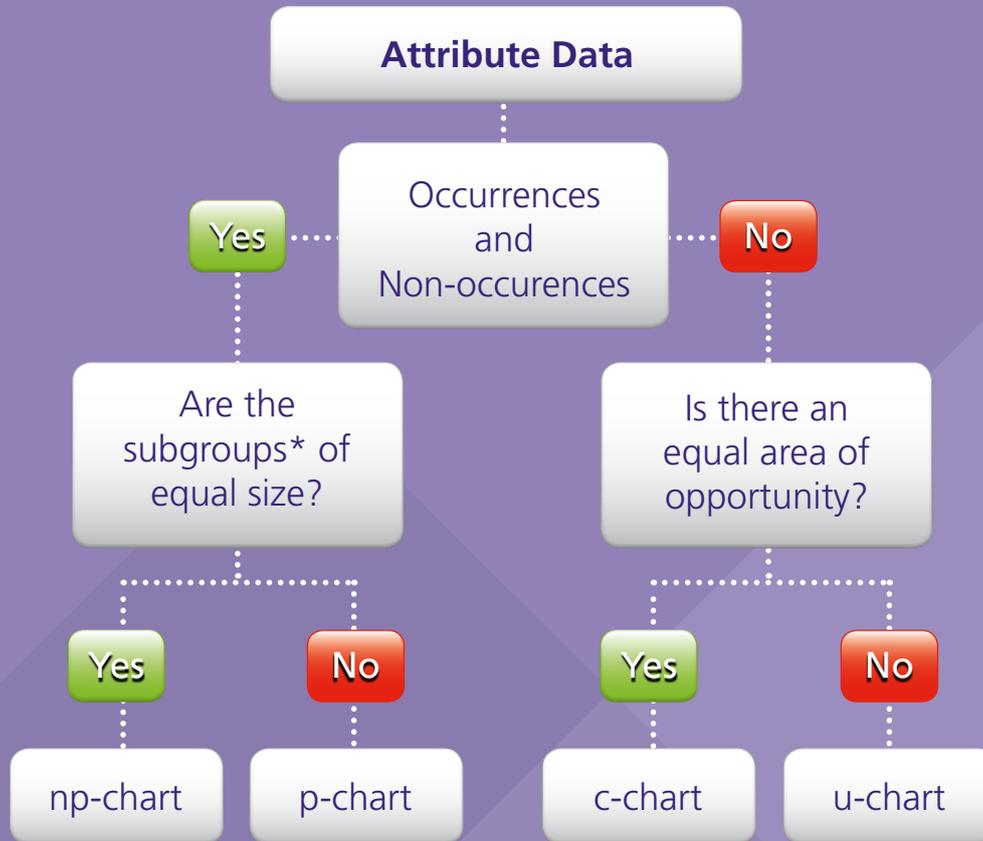
Examples of attribute data

Defectives:
- % deaths
- % caesarean sections
- % patients achieving above a specified outcome score
- % smoking quitters
- % of readmissions
- % of patients who made one or more complaints

Examples of variable data:
- Waiting times
- Blood pressure readings
- The number of procedures performed in a day

The control chart decision tree

Use this decision tree to decide which type of control chart to produce.

In many health applications you will most frequently use XmR charts (for variable data) and p-charts or u-charts (for attribute data) .

Variable Data

More than one observation per group?

Yes

No

Less than ten observations per subgroup*?

Yes

No

X bar & R

X bar & S

XmR

Attribute Data

Occurrences and Non-occurences

Yes · · · · No

Are the subgroups* of equal size?

Is there an equal area of opportunity?

Yes — No

Yes — No

np-chart — p-chart

c-chart — u-chart

* A 'subgroup' is defined as a sample of data pulled from the stream of data produced by a process.

For example, in a laboratory setting a subgroup could be the hour of the day where we measure a sample of 50 report turnaround times within each hour. In this case the sample size (50) is our number of 'observations'.

Alternatively, if we measured the weight loss of each patient on a particular drug regime then our subgroup is now 'each patient' and we have one observation per patient.

Types of control chart (the seven basic types) with examples

Charts for variable data

X & R chart	Samples of observations (<10): Lab turnaround time
average & range chart	(based on a small sample of requests), blood pressure (based on three readings per day)

X & S chart	Samples of observations (>=10): Lab turnaround time
average & standard deviation chart	(based on a large number of requests), patient satisfaction scores (from a sample of 50 patients per week)

XmR chart (also known as an I chart)	Single observations: Waiting times, the number of calls
individuals & moving range chart	each day, average length of stay for an HRG, weight of waste produced each day

Charts for attribute data

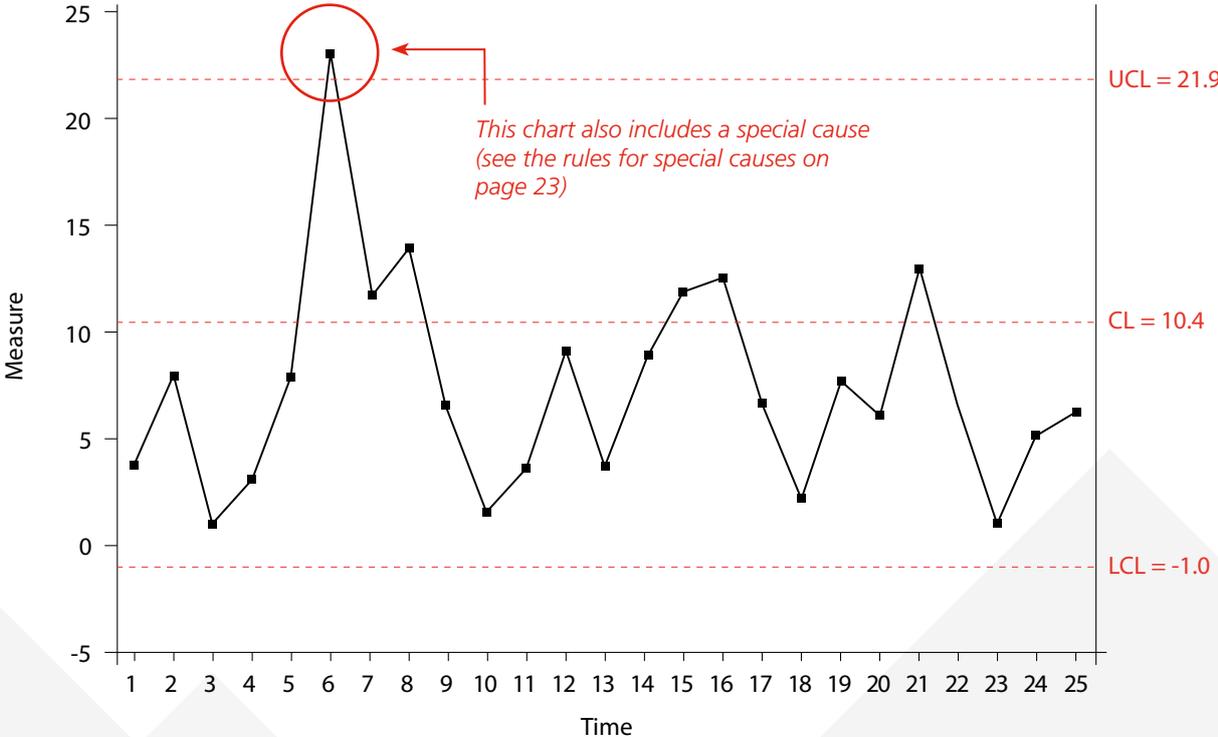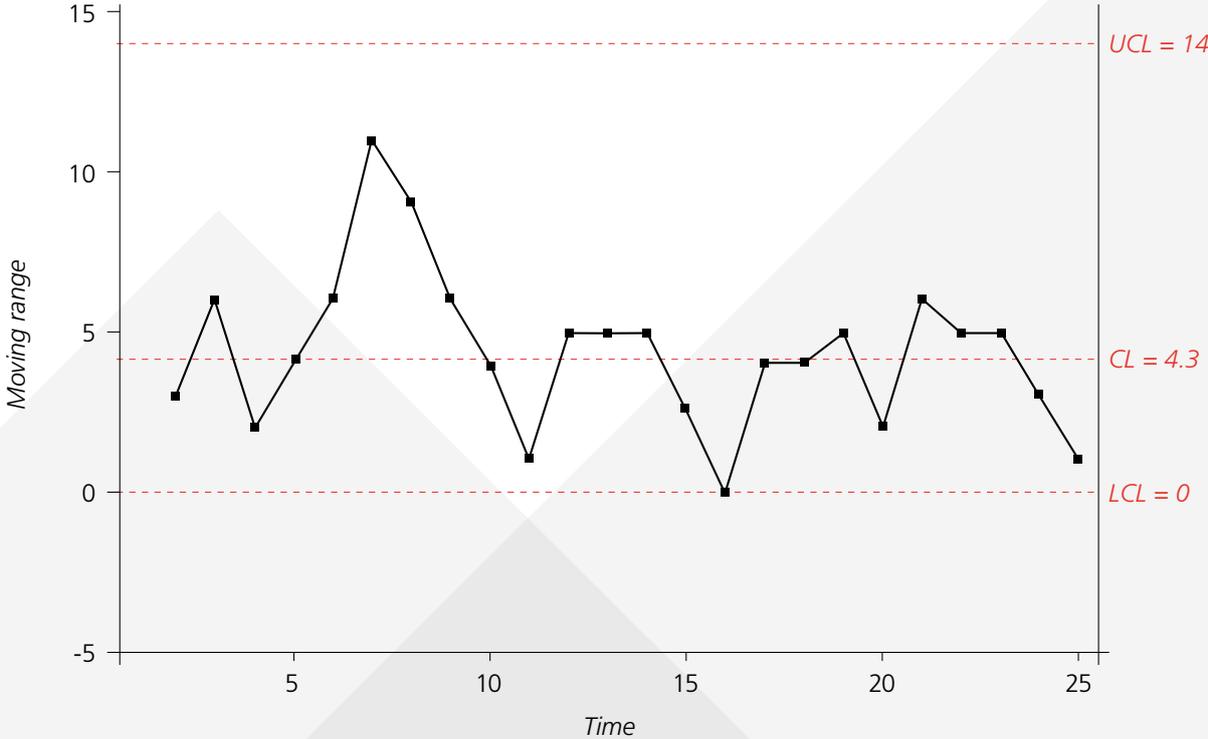| **p-chart** proportion or percent of defectives	**Defective percentage (or proportion):** % caesarean sections, % mortality, % late surgery starts
np-chart number of defectives	**Defective number (from a constant sized sample):** number of caesarean sections, number of deaths, number of late surgery starts
c-chart number of defectives	**Counts (within an equal area of opportunity):** Number of falls (over a defined period), number of infections (over a defined period). Note that the "defined period" is fixed (eg, falls are counted each week and plotted weekly)
u-chart defect rate	**Rates (within an unequal area of opportunity):** Number of falls per 1000 bed days, number of ventilator associated pneumonias (VAPs) per 100 ventilator days. Note that the area of opportunity may vary (eg, each month the number of ventilator days will vary)

An example of an XmR chart

This chart plots the measures over time with upper and lower control limits calculated.

This chart also includes a special cause (see the rules for special causes on page 23)
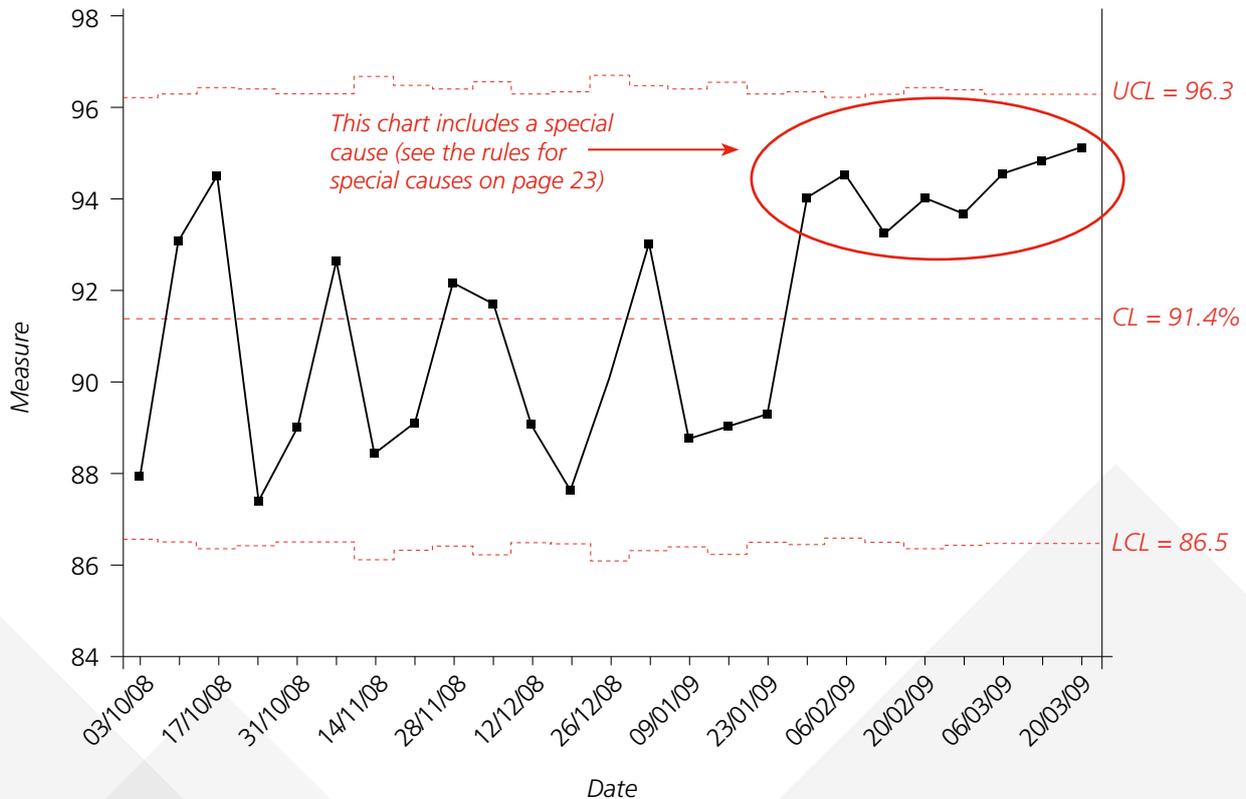
UCL = 21.9

CL = 10.4

LCL = -1.0

This chart plots the moving range over time (ie, the absolute difference between consecutive measures). Upper and lower control limits are also calculated for the moving range.

An example of a p-chart

In a p-chart the control limits have this characteristic stepped appearance. This is because a control limit is calculated for each individual measure (and depends on the denominator in the percentage)

Rules to identify special cause patterns on a control chart

There are many rules to detect a special cause on a control chart. The following five rules are recommended for general use and will suit most applications of control charts in healthcare.

The rules introduce the concept of "Sigma". This is a value calculated when producing control limits (and is routinely calculated in all software that produces control charts). The calculation of sigma depends on the chart type but it is based upon the variability in the data. The upper and lower control limits are set at +/- three sigma.

Rule 1
• 1 point outside the +/- 3 sigma limits

Rule 4
• 2 out of 3 successive points beyond
  +/- 2 sigma limits

Rule 2
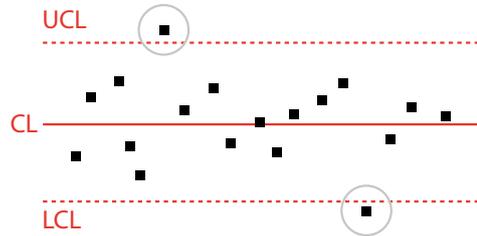• 8 successive consecutive points above
  (or below) the centre line

Rule 5
• 15 consecutive points within +/- 1
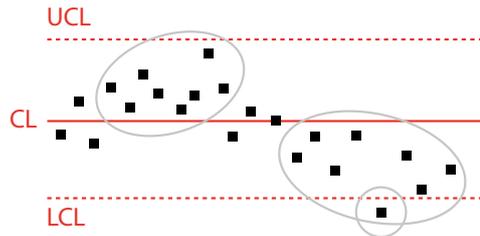 sigma on either side of the centre line

Rule 3
• 6 or more consecutive points steadily
  increasing or decreasing

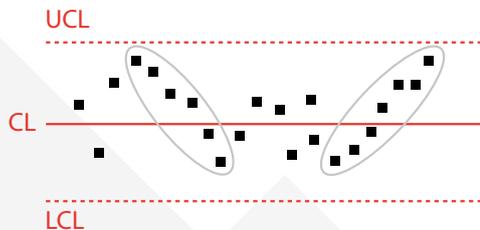# Examples of the special cause rules for control charts

1 A single point outside the control limits

Note: A point exactly on a control limit is not considered outside the limit. When there is not a lower or upper control limit Rule 1 does not apply to the side missing the limit.
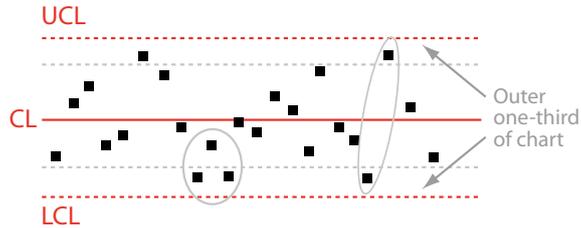

2 A run of 8 or more points in a row above (or below) the centre line

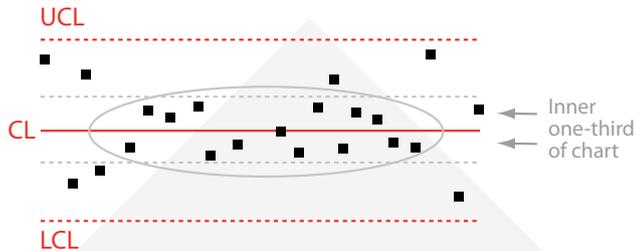**Note:** A point exactly on the centre line does not cancel or count towards a shift.

3 Six consecutive points increasing (trend up) or decreasing (trend down)

Note: Ties between two consecutive points (ie, equal values) do not cancel or add to a trend. When control charts have varying limits due to varying numbers of measurments within subgroups, then Rule 3 should not be applied.

UCL

CL

LCL

Outer
one-third
of chart

4 Two out of three consecutive points near a control limit (in the outer one-third)

When there is not a lower or upper control limit Rule 4 does not apply to the side missing a limit.

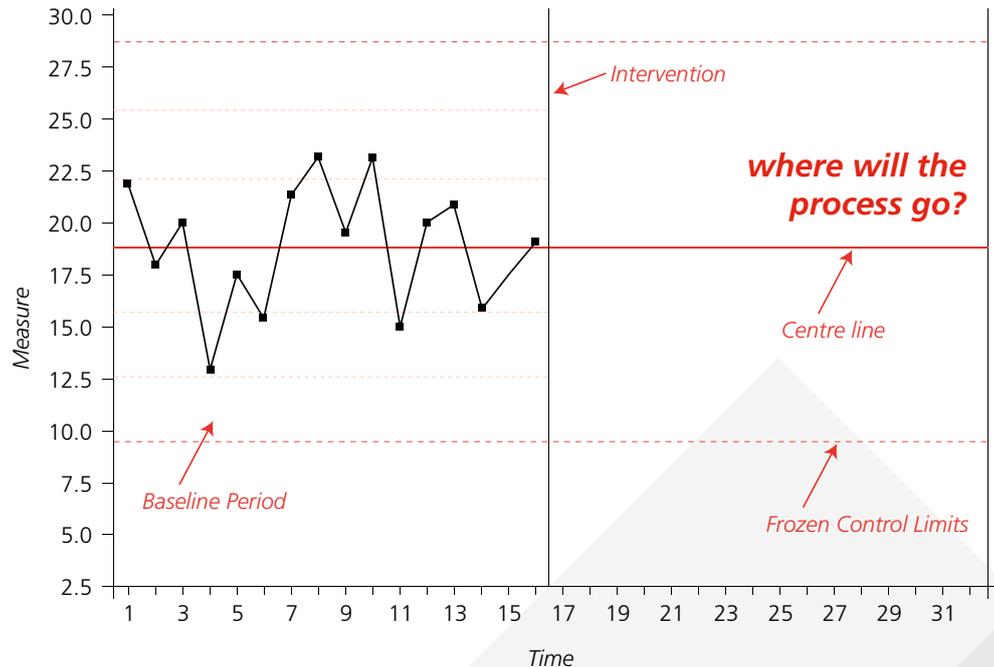
UCL

CL

LCL

Inner
one-third
of chart

5 Fifteen consecutive points close to the centre line (in the inner one-third)
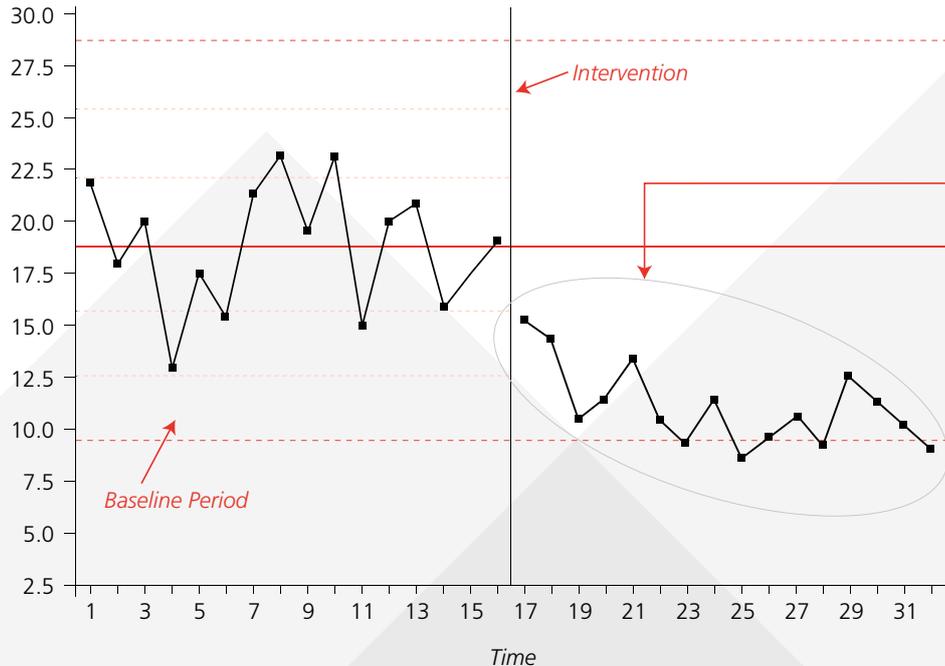
Hugging the centre line.

Process Changes

Testing a process change (freezing the control limits)

To test whether a process change has improved a stable process, firstly freeze the control limits and the centre line at the pre-change levels. Then extend these into the post-change period.

Intervention

where will the process go?

Centre line

Baseline Period

Frozen Control Limits

Measure

Time

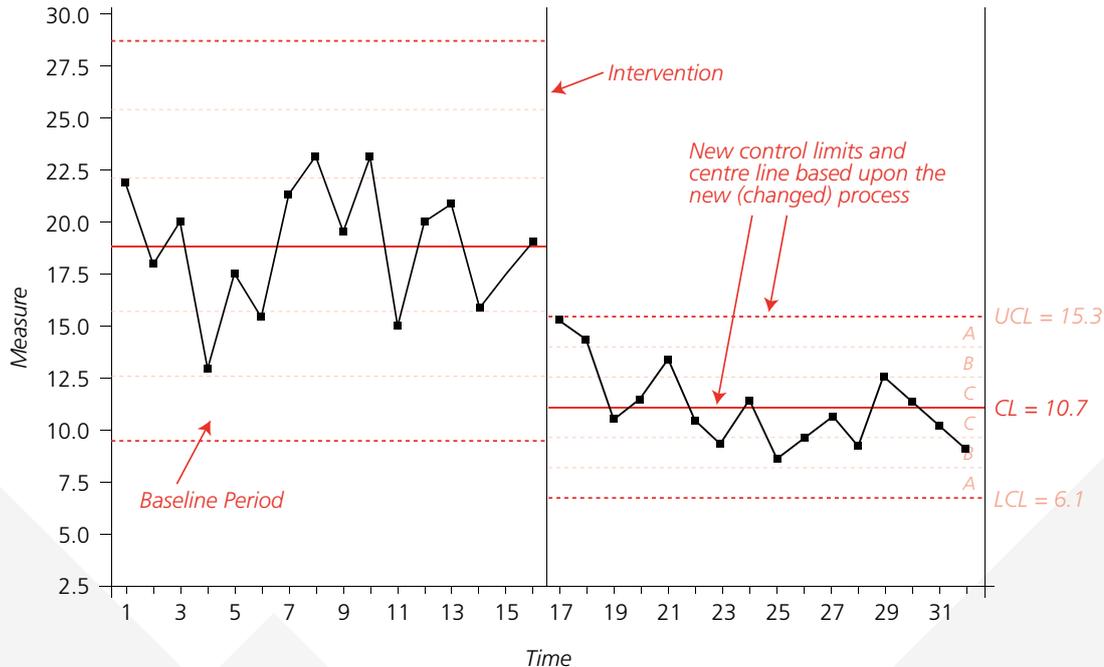## Testing a process change (looking for a special cause)

Next plot the post-change data. Using the old control limits and centre line look for a special cause. If you detect a special cause it is a sign that the process has measurably changed.

Intervention

*A special cause is detected.
A run of 8 or more data points on one side of the centre line reflecting a shift in the process (Rule 2)*

Baseline Period

Time

Testing a process change (understanding the new process)

If a special cause is detected, calculate a new centre line and control limits for the post-change data. These are calculated in exactly the same way as usual but only using the post-change data.

Recommended Reading

This short guide has been produced by the NHS Institute for Innovation and Improvement to support teams using run and control charts in service improvement projects.

The content of this guide is based upon the work of Dr Robert Lloyd (Executive Director Performance Improvement, Institute for Healthcare Improvement). We are indebted to Dr Lloyd for his support in helping us to promote the science of improvement in the NHS.

To learn more about the science of improvement and the use of run and control charts, we recommend:

- **R C Lloyd, *Quality Healthcare: A guide to developing and using indicators,* Jones and Bartlett (2004)**

- **J C Benneyan, R C Lloyd, P E Plsek, *Statistical process control as a tool for research and healthcare improvement,* Quality and Safety in Health Care 2003;12:458–464**

- **M A Mohammed, P Worthington, W H Woodall, *Plotting basic control charts: tutorial notes for healthcare practitioners,* Quality and Safety in Health Care 2008;17:137–145.**

- **D Balestracci, J L Barlow, *Quality Improvement: Practical Applications for Medical Group Practice,* Medical Group Management Association (1996)**

Notes

Further copies of this guide can be ordered from our online catalogue.

Product code: NHSICommruncont1

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