NHS
Institute for Innovation and Improvement

The *Organising for Quality and Value: Delivering Improvement* programme

Measurement for Improvement and Return on Investment

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Introduction

This learning resource has been designed to support you in your work.

This is your opportunity to identify your aspirations for service improvement and work through your own projects using this resource as a reference and as part of your own development.

By working through the materials and then applying your learning to your work, you will enhance your measurement skills and your understanding of return on investment.

Key for symbols used in this workbook

Exercise

Distracting thoughts - write them down

Reflection

Take a break

Measurement for improvement and return on investment

The aims and objectives of the measurement and return on investment module of the *Organising for Quality and Value: Delivering Improvement* programme are:

Aim

- To improve your knowledge and understanding of data analysis and return on investment

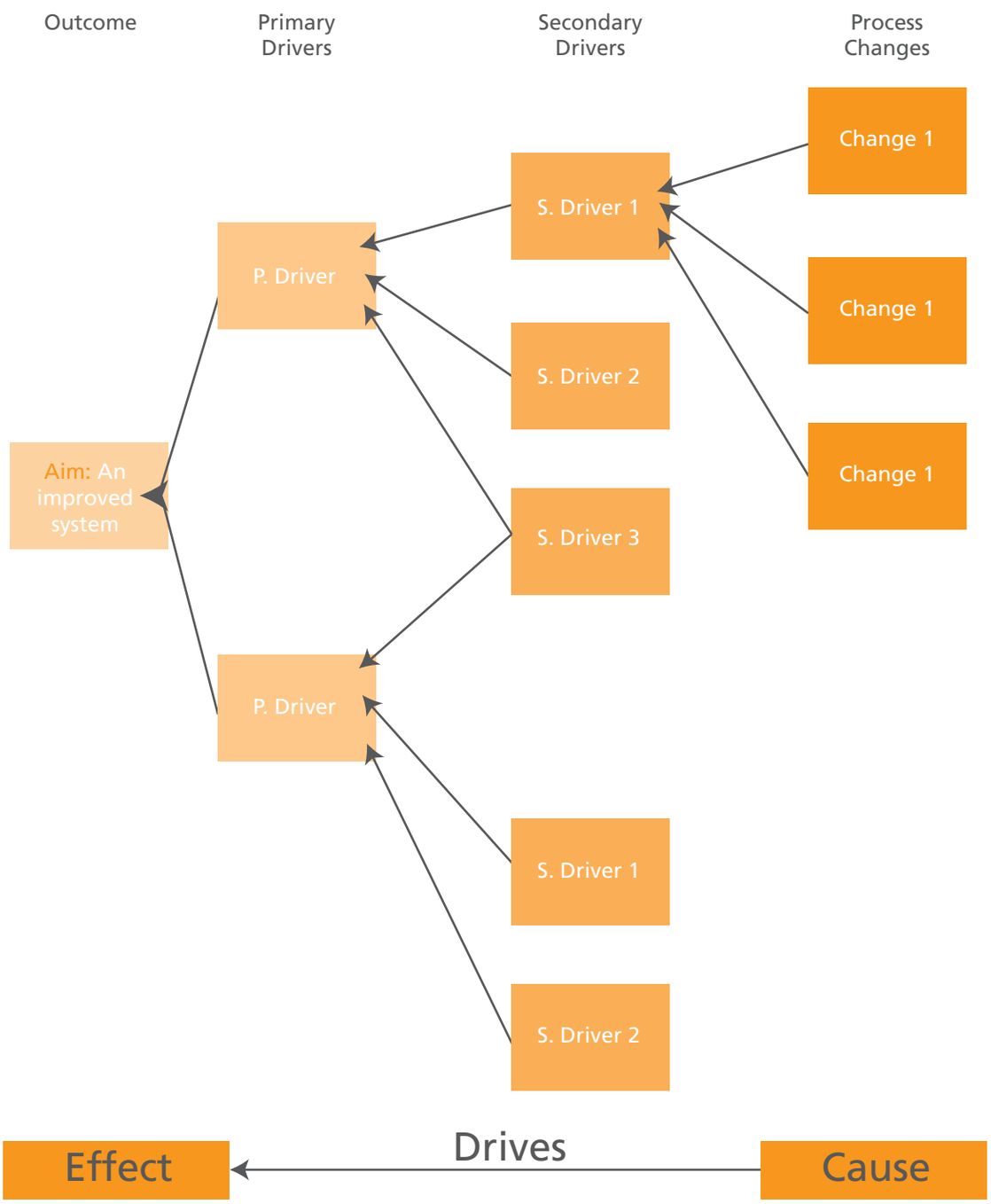
Objectives

- Understand how to do 'real' analysis
- Use data to improve decision-making and identify real improvements
- Understand how to calculate the true return on investment of an improvement initiative

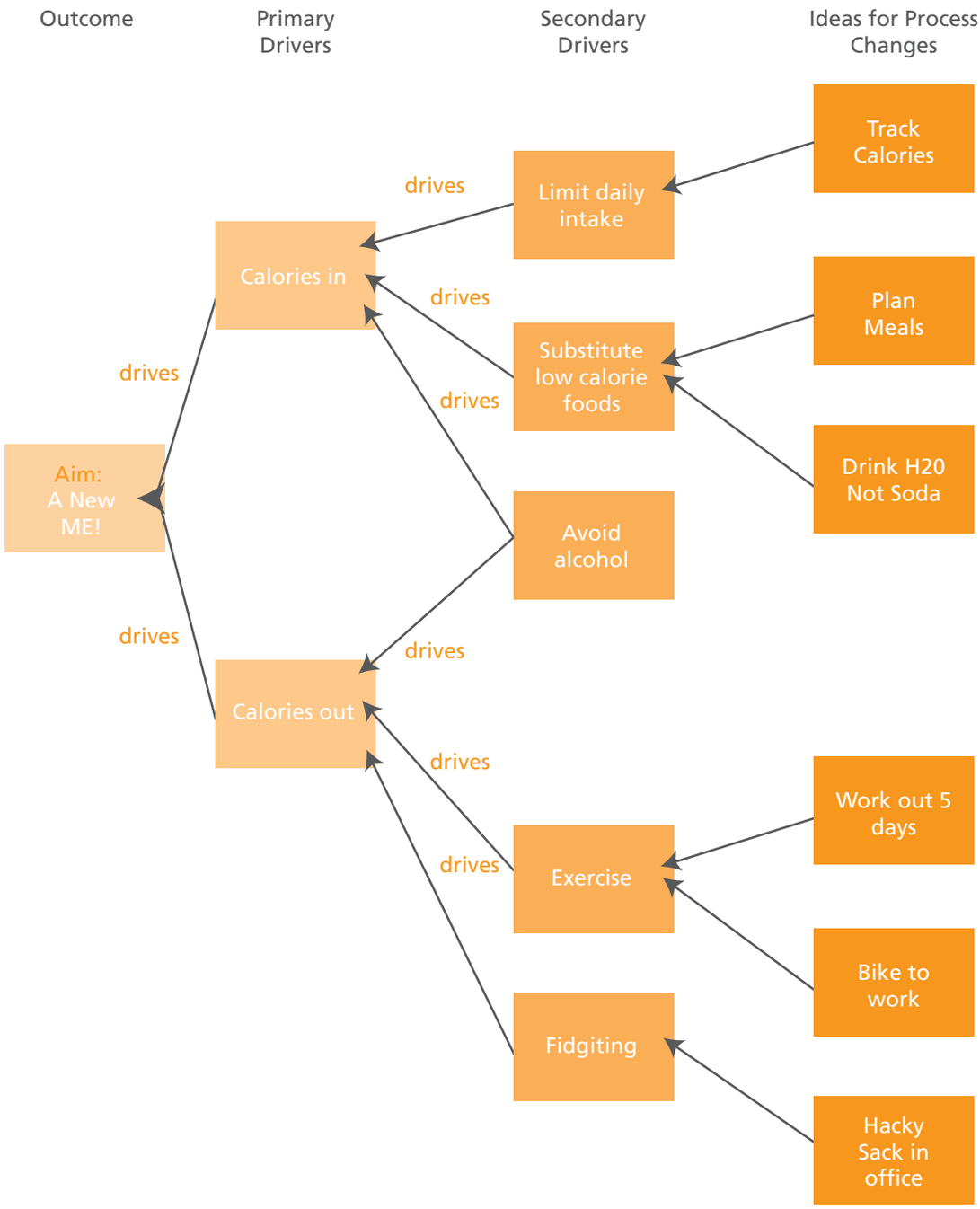
Measurement - more on driver diagrams

Here's a schematic view of a system – a 'driver diagram'. On the left we depict the outcome in the orange box. As we move right we drill down into the network of causes that drive the outcome, from 'primary' to 'secondary' drivers. On the right we depict the ideas for system changes that might ultimately impact the outcome.

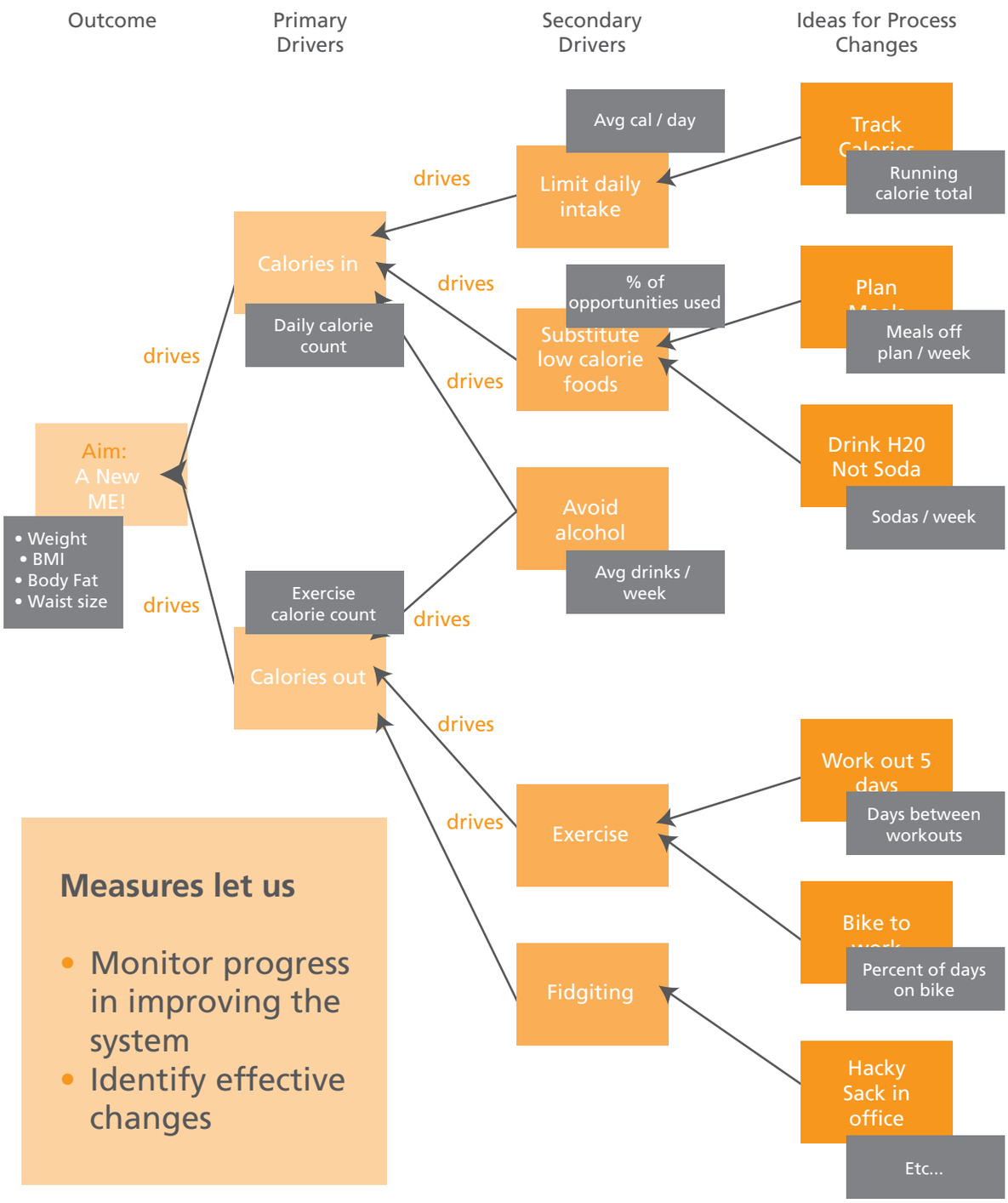
This diagram represents our theory about how to modify the system to change the outcome.



Example driver diagram - weight loss



Example driver diagram - weight loss - with measures



Exercise 1: Driver diagram template

Create a driver diagram for your project

Aim Write your project here.	**Primary drivers** List the main drivers that influence your aim here. Use a verb to describe the driver e.g. do exercise as this helps you focus on exactly what the driver is.	**Interventions** List the actions, processes or interventions that when performed correctly will lead to a positive effect on a driver. Link these to the relevant driver.

Exercise 2: Measures checklist

Part 1: Measures setup

Measure name:		
Why is it important? (Provides justification and any links to organisation strategy)		
Who owns this measure? (Person responsible for making it happen)		
Measure definition	**What is the definition?** (Spell it out very clearly in words)	
	What data items do you need?	
	What is the calculation?	
	Which patient groups are to be covered?	
Goal setting	**What is the numeric goal you are setting yourselves?**	
	Who is responsible for setting this?	
	When will it be achieved by?	

Exercise 2: Measures checklist

Part 2: Measurement process

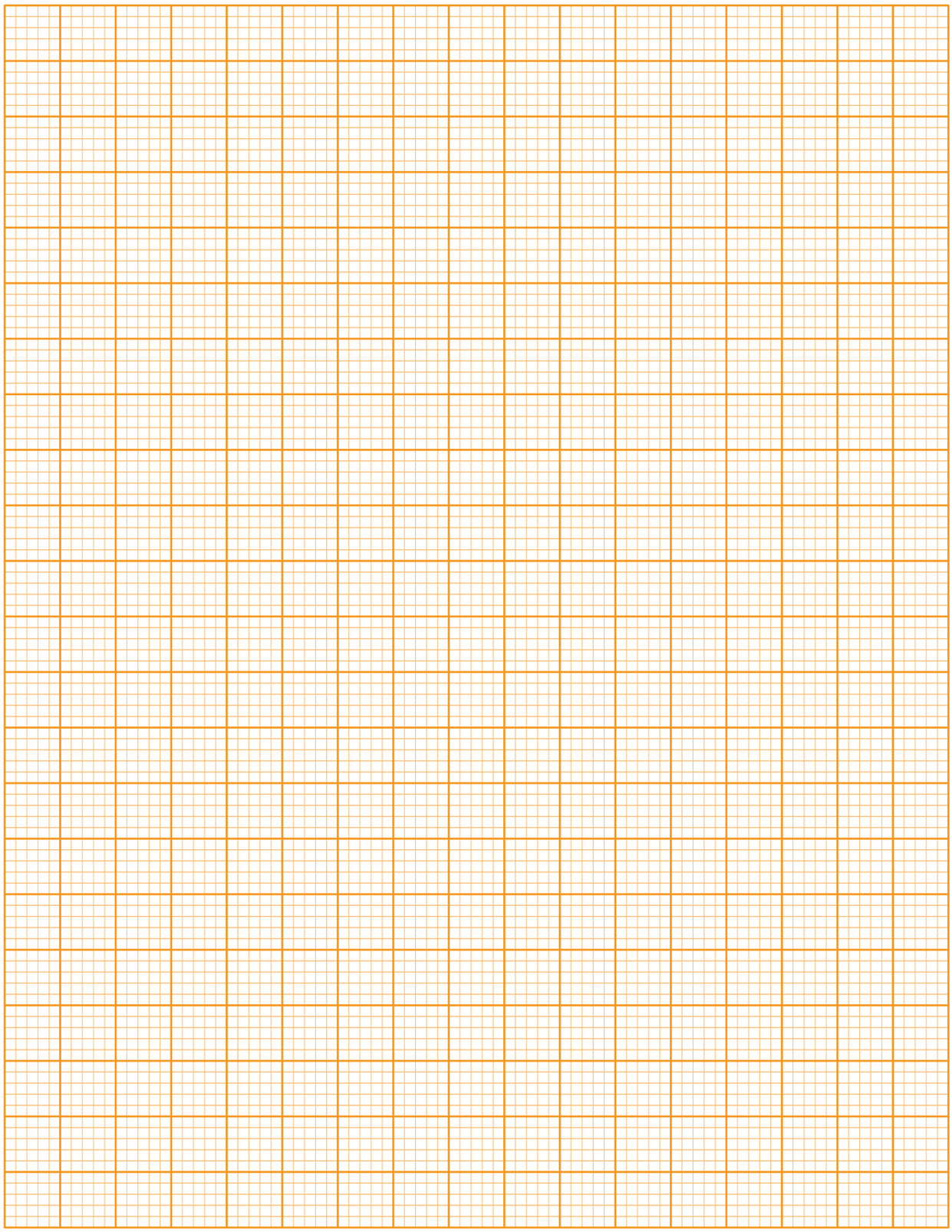
Collect	**Is the data available?** (Currently available / available with minor changes / prospective collection needed)	
	Who is responsible for data collection?	
	What is the process of collection?	
Analyse Calculate measure and present results	**What is the process for presenting results?** E.g. create run chart or bar chart in Excel	
	Who is responsible for the analysis?	
	How often is the analysis completed?	
Review	**Where will decisions be made based on results?**	
	Who is responsible for taking action?	

Exercise 3: Run chart

Using these figures create a run chart on the graph paper provided. Then analyse it.

Week	% compliance with hand hygiene	Median
01-Apr	50	
08-Apr	43	
15-Apr	20	
22-Apr	45	
29-Apr	70	
06-May	54	
13-May	34	
20-May	67	
27-May	32	
03-Jun	79	
10-Jun	85	
17-Jun	90	
24-Jun	70	
01-Jul	89	
08-Jul	78	
15-Jul	92	
22-Jul	50	
29-Jul	65	
05-Aug	40	
12-Aug	54	
19-Aug	48	
26-Aug	37	
02-Sep	50	
09-Sep	63	
16-Sep	45	

Exercise 3: Run chart graph paper



Exercise 3: Run chart graph paper

Exercise 4: Interpretation of rule for the presence of special causes

Objectives

1. To understand the four rules associated with special causes.
2. To apply these to detect specific control chart patterns.

Method

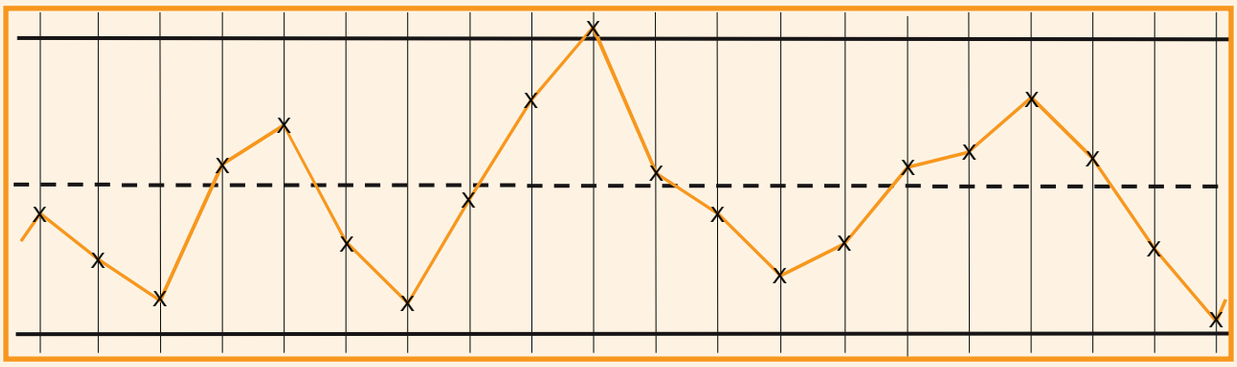
Chart patterns are to be analysed using the following rules:

Rule 1	Any point outside one of the control limits
Rule 2	A run of seven points all above or all below the central line, or all increasing / all decreasing
Rule 3	Any unusual patterns or trends within the control limits
Rule 4	The proportion of points within the middle 1/3 of the region between the control limits differs from 2/3

Analysis

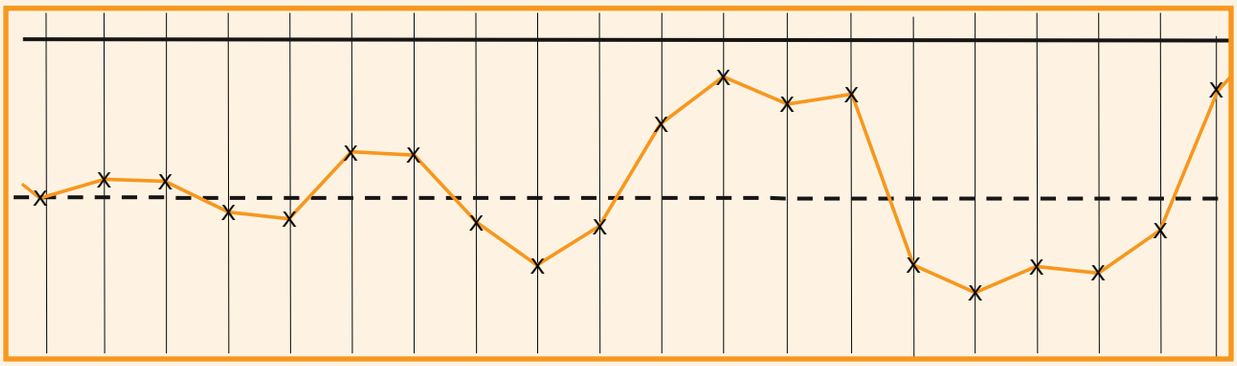
For each of the processes shown on the following pages, indicate which, if any, of the four rules apply and define the corresponding status of the process.

Process 1



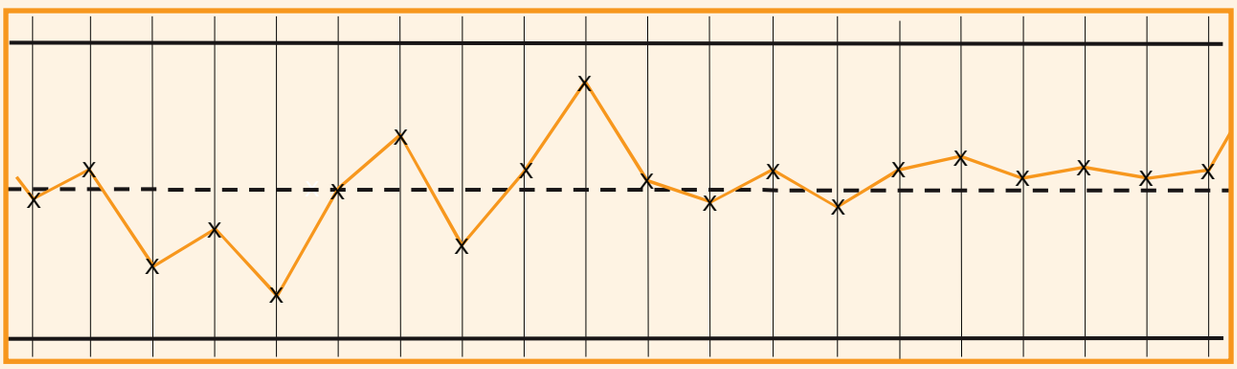
Rule	1	2	3	4	In control?	Yes / No / Not sure

Process 2



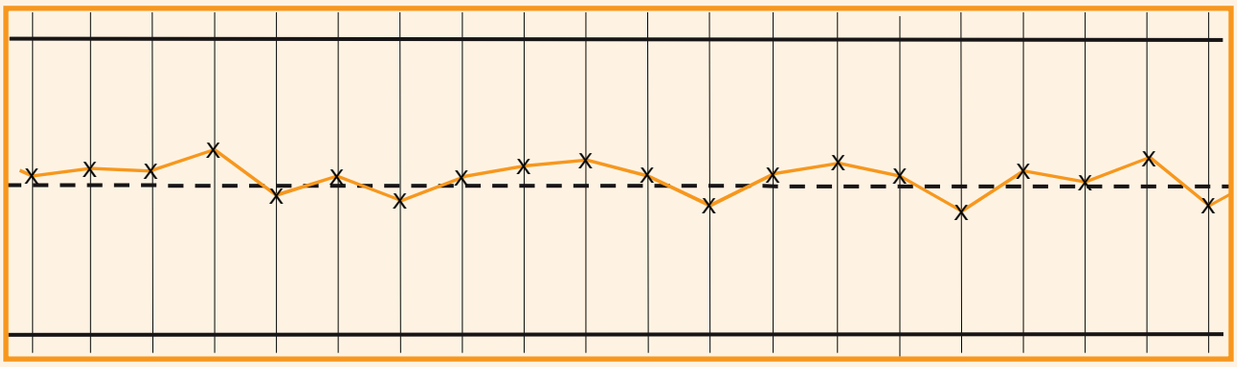
Rule	1	2	3	4	In control?	Yes / No / Not sure

Process 3



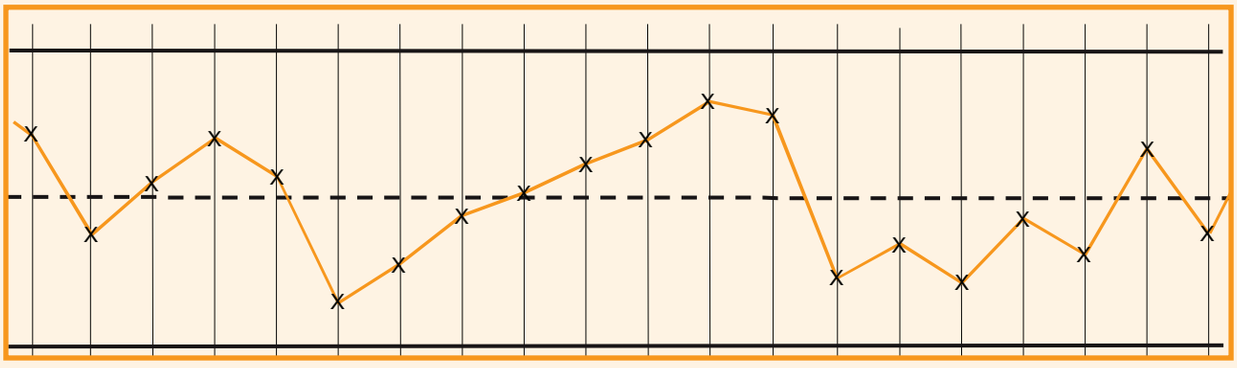
Rule	1	2	3	4	In control?	Yes / No / Not sure

Process 4



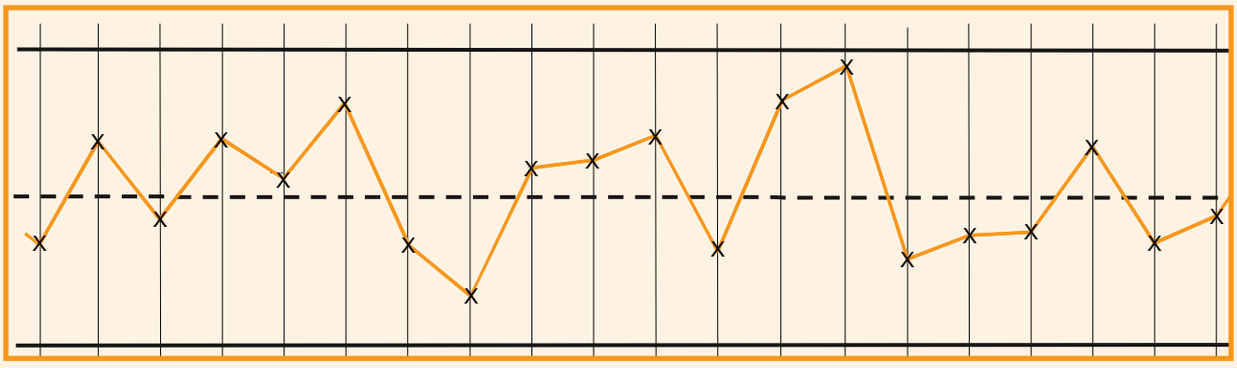
Rule	1	2	3	4	In control?	Yes / No / Not sure

Process 5



Rule	1	2	3	4	In control?	Yes / No / Not sure

Process 6



Rule	1	2	3	4	In control?	Yes / No / Not sure

Answers

Interpreting patterns

Six control charts are provided.
Bear in mind that for all these processes the control limits have been worked out earlier, based on the first 20 points, and so we are using the charts in an ongoing monitoring sense.

A reminder of the rules.

Rule 1	Any point outside one of the control limits
Rule 2	A run of seven points all above or all below the central line, or all increasing / all decreasing
Rule 3	Any unusual patterns or trends within the control limits
Rule 4	The proportion of points within the middle 1/3 of the region between the control limits differs from 2/3

Process 1

Here we have a point outside the control limits and so the process is:

Out of control

Be careful however. Remember that the control limits as defined by Shewhart were set to minimise the risk of reacting to a point when you shouldn't and alternatively not reacting to a point when you should. So, sometimes, you will find a point just outside the control limits for which you cannot find a reason. You then take this point as being part of the system. Alternatively, sometimes you find a point just inside the control limits and you can associate it with a special cause.

Both these events are rarities and in the great majority of cases you would be safe in associating a point outside the control limits with a special cause.

Process 2

Here Rule 3 is operating. We have an unusual pattern. The readings are beginning to oscillate in an increasingly wilder pattern. There is enough evidence available to suggest that the variation will carry on in a similar way and shortly provide readings that will be outside the control limits.

The answer is Out of control

Note that you could not make this judgement earlier. For example, if you look at the process up to sample no. 9, there is not enough evidence to indicate that something unusual is happening. We need more data. The reaction is somewhat subjective and will be determined by the experience of the process owner.

Note also that Rule 4 might also apply. However, it is Rule 3 that is dominant and the presence of Rule 3 results in Rule 4 operating on its back.

Process 3

Three of the rules operate.

First Rule 2. We have a run of seven points above the central line at the back end of the chart. I know we only have six points plotted, but the line onwards from the sixth point is going upwards, which must result in seven points above the central line.

Of more interest is the presence of Rule 3.

If you look at points from 10 onwards, they represent a much tighter level of variation than that represented by the earlier points. Therefore there is a need to see if anything has happened somewhere about sample 10, or possibly earlier, to result in reduced variation.

As it happens, Rule 4 is probably applicable, taking into account the latter points in the process. Again, Rule 4 is only operating because Rule 3, the dominant one in this case, is operating as well.

Process 4

A clear case of the application of Rule 4.

All the points are in the middle third zone, and recognising that the control limits were set up earlier in the process, this cannot be.

So, technically, the process is **Out of control**

Delegates have a real difficulty here. They cannot understand how it is that we have a case of a process showing real improvement, yet the process is defined as being out of control.

It is a case of understanding what is meant by 'out of control' in a statistical sense.

By 'out of control' we mean a signal that indicates a change from the original situation, either for better or for worse.

It is understandable that people associate out of control with things going wrong. However, in a control chart sense we can have a signal that things have gone right, as in this case.

Most people agree what to do next. We need to calculate new control limits that represent the improved situation.

Process 4 therefore represents the best example of process improvement.

Process 5

Rule 2 is operating. We have a run of seven points all moving upwards. As you may have picked up, the run of seven rule can be interpreted in slightly different ways. I have suggested a run of seven including the first point. An alternative is to have a run of eight, not including the first point, or even including the first point. Software packages provide different options. It doesn't really matter as long as within the organisation we decide on what definition to use.

Whether our process is under control or not is another issue. Two scenarios present themselves.

In the first case we look for a special cause, which should appear somewhere about the beginning of the run. We find one and eliminate the reason. After doing so the process returns to a natural random pattern.

In the second case we again look for a special cause but here we cannot find one. The rule has operated, but it does not necessarily mean that there is a special cause present. This time we have a run operating but it is a chance event. This being the case, the process will naturally return to representing a random pattern.

So the answer to the question is **Not sure**. It depended on whether or not we found a special cause and how we reacted.

Process 6

The process is **Under control**

Folk will have enough to do with other processes before they start digging and delving into Process 6, seeing if there is something unusual when there isn't.

Exercise 5: SPC calculations worksheet

Week	% compliance with hand hygiene	Average	Moving range	Average moving range	Upper control limit	Lower control limit
01-Apr	50					
08-Apr	43					
15-Apr	20					
22-Apr	45					
29-Apr	70					
06-May	54					
13-May	34					
20-May	67					
27-May	32					
03-Jun	79					
10-Jun	85					
17-Jun	90					
24-Jun	70					
01-Jul	89					
08-Jul	78					
15-Jul	92					
22-Jul	50					
29-Jul	65					
05-Aug	40					
12-Aug	54					
19-Aug	48					
26-Aug	37					
02-Sep	50					
09-Sep	63					
16-Sep	45					

Answers - SPC calculations worksheet

Week	% compliance with hand hygiene	Average	Moving range	Average moving range	Upper control limit	Lower control limit
01-Apr	50	58		19.29	109.31	6.69
08-Apr	43		7			
15-Apr	20		23			
22-Apr	45		25			
29-Apr	70		25			
06-May	54		16			
13-May	34		20			
20-May	67		33			
27-May	32		35			
03-Jun	79		47			
10-Jun	85		6			
17-Jun	90		5			
24-Jun	70		20			
01-Jul	89		19			
08-Jul	78		11			
15-Jul	92		14			
22-Jul	50		42			
29-Jul	65		15			
05-Aug	40		25			
12-Aug	54		14			
19-Aug	48		6			
26-Aug	37		11			
02-Sep	50		13			
09-Sep	63		13			
16-Sep	45		18			

SPC calculations worksheet - calculations

Week	% compliance with hand hygiene	Average	Moving range	Average moving range	Upper control limit	Lower control limit
01-Apr	50	= 1450 divided by 25		19.29	109.31	6.69
08-Apr	43		= the difference between 50 and 43	=the total of the moving range column divided by 24	=average + 3 times (average moving range divided by 1.128)	=average - 3 times (average moving range divided by 1.128)
15-Apr	20					
22-Apr	45					
29-Apr	70					
06-May	54					
13-May	34					
20-May	67					
27-May	32					
03-Jun	79					
10-Jun	85					
17-Jun	90					
24-Jun	70					
01-Jul	89					
08-Jul	78					
15-Jul	92					
22-Jul	50					
29-Jul	65					
05-Aug	40					
12-Aug	54					
19-Aug	48					
26-Aug	37					
02-Sep	50					
09-Sep	63					
16-Sep	45					

Your notes

Financial return on investment

When someone asks about return on investment (ROI), they are really asking:

- What do I get back (return) for the money I'm being asked to spend (investment)?
- What is it really worth (the ROI)?

The formula for calculating return on investment:

Benefits – costs = dividends

Return on investment can also be provided as a percentage, showing the savings as a percentage of the total

costs: (benefits – costs) ÷ costs x 100

While ROI is usually thought of as being purely about 'financial' benefits, it is helpful to start by thinking about the quality benefits of investments. Many seemingly 'non financial' benefits already have a financial element (for example: reducing patient safety incidents often results in lower length of stay and/or less intensive treatment, and improving the patient experience results in a financial benefit through the payment system described in the Operating Framework for 2010) . Though calculations of ROI only use benefits that can be expressed financially, it is important that all benefits are captured and recorded.

Used correctly, ROI can be used at the start of a project to provide an estimate of the costs for upfront justification and again towards the end of a project as a measure for the success of the improvement project (not only by confirming initial costing validity but also by validating any ongoing project maintenance and sustainability costs). In fact, ROI can be used throughout the life of project to continually see if benefits are being realised and make decisions about whether to continue, modify, amplify or terminate a project.

Using a robust approach to ROI will remove the need for reactive evidence gathering by consistently developing a clear evidence base on which to build the business case for improvement.

Identifying the costs of patient care

Estimating what patient care will cost to provide before and after an improvement initiative provides data for the benefits element of the return on investment formula.

Three key categories of costs appear on a finance director's balance sheet:

- Staff costs
- Occupancy costs
- Medicine costs

There will be both fixed and variable costs in each of these three categories. Your improvement work - at least in the early phases - is likely to impact the *variable* costs.

Use these three categories of costs to keep it simple and relevant to the financial outcomes recognised by your finance staff.

Commissioners currently use nationally agreed tariffs to identify the costs of patient care to them. Commissioners will also incur staff costs if they are funding the improvement initiative. Providers will use all three categories to estimate the costs of patient care to them.

Some questions in the ROI spreadsheet (available from the NHS Institute's website) help you to think about what kind of financial benefits your improvement project may demonstrate. Here are some examples of how to calculate the annual financial benefits for the ROI spreadsheet:

What are the costs of waiting (outpatient appointments, GP appointments, pain relief)?

For example, Primary Care Trust A reduced the proportion of GP appointments by 75% within two months by implementing guidance in Focus On: Cataracts, which recommends that patients visiting optometrists should be directly referred to hospital eye services rather than via GP. This projects to £25,920 over the course of one year (based on an estimated 1,728 cataract operations per year, approximately 80% of whom visit an optometrist and then onto a GP, at a cost of £25 per patient).

Costs for unnecessary procedures?

For example, Primary Care Trust B reduced unnecessary MRI scans at one acute trust by 15% through GP education initiatives over the course of four months. This projects to £111,078 over the course of one year (based on an estimated 4,488 MRI scans per year at a cost of £165 per scan).

Cancelled procedures/DNAs?

For example, GP Practice A reduced DNAs from 20% to 2% in one week by sending reminder texts to patients one hour before their appointment. This projects to £180,000 over the course of one year (based on an estimated 40,000 scheduled appointments over 50 weeks of the year (excluding bank holidays and GP sickness leave/absence) at a cost of £25 per appointment).

Payment by Results (PbR) is a system in which PCTs pay hospitals for the number and complexity of patients treated, using a price list – the national tariff – for all activity within the scope of PbR. This type of arrangement is known internationally as 'casemix' funding. In simple terms, the tariff is based on the average cost of services reported by NHS providers through the annual reference costs collection. Healthcare Resource Groups are the unit of payment, or 'currency', for the tariff. HRGs are clinically meaningful groups of diagnoses and procedures that consume similar levels of NHS resources. The tariff is the minimum a provider receives, because the PCT also applies a nationally determined market forces factor (MFF) adjustment to reflect the fact that it is more expensive to provide services in some parts of the country than in others.

Identifying the costs of patient care

Here are some useful sources of information about the costs of patient care:

1. Costs of adverse events

The Patient Safety First Campaign (www.patientsafetyfirst.nhs.uk) identified the average costs associated with different categories of adverse incidents in 2009. For example, a central line infection was estimated to cost £8,190 for medicine and staff costs and required an average of two additional bed days.

2. Costs of bed days, admissions and re-admissions

The bed day cost figure most commonly used by health organisations and the Department of Health is currently between £250 and £300 (2009). This estimate includes fixed overhead costs of heating, lighting, laundry and provision of food for the patient occupying the bed and an average cost for medicines and staff. An alternative is the excess bed day tariff. Tariff payments will also provide a specialty-specific estimate of the cost of an admission and a re-admission. All of these figures are published in an Excel file on the Department of Health's 'publications policy and guidance' page. However, trusts must be aware that they may incur higher or lower costs than the tariff payment depending on how well streamlined the services are that they provide. In this case, reference costs might be used (see online source below).

3. Costs of waiting

Patients who are waiting for less time for treatment will probably require fewer outpatient appointments, fewer trips to their GP, fewer tests and less time in hospital if test results are made available more quickly. The Audit Commission often publishes papers summarising these costs. Outpatients appointments and follow-up appointments are available in the Excel file on the Department of Health's 'publications policy and guidance' page.

4. Opportunity cost

This is the value of benefits forgone by using resources to provide alternative products or services. For example, the value of a nurse's time engaged in work outside of primary job duties, the value of resources spent on an unnecessary lab test.

Opportunity costs are also not restricted only to monetary costs. For example, if a new improved health service requires patients to walk further than they did before the change, their lost time and convenience should also be considered opportunity costs although it might be difficult to quantify financially. Assessing opportunity costs is fundamental to assessing the true cost of any change.

5. Other sources of costs information

- National audits e.g. the National Diabetes Audit
- Hospital Episodes Statistics (HES) database: Tariff payments made to trusts are available via the HES database NHS analysts within trusts also have access to this database.
- The Information Centre
- The Audit Commission
- The Care Quality Commission
- Reference Costs database: The reference costs for 07/08 can be obtained from: http://www.orderline.dh.gov.uk/ecom_dh/public/saleproduct.jsf?rowId=295505 (accessed January 2010)

What does an improvement initiative cost to implement and sustain?

Estimating what an improvement initiative will cost to implement and sustain provides data for the costs element of the return on investment formula.

Some questions in the ROI spreadsheet (available from the NHS Institute's website) help you to think about what kind of costs to consider:

What other staff release/commitment costs does the organisation incur?

One band 8a member of trust staff will be required to spend 50% of their time for six months on the project management and implementation of the Think Glucose project at a cost to the trust of £10,000 (this figure includes salary plus National Insurance and pension contributions made by the employer).

What other implementation costs does the organisation incur?

Purchasing external support to implement the Rapid Improvement Programme will cost £28,000.

What other sustainability costs does the organisation incur?

£3,000 per year will be required to cover the cost of additional training and restocking of materials (e.g.re-printing and distribution of posters and leaflets). £1,000 per year will be required for two days of band 8a staff time for awareness raising activities.

What is the cost of measuring/monitoring the problem?

For example, Primary Care Trust C invested £10,000 in training two heart failure specialist nurses to monitor prevalence rates, levels of prescribing and referral patterns to hospitals at eight GP practices. They also gathered intelligence through systems such as the Hospital Episodes Statistics (HES) database, which enabled them to target GP practices and develop improvement plans. Instead of visiting the hospital, patients are either seen at home or in heart failure clinics in their GP practices. This reduced hospital admissions by 27% at one acute trust. £50,000 will be required to train eight additional heart failure specialist nurses to replicate the work across the remaining 29 GP practices in the region, in order to realise the improvements across the other hospitals funded by the PCT.

Cost of change (cancelled appointments/increased activity in primary care etc.)?

Reduced activity in the secondary sector will result in increased activity in the primary care sector. An estimated 2,000 additional GP appointments will be required at a cost of £25 per appointment. This results in a total cost of £50,000.

Calculating return on investment: an example

The ROI spreadsheet (available from the NHS Institute's website) contains the data from the example below.

Summary ROI information for a business case for the implementation of Think Glucose across three specified wards in an acute trust.
This business case projects a 50% improvement and savings of £87,000 from the reduction of adverse incidents (e.g. insulin errors) and length of stay of patients with diabetes as a secondary diagnosis by referring these patients to a specialist diabetes nurse on admission to hospital.

Evidence
In a sample of 40 emergency patients (20 baseline and 20 post-intervention) from general surgery and trauma & orthopaedics, we reduced average length of stay of patients with a secondary diagnosis of diabetes by an average of two days over a 12-week period, through the implementation of Think Glucose.

Benefits
50% of 500 patients' average length of stay will be reduced by two days over the course of one year by reducing adverse incidents/insulin errors.
£250 per bed day x 500 = £250,000
£250,000 x 50% = £125,000

Costs
Purchase external support programme to implement the NHS Institute's Think Glucose product – £28,000
Assign one member of trust staff band 8a (50% of their time) for six months – £10,000

Dividends
£125,000 - £38,000 = £87,000

Reference:
www.institute.nhs.uk/thinkglucose

Bibliography and quotes

Adapted from Leatherman, Berwick, Iles, Lewin, Davidoff, Nolan, Bisognano (2003) **The business case for quality: case studies and an analysis** Health Affairs, v 22, no.2

"A business case for a health or healthcare improvement intervention exists if the system or entity that invests on that service or intervention realises a financial return on that service or intervention in a reasonable timescale, using a reasonable rate of discounting. This may be realised as cash released, a reduction in losses for a given population or programme and/or avoided costs. In addition, a business case may exist if the investing system or entity believes that a positive indirect effect on organisational (or system function and sustainability will accrue within a reasonable timeframe."

Bernard Crump and Mahmood Adil (2009) **Can quality and productivity improve in a financially poorer NHS?** BMJ, Vol 339, 1175-1177

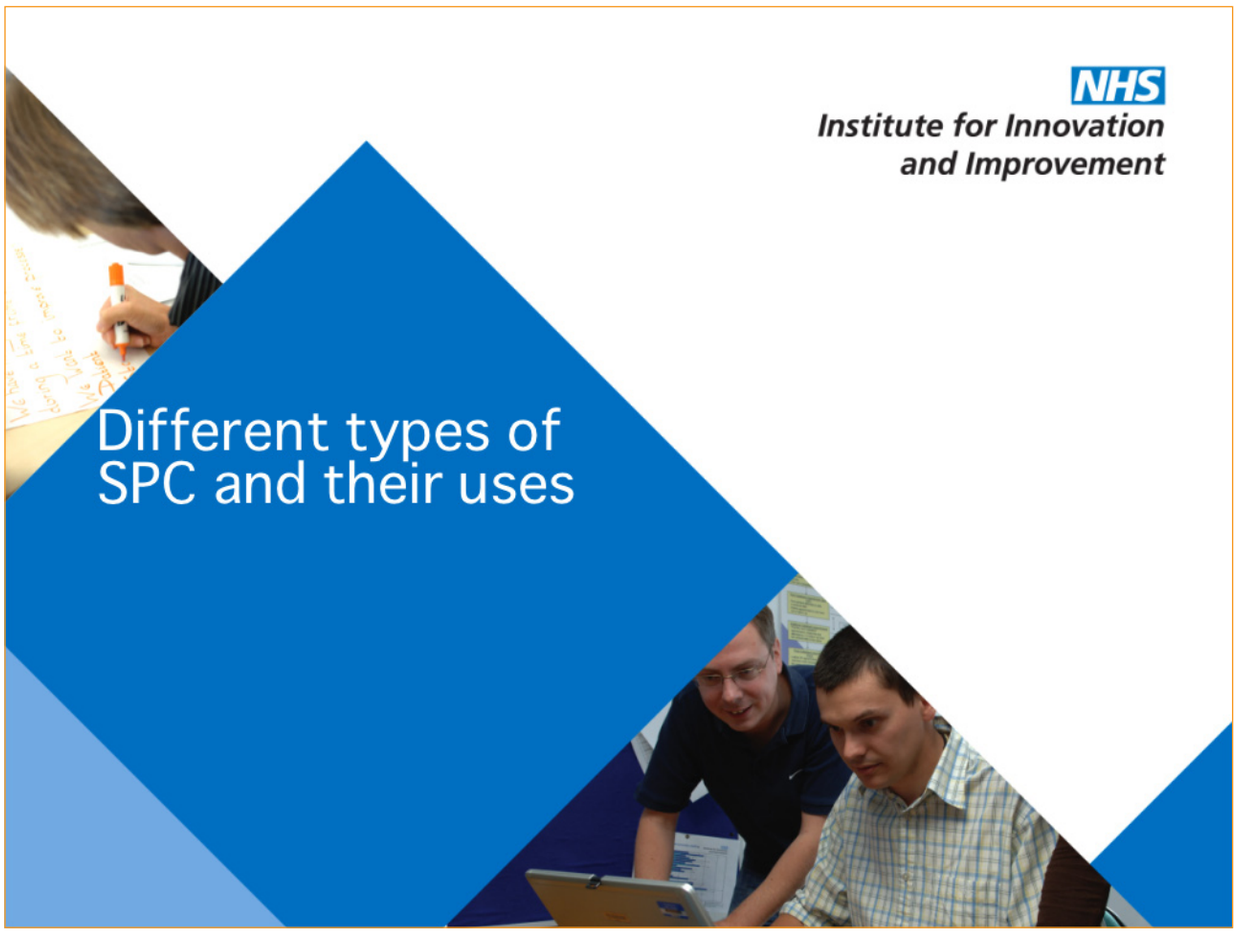
"Although the application of improvement science in health care has grown rapidly, there are few high calibre studies from the UK that have included the direct and opportunity costs of the improvement intervention."

Sarah W Fraser (2009) *Gross and net are not the same* BMJ;339:b5331,doi: 10.1136/bmj.b5331 (Published 9 December 2009)

"Improvement teams need not only to consider the gross benefits (such as the reduction in bed days) but also calculate the amount spent on making the change. This may include staff time—one of the most expensive resources. A standard return on investment calculation is benefits minus costs divided by costs. Carrying out these types of analyses before starting a project will help with prioritisation".

Appendices contents

Appendices - different types of SPC charts



Appendices - different types of SPC chart

Types of SPC chart

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- XmR chart
- X bar chart
- np chart
- P chart
- C chart
- U chart

Appendices - different types of SPC chart

SPC Charts

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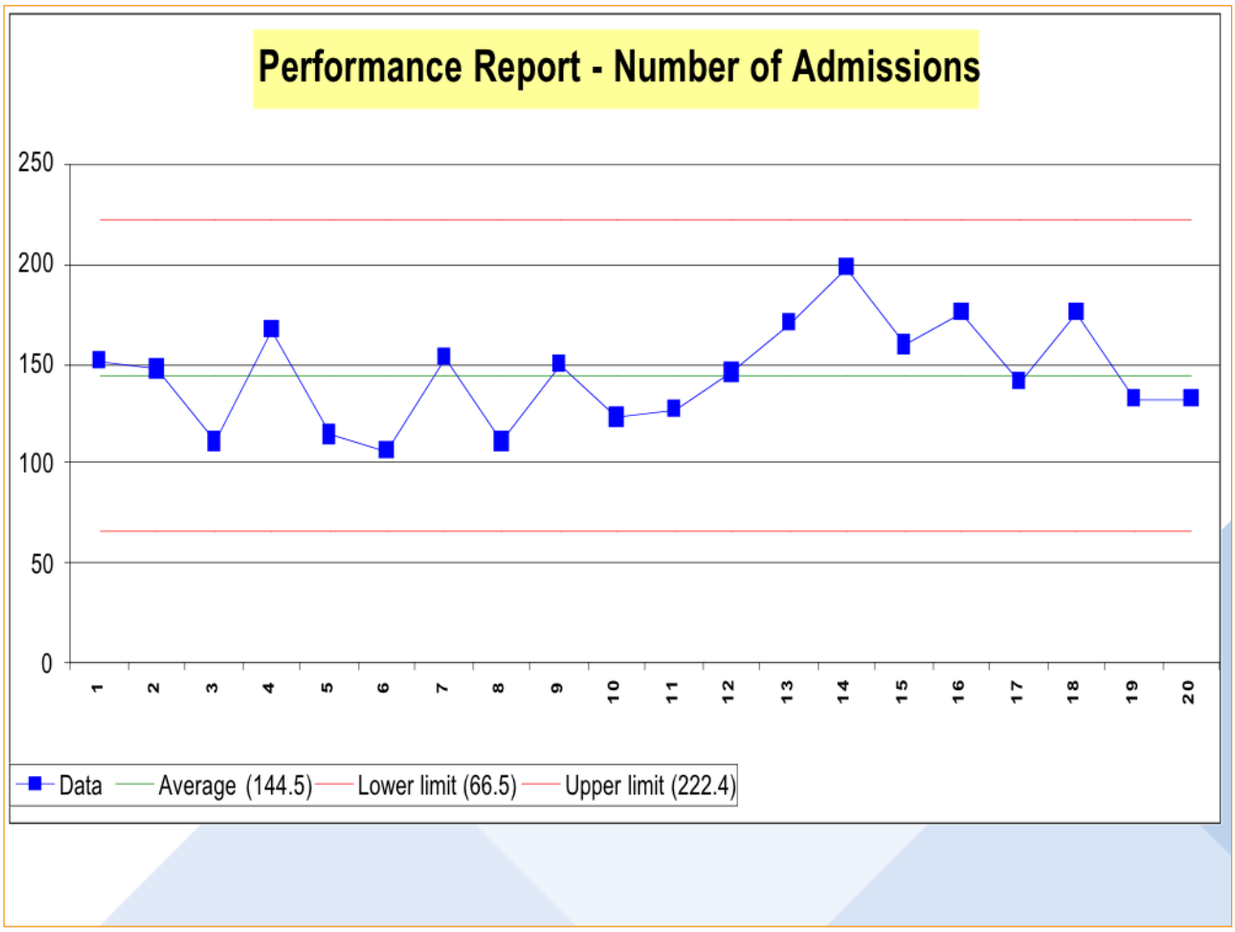
If in doubt – just use the XmR chart

- The XmR chart is correct in almost every case
- The np, p, u & c spc chart CAN be wrong if data is not appropriate

All SPC charts have the same components

- Centre line
- Control limits
- Data line

Appendices - different types of SPC chart



Appendices - different types of SPC chart

X bar and S chart

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Individual values are the average of a sample of a number of events.

X-bar and S chart: Control chart presenting a continuous variable for subgroups of more than one observation (e.g. turnaround time for a daily sample of blood tests). Actually two charts - one of subgroup mean (X-bar), plus one of within-group standard deviation (S).

Appendices - different types of SPC chart

p – 'proportions' Chart

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$$\bar{p} \pm 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

Based on the binomial distribution – there are two possible outcomes
E.g. patients can be given the correct drugs or incorrect drugs

Example – The count of incorrect drugs given (numerator) divided by the total number of drugs given (denominator)

Example - proportion of each week's blood samples which test positive (where number taken varies from week to week).

Appendices - different types of SPC chart

P Chart example

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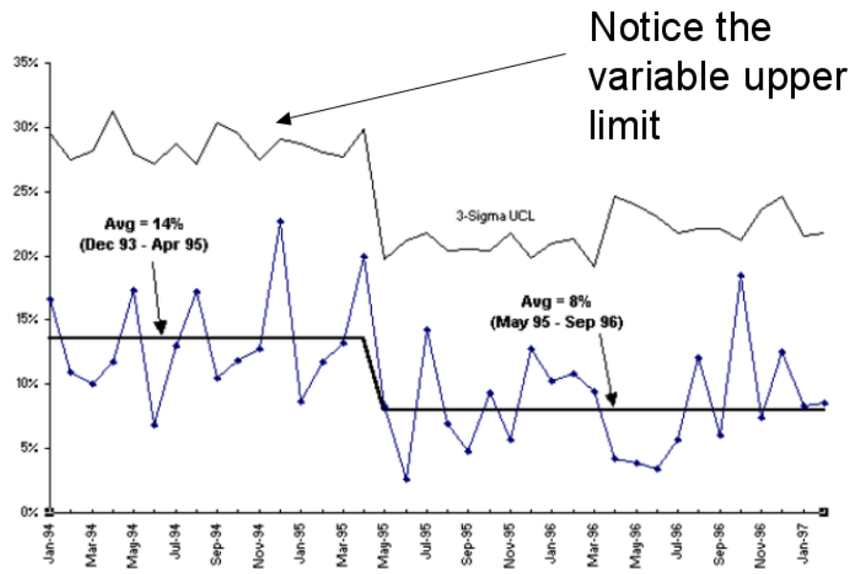

Appendices - different types of SPC chart

np - Chart

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Same requirements as for the p chart but all the counts must be the same.

Not so commonly used

c – 'Count' Chart

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'C' Stands for 'Count'

The same as an np chart but for data with a poisson distribution

- Each count must be the same. ie they are all out of 10
- p denotes the probability that a single item possesses the attribute (p must remain constant for each of the n items in the sample) The count is a count of events

u – 'Unit' Chart

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The sub groups are all different sizes.

E.g. the number of patients in a hospital week by week varies greatly

The 'U' chart converts these differing sub groups into a 'fair playing field' by dividing each group count by the size of the group.

The resulting value is called the 'U' value and then can be plotted and compared.

Appendices - different types of SPC chart

Funnel plot

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Funnel plot: Control chart showing data for different institutions at the same point in time, arranged so that their control limits become narrower from left to right.

Appendices - different types of SPC chart

Funnel chart example

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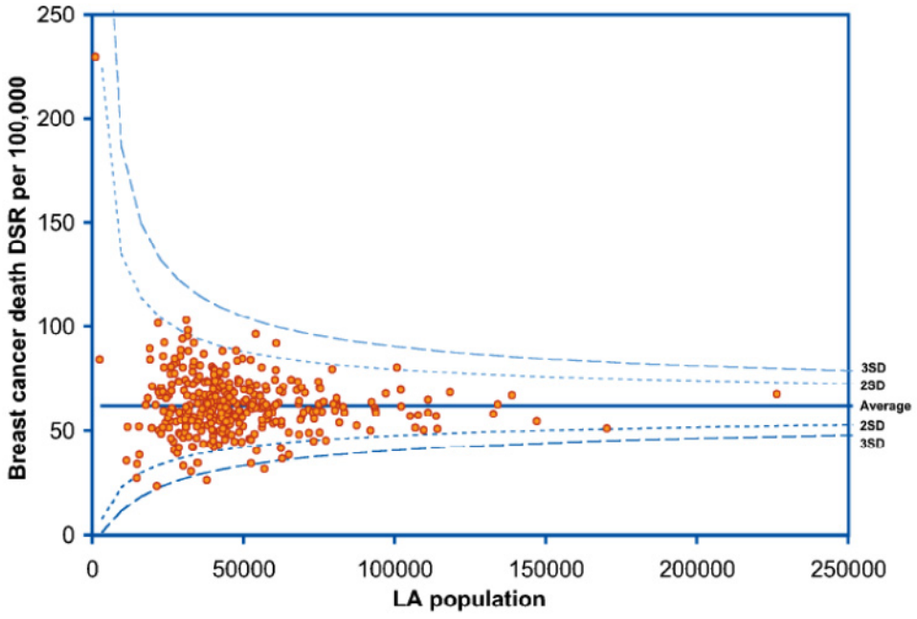
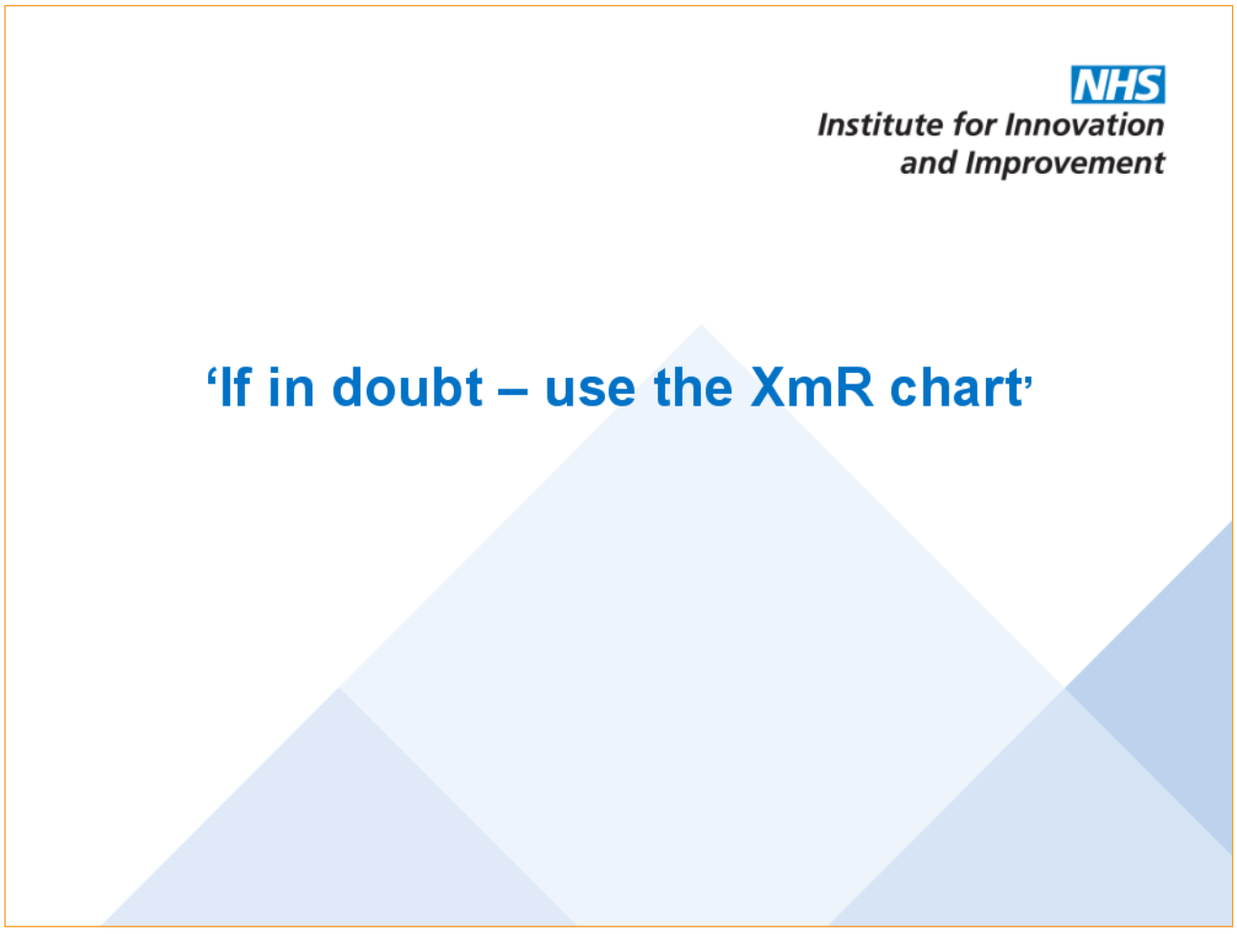
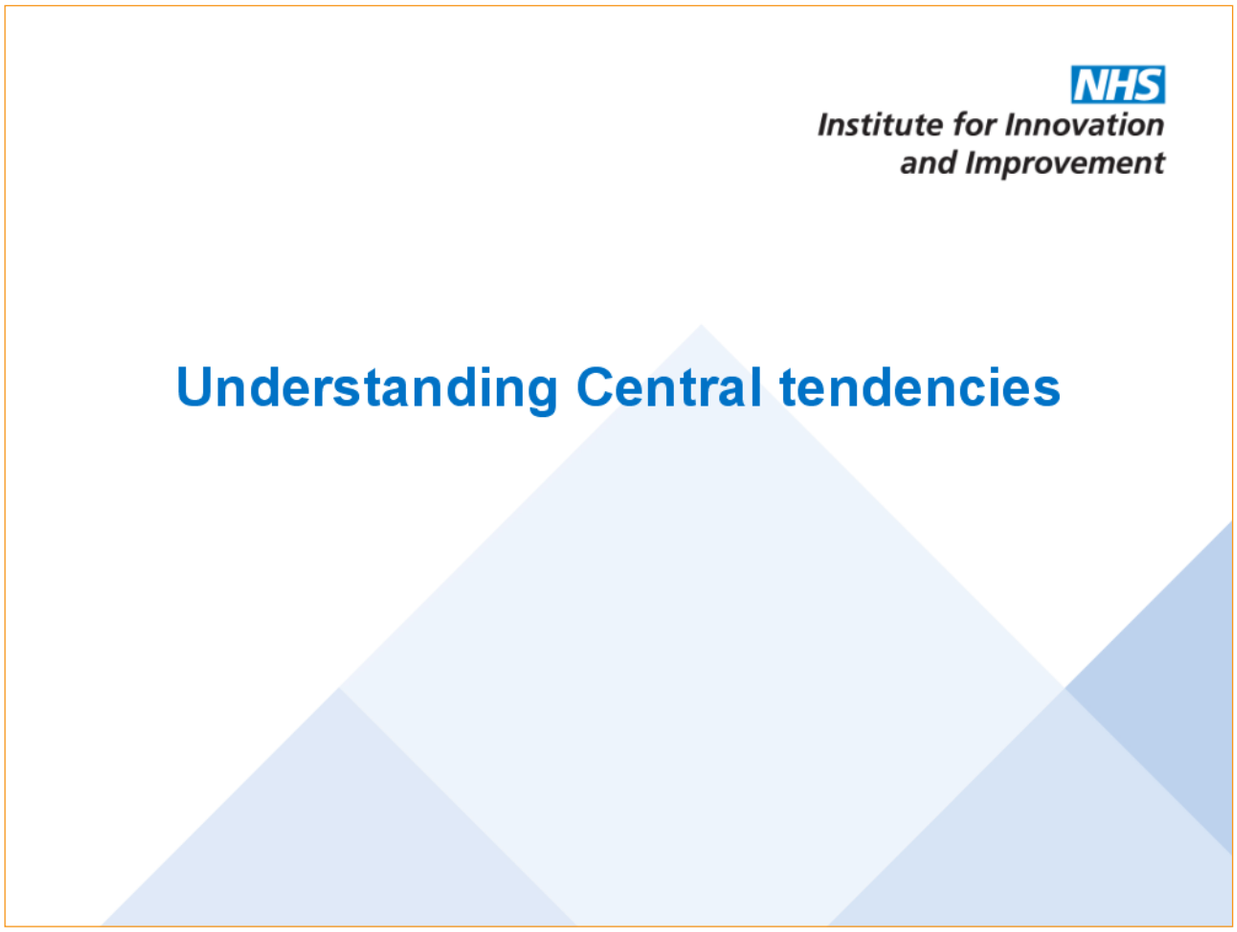


Appendices - different types of SPC chart



Appendices - Understanding central tendencies



Appendices - Understanding central tendencies

Averages

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Where is the centre of my data?

What's a typical value of my data?

It can be measured in different ways:

- Mean
- Median
- Mode

Appendices - Understanding central tendencies

Mean

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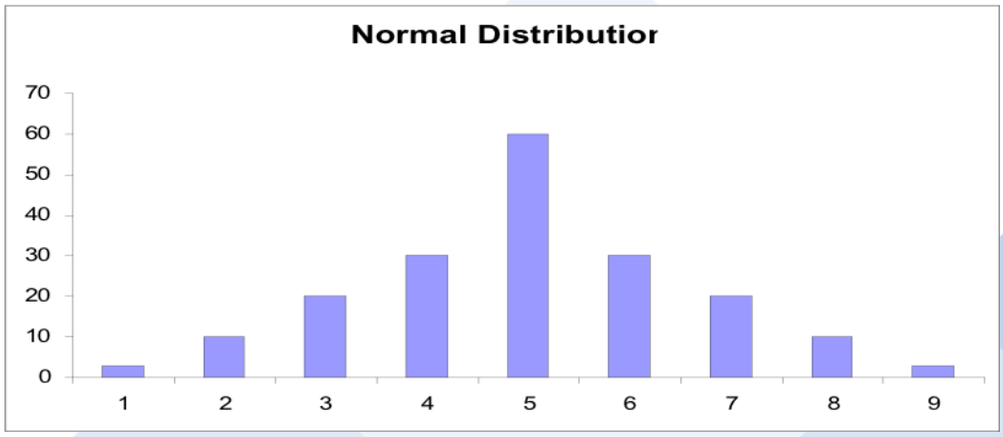
The sum of the numbers divided by the count of the numbers



Appendices - Understanding central tendencies

Median

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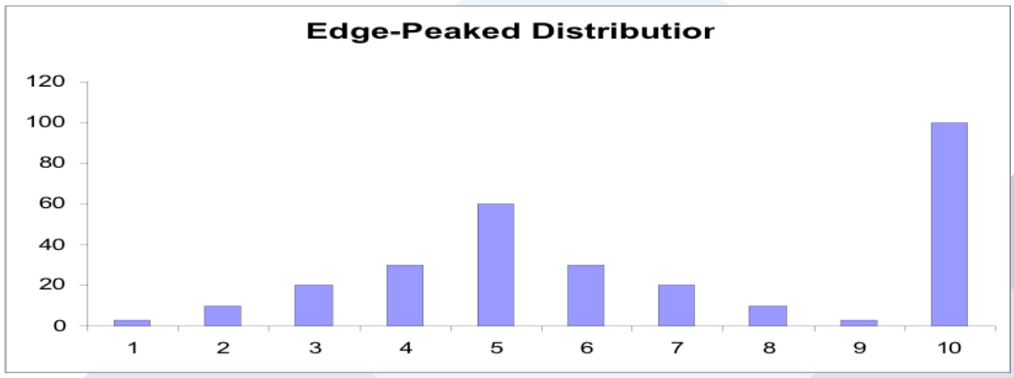
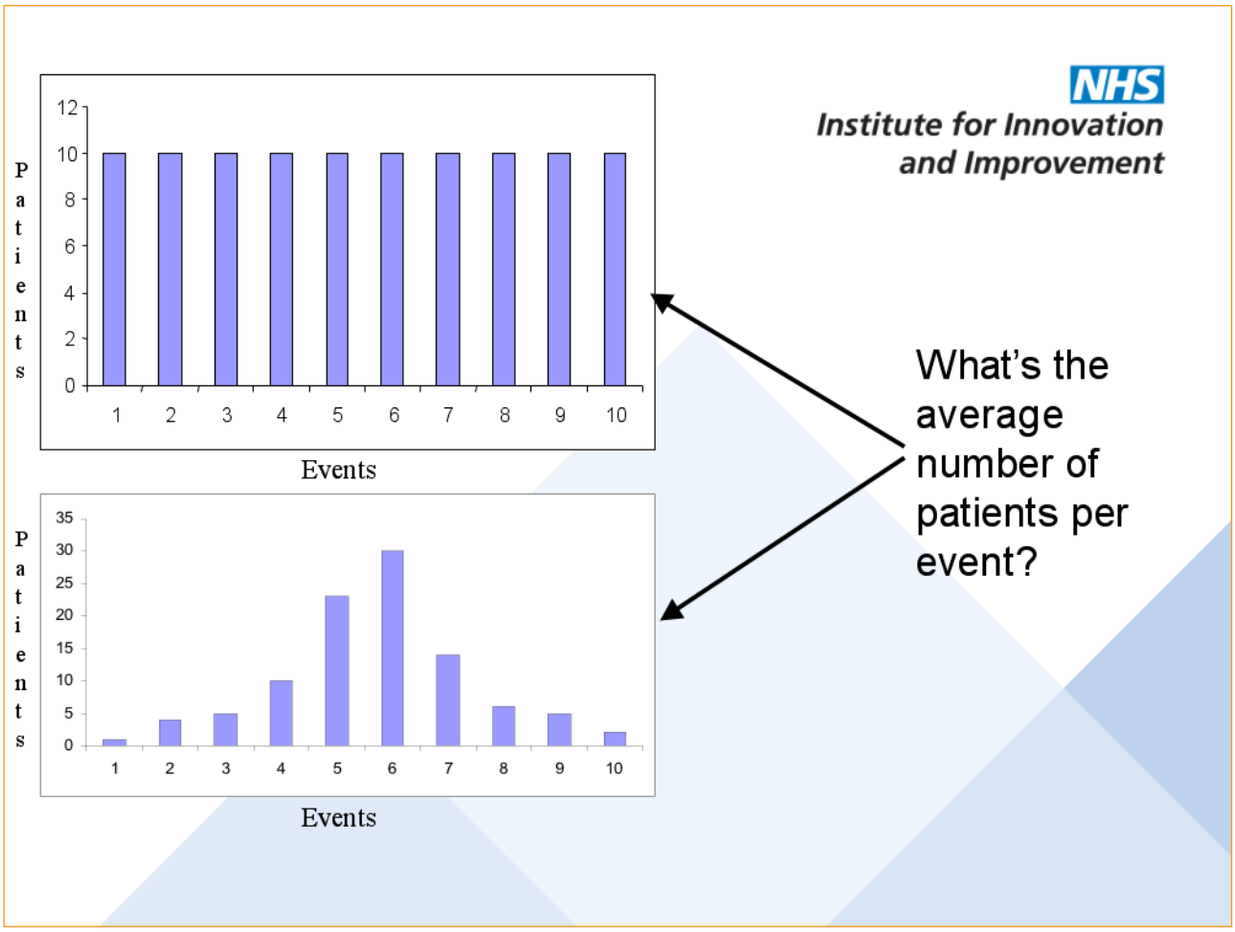
The median is the point at which there are an equal number of data points whose values lie above and below the median value.



Appendices - Understanding central tendencies



Appendices - Standard deviation

Appendices - Standard deviation

Standard Deviation

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A measure of variability.

"It represents the typical distance from any point in the data set from the average"

Appendices - Standard deviation

What is the question we are asking with Standard deviation?

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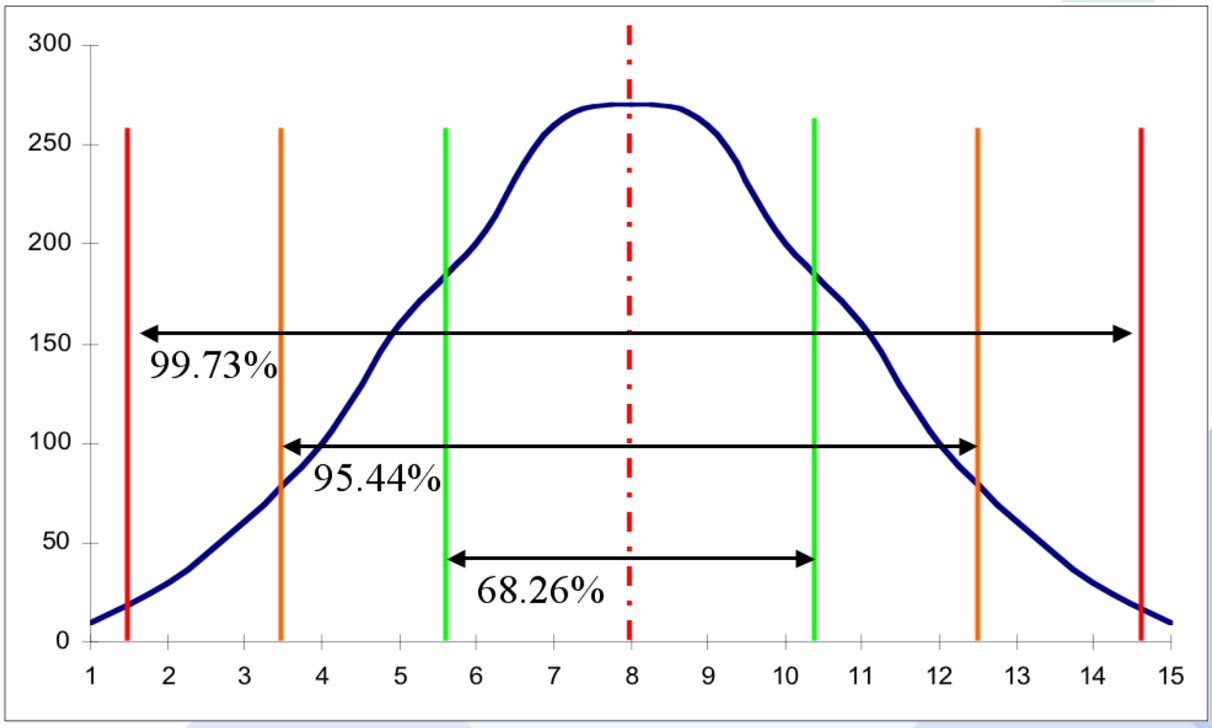
What will the next value be?

based on a normal distribution…….

68% of the observations are within 1 StDev
95% of the observations are within 2 StDev
99.7% of the observations are within 3 StDev

Appendices - Standard deviation



Appendices - Standard deviation

Appendices - Standard deviation

Type 1

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$$S = \sqrt{\frac{\sum(x - x)^2}{n - 1}}$$

Find the average
Take each number and subtract the average
Square each of the differences
Add up the results (from the squares)
Divide the sum of squares by the number in the data set, and minus 1
Square root the answer

Appendices - Standard deviation

Type 2

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$$\frac{\text{Average moving range}}{1.128}$$

Work out the moving ranges between the values

Work out it's average

Divide it by the bias correction factor

There are lots of others

Appendices - distributions

Appendices - distributions

What are we going to look at?

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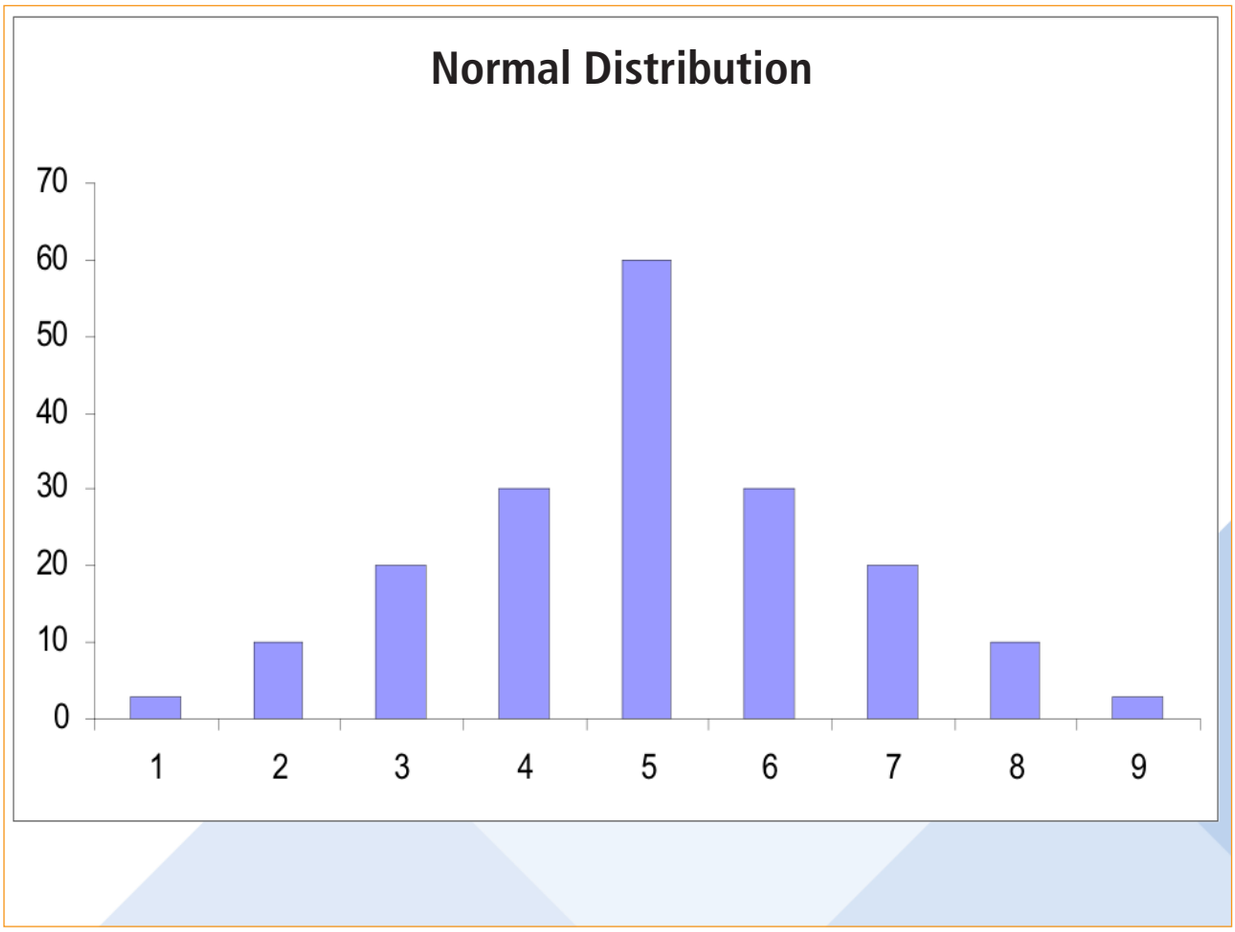
What is a distribution?

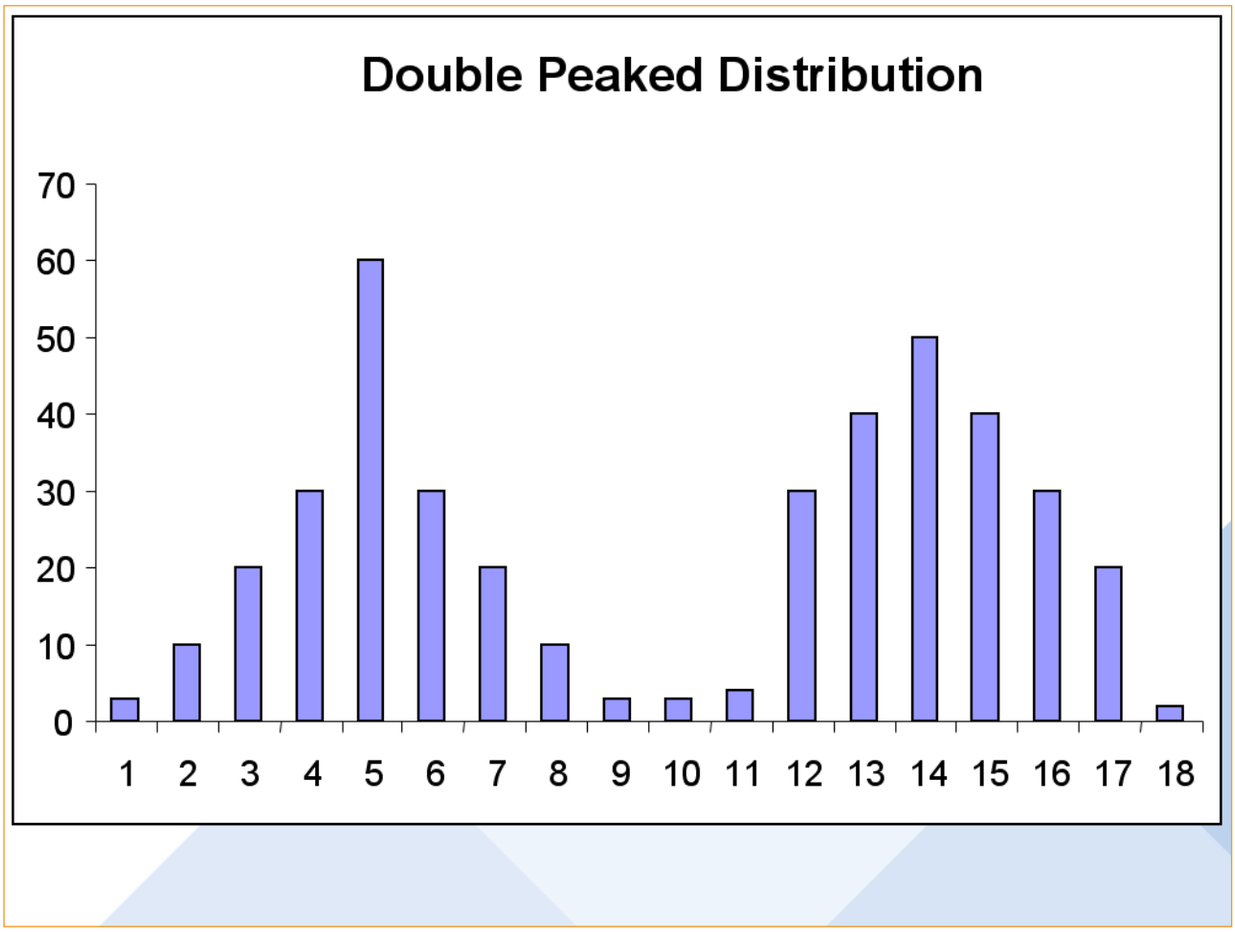
Differing types of distribution

Why is it important?

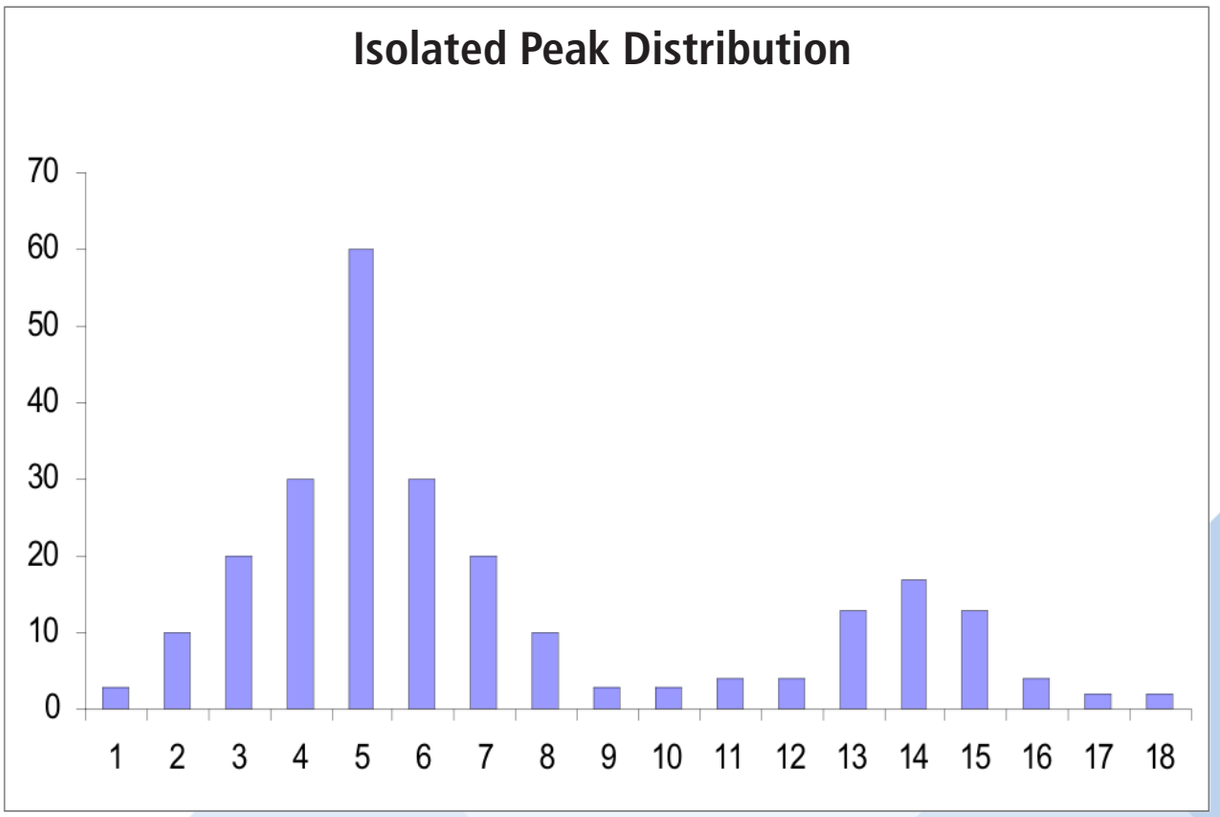
Appendices - distributions



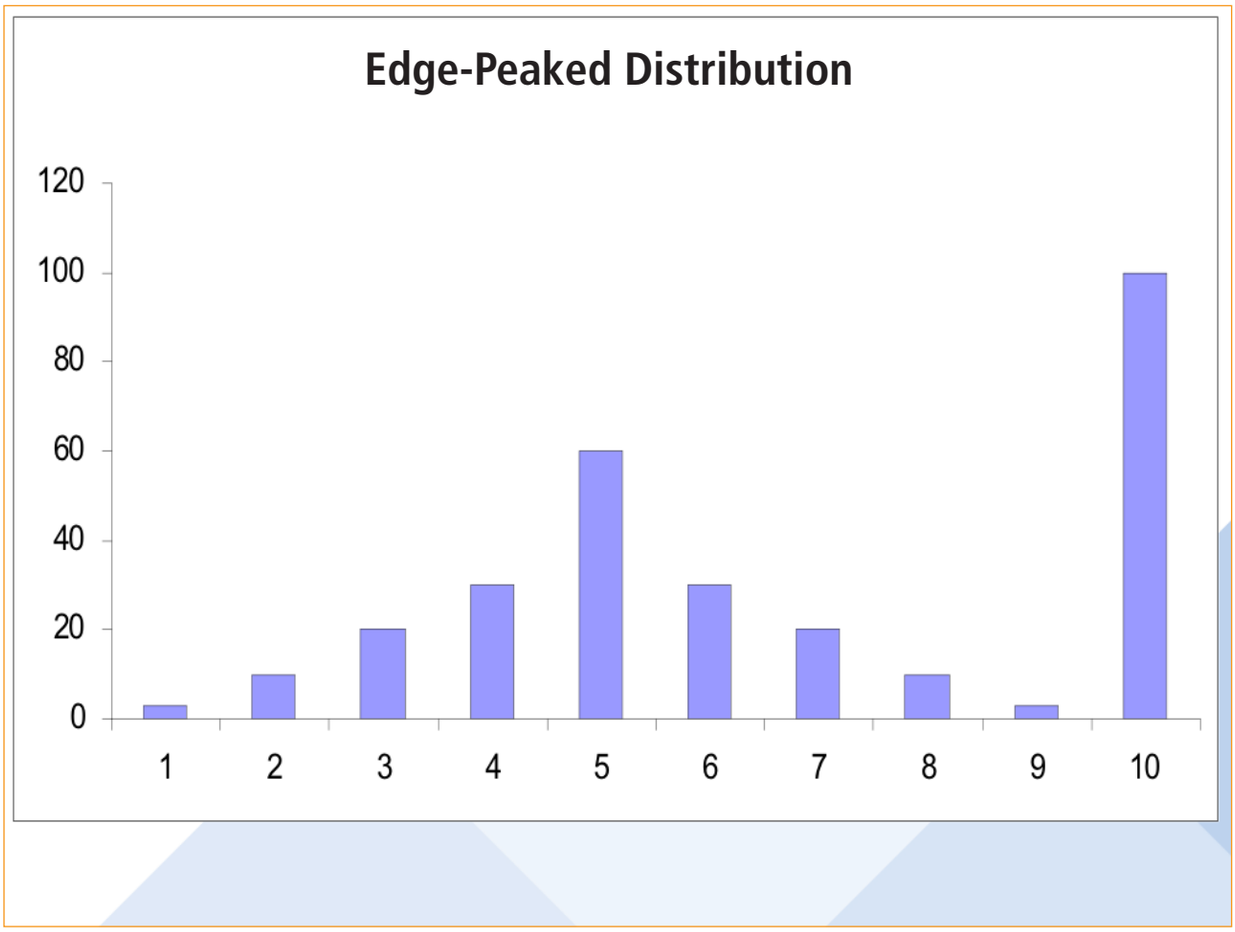
Appendices - distributions



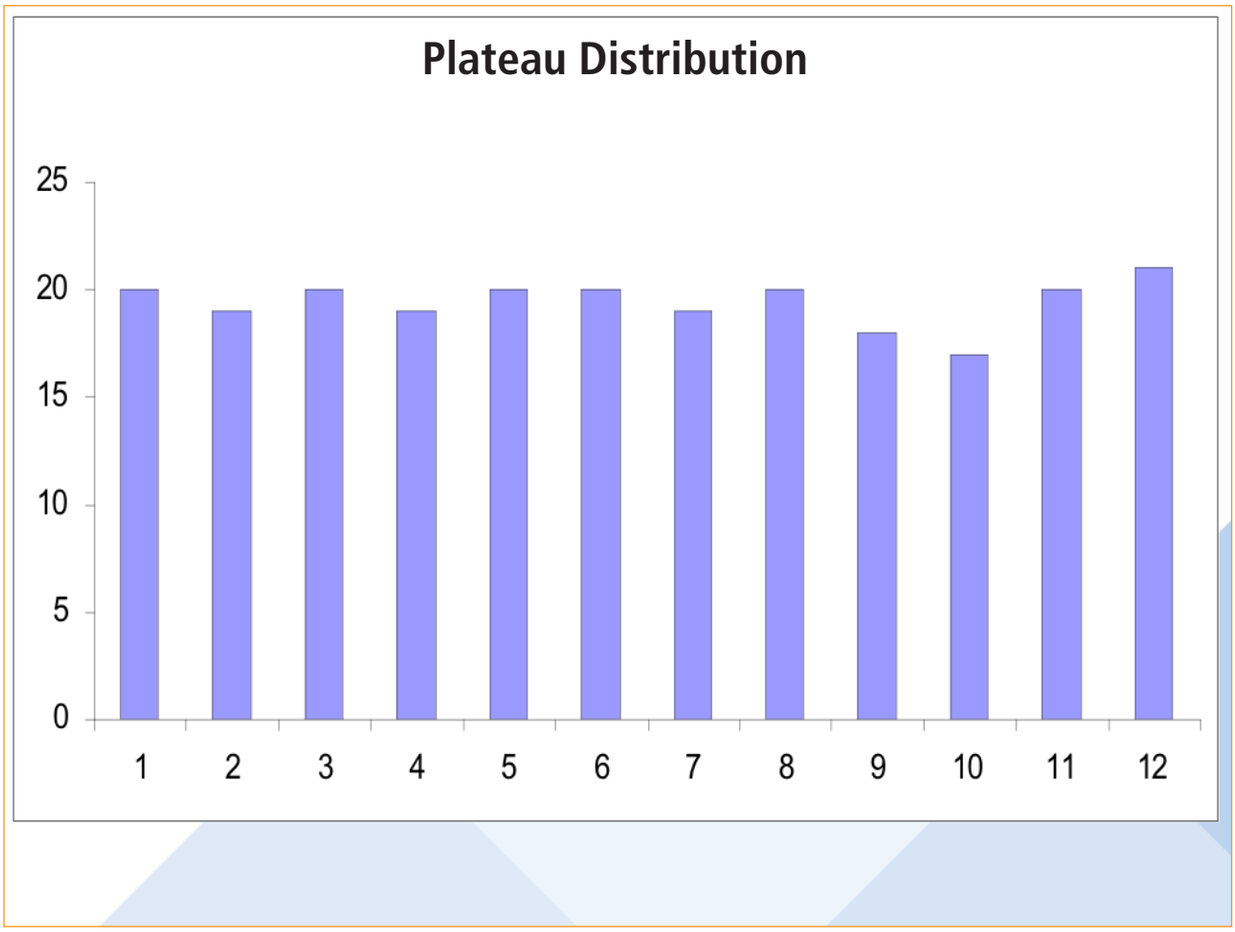
Appendices - distributions



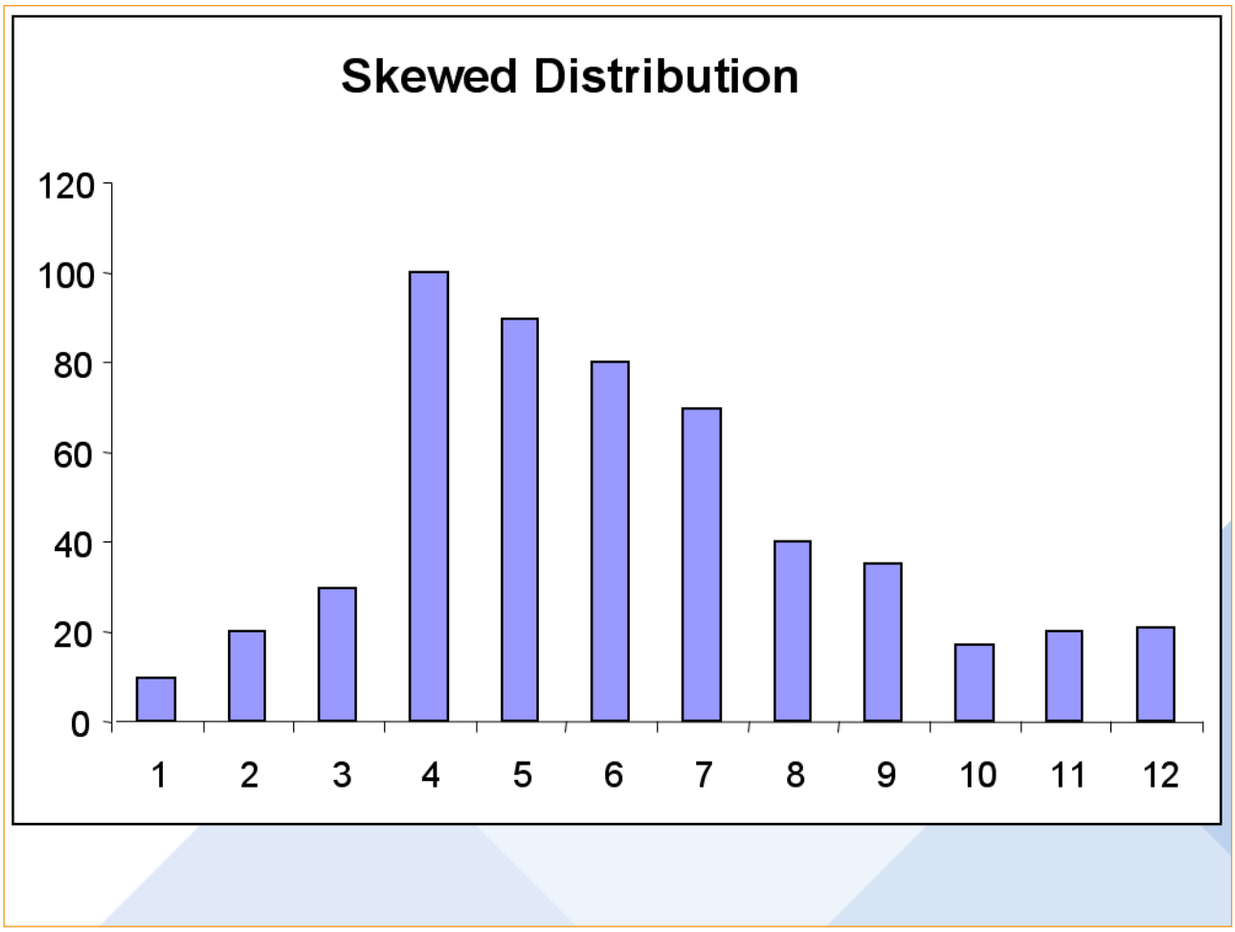
Appendices - distributions



Appendices - distributions



Appendices - distributions



Why are distributions important?

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It provides an easy to read picture of the location of the variation.

Although be careful as things can be grouped and too few or too many bars can be displayed.

It suggests which type of SPC chart can be used

Appendices - calculating capability

Appendices - calculating capability

Formula

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$$\text{Capability} = \frac{\text{Target - Average}}{3 * \text{sigma}}$$

Appendices - calculating capability

Calculation

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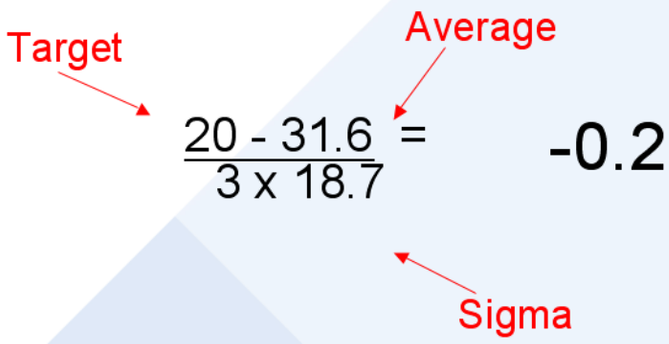
Target 20 mins
Average 31.6
Sigma 18.7



Appendices - calculating capability

Interpretation

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How capable is the process of achieving the target?

Value	Capability of Achieving Target
more than 1	100%
0-1	50-100%
less than 0	0-50%

Appendices - calculating capability

Table of Capability Values

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Capability value	% Capability	Capability value	% Capability
0	50	0.42	89.6
0.02	52.4	0.44	90.7
0.04	54.8	0.46	91.6
0.06	57.1	0.48	92.5
0.08	59.5	0.5	93.3
0.1	61.8	0.52	94.1
0.12	64.1	0.54	94.7
0.14	66.3	0.56	95.4
0.16	68.4	0.58	95.9
0.18	70.5	0.6	96.4
0.2	72.6	0.62	96.9
0.22	74.5	0.64	97.3
0.24	76.4	0.66	97.6
0.26	78.2	0.68	97.9
0.28	80	0.7	98.2
0.3	81.6	0.75	98.8
0.32	83.2	0.8	99.2
0.34	84.6	0.85	99.5
0.36	86	0.9	99.7
0.38	87.3	0.95	99.8
0.4	88.5	1	99.9

For our example

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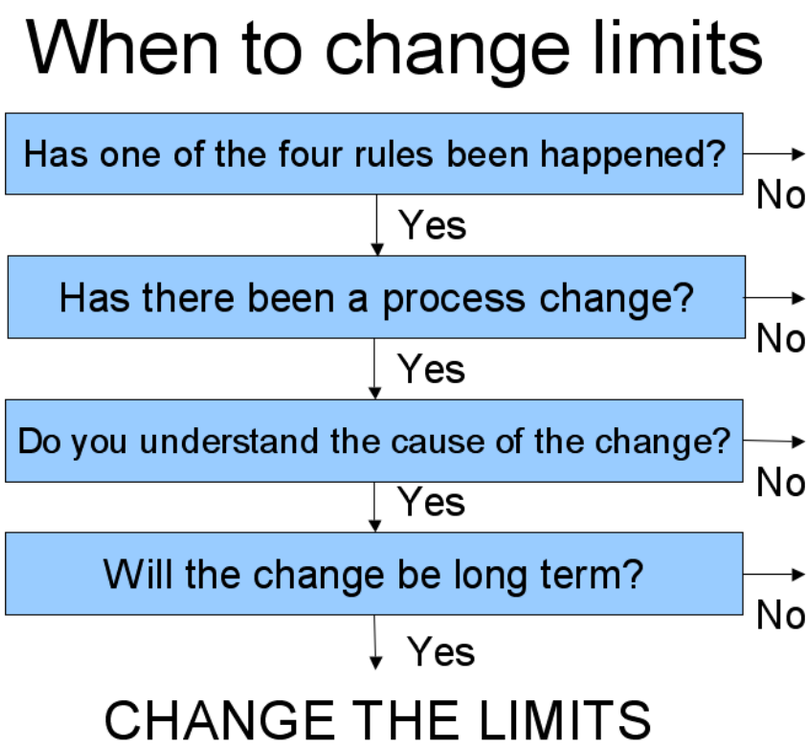
Value of –0.2 gives 72.6

As negative: 100-72.6 = 27.4%

Process needs significant redesign to meet target

Appendices - when to change limits



Data analysis questions

Question	Practical answers (Questions to be answered)	Graphical answers	Analytical answers
Is my data valid?	**Ask critical questions:** • Where is the data from? • When was the data taken? • Who took the data? • How was the data taken? • Has an MSA been done? **Look at the data:** • Does the data pass the "sniff" test?		
Is my measurement system valid?	**Ask critical questions:** • When was the last time a MSA was run? • How often are the measurement • devices calibrated? • Who uses the measurement devices? • What is the part tolerance window? **Look at the data:** • Do all operators get the same measurement when measuring the same part? • How does measurement-to measurement variation compare to part-to-part variation? • How does measurement-to measurement variation compare with the part tolerance window? • Does measurement-to-measurement variation change with part size? • Are the operators having trouble • measuring a particular part?	**Discrete data:** Attribute agreement analysis charts **Continuous data:** X-bar and R charts	Measurement system analysis (MSA)
How much data do I need?	**Ask critical questions:** • What am I trying to learn? • How long will it take to analyze the data?		• Random sampling • Stratified random sampling • Acceptance sampling
How can I describe this data?	**Ask critical questions:** • What is the inference space of the data? • What does the data values mean? • Has the measurement system been validated? **Look at the data:** • Do you see any outliers?	Dot plot, Individual value plot, Interval plot	**Normal data:** / **Non normal data:** **Central Tendency**: Mean / Mean **Spread**: Standard deviation / Inter-quartile range
What type of distribution do I have?	**Ask critical questions:** • What type of distribution do you • expect? **Look at the data:** • Do you see any outliers?	Dot plot, Individual value plot, Histogram, Symmetry plot	Normality tests, Individual Distribution Identification

Data analysis questions

Question	Practical answers (Questions to be answered)	Graphical answers	Analytical answers		
Do these populations have the same central tendency?	**Ask critical questions:** • Is the data normal? • Are the variances equal? • Is there a reason to believe that they • should have the same central • tendency? • Is the data time ordered? **Look at the data:** • Do you see any outliers?	Dot plot (with groups or multiple Y's), Individual value plot (with groups or multiple Y's), Box plot (with groups or multiple Y's), Histogram (with groups or multiple Y's) Residual analysis Analysis of means (ANOM)		**Normal data:**	**Non normal data:**
			1 population	1-sample t Test	1-sample Wilcoxon
			2 populations	t Tests	Mann-Whitney
			3 or more populations	ANOVA	Kruskal-Wallis
			Two-way tables	Two-way ANOVA	Friedman
Do these populations have the same spread?	• Ask critical questions: • Do I expect the populations to have the • same spread? Why? or Why not? • Is the data normal? • Look at the data: • How do the ranges compare?	Dot plot, Individual value plot, Box plot, Histogram		**Normal data:**	**Non normal data:**
			2 populations	F Test	Levene's test
			3 or more populations	Bartlett's test	Levene's test
Do these populations have the same proportions?	**Ask critical questions:** • Where is the data from? • Are the operation definitions • consistent? **Look at the data:** • Do the proportions look the same?	Pie charts, Stacked bar charts	**1 population**	1-proportion test	
			2 populations	2-proportions test	
			3 or more populations	Chi-square	
How do I distinguish between the "vital few" and the "useful many"?	**Ask critical questions:** • Should I be weighting the results? **Look at the data:** • Which factors appear to be the "vital-few"?	Pareto analysis			
Is my process capable?	**Ask critical questions:** • What are the specification limits? • Where did the specification limits come • from? • What period of time is the data from? **Look at the data:** • How many data points are outside the • specification limits? • Is the population centered within the • specification limits?	Capability analysis graphs	Defects per million opportunities (DPMO), Cp, Cpk, Sigma quality level		

Data analysis questions

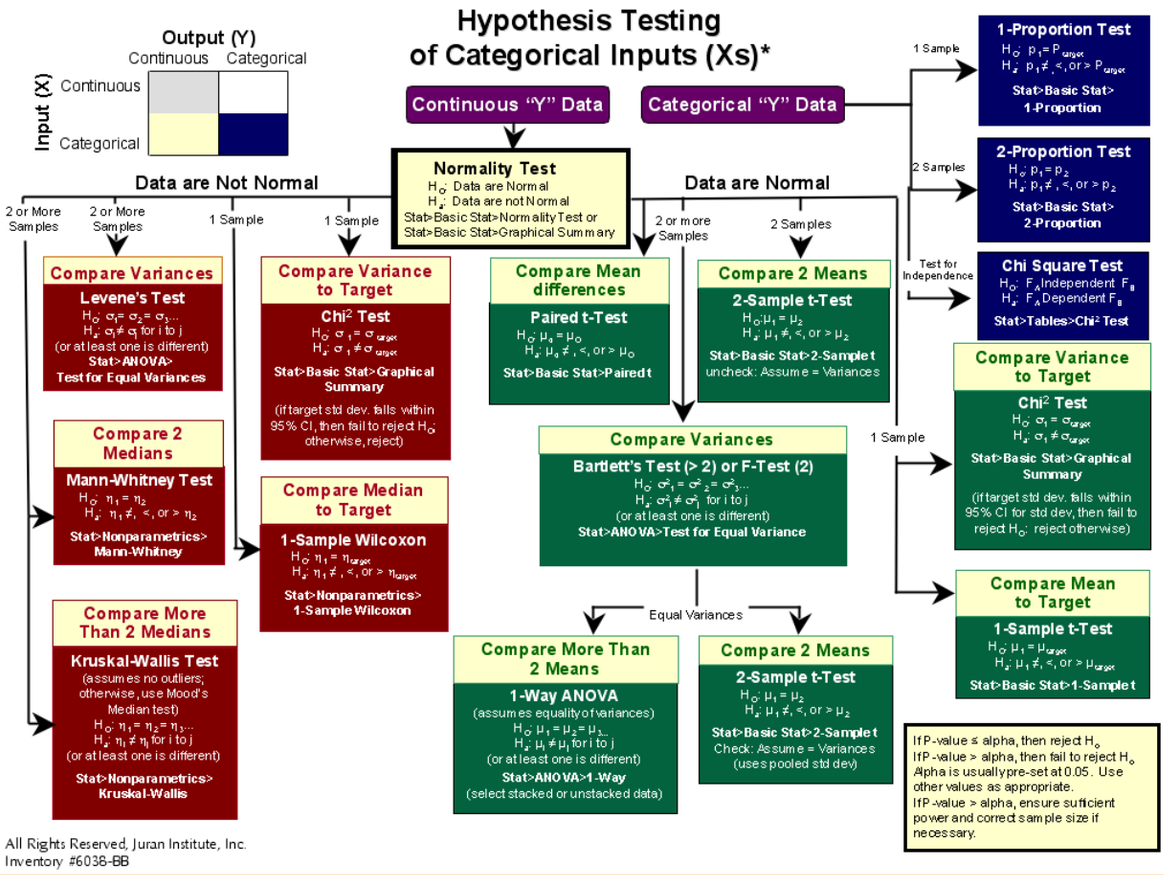
<table>
<tr><th>Question</th><th>Practical answers (Questions to be answered)</th><th>Graphical answers</th><th>Analytical answers</th></tr>
<tr><td>Is there a relationship between my inputs and outputs?</td><td>Ask critical questions:
• What type of relationship do you expect
• to see?
•
Look at the data:
• What relationships do you see?
• Are there outliers?</td><td>Scatter diagrams,
Matrix plot</td><td>Correlation,
Regression (including Logistic Regression, Stepwise Regression and Best Subsets)
Residual analysis
Multivariate analysis</td></tr>
<tr><td>What is the behaviour over time?</td><td>Ask critical questions:
• What behaviour do you expect over
• time?
• What is good?
•
Look at the data:
• Do you see any shifts, drifts, or special
• causes?</td><td>Run chart,
Statistical process control charts (SPC),
Exponentially weighted moving average (EWMA),
Cumulative sum charts (CUSUM)

Statistical process control charts
<table><tr><th>Type of</th><th>Constant subgroup size</th><th>Variable subgroup size</th></tr><tr><td>Normal</td><td>IMR</td><td>X-bar & R
X-bar & s</td></tr><tr><td>Binomial</td><td>np, p</td><td>p</td></tr><tr><td>Poisson</td><td>c</td><td>u</td></tr></table></td><td>Runs test,
Trend analysis,
Decomposition,
Fourier analysis,
Autocorrelation,
Autoregressive Integrated Moving Average (ARIMA)</td></tr>
<tr><td>How can I quantify the variation of various factors impacting my process?</td><td>Ask critical questions:
• What factors are important?
Look at the data:
• Where is most of the variation?</td><td>Dot diagrams,
Factor relationship diagram (FRD),
X-bar & R charts,
Individual and moving range chart (IMR)</td><td>• Factor analysis
• Components of variation (COV)</td></tr>
<tr><td>How can I experimentally determine the effect of changing inputs?</td><td>Ask critical questions:
• What factors should I chose?
• Are the level settings reasonable?
• What are the responses?
• Are there other re-sponses I need to
• consider?

Look at the data:
• Analysis of good (ANOG)</td><td>Cube plots,
Interaction plots,
Main effect plots,
Response surfaces</td><td>Design of experiments (DOE)
Residual analysis

Design of experiments (DOE)
<table><tr><th>Degree of knowledge</th><th>Type of experiment</th></tr><tr><td>Low</td><td>Fractional factorial designs</td></tr><tr><td>High</td><td>Full factorial design,
Response surface designs,
Method of steepest ascent,
One factor at a time (OFAT)</td></tr></table></td></tr>
</table>

Data analysis questions



Glossary

Binomial distribution: Applies to the probability distribution of discrete data with only two possibilities - e.g. alive or dead, male or female. It is used to generate control limits for percentages or proportions.

Normal distribution: A familiar bell-shaped curve, which is a good representation of the distribution of many naturally-occurring variables.

Poisson distribution: Statistical distribution which applies to discrete data concerning the number of events (e.g. accidents) in a fixed space of time. Poisson data tends to have distribution that is skewed to the right, though it becomes closer to symmetric as the mean of the distribution increases. If your data comes from a Poisson distribution, then the mean and the variance of your data should be roughly equal.

C-chart: Control chart suitable for plotting counts of (adverse) events, where the opportunity for them to occur can be assumed equal from one time period to the next.

Funnel plot: Control chart showing data for different institutions at the same point in time, arranged so that their control limits become narrower from left to right.

I-chart (or XMR): Control chart presenting a continuous variable for 'individuals'. However, in practice the 'individual' is often a single day, week, month etc.

P-chart: Control chart plotting the proportion of observations meeting some criterion. E.g. proportion of each week's blood samples which test positive (where number taken varies from week to week).

U-chart: Control chart for plotting the rate of events per time-period, where the opportunity for these to occur is not constant. E.g. if bed occupancy varies from month to month, patient falls would be divided by the number of patient days before plotting.

X-bar and S chart: Control chart presenting a continuous variable for subgroups of more than one observation (e.g. turnaround time for a daily sample of blood tests). Actually two charts - one of subgroup mean (X-bar), plus one of within-group standard deviation (S).

Continuous data: Variables which can take any value within an uninterrupted range - not just whole numbers. E.g. temperature, weight (Opposite of discrete data)

Discrete data: Variables which can only take specific distinct values - often whole numbers. E.g. number of operations, number of errors (Opposite of continuous data)

Direct standardisation: Method of working out the overall number or rate of deaths, etc, that would result locally if the population followed a standard (hypothetical) age profile. Allows comparison between local populations of different age structure. E.g. DSR (Directly Standardised Rate).

Indirect standardisation: Method of working out the overall number of deaths, etc, that would result locally if the standard (e.g. national) rate for each age-group prevailed. Allows local populations of different age structure to be compared with the standard. E.g. SMR (Standardised Mortality Ratio).

Reading list

- Wheeler DJ – **Understanding Variation: The key to managing chaos 1986**
- Walter A Shewhart **'Economic Control of Quality of Manufactured Product'** New York, D Van Nostrand 1931
- Donald Wheeler **'Making Sense of Data. SPC for the Service Sector'** Knoxville, SPC Press Inc, 2003
- Hart and Hart. **Statistical Process Control for health care**. Duxbury 2002
- Deborah Rumsey - **Statistics for Dummies.** Wiley Publishing 2003
- Meeker and Escobar – **Statistical Methods for reliability Data.** 1998
- DeVor et al. **Statistical Quality Design and Control – Contemporary Concepts and Methods.** Prentice Hall 1992

Your notes

Your notes

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