Leaving Certificate

Technology

## Manufacturing Systems

The Context of Manufacturing

Quality Management

The Context of Manufacturing

Introduction

Manufacturing is part of a bigger scheme known as **operations**. The term **Operations** takes in all systems that involve getting **work done**. This includes *services* as well as *manufacture*. The process always involves a transformation of some raw materials (or inputs) to a finished item or service. The goal is to create and add value to the inputs during the transformation. In the case of manufacturing, the goal is to add value to a raw material by changing its shape or properties. In the case of a service, often knowledge or know how is brought together to fulfil some need. The process is shown in the diagram below.

Inputs
- Materials
- Labour
- Equipment
- Capital

Transformation process

Outputs
- Goods
- Services
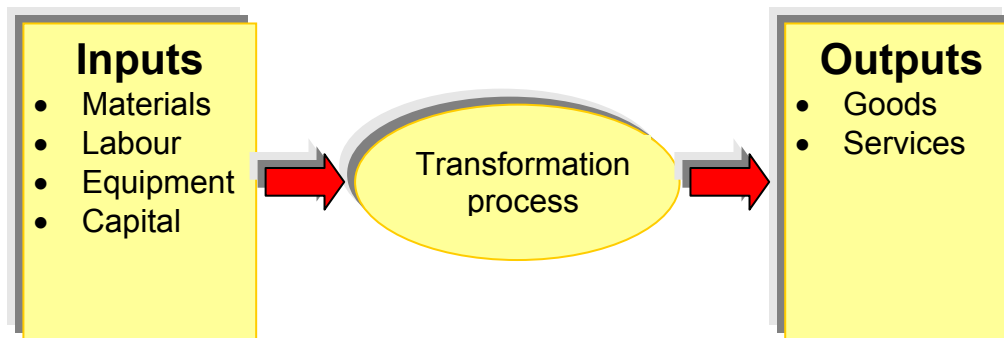
Activity 1

Take the following items and state (i) what the inputs are and (ii) what transformation processes are need to take place to achieve the finished item:

    (a) 500g packet of butter
    (b) A daily newspaper

In each case look at the materials, labour, equipment and management required and say how they are used to make the product.

The exercise shows that there are several dimensions to the process e.g. technical, economic etc. and they work in combination to bring about the end result. Almost always, manufacturing is intended to make a profit for the owners of the company. Companies set up to make a profit are known as **enterprises.** Manufacturing systems themselves can be thought of in either **technical** or **economic** terms.

Looking at the process purely in technical terms the main features are those shown below. The manufacturing process is used to turn raw material into finished items. The manufacturing process contributes the technology to bring this about.
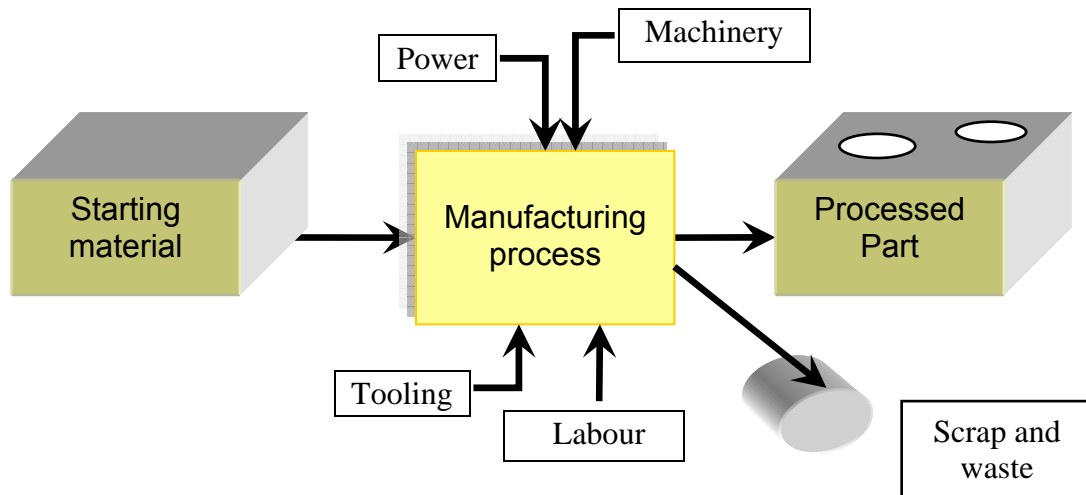
However, if we look at manufacturing in terms of economics then a different picture is apparent. In this case it is the **value that is added** to the inputs that is important
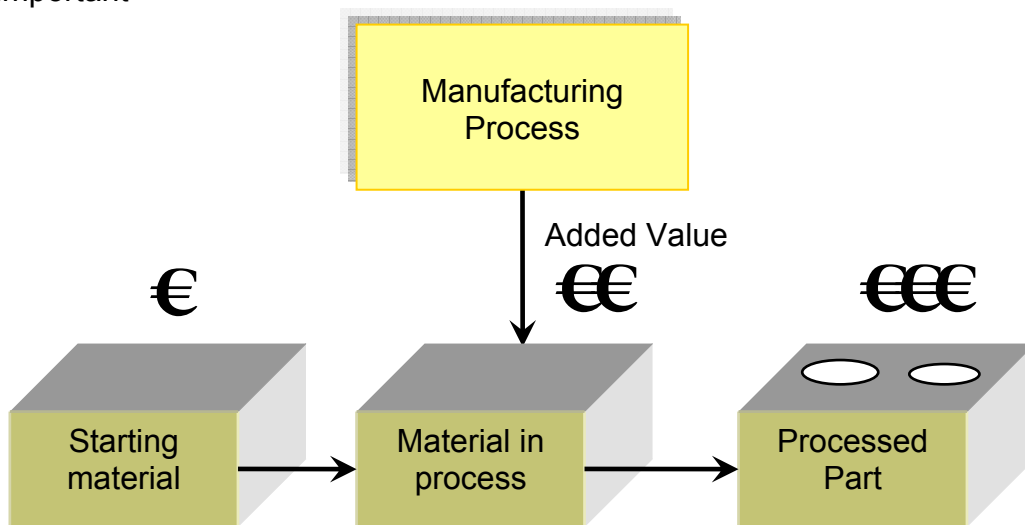
Activity 2
Take the two items from the previous example. In each case say how the manufacturing process adds value to the raw materials (or inputs) to the process

> **Activity 3**
> Choose one company or business from the area where you live.
> Try to decide what the inputs, transformation and outputs are.
> State how it adds value to the inputs.

Manufacturing industries can be grouped into either **Primary, Secondary or Tertiary industries.**

- **Primary Industries** exploit natural resources e.g. agriculture or mining
- **Secondary Industries** take the output of primary industries and convert them into consumer goods. **Manufacturing** is mostly concerned with this category but construction can also be included here.
- **Tertiary Industries** contribute to the service sector of the economy. e.g. Banks, insurance,

> **Activity 4**
> Name one company you have heard of from each of the categories above

Generic Business Strategies

Companies exist to make a profit. Usually there is more than one company offering a particular item or service. Therefore companies **compete** with one another for a particular **market**. In order to be able to compete, a company needs to have a **Strategy**. This keeps the organisation moving in the right direction and provides a focus for decision making.

A Strategy consists of four basic steps:
1. Define a primary task
2. Assess Core Competencies
3. Determine order qualifiers and order winners
4. Positioning the Firm

1. **Define a primary task**. The primary task represents the purpose of the firm i.e. what it is in the business of doing. It also defines the area in which it will be competing. This is stated in broad terms. e.g. Iarnrod Eireann would be in the business of *Transportation*, not *Railways* This is often expressed as a **mission statement.** Some examples are given below:

Amazon.com - '*To provide the fastest, easiest, most enjoyable shopping experience'*

Dell Computers - *'to be the most successful computer company in the world at delivering the best customer experience in markets we serve. In doing so, Dell will meet customer expectations of:*

- *Highest quality*
- *Leading technology*
- *Competitive pricing*
- *Individual and company accountability*
- *Best-in-class service and support*
- *Flexible customization capability*
- *Superior corporate citizenship*
- *Financial stability"*

McDonald's - "McDonald's vision is to be the world's best quick service restaurant experience. Being the best means providing outstanding quality, service, cleanliness and value, so that we make every customer in every restaurant smile. To achieve our vision, we are focused on three worldwide strategies:
Be the best employer for our people in each community around the world,
Deliver operational excellence to our customers in each of our restaurants, and
Achieve enduring profitable growth by expanding the brand and leveraging the strengths of the McDonald's system through innovation and technology."

2. Assess Core Competencies
This is what a company does best, better than any of its competitors. This might be the ability to provide exceptional service, or to be first to the market with a new design. For this reason, a core competence is rarely a *single* product or technology as these are easily copied and replicated – it is usually based on knowledge or processes.

An example of a core competency possessed by Dell Computers is the ability to quickly assemble computers to order and to deliver them to customers without delay. Assembling a computer itself is not a very complex task – however managing the ordering/assembly/delivery of thousands of differently configured machines each day is what Dell do very well. Therefore it is their core competence.

3. Determining order qualifiers and order winners.
An order qualifier is a characteristic of a product that will make a consumer consider buying it. An order winner is the characteristic of a product that will **make** the consumer purchase it.

When buying a car, a person might have a fixed amount of money available – say €20,000. Therefore the price range would be the **order qualifier** for this person. They can't buy a car above this price no matter how good it may be.

Within this price range there are a number of models available. The one with the most features might be the one chosen –this would be the **order-winning** characteristic.

Alternatively, a consumer might decide on a certain desirable feature such as a Diesel engine (order qualifier) and then buy the least expensive car available in this category (order winner)

Ideally a firm's core competence should match the order winning characteristic of its product. For example one of Japanese car manufacturers' core competencies would be quality. This would be an order winner for many people. In this case price would be a qualifier as they are able to deliver the quality at an affordable price.

4. Positioning the Firm
A firm should choose one or two important things to concentrate on and do them extremely well. This defines how well it will compete in the marketplace and what unique value it will deliver to the consumer. The relative strengths of its competitors must be taken into account when doing this. For example, Apple computer do not compete with companies such as Dell for its market – instead they concentrate on a niche market for innovative products such as the iPhone, IPod where they are often first to the market.

Once the company has a strategy it has a clear picture of what it does best and where it should be going. The next step is to decide how to compete with the other companies in the same area.

Generic Manufacturing Strategies

Deciding on the strategy used to produce a product is a complex one and it involves strategic decisions by the management. Some items affecting the decisions are looked at below.

There are different ways of offering a product or service from a company.

Make to Order: Products are designed, produced and delivered to customer specifications in response to an order. Examples are custom-tailored clothes, custom-built homes, and component parts for a machine, a PCB for a school-based project. The important issues here are to meet the needs of the customer and to complete the order in the minimum amount of time.

Make to Stock: Products are designed and produced for a 'standard' customer in anticipation of demand. The items are stored and the consumer chooses from a range of items that are available. Examples of this type of product would be consumer electronics such as an MP3 player, a house in a scheme built by a developer, or a litre carton of milk. The main issues relate to forecasting the demand for the item and maintaining the correct amount of item in stock.

Assemble to Order Items: In this case, a base unit or module is produced onto which options can be added according the specification of the customer. A computer motherboard and cabinet can have different memory modules, hard drive, processor etc fitted during assembly to make a custom-built

product. The difference between this and a make to order product it that the individual components have already been made and held in stock.

Activity 5
Decide which category the following items fit into
1. A Burger in a fast food restaurant
2. A specially iced birthday cake from a baker
3. A made-to-measure suit of clothes
4. An off-the-hook jacket from a department store
5. A garden table set sold by a hardware shop

Types of Production Processes

The choice of the processes used to make an item depends on the characteristics of the product and the volume of the product being made. Production processes can be classified into projects, batch production, mass production and continuous production. These are outlined below.

A Project takes a long time to complete, involves a large investment of resources and produces one item at a time to a customer order.
Examples include
- roads,
- construction projects,
- aircraft manufacturing
- new product development e.g. iPhone where the outcome of the project is a prototype iPhone.

Batch Production involves moving groups of the product through the manufacturing process in groups or batches. The volume is relatively low and demand for the items can fluctuate.
Examples of batch production are
- bakeries,
- furniture making
- cheese making etc

Mass Production produces large volumes of a standard product for a mass market. The demand for the product is stable and the demand is high. Most consumer goods are produced using this method.
Examples are
- cars,
- computers
- fast food such as burgers

There is usually a degree of automation involved.

Continuous Production is used for very high volume products. These are highly standardised and are produced using highly automated systems. Examples of this are
- electricity,
- treated water,
- foodstuffs,
- paper

The Product Process Matrix

Production can range from a single product, through batch and mass production depending on the volume of items required. As this increases the amount of standardisation in the production process increases also. Compare a bakery with a family kitchen for example. It is set up to produce one kind of food only (bread). The kitchen is more versatile but a lot less efficient at producing large volumes of output.

The relationship between these issues is often described using the **product process matrix** shown below.
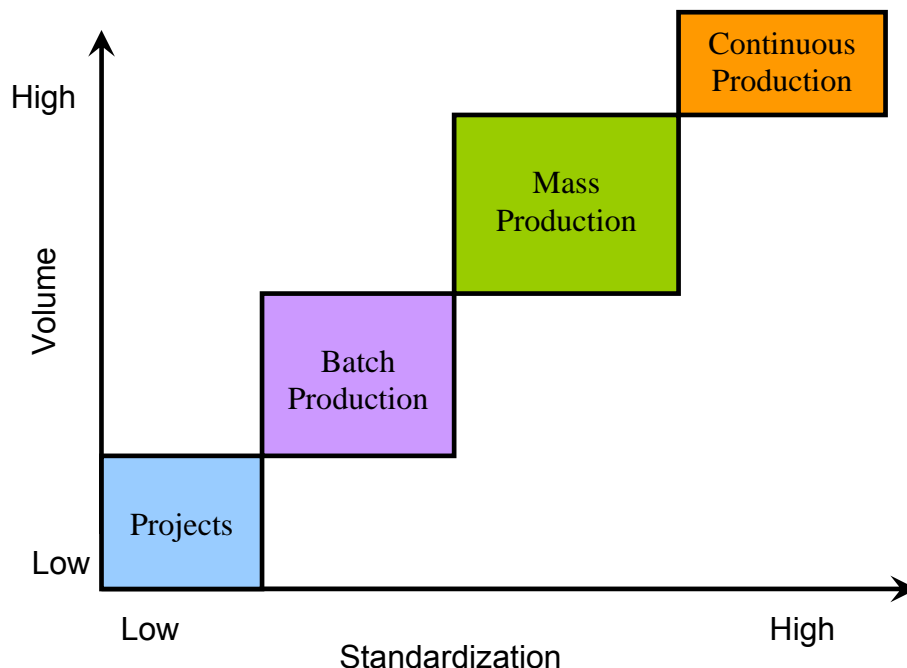
The matrix shows the relationship between the levels of volume and standardisation of a product and its manufacturing process.

Using the matrix:
Ideally a manufacturing process should be positioned on the diagonal line drawn from the bottom left to the top right of the matrix. This means that the product and process used to make it are matched.

The further away from the diagonal line the less matched the product and process would be. If the product and process are not matched it is unlikely that they are working efficiently. The matrix also allows a company to see where they are best placed to compete with others.

For example, firms whose equipment and abilities lie at the bottom left of the matrix would be best suited to offer flexibility and customisation in their products, however, others who would be located near to the top-right would be better positioned to compete in stable, high-volume products where change is uncommon.

Case Study:
A PCB manufacturer produces a low-volume customized product but uses a highly connected assembly-line process. This would appear to place them in the lower right corner of the matrix which is not a desirable place to be. This knowledge forced the company to realise that what they were offering was not really circuit boards after all but design capability. So in essence they were mass producing designs rather than the boards themselves. This insight allowed them to market their ability to design PCBs which was their real strength.

Functional Organisation of a Manufacturing Enterprise

Many years ago manufacturing was carried out by skilled crafts-persons who fashioned goods for individual customers. The quantity of goods produced was small and each item was unique. With the industrial revolution in the1700s the availability of steam power, coal and machinery allowed workers to be grouped together in factories under an overseer. This first happened in textile, grain and metalworking facilities.

Around this time Adam Smith (1776) wrote a book called the *Wealth of Nations* where he proposed that the production process be broken down into a series of small tasks, each of which was performed by an individual worker. This is called the *division of labour* and was an important milestone. Each worker was specialised in his own task. This also led to specialised machinery. Both of these developments made the production process much more efficient.

Early in the 1900s Frederic W. Taylor proposed a system of Scientific Management. He observed, measured and analysed in order to identify the best method for performing each job. Once determined, he standardized the method for all workers. One of Taylor's biggest advocates was Henry Ford who applied scientific management to the production of the Model T ford in 1913. This enabled him to reduce the manufacturing time for the car from 728 hours to 1 ½ hours. He used a conveyor to move the car through the manufacturing part where the workers picked up parts from carefully spaced piles on the floor and fitted them to the car. This was the first instance of mass production.

Mass production continued to be developed over the next 50 years with Europe and America becoming the world leaders in this respect.

However during the 1970s, countries from the far-east – notably Japan – began to overtake the west by producing cheaper items that were superior in quality. At the end of the Second World War, Japan had a reputation for making poor quality copies of western goods. During the 1950s and 1960s they developed systems for managing quality and achieving flexibility that allowed them to produce goods of the highest quality, to adapt quickly to changing consumer needs to eliminate all waste during the manufacturing process.

They used concepts such as **Just-in-Time** manufacturing, **Lean Production** and **Total Quality Management** to achieve this. Using this approach, the manufacturing, business and marketing functions are all integrated and work closely together. During the 1980s and 1990s Europe and America worked hard to catch up and these approaches are the norm in business enterprises today.

Activity 6

Use the internet to find out about the following people who influenced the quality revolution.

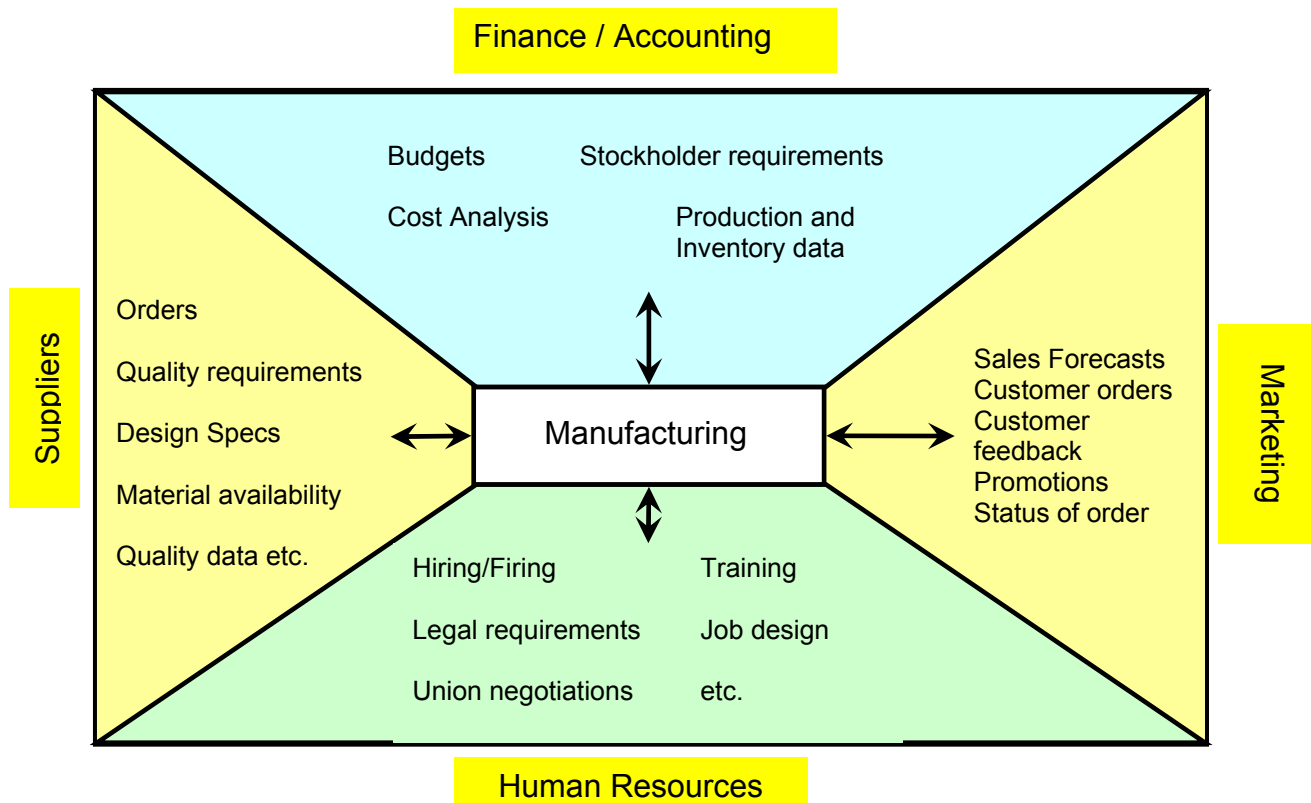- W Edwards Deming
- Joseph M Juran
- Kaoru Ishikawa

Many businesses have become increasingly globalised in recent years, especially with the advent of information technology such as the internet. It is common for European and Asian businesses to compete directly with one another for the same market (e.g. Japanese/ European car manufacturers). Often a company will locate part of its operations in a country that allows it to make most profit e.g. locating a call center in India (BSkyB) or Kerry (Fexco). Recent coverage in the media suggests that China will become a significant market for the Irish economy in the future.

Having a global marketplace means more customers but also more intense competition. Competitiveness is the ability to produce goods and services that meet the test of international markets.

Activity 7

Use the internet to find out about the Irish company Fexco and what it does. Describe two technologies that allow it to operate.

Manufacturing enterprises can range from very small companies having just a few people to very large multinational companies who employ thousands. Apart from the very small companies, a modern manufacturing enterprise usually has a structure like that shown below. It can be seen that manufacturing is just one part of a complex process that represents the company as a whole.

Finance / Accounting

Budgets   Stockholder requirements

Cost Analysis   Production and
                        Inventory data

Suppliers

Orders

Quality requirements

Design Specs   Manufacturing

Material availability

Quality data etc.

Sales Forecasts
Customer orders
Customer
feedback
Promotions
Status of order

Marketing

Hiring/Firing   Training

Legal requirements   Job design

Union negotiations   etc.

Human Resources

In the above diagram, the arrows show how the various components of a manufacturing enterprise interact with one another. The four segments describe what type of information is exchanged between itself and the manufacturing department. The type of information determines which direction it flows. For example, Marketing will provide customer orders to manufacturing. On the other hand the status of the order at any given time will be sent from manufacturing to marketing.

Manufacturing is the technical core and is linked with Suppliers/Finance/ Accounting/ Human Resources. In a modern enterprise, all of the functions are integrated to increase efficiency.

Taking a company such as Dell computers, where each computer is built to an individual order, the marketing and sales function (which is online for the most part) is closely integrated with the production scheduling and materials ordering. The scheduling and ordering is automated using IT to a large extent and is driven by the number of orders submitted on a given day. The correct components are delivered on time to the assembly/manufacturing centre. The

Human resources division ensures that enough workers are hired and available to carry out the work. The accounting division manages the company's finances which would involve a large flow of money through the company which would be allocated to different areas such as payroll, capital investment, research and development etc.

Key Success Factors in Manufacturing Competitiveness

Companies usually choose to compete on one of the four areas listed below:

1. Competing on Cost

Companies who compete on cost try to eliminate all waste in the production process. Usually the production process is **high-volume**, **standardised** and **automated**.

Supermarket chains such as Aldi and Lidl have a Europe wide network of distribution and sales. The buildings themselves are standardised as are the layout and the goods on sale. These *economies of scale* allow them to compete effectively on price.

With Ryanair, flights are typically short meaning no baggage transfers or meals are required. There are no assigned seats or tickets that cost money. All booking is done via the web meaning there are no agents' commissions etc.

2. Competing on Quality

To compete on quality, quality needs to be viewed as a means to please the customer, not just a way to avoid mistakes or defects. Taking a car as an example, this may involve reliability (Toyota), a premium product (e.g. Mercedes) etc. Customers are often prepared to pay more for a product that they believe is of higher quality than its competitors.

3. Competing on Flexibility

Flexibility is the ability to adjust to changes in the type of product being produced, the quantity of it or its design. This causes problems to traditional manufacturing methods because it upsets the stability and efficiency of a production system. For example, repeatedly changing tooling or machine settings to cater for different products will slow the process down.

In recent years, developments in IT and Quality have allowed greater flexibility to be incorporated without affecting the efficiency of the process. Computers can be built to order by companies such as Dell and it is common to order a new car with a specific set of features e.g. engine/colour/trim and have the car assembled to order and delivered a few weeks later.

4. Competing on Speed

To compete on speed, a company must have close contact with both suppliers and customers. Dell computers provide a good example of this where the product is ordered online and assembled to order and delivered in a few days. The company has close contact with the suppliers of the component parts and these are delivered to the factory exactly when they are

needed and the assembled machine leaves the factory as soon as it is tested and packed.

Another common example is McDonalds where a standard range of products (Happy Meal etc) is available for consumption without delay.


Activity 8
Suggest reasons for the following statements:

1. McDonalds menus are mostly standardised
2. Ryanair do not guarantee connecting flights
3. Mercedes cars are more expensive than Toyota

Basic Manufacturing Systems

Often it will be necessary to choose which process is best suited to making a particular item. This is often based on which process is the most economical to make the part. Take the following scenario as an example.
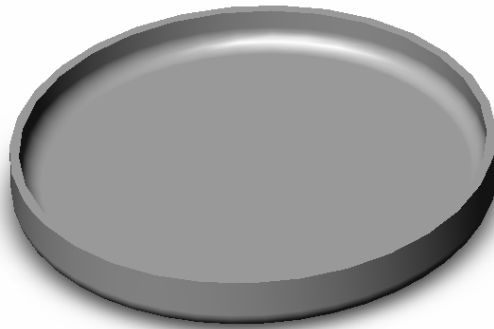
The figure above shows a pressed metal base for a prototype outdoor drinks bottle. 500 items are needed to carry out testing. There are two possible ways to make the component.

- The first is to manufacture the part by hand using a skilled operator on a one by one basis.
- The second way is to automate the process by manufacturing a press tool to punch the items from sheet metal. A skilled operator is not needed for this process but there is a significant cost in manufacturing and setting up the press tool.

The material cost is the same in both cases. There are two questions that can be asked.
1. Which method costs the least to manufacture the 500 items?
2. How many items would need to be made so that the cost of the press tool can be justified? This is called the **break even** quantity.
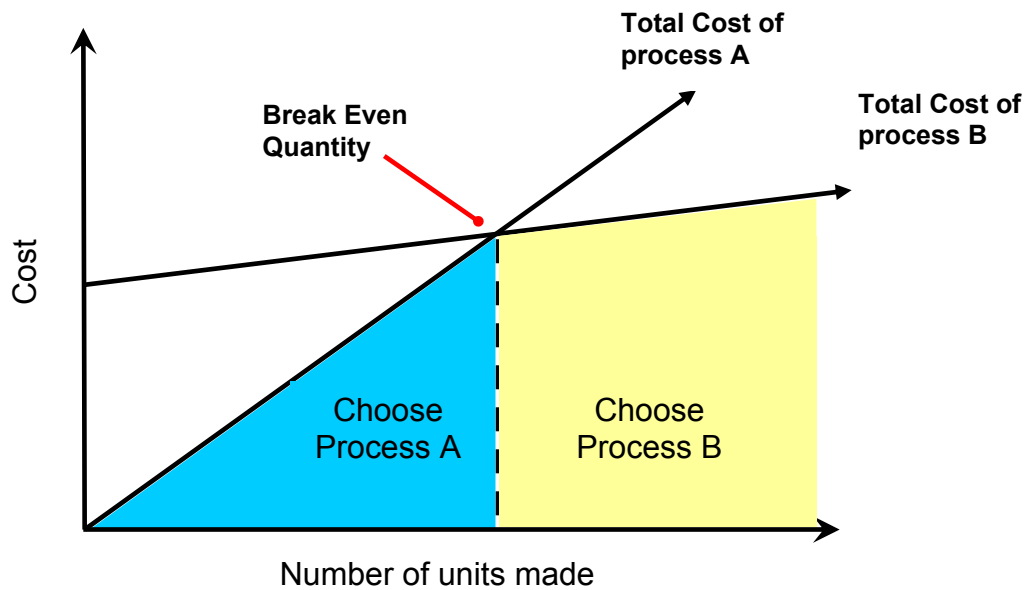
The graphic above shows how the costs relate to one another. Each line shows the total cost as the number of items made increases. For small quantities the direct labour cost (Process A) is cheaper. The point where the lines cross is called the **Break Even Quantity** i.e. either process will cost the same. Above this quantity the automated process (Process B) is cheaper.

Taking the drinks bottle example above, the following costs apply:

- Skilled labourer costs €2.50 per item to manufacture using the lathe.
- Unskilled labourer costs €0.50 per item to manufacture using the automated press.
- The setup cost of the press tool is €500

Graphing the data we get the following. From the graph we can see that the BEQ is somewhere around **250 items**.
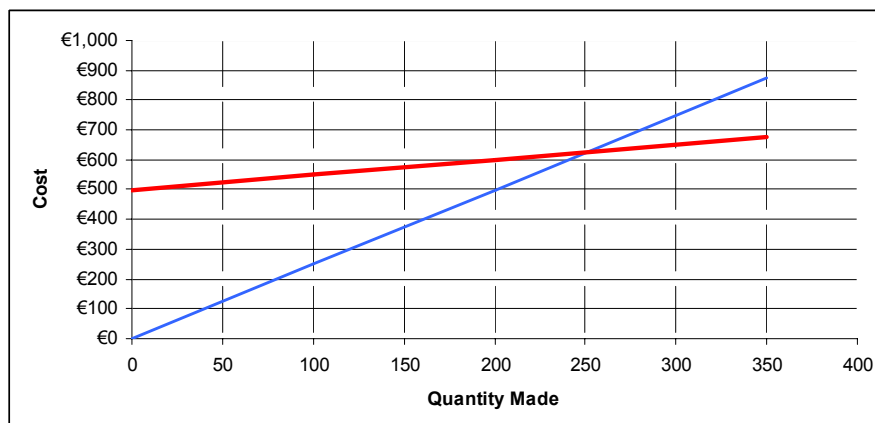
Alternatively we can calculate the BEQ numerically:
Say the BEQ is *n* items

For the skilled labour then the cost for *n* items is (*n*) x €2.50

This must be the same as the other process i.e. €500 + (*n* x 0.50)

So at the Break Even Quantity:

$$2.50n = 500+0.5n$$

$$2.50n-0.5n=500$$

$$2.00n=500$$

$$n=500/2.0 \quad = \textbf{250} \text{ items}$$

In General:

$$BEQ = \frac{Setup\ Cost}{(Manual\ Cost\ per\ item) - (Automated\ Cost\ per\ item)}$$

At any quantity above 250 items, the direct labour method will cost more than the automated process. Therefore the automated process is the most economical one in this instance.

Activity 9
Work out the BEQ for the following: Soldering of a prototype PCB for a new product design.

Cost per item (manual soldering) is €5
Setup Cost for automated (wave solder) including fixtures is €2000
Soldering cost per item (wave solder) 50c

Quality Management

The Pareto Principle

This is an approach used to pinpoint problems through the identification and separation of the 'vital few' problems from the trivial many. The process is named after Vilifredo Pareto who concluded that 80% of the problems with any process are due to 20% of the causes. Pareto analysis allows these problems to be identified.

Taking a soldering problem similar to that described earlier as an example. The faults recorded are as follows:

Dry Joint	Oversolder	Not Soldered	Wrong Placement	Faulty Comp	PCB fault	Des.Error	Heat Damage
120	40	14	10	6	5	4	1

The bar chart below shows the respective causes of each problem. A cumulative plot can be made of all of the causes, and from this a cut off point at around 80% will show the main causes that would need to be addressed.
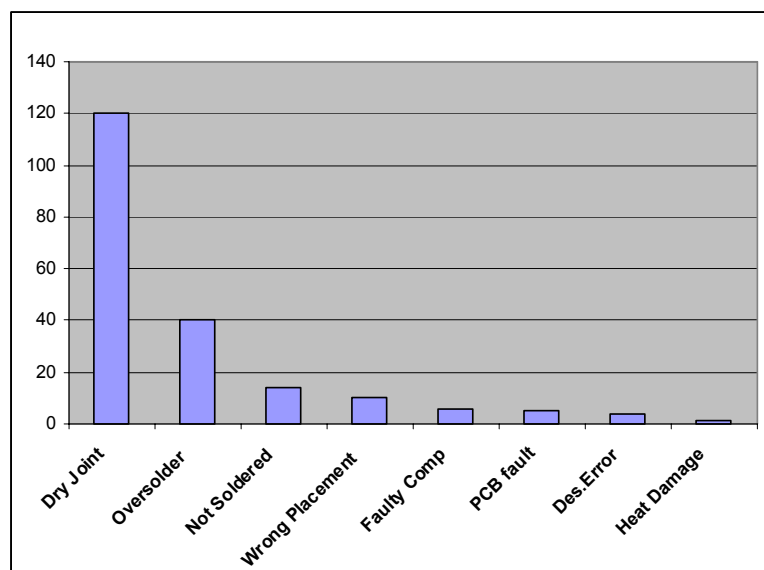
To create a Pareto Chart, first arrange the causes in **descending** order as shown in the table below. Then add each of the percentages from left to right, one cell at a time to produce a cumulative total for each fault, i.e each point is the sum of all the values preceding it.

	Dry Joint	Over solder	Not Soldered	Wrong Place	Faulty Comp	PCB fault	Des. Error	Heat Damage		
Number	120	40	14	10	6	5	4	1	Total	200
Percent	60	20	7	5	3	2.5	2	0.5	Total %	100
Cumulative percent	60	80	87	92	95	97.5	99.5	100		

Finally, plot the values as an X-Y plot. Draw a horizontal line at 80% and look at the causes that lie beneath it. From the chart it can be seen that there are two causes contribute 80% of the total and should be addressed. These are: Dry Joint and Oversoldering.
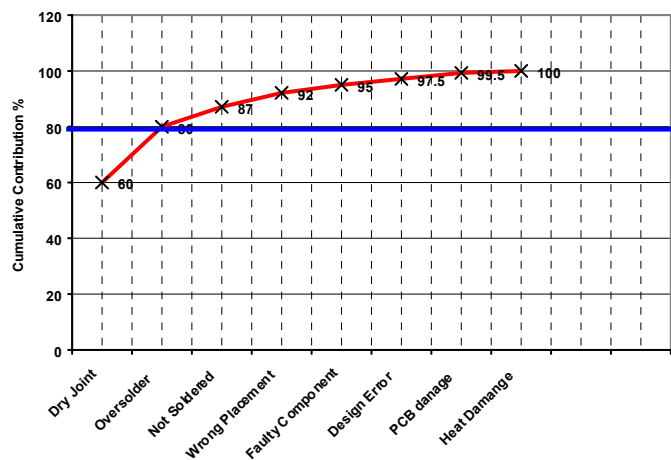
Statistical Process Control

Many manufacturing enterprises are large and have complex manufacturing processes. Therefore it is not always easy to see directly what the causes are of a particular quality problem. In fact, even identifying whether a problem exists in the first place is often a complex task. Where a large number of items is being manufactured e.g. cars, computers, footwear, it is often not possible to inspect each and every component that goes into their manufacture. Instead, quality engineers rely on **statistical techniques** that allow an **estimate** of the quality of the parts by only measuring a **small proportion** of them. The estimate establishes the **probability** of the occurrence of a defective item. The goal is to reduce this probability so that it becomes insignificant.

Euro coins are produced in vast quantities using automated manufacturing processes. However the specifications for the size, weight, composition for a euro coin is very stringent. This discourages forgery and helps when machines need to identify what coins have been fed into them e.g. toll barriers and vending machines. It is therefore very important that the manufacturing process for the coins is controlled carefully – over time, machine settings will

drift, tools will wear etc. It would be clearly impossible to inspect each and every coin produced by the minting factory.

In practice, a small fraction (called a sample) of the coins produced each day are inspected. The data from this small sample along with knowledge of the behaviour of the manufacturing process allows the quality engineer to know whether there are any quality problems affecting the remainder of the coins.

These techniques are used everywhere a large volume of items are being produced or delivered e.g. computers, mobile phones, even large hotels use these methods to monitor the quality of their rooms and customer satisfaction. The general name for these methods is **Statistical Process Control**.

Modern statistical process control relies heavily on computing. Specialist software is widely used by professional quality engineers to produce and analyse the data they need. In the following examples, we will use Microsoft Excel to set up spreadsheets that will perform the calculations.

Variation in Processes

A bar-chart is often used to display data graphically and usually this shows some fundamental properties of the data. For example, the chart below shows the sizes obtained when laser cutting a hole on a particular laser cutting machine. The target size is 20mm and 39 components were measured.
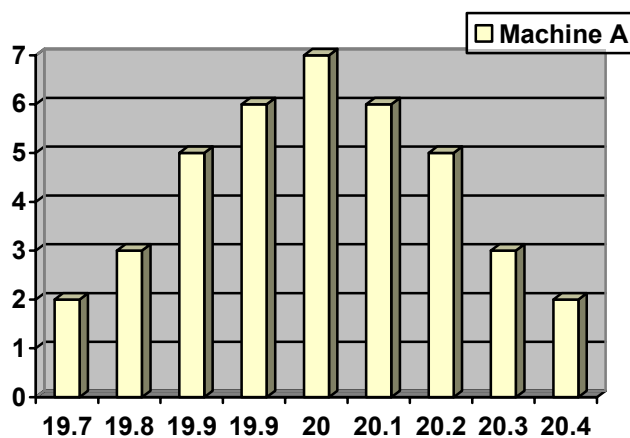
The chart shows that the sizes tend to cluster around the target size of 20mm, with a decreasing number of parts occurring as the difference between them and the target size increases. Now imagine a second machine is available and it is used to produce the same part to save time.

In the second diagram it can be seen that the distribution of sizes follows the same general pattern but now the mean is centred on 20.2. This might indicate a problem such as the wrong power setting by the operator.
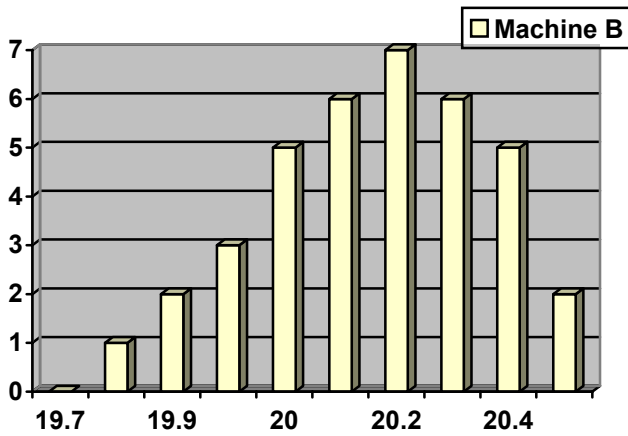

Variance and Normal Distribution

Measurable attributes such as size, temperature etc tend to have a natural variance similar to that shown above. For example, if the height of a group of Irish people is measured it will probably be found that the average is a bit less than 1.8m (six feet) with most people being reasonably close to this height. There will be a smaller number of people who are considered short or tall and an even smaller number of people who are very short or very tall.

Activity 10
Open the excel spreadsheet and select the tab called **HEIGHTS.** Look at the data and the associated bar chart. Note the shape of the bar chart. Take a survey of the heights of the people in your class and input them to the sheet. See whether the pattern is the same.
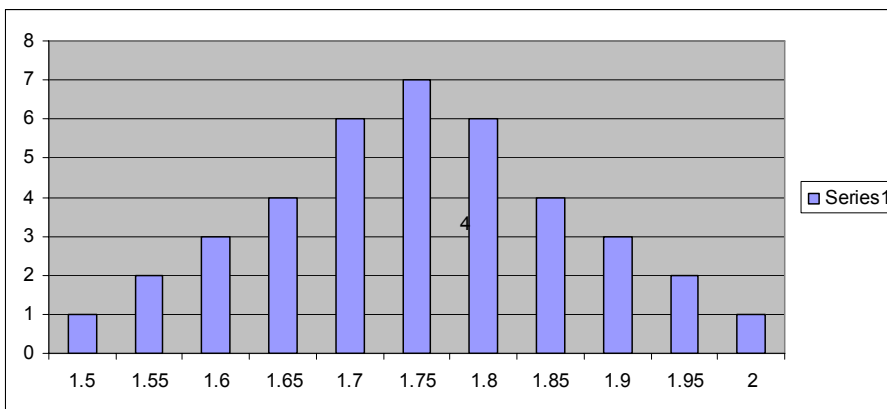
| Survey of the heights of the pupils in a Technology class											
Height (m)	1.5	1.55	1.6	1.65	1.7	1.75	1.8	1.85	1.9	1.95	2
Number of people	1	2	3	4	6	7	6	4	3	2	1

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Histograms: a quick overview

A histogram is a special type of bar chart that can convey some **statistical** information. Each bar has a width corresponding to a **range** of sizes. e.g. between 1.6 and 1.7m. The width of the bar is drawn in proportion to the size of the interval. Therefore the shape of the histogram will be in proportion to the spread of the data.
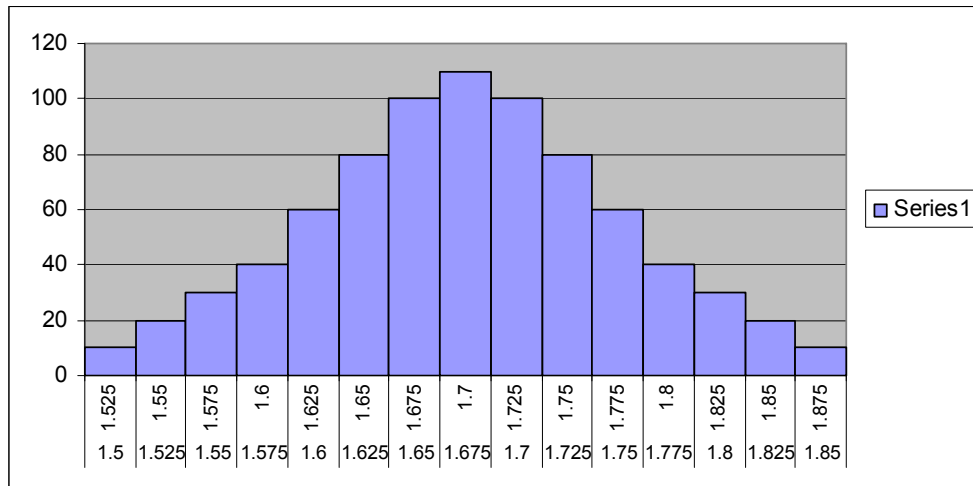

The histogram above shows the results of a survey on the heights of a group of pupils in a large school. An interval of 0.025m (25mm) is used for the columns. This means that each column corresponds to the number of people who fall between the limits of each category. i.e. between 1.60m and 1.625m. (60 people in this example)
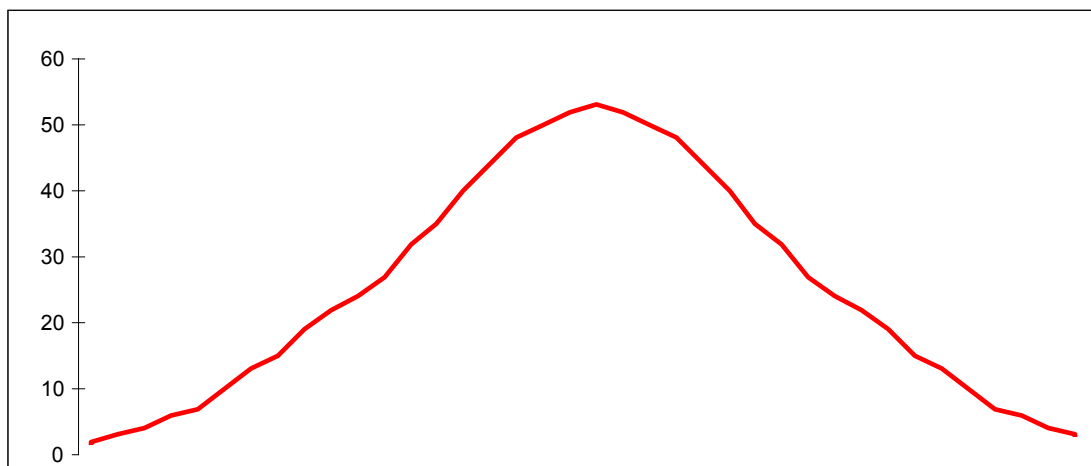
If a larger survey is conducted using a smaller interval of 0.010 m (10mm) on the population of a town then the chart from the data might look like the following.
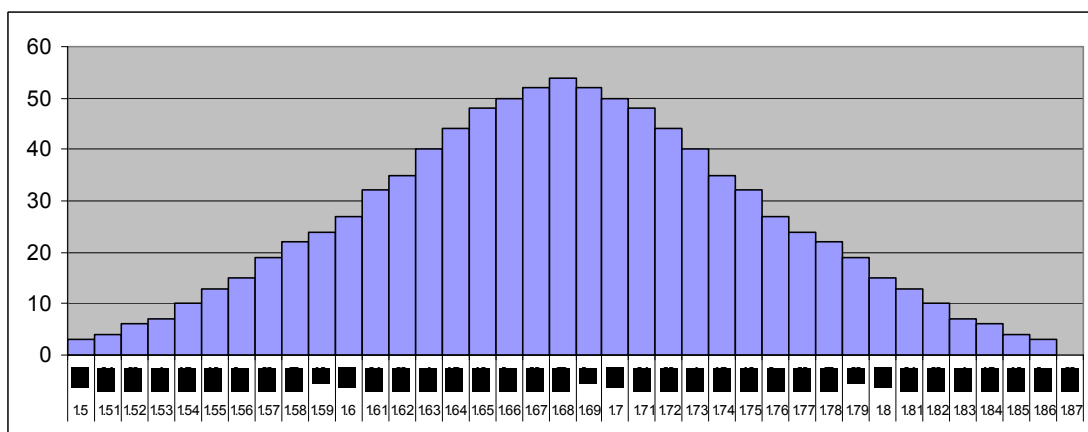
Notice the shape of the graph is more or less the same but now the peaks of the bars start to define a distinct curve.
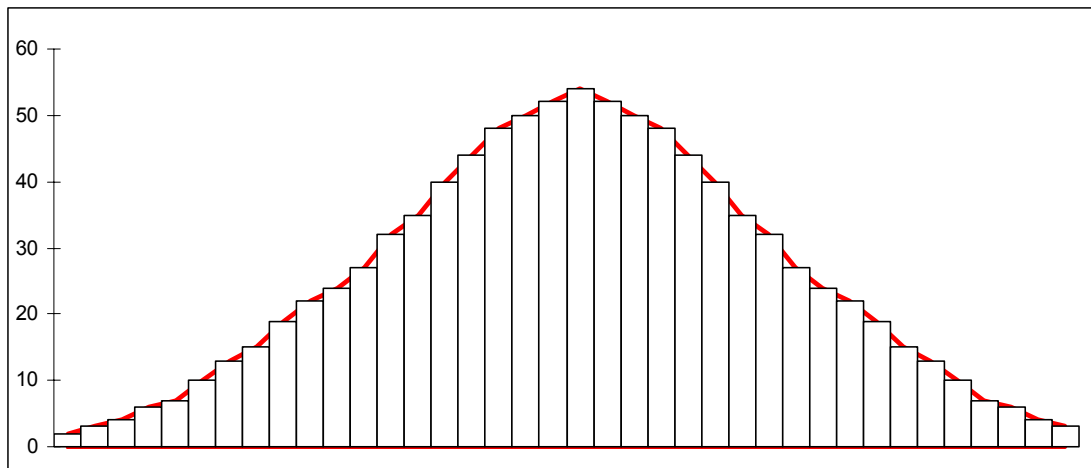
We can trace the midpoints as shown above. The curve with the histogram removed is shown below.


This spread of the sizes is called a **normal distribution.** It often occurs naturally where a variation is present in a size or dimension like the example we have just seen. The curve has some useful mathematical properties that we will look at later. **Note there are other types of distribution that we will not be considering here.**

The normal distribution curve has the following properties:
- Most of the sizes are grouped symmetrically about the centreline or mean.
- As the size moves away from the mean the number of occurrences of it decreases.

The graphic below shows the shape of a typical normal distribution curve.
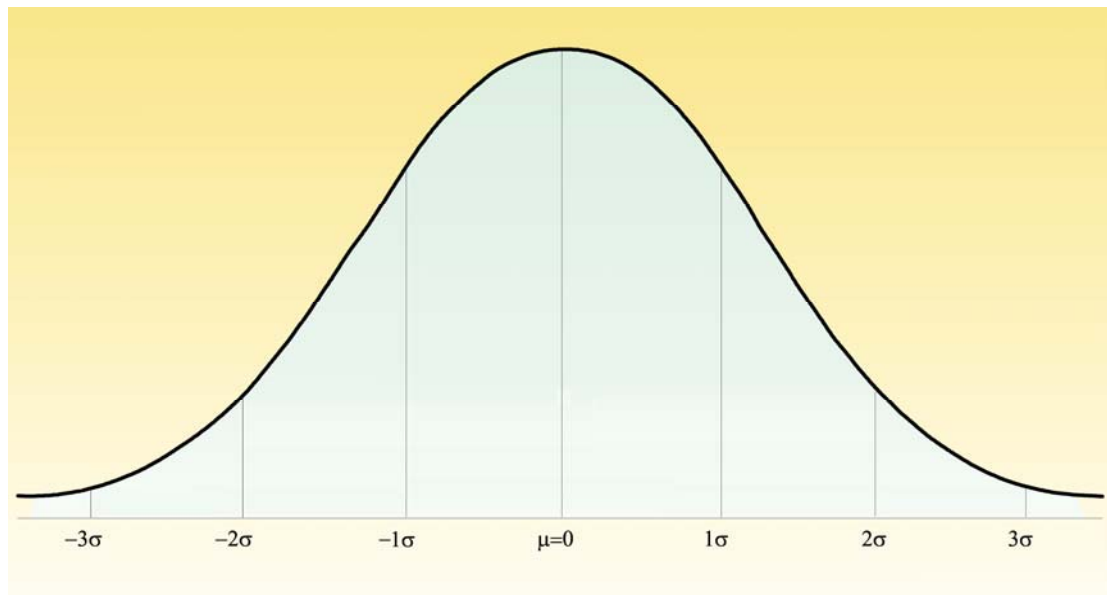
Example:
A student wants to determine the accuracy of 330Ω silver banded resistors that are being used in an electronics project. She measures a number of standard silver banded resistors using a multimeter and records the data as follows:

Measured resistance in Ohms

FROM	TO	Quantity found
240	250	2
250	260	3
260	270	4
270	280	5
280	290	7
290	300	10
300	310	15
310	320	18
320	330	20
330	340	18
340	350	15
350	360	10
360	370	7
370	380	5
380	390	4
390	400	3
400	410	2
410	420	1

A graph of the data shows that the resistance follows a normal distribution centered on the resistor value of 330Ω. Notice that the measured value of the resisters varies between 240 and 430 ohms. This is called the **range** of the data.
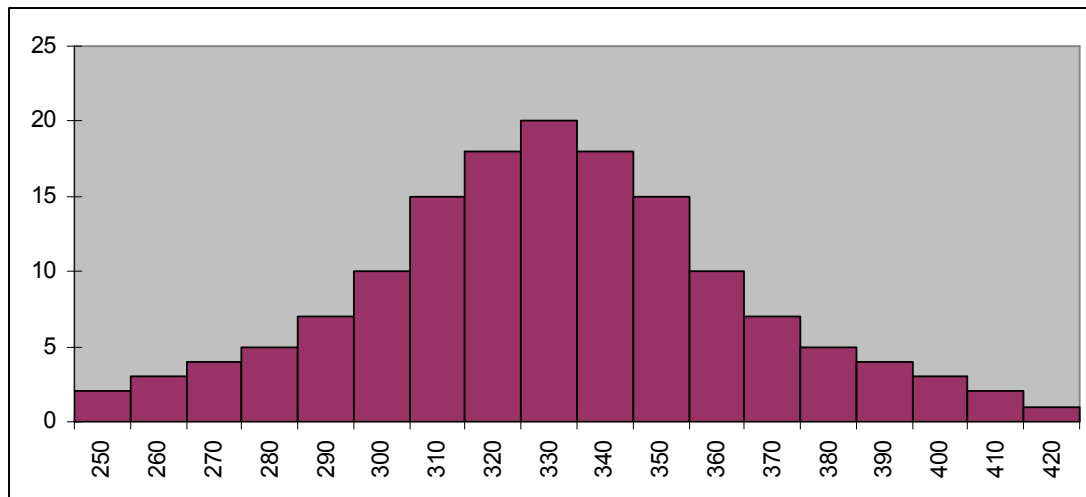

Next the student measures a quantity of gold banded resistors and gets the following results:

Measured resistance in Ohms

FROM	TO	Quantity
250	260	
260	270	
270	280	
280	290	
290	300	
300	310	**10**
310	320	**18**
320	330	**27**
330	340	**25**
340	350	**20**
350	360	**11**
360	370	
370	380	
380	390	
390	400	
400	410	
410	420	
420	430	

Notice that the values are once again spread more or less symmetrically around the target value of 330Ω but the range is much narrower this time. This is what would be expected with the tighter tolerance on the gold banded resistor.
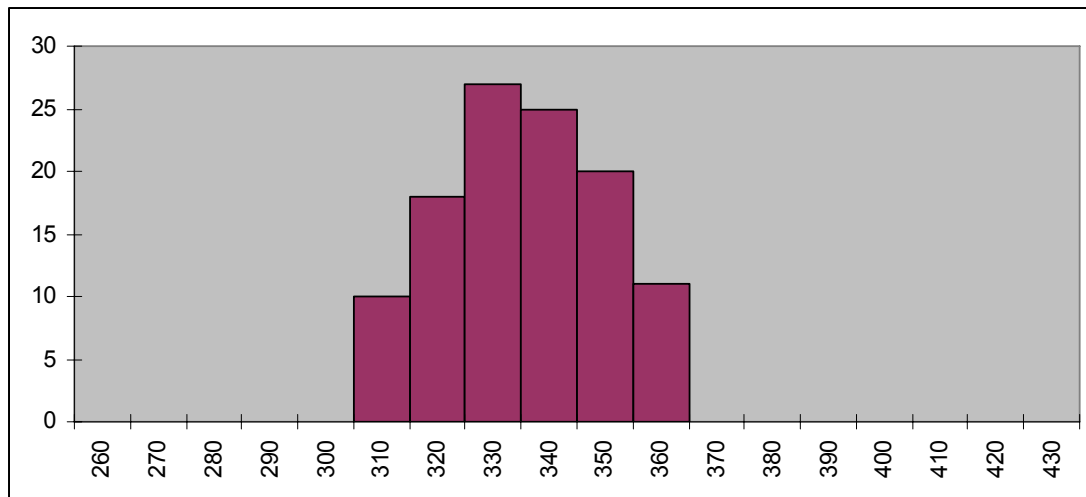
From looking at the two charts, some general conclusions can be drawn:

a) Taking another **silver** banded resistor at random from the box and testing it, it is likely that the value will fall somewhere between 250 and 430 ohms.

b) It is more likely to measure at some value close to 330 ohms than the extremes of the test

c) Taking another **gold** banded resistor and measuring it, it is likely that the value will fall somewhere between 300 and 360 ohms.

d) It is more likely to measure at some value close to 330 ohms than at the extremes of the chart.

e) Importantly, it would be surprising if one of the gold resistors gave a reading very far outside the limits established by the tests in either of the two cases above.

With a normal distribution these concepts can be given precise mathematical definitions and used to predict the likelihood of the values of future measurements. These are explained in the next section.

Variance and Standard Deviation
In a normal distribution, the 'width' of the distribution has a precise mathematical meaning called the **variance**. The greater the variance, the 'wider' the curve. The amount of variance is defined by a parameter called the **Standard Deviation.**

The standard deviation (sigma) can be calculated from the measured sizes of a sample of parts using the formula below:

$$\sigma = \sqrt{\frac{(y_1 - \bar{y})^2 + (y_2 - \bar{y})^2 + ...(y_n - \bar{y})^2}{N}}$$

y_1, y_2...etc are the measured values,

$\bar{y}$ is the average value.,

N is the number of samples taken.

The formula above has been included for completeness. In practice the standard deviation is rarely calculated by hand.

More usually, it can be found using a scientific pocket calculator or in Excel using the **STDEV** function.

Activity 11

Measured resistances
255
253
266
265
264
271
271
277
278

Open the excel sheet named **Resistor Example** and look at the data from the column on the left. The sheet contains the data from the silver resistor example above. The Mean and Standard deviation have already been calculated.

*Note the units are in ohms the same as the data they were derived from.*

1. Using the measured data on the far left column, use the excel AVERAGE and STDEV functions to calculate the mean and standard deviation.

2. Open the worksheet named **Resistor Example 2.** This contains the data from the gold band resistor example. Look at the graph and the standard deviation for the data.

   a) How does it compare to the standard deviation from the previous example?
   b) What do you think the standard deviation can tell us about the spread of the data?

Now we know how to calculate the standard deviation the next step is to use it. The following concept forms the basis of much of the statistical work used in quality management. The standard deviation is often referred to by the greek letter **sigma (σ)**. This will be used from now on.

The important property of a normal distribution is that once sigma is known, the following can be said:

95% of all measured items will lie within two sigma of the mean value in either direction. This is often referred to as plus or minus two sigma (+/- 2σ) of the mean.

Furthermore, 99.74% of all measurements will lie within +/- 3σ of the mean. The diagram below shows the concept.
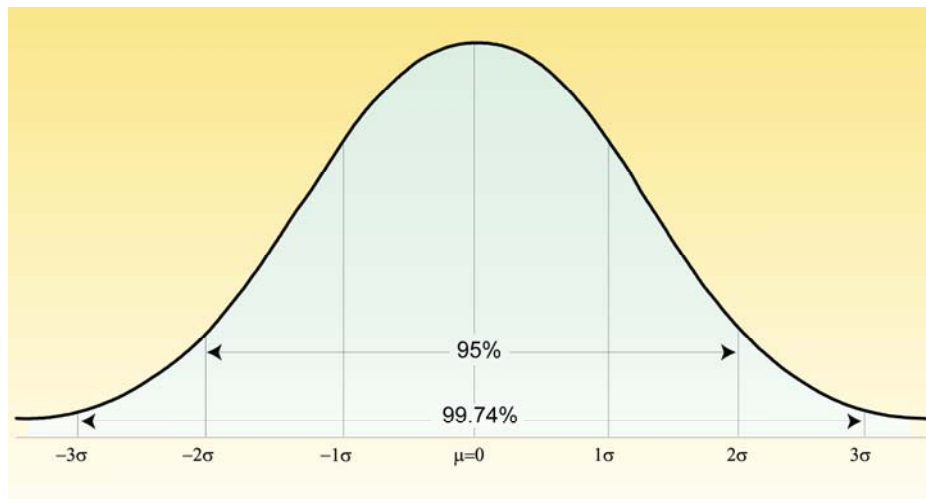
Activity 12
Return to the Resistor example spreadsheet for the silver band resistors.
Look at the Upper limit and Lower limit values. They have been calculated as follows.

>   Upper limit = Mean plus three sigma
>   Lower limit = Mean minus three sigma

99.7% of all expected future measurements should lie within these limits. **This means that if a further 1000 resistors are measured no more than three of them should exceed the size limits we have derived.**

1. Using the mean and standard deviation values already shown on the spreadsheet, use excel to calculate these values yourself.

2. Look at the data on the histogram. Compare the values of the limits to the measured data shown on the graph. Do they seem plausible?

3. Measure the heights of your classmates. Enter the data into a new excel spreadsheet and calculate the standard deviation.

4. The range of size between the upper and lower limits is known as the **Confidence Interval**. Suggest why this is so.

Activity 13

Boxed items such as matches or smarties are packaged by machine. The numbers of items in the box are not counted individually – the packaging equipment is expected to fill the box with an approximate number of items. The variation of this number is controlled within certain limits, i.e. the box should not be too full or too empty that a customer might notice.

Carry out your own survey to assess the limits as follows:

Each person in the class buys one small packet of sweets such as smarties. Count the number of sweets in each box. Input the data into an excel worksheet. Use the one provided or set up your own one.

1. Calculate the mean value for the number of sweets in each box
2. Calculate the standard deviation for the number of sweets in the boxes
3. Calculate the upper expected limit using three sigma
4. Calculate the lower expected limit using three sigma

Now, fill one box so that it is obviously over full. Next, count the sweets. Does the number exceed the upper limit?

Empty one box to the point where it looks like it has been under-filled. Once again, count the sweets and see if the number is outside the lower limit.

Control Charts in Manufacturing

As we have seen above, all process have a natural variation in output. We have seen that it can be determined by taking a sample of items, measuring them, calculating the standard deviation, and using it quantify the process.

Control charts are graphs that visually show if a sample is within statistical control limits. The charts serve two purposes:
- They are used to establish the control limits for a process
- Then they are used to monitor the process to show when it is out of control

The upper and lower limits of size produced by the process are determined by plus/minus 3 sigma. These are called the **upper control limit** and the **lower control limit** of the process.

THE UPPER CONTROL LIMIT (UCL) IS EQUAL TO THE PROCESS MEAN *PLUS THREE SIGMA*

THE LOWER CONTROL LIMIT (LCL) IS THE PROCESS MEAN *MINUS THREE SIGMA*.

IF SIGMA IS KNOWN FOR A PROCESS, FINDING UCL AND LCL IS STRAIGHTFORWARD.
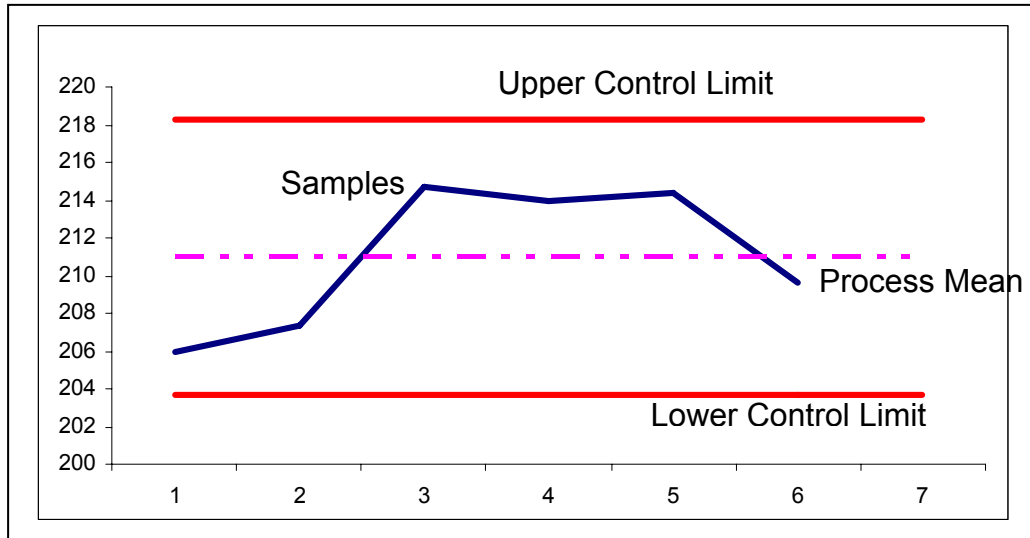
If the process is running normally, all the output should lie within the UCL and LCL. Control charts are used to identify patterns in the output while the process is running and to show up any potential problems before they occur.

The control chart shown below shows the process mean and the **average size of a sample** of items measured over time. All the samples are within the control limits so the process is **in control**.
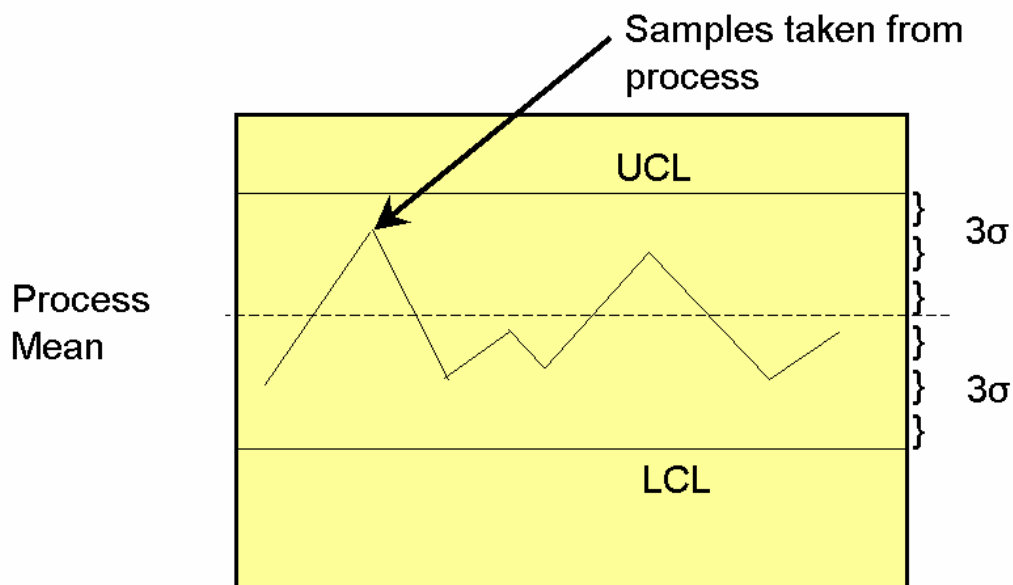
Constructing Control Charts

There are a number of different types of control charts. Each type is for a particular type of data and purpose. We will look at the construction of one type of chart that is used when monitoring a **varying quantity** such as the size of an item or the temperature of an oven. These charts are used to compare individual readings with the process average and UCL/LCL values.

There are two types,
- Mean Charts (often known as X-Bar or $\overline{X}$ Charts)
- Range Charts (often known as R charts)

Mean Charts

With a mean chart or X-Bar chart, each time a sample of a group of items is taken, their mean is computed and plotted as a point on the chart. The samples taken are usually small – four or five. The centre line of the control chart is the process mean i.e. the mean of the sample means.

Example:

A traditional pizza restaurant uses a wood fired oven to bake its product. The temperature of the oven is regulated by the amount of fuel as well as the airflow to the fire. The ideal oven temperature is 210 degrees. From previous testing the owners have established that the standard deviation for the temperature is 4.2 degrees.

To monitor the temperature, it is recorded three times daily and the mean temperature is calculated from the three values as shown below

Oven temperature data			
	Morning	**Midday**	**Evening**	**Daily Means**
Monday	210	208	200	206
Tuesday	212	200	210	207
Wednesday	215	209	220	215
Thursday	216	207	219	214
Friday	220	208	215	214
Saturday	210	219	200	210

By getting the mean of the daily means, a mean for the process is obtained.

i.e. $\dfrac{206 + 207 + 215 + 214 + 214 + 210}{6} = 211 \; Degrees$

We can start to create the chart by plotting the process mean as a horizontal line and the daily means as points in the chart.
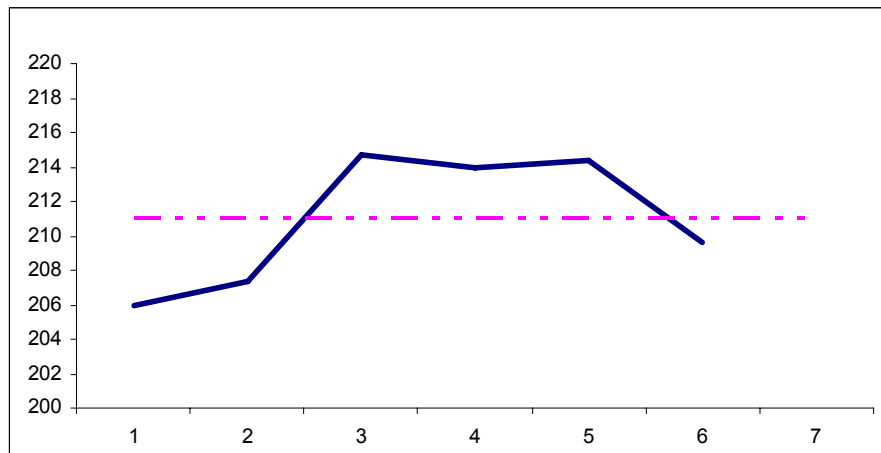
Next, we need to determine the UCL and LCL for the process. To do this we need to use the following data:

- The process mean that we have just calculated

- The process standard deviation σ (already determined as 4.2 degrees from previous tests)

- The standard deviation σ_{sample} of the sample means. This is equal to $\dfrac{\sigma}{\sqrt{n}}$ where n is the sample size. (Three temperature readings in this instance)

From this we can calculate the UCL and LCL:
The process mean as calculated above is 211 degrees.

UCL = process mean + 3σ_{sample}

and

LCL = process mean - 3σ_{sample}

Using the figures from the example above, the sample sigma
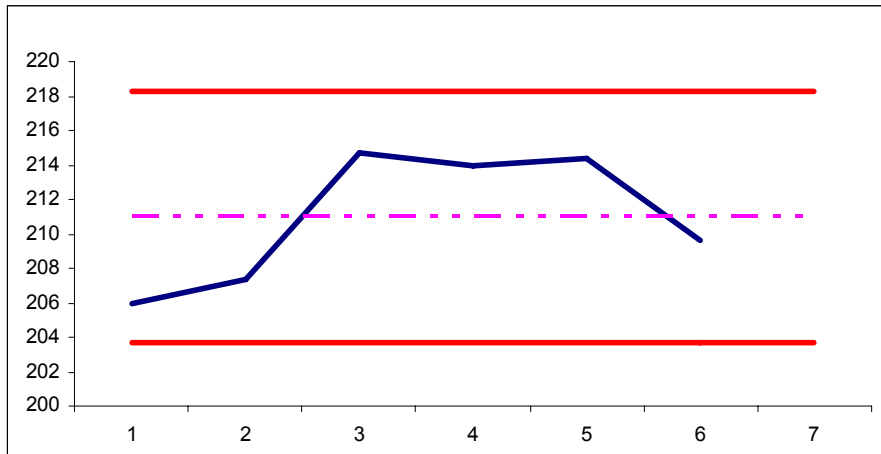$$\sigma_{sample} = 4.2 / \sqrt{3} = 2.42 \text{ degrees}$$

Then UCL   = process mean + 3(σ_{sample})
            = 211 + 3(2.42)
            = 218.27 degrees

And

LCL   = process mean – 3(σ_{sample})
        = 211 – 3(2.42)
        = 203.72 degrees

These UCL and LCL are then plotted as horizontal lines on the chart as shown below.

Interpreting Control Charts

If the process is in control, there should be a natural variation in the data points within the limits set by the UCL and LCL. There should be roughly an equal number of points above and below the process average. The chart above shows a process that is in control.

Some patterns in the plotted data may indicate an existing or a developing problem. The points on the chart should not show any particular pattern – they should be randomly placed within the control limits. Any appearance of a pattern suggests a non-random influence on the process that should be investigated.

A few of these are shown below:

Process out of control
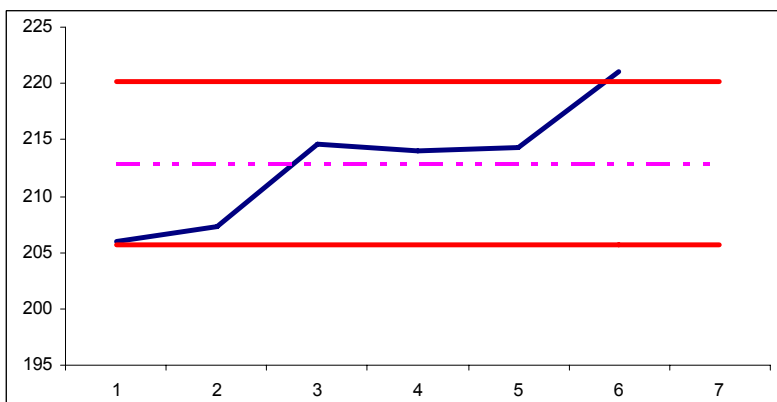
In this chart the last data point is out of control – this indicates a definite problem that must be addressed immediately as defective products are being made. Note that there has been a steady increase over the last six readings. This may give a clue to the cause of the problem.
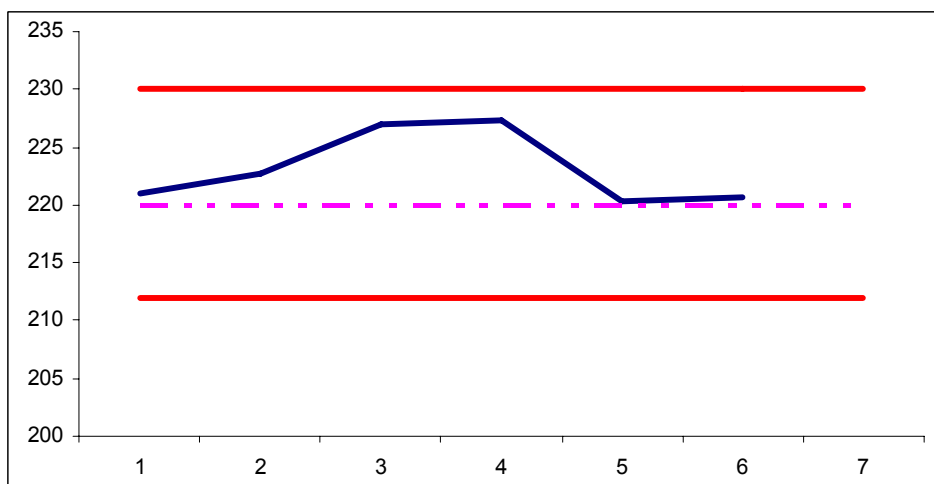
Process in control but a steady increase in readings
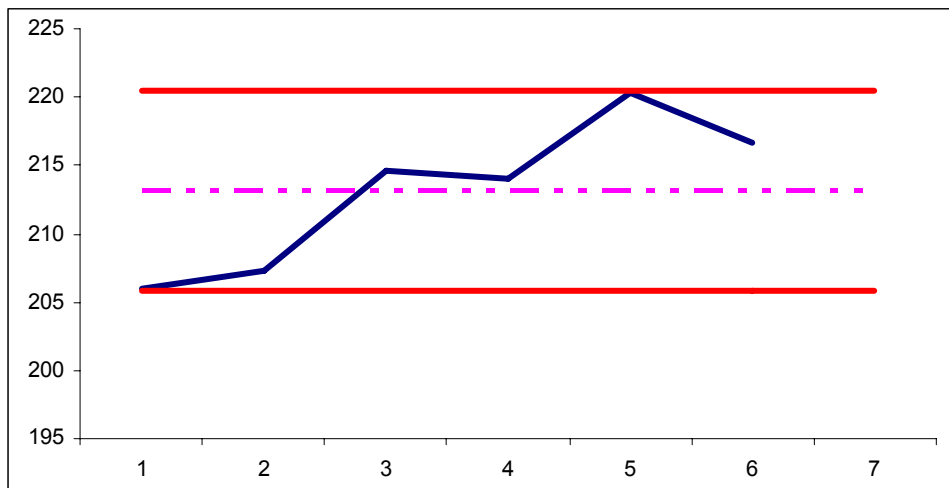
In this case, the process is still in control but there has been a steady increase toward the UCL. There may be a possible problem and it should be investigated.

Points clustered to one side of the mean

In this case the data points are all above the process mean. This suggests some non-random influence on the process that should be investigated.

Range Charts

In a Range chart, the range is the difference between the largest and smallest values in a sample. This range is used to measure the process variation in contrast to the last example where it was compared to a mean value.

The chart is constructed as follows:
A number of samples are taken each consisting, in turn, of a number of readings. The range (R) of each of these samples (largest reading minus smallest) is established. Then the average range is calculated as follows:

$$R_{Average} = \frac{R_1 + R_2 + ..etc}{Number\ of\ samples}$$

The formulas for finding the control limits are

$$UCL = D_4 R_{average}$$
$$LCL = D_3 R_{average}$$

D4 and D3 are values from a table. They are based on the number of readings taken in each sample.

Sample size (n)	D_3	D_4
2	0	3.27
3	0	2.57
4	0	2.28
5	0	2.11
6	0	2.00
7	0.08	1.92
8	0.14	1.86
9	0.18	1.82
10	0.22	1.78
11	0.26	1.74

An R-Chart is constructed using the same data used for the Pizza oven example.

| Oven temperature data			
Morning	Midday	Evening	Range
210	208	200	10
212	200	210	12
215	209	220	11
216	207	219	12
220	208	215	12
210	219	200	19

To draw the chart proceed as follows:
The number of samples (n) is 3. This gives D_3 as 0 and D_4 as 2.57 from the table.

The average range $R_{average}$ = $\dfrac{10+12+11+12+12+19}{6} = 13$ degrees

The upper control limit UCL   = D4 x $R_{average}$
                                       = 2.57 x 13
                                       = 33.41 degrees

The lower control limit LCL = D3 x $R_{average}$
$$= 0 \text{ x } R_{average}$$
$$= 0 \text{ degrees}$$

Now draw the chart with the UCL, LCL and $R_{average}$ lines
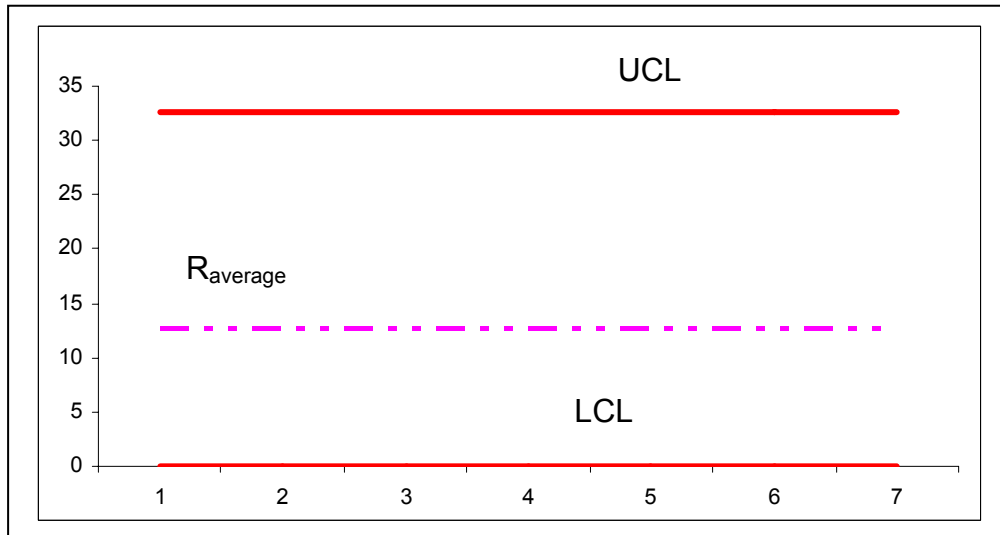
Finally, the data points are plotted in the chart
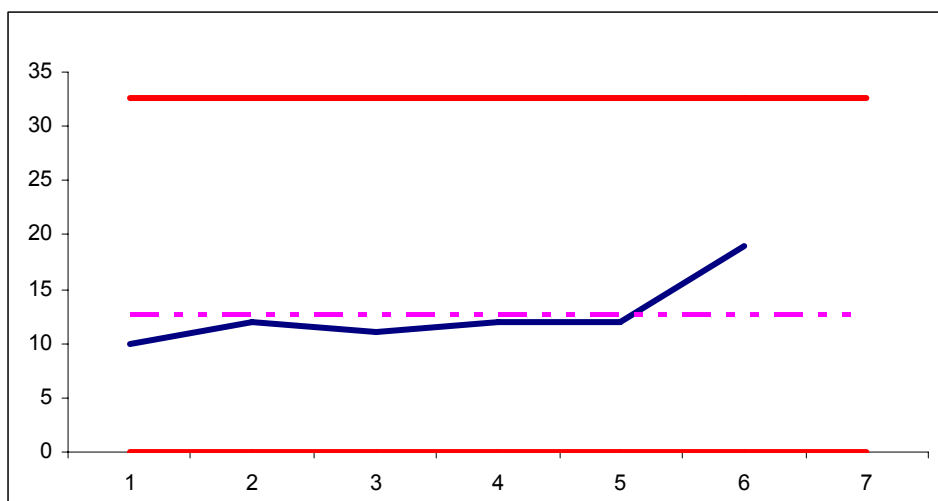
These two types of charts are often used together to give a quality engineer a better picture of what is happening in a process.

Activity 14
Irish weather example – use statistical data and plot daily weather/ temperature data. See if the process (Irish weather) is in control.

Process Capability

Process capability is an important concept used in matching the natural variation in a process to the size requirements imposed by the design of an item.

In the previous sweet box example, we overfilled and under-filled the box so that it was outside the acceptable limits. If it is under-filled, customers are likely to be dissatisfied. Overfilling is a waste from the manufacturer's point of view as well as causing problems with the packaging process e.g. closing the box.

Now, imagine that the manufacturer decides on an upper limit and a lower limit on the number of sweets that should be in a box. These are chosen for the same reasons we discussed earlier. In between these will be a target value which is midway between the two extremes.

The box filling equipment should be able to fill the box within these limits – ideally the target number of sweets should be in every box. However, the machine will probably not fill the same number of sweets into each box – in other words there is a natural variation in the filling process. In addition, some packaging machines may have a greater variation than others.

We have seen that we can measure this variation by finding the standard deviation. Next we will see how this can be used to ensure that the correct machine (or process) is matched to a particular job.

Shown below are three possible scenarios where the variability of a process is compared to the requirements. In each case imagine that the design specifications refer to the limits of the number of sweets that are acceptable in a packed box.
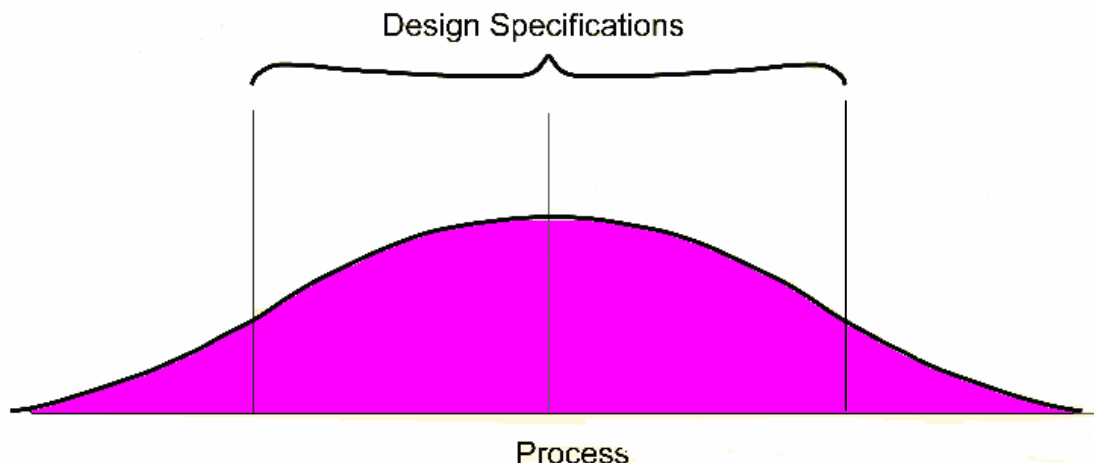
1. The variation of the process is too great and a proportion of boxes will be overfilled and under-filled. In this case we say that the process is **not capable**. Note that this is not necessarily a fault in the machine but rather, a natural feature of it.

Design Specifications

Process
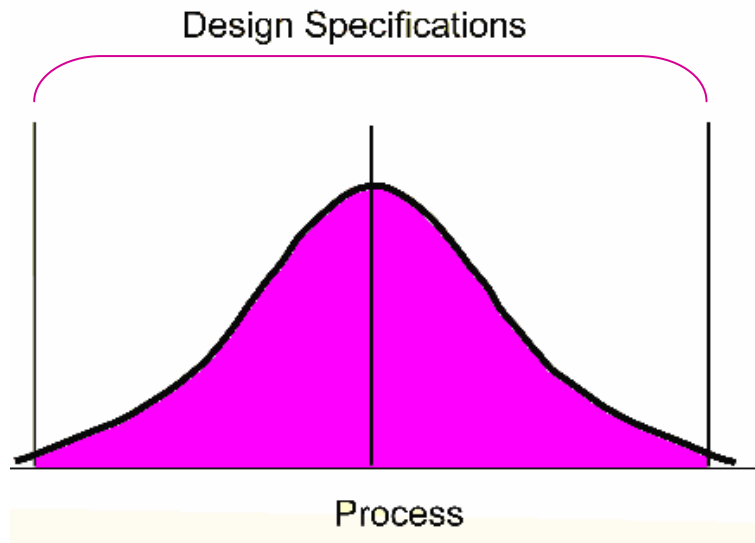
2. The natural variability and the limits of the size for the item coincide. In this case there will be a small number of boxes that will be under-filled or overfilled. In many cases this is acceptable, especially as the increased accuracy usually comes at an increased expense. This process is considered to be **capable.**


Design Specifications
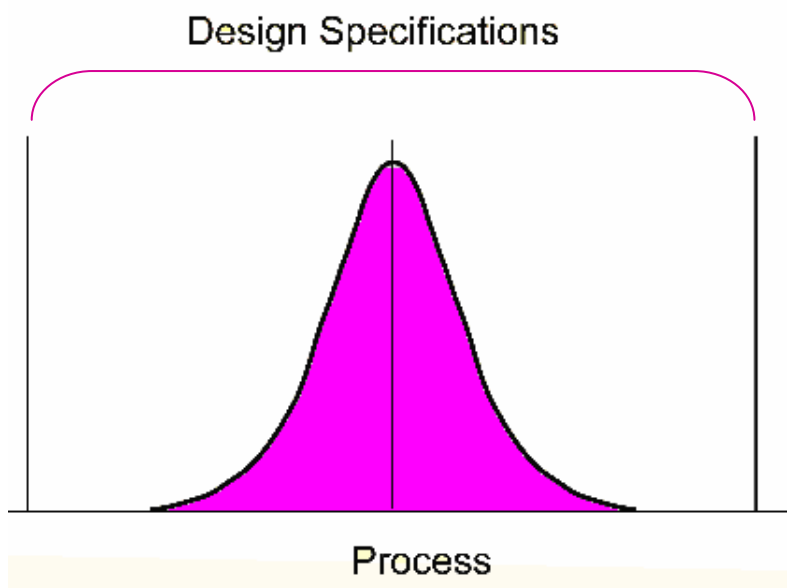
Process

3. The variation of the process is well inside the tolerance limits for the item being produced. There will be no boxes under-filled or overfilled and the items produced will always fall within specification – this process is considered to be **capable**.

Notice that in all the figures above, the width of the tolerance range remains constant – it is the variation in the process that brings about the difference in capability. If a process is capable, the natural variation of the process is within the tolerance limits of the part being produced so this eliminates the need to measure each part being produced.

Calculating the Process Capability index

The process capability index is a measure of whether a process is capable or not. As seen earlier the amount of variation in a process is defined by the standard deviation (sigma). 99.74% of all items produced will fall within +/- three standard deviations from the mean.
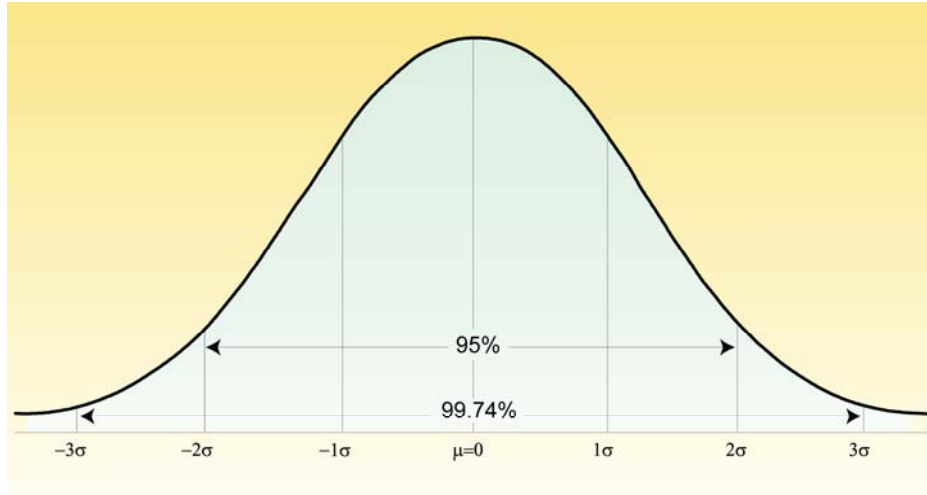

So if the tolerance limits on an item are equal to six times sigma (Three sigma on either side of the mean) then 99.74% of the items produced should fall within the size limits. This is considered acceptable to many manufacturers (but by no means all as will be seen)

The process capability index is calculated using this as a basis and is found by the following formula:

$$C_p = \frac{Tolerance\ Range}{6\sigma} = \frac{Upper\ Size\ Limit - Lower\ Size\ Limit}{6\sigma}$$

Looking again at the diagram below, we see the condition when C_p is equal to 1. Notice that the natural variation of the process exactly equals the requirements of size from it. If C_p is equal to 1 then the process is considered to be capable.

Design Specifications
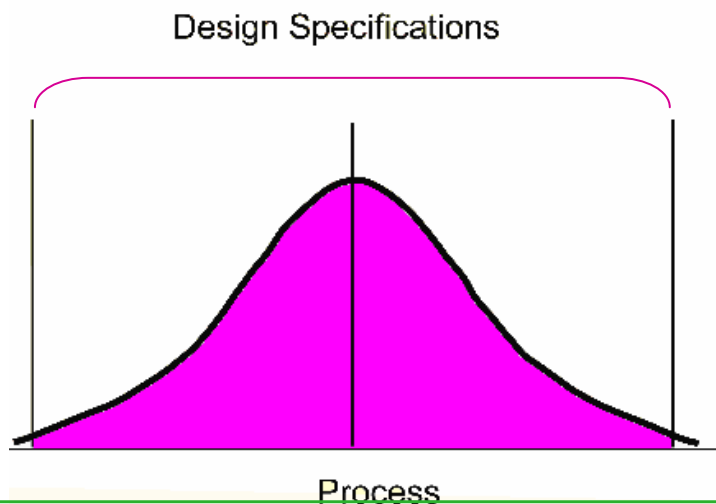
Process

- **This means that 99.97 of the natural variation of the process will be within the limits acceptable for whatever it is being used for. i.e. three defects per thousand**

If C_p is greater than 1 then the natural variation in the process is smaller than the limits required and the process is considered to be capable. This is shown in the diagram below.

Design Specifications
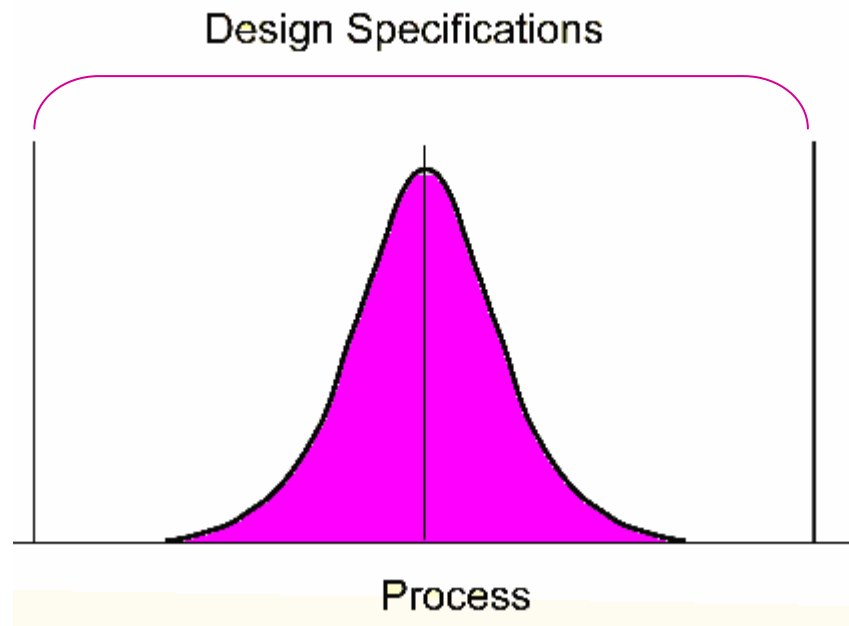
Process

- **This means that very few defects will be found – less than three per thousand, often much less**

If C_p is less than 1 then the process is considered to be NOT capable. This condition can be seen in the diagram below.

Design Specifications
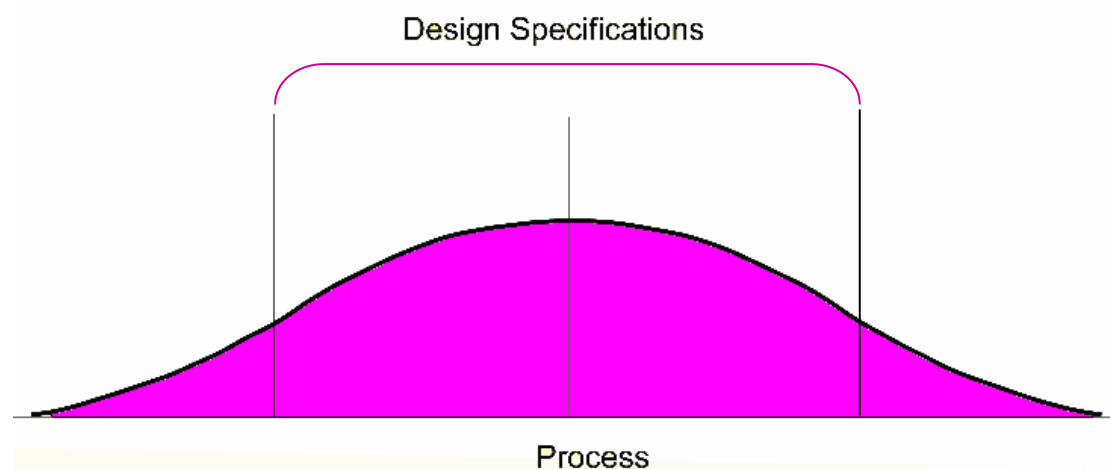
Process

- **This means that the natural variation in the process will cause outputs that are outside the acceptable limits of whatever it is being used for.**

Example:

MP3 players often require a precise voltage from their charging devices. If the voltage is too low or too high the device will not charge.

Imagine you work in an electronics wholesale company. You see a business opportunity where you can import MP3 chargers from the Far East for resale in Ireland. The chargers plug into a mains socket and produce 5v on a USB style socket that the MP3 player can be connected to. Before committing to a full shipment you buy 20 chargers to see if they are suitable. In order to function properly, they must produce 4.9v minimum and 5.1v max.

You test the 20 chargers and record the output voltage as follows.

Sample	Voltage produced	
1	5.05	**Upper voltage limit 5.1 volts**
2	5.01	
3	4.99	**Lower voltage limit 4.9 volts**
4	5.1	**Standard Deviation 0.064759 v**
5	4.99	
6	4.95	
7	5.05	**Process Capability index 0.514732**
8	5.05	
9	5.09	
10	5.09	
11	4.91	
12	4.92	
13	4.99	
14	5	
15	4.9	
16	4.95	
17	5.05	
18	5.09	
19	5.09	
20	5.05	

When tested, none of the chargers actually exceeded the voltage limits and taking this alone it would seem that they are acceptable. However, this is not the case.

When the process capability index is calculated it works out at just over 0.5 which means that in a large batch there would be a high likelihood of receiving chargers that provide voltages outside of the limits. The correct decision in this case would be to look for another supplier or a different model of charger.

Activity 15

Open the MP3 charger spreadsheet and examine how the C_p index is calculated.

1. Change the limits of voltage and see what affect it has on the process capability.

2. Try to invent a set of voltage data that gives a C_p index of 1 or greater.

Six Sigma in Quality Management

In the examples above, three-sigma variation **on each side of the mean** was used to determine process capability. This allows a small margin of error equal to 0.27%. This would mean with C_p=1 that there would be 2.7 defects per thousand items. For many applications this is not satisfactory – consider an aircraft manufacturer - so a process capability based on plus or minus **six sigma** is used instead. This equates to **3.4 defects per million**. Companies such as Motorola pioneered this approach and many companies throughout the world have adopted it as a benchmark.

Activity 16

1. List two situations where it would be essential to maintain quality within six sigma limits.

2. Companies who achieve six-sigma quality assurance are able to set a realistic target of zero defects in their product. Suggest two advantages this would give to an enterprise over its competitors.

3. Recall the term '*Confidence Interval'* from an earlier section. Suggest the meaning of having a confidence interval of 12 sigma.

4. Six Sigma has become a by-word for zero defects in manufacture. Suggest why.

Sampling and its Application in Manufacturing

Where a large number of items are being produced e.g. screws or mobile phones, it is not feasible to measure or test each one as it is being made. Instead the quality of the process is controlled by taking a measurement from a sample of the parts made and using methods based on the concepts shown above to determine the quality of the batch as a whole.

How big should the sample be?

The idea is to measure just enough samples to allow an accurate assessment of the process as a whole. Any more than this amount does not improve the accuracy of the analysis and any less will result in a reduced confidence in the result.

The following simple calculation allows us to choose a sample size where the standard deviation (sigma) of a process is known.

A large volume of sugar is manufactured and packed daily. To find the mean value for the weight of sugar a sample of the packets are measured. The larger the sample, the more certain it becomes that we have a mean that reflects the population as a whole. The smaller the sample the greater the margin of error that will occur. In this case we are happy to tolerate a small error if it allows us to measure a reasonable sized sample.

The weight of a packet of sugar is 1000g (1kg) and the process has a standard deviation (sigma) of thirty grams (10g). The following formula is used to calculate the sample size:

Sample Size

$$s = \left(\frac{z}{e}\right)^2$$

s = the sample size
e = the error you are prepared to accept, measured as a proportion of the standard deviation (accuracy)
z = a number relating to the degree of confidence you wish to have in the result.

Values for z

Confidence	Value for z
99%	2.58
95%	1.96
90%	1.64
80%	1.28

To measure the average weight with a confidence of 95% and with an acceptable error of 10% of the population standard deviation (i.e. 1 gram of sugar).

This gives

z = 1.96 from the table above
e = 0.1 (i.e.10%)

Therefore the sample size s = (1.96 / 0.1)^2

Therefore s = 384.16
Therefore 385 samples need to be taken to meet the criterion.
Assuming 385 packs of sugar are weighed and the mean weight is calculated to be 1005 grams. Sigma is 10 grams so 10% error is added on to this makes it 11 grams.

From this sample the following information about the population as a whole can be inferred:

It can be said with 95% confidence that the average weight of the entire population lies within 994 grams and 1016 grams.

Activity 17
Work out the sample size to measure to 99% confidence with 10% error
Work out the sample size to measure 80% confidence with 10% error

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Example:
The standard deviation of the resistance for a given type of resistor is known to be 1.5 Ω
A large batch of resistors has been purchased by your school and you want to know with 99% confidence what the average resistance is. You are able to measure the resistors using a multimeter to within 0.05 ohms and you want the error in your estimation to be restricted to this. Calculate how many resistors you need to test.

Answer:
The error from the multimeter reading is 0.05 ohms which, expressed as a proportion of the standard deviation is 0.05/1.5 = 0.033
Therefore e = 0.033
From the table z = 2.58 for 99% confidence

Therefore the sample size $s = \left(\dfrac{z}{e}\right)^2$

$$s = \left(\dfrac{2.58}{0.1}\right)^2 = 665.6 \approx 666 \quad samples$$

History of Quality Management.

Quality Control

The advent of mass production during the twentieth century increased the demands upon the control of product quality. Quality Control emerged during the 1940s and 1950s as organisations tried to increase profit and reduce cost by the inspection of product quality.

Quality control involves inspecting components after they have been manufactured and rejecting or reworking any defective ones. There are two problems with this approach:

1. The inspection process just detects non-conforming products – it does not help to prevent them happening so there is wastage of material and time on scrapped and reworked parts.
2. The inspection process is not necessarily foolproof so there is a possibility of non-conforming parts being shipped by mistake.

Quality Assurance

The success of Japanese manufacturers during the 1960s and 1970s changed the focus from a quality control to a quality *assurance* approach. Quality assurance involves more of the business functions being involved in quality and takes longer to implement. It involves setting up a *quality system* and having a documented approach to all procedures and processes that affect the quality of a product. Prevention is a large part of this process as well as inspection. To achieve this, all aspects of the production process are involved. The system can be accredited using international standards such is ISO9000
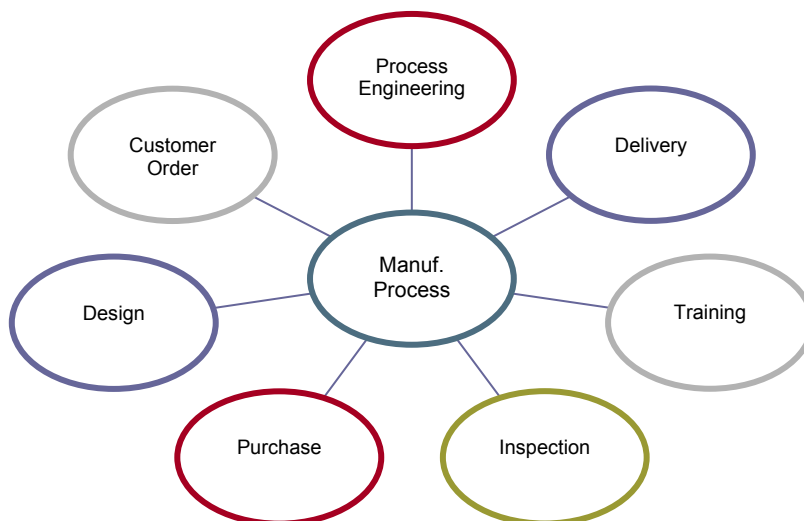
Quality Assurance

Total Quality Management

The 'total' approach to quality management arose from fierce international competition during the 1980s and 1990s. Everybody in the organisation is involved in developing a quality improvement and prevention system that is focussed on the needs of the customer through teamwork. The aim is 'zero defect' production.
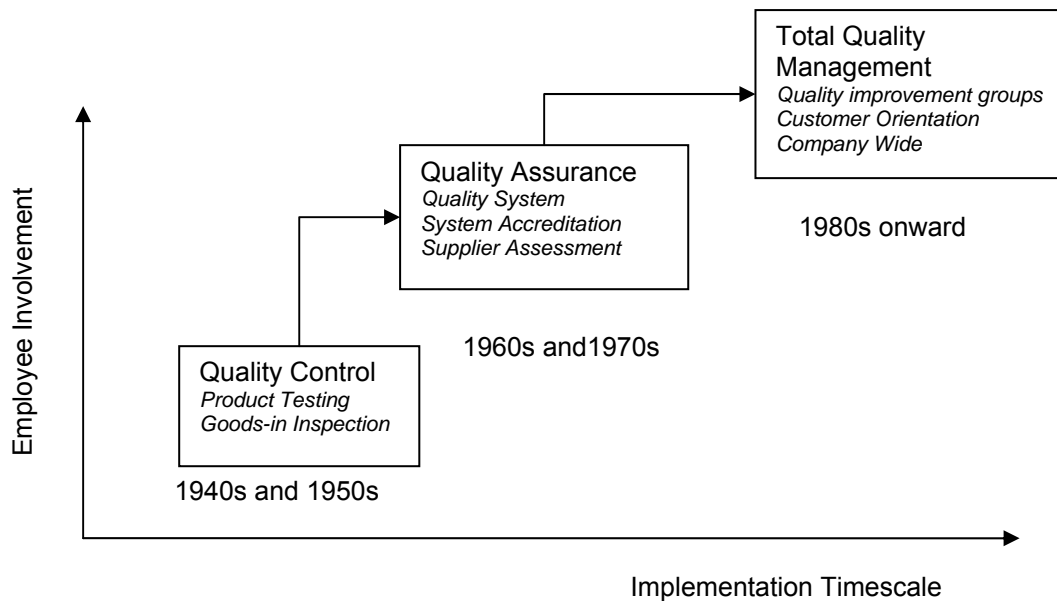
For TQM to be effective, the involvement of all employees is essential. The employees are encouraged to participate in problem solving at all levels and to make suggestions for improvements where necessary. This is called participative problem solving and the employees are encouraged to 'take ownership' of the quality management process throughout the company. Employees are often organised into Quality Circles or 'Process improvement teams' to help achieve this.

Just in Time Manufacturing (JIT)

Modern products have shortened life cycles, and there is much pressure on manufacturers for a quick response to the customer. One way of ensuring a quick turnaround time is to hold an inventory of stock items to that they are available when they are needed. However holding these items costs money as they need to be bought and stored prior to use. In a climate of rapid product change, there is a possibility that the inventory items may become obsolete before they are used, therefore increasing the cost even further.

A better approach is to make the production process **leaner** and more **agile**. If the suppliers are coordinated with the manufacturing company then it is possible to implement what is known as **Just in Time** manufacturing.

Dell Computers use JIT at their manufacturing plants around the world. A typical Dell plant allocates just a tiny part of its floor area for incoming parts. In one plant that has a floor area the size of 23 football fields, the incoming parts area is just 3metres square – the size of a bedroom in an average house. A plant will assemble tens of thousands of computers each day. Computer controlled conveyors move the parts quickly through the plant where components are added to the computer. Drives, chips and other components are added according to customer order by workers who respond to red or green lights on component drawers. The assembly process takes three or four minutes after which the computers are moved to the finishing area where they are customised, boxed and sent to waiting delivery trucks.

Online orders are downloaded to a factory planning system which generates a production schedule every two hours for the plant. The system notifies suppliers of Dell's exact material needs and works out schedule for assembling the machines depending on the availability of the materials. As the machines are being built, the parts needed for the next two-hour set of orders are being shipped from supplier **hubs**. These are mini-warehouses that are maintained by the suppliers and contain two weeks worth of components near the Dell factory. The hub has 15 minutes to confirm that the parts ordered from it are available and 1 hour and 15 minutes to deliver them to the plant.

Issues such as quality of the supplied parts must be guaranteed if JIT is to work. Therefore quality systems must be in place before a supplier is accepted by a large manufacturer such as Dell. Concepts such as six-sigma described earlier allow the quality of the supplied parts to be guaranteed.

JIT originated in Toyota in the 1950s and is more than just a means for reducing inventory. To work properly, the entire production process must be streamlined and efficient. The underlying concept is 'eliminate waste' This means eliminating anything other than the minimum amount of materials, parts, space, tools or time than is essential.

Kanban Systems:

Kanban is the Japanese word for card. Kanbans are used in JIT as part of a 'pull' system that is used to regulate flow of the materials and component parts through the manufacturing system. A major problem in assembling a complex item is the coordination of the parts and sub-assemblies as they move along the production line. With a car, these amount to dozens of sub-assemblies consisting of thousands of components.

Taiichi Ohno who worked with Toyota got inspiration for the idea when visiting a supermarket in America. He observed that most Americans did not keep large stocks of food at home. Instead, they visited the nearby supermarkets to purchase items as they needed them. The supermarkets in turn fully control their inventory by replenishing items on their own shelves only as they are removed. Customers actually 'pull through' the items they need and supermarkets only order as much as they can sell.

Applying this concept to the manufacturing system, each stage of the processs requests parts/assemblies from the preceding stations only as they need them. This is in contrast to the traditional 'push' model where one station would complete its work and pass it on to the next whether it was needed or not. With a 'pull' system the operations are forced to work in coordination with one another.

To regulate the flow of materials, Ohno introduced kanbans in the Toyota plant. Kanbans are a very simple concept. A Kanban contains a basic description of the part required, the number required, and other information about the part. Kanbans are used like order forms for components and are passed from one station to another to initiate the production or movement of parts within the manufacturing plant.