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**AQA**

**AS/A-level**

# Design & Technology

## Product Design



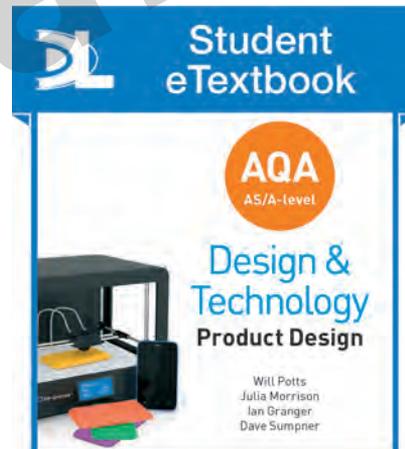
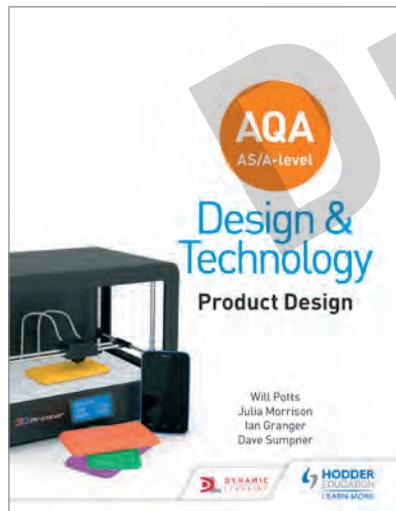
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**Encourage your students to be creative, innovative and critical designers with a textbook that builds in-depth knowledge and understanding of the materials, components and processes associated with the creation of products.**

The following print and digital resources have been selected for AQA's official approval process:

AQA AS/A-Level Design & Technology: Product Design Student's Book	Will Potts, Julia Morrison, Ian Granger, Dave Sumpner	9781510414082	May 2017
AQA AS/A-Level Design & Technology: Product Design Student eTextbook	Will Potts, Julia Morrison, Ian Granger, Dave Sumpner	9781510413481	June 2017



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# Section 1

## Technical principles

In this section you will learn about the following:

1.1	Materials and their applications	000
1.2	Performance characteristics of materials	000
1.3	Enhancement of materials	000
1.4	Forming, redistribution and addition processes	000
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1.14	Design communication	000
1.15	Modern manufacturing systems	000

# 1.7

## Digital design and manufacture

### LEARNING OUTCOMES

By the end of this section you should have developed a knowledge and understanding of:

- the use of computer-aided design (CAD) to develop and present ideas, and the advantages and disadvantages of using it compared to manually generated alternatives
- how computer-aided manufacture (CAM) (including laser cutting, routing, milling, turning and plotter cutting) is used in the manufacturing of products.

**If you are studying at A-level you should also have developed a knowledge and understanding of:**

- virtual modelling/testing procedures used in industry
- rapid prototyping processes and additive technologies, and the benefits they offer to designers and manufacturers
- the use of electronic point of sales (EPOS) for marketing purposes and the collection of market research
- the role of production, planning and control (PCC) systems in the planning and control of all aspects of manufacturing.

### Computer-aided design (CAD)

**Computer-aided design (CAD)** includes the use of computers to produce either 2D working drawings or 3D full-colour virtual models. In recent years, CAD software has become easier to use, more powerful with a wider range of features to help in the design and development of products (Figure 1.7.1), and now has the ability to download drawings to computer-aided manufacturing equipment.



**Figure 1.7.1** CAD software has a wide range of features to help in the design and development of products.

## Advantages and disadvantages of CAD

### Main advantages

- Computer-aided design speeds up the product design and development process. It provides the ability to edit and develop existing drawings that are stored on computer, which is faster than having to redraw items by hand.
- Using CAD makes it easier for teams of designers to work collaboratively. Such teams may be located in different offices and even different countries. The use of CAD and web conferencing makes collaborative working possible and reduces the need for people to travel.
- Completed CAD drawings can be downloaded to computer-aided manufacturing (CAM) equipment such as laser cutters, routers, lathes and milling machines. Alternatively they can be sent to 3D printers to make models or prototypes.

### Main disadvantages

- The initial set-up cost can be quite expensive, especially when staff have to be trained in the use of software.
- Software has to be updated on a regular basis which can be expensive.
- CAD software is not very easy to use for quick sketches.

## The use of CAD to develop and present ideas for products

3D CAD software allows designers to produce high-quality 'artists' impressions' of their designs. This can include full-colour rendering, light, tone and texture to give a real impression of what a product would look like when made. These drawings can be rotated and viewed from any angle. When a designer can produce such drawings, they are able to show them to clients or marketing teams for feedback. This allows the design to be modified and developed more quickly than if models or prototypes were made.

Other ways in which CAD is used to develop products include the following.

- Original artwork can be scanned and copied into CAD software so that the drawing can be digitally developed. Editing tools such as 'copy', 'mirror', 'rotate', 'scale' and 'array' allow designers to quickly change drawings.
- Libraries of standard component drawings can be used to complete designs. This is particularly useful for design engineers that might need to do circuit designs in electronics, pneumatics or hydraulics.
- Designers can use 'layers' to draw on. This allows complex designs such as electronic circuits to be built up layer by layer or for architects to overlay services such as plumbing, electrics and air conditioning over the layout of rooms.

## Simulation

Computer Aided Design and Manufacture (CAD/CAM) software often has the facility to run a simulation of what will be machined when a drawing is downloaded to a piece of equipment such as a laser cutter, router or 3D printer. Such simulation will highlight any potential problems and indicate if the item being made will turn out as expected. In the case of laser cutter, simulation will often show if an outline of an object has gaps which would result in the product not being able to be removed from the stock material.

In the case of a product being laser cut and engraved, simulation can show how long the item will take to be machined but also that the cutting and engraving is done in the correct order (usually engraving first).

Simulation can be used to show the tool path (the direction in which tooling will move across a piece of stock material). This will highlight any problems such as potential clashes with clamps, vices or the tool moving beyond the X, Y or Z limits.

Simulation is used in 3D printer software, not only to show what the model will look like and how long it will take to machine, but also to indicate where the support material is required so that the model will not collapse under its own weight when being printed.

Finally, simulation can be used to ensure that multiple copies of the same item are machined in the most efficient way. When cutting items from sheet material this is known as 'nesting' - where the tooling would be set to start in one corner of the sheet, and there would be the minimum amount of space left between each part to be cut so that the material is not wasted.

#### ACTIVITY

Using the internet, carry out research on the use of computer-aided design and find real-life examples of how it is used in industry.

## Computer-aided manufacturing (CAM) processes

**Computer-aided manufacturing (CAM)** usually involves downloading completed CAD drawings to machines that will cut and shape materials. Most CAM equipment uses software to convert CAD drawings into a machining program and only requires the operator to set parameters such as speeds or power. The material being machined will influence what power and speed settings are used. For example, harder or denser materials being laser cut will require a slow speed and a high power setting. Conversely, if a material such as card is being laser cut, a fast speed and low power setting is used to avoid burning the card.

CNC machines usually have an easy to understand software that allows simple adjustment of the speed and power settings.

For more complex machines or machining processes such as milling and turning, the operator may have to program in various machine stops and tool changes depending upon the job being done. For example, on a lathe a bar might be turned to reduce the diameter with one tool, but then another tool used to machine a thread onto the end of the bar. These different processes will also require the speed of the machine to be changed. For this reason, CNC machine operators are usually highly trained and skilled in their job. This ease of use has made it possible to use CAM processes for one-off production.



**Figure 1.7.2** CAD drawings can be converted to a CNC program, which controls laser cutters.

## Laser cutting

Laser cutting uses a high-energy laser beam to cut or vaporise materials and compressed gas or air to blow the waste material away leaving a clean edge. 2D CAD drawings are downloaded to laser cutters, which converts the drawing into a **CNC (computer numerical control)** program (Figure 1.7.2). This program controls the movement of the laser in the X and Y axes, and the power and speed can be adjusted to cut different materials. Laser cutters in schools are usually powerful enough to cut and engrave materials such as woods and plastics, but in industry more powerful lasers are commonly used to cut sheet metals.

## Routing

Both 2D and 3D CAD drawings can be downloaded to computer-controlled routers. They are usually used to cut sheet materials that are too thick for laser cutting such as 9 mm MDF or thicker materials such as blocks of timber and Styrofoam or high-density modelling foam to make moulds or 3D models (Figure 1.7.3).



**Figure 1.7.3** Computer-controlled routers are used to cut materials that are too thick for laser cutting.

## Milling

Milling machines work in a similar way to routers and can be fitted with tools to drill holes, cut slots or shape the surface and edges of a range of materials (Figure 1.7.4). Milling machines can move the 'bed' of the machine in the X and Y axes, but the cutter can also be moved in the Z axis to vary the depth of cutting. Some milling machines can also angle the cutting head and angle the machine bed; these are called '5-axis machines' and are ideal for complex engineering components. Modern CNC milling machines often have the ability to automatically change tools to suit different machining jobs and different materials.



**Figure 1.7.4** Milling machines can drill holes, cut slots or shape a range of materials.

CNC milling machines are usually totally enclosed which improves safety in the work area. They will be fitted with automatic coolant which floods the tooling and workpiece with a lubricant - resulting in improved tool life and surface finish. Being, fully enclosed, workers are protected from potential health and safety problems from flying debris and exposure to coolant.

CNC milling machines can obviously operate much more quickly and accurately than human operators and they can continue to machine for long hours with the exception of stoppage for maintenance.

## Turning

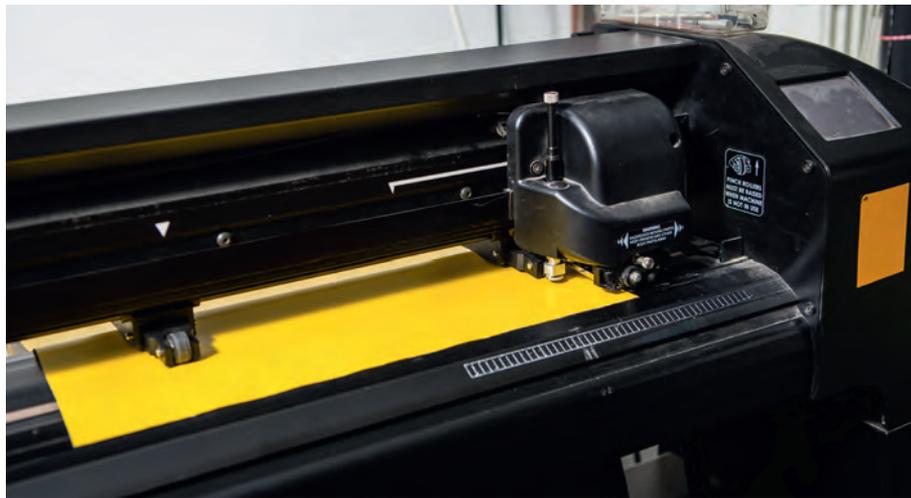
Turning involves the use of lathes, usually to machine metals in bar form or plastic rods. This could be to reduce the diameter and length of a bar or it could involve more-complex operations such as thread-cutting and boring (Figure 1.7.5). Like milling, modern CNC lathes are able to automatically change tools. Industrial CNC lathes might form part of a **flexible manufacturing system (FMS)** together with milling machines, laser cutters or punches, all served by robot arms loading material and transferring parts between machines.



**Figure 1.7.5** CNC lathes can be used to reduce metal bars or plastic rods, and for thread-cutting and boring.

## Plotter cutting

Plotter cutters convert 2D CAD drawings into a CNC program that uses X and Y coordinates to cut out what has been drawn, usually on thin sheet materials such as self-adhesive vinyl for graphics applications (Figure 1.7.6). Most plotter cutters pull the sheet material in and out of the machine (Y-axis), while the cutter moves from side to side in the X-axis.



**Figure 1.7.6** Plotter cutters convert 2D CAD drawings into a CNC program to cut out from sheet materials.

### ACTIVITY

Using examples, list the advantages of using computer-aided manufacturing when compared to machining by hand.

## Virtual modelling

Virtual modelling can be used to test products before they are manufactured (Figure 1.7.7). By creating 3D CAD drawings, the product or a component can be put into a virtual model of where it may be used. For example, an engine component can be 'connected' to other parts in a virtual engine to check it 'fits' and that it could be removed for maintenance. Virtual modelling can be used to simulate a manufacturing process – for example to check that a product will be machined correctly. In industry it might also be used to plan a whole production line before investment is made in purchasing new equipment.



**Figure 1.7.7** Virtual modelling is used to test products before they are manufactured.

### ACTIVITY

Find three specific examples of where virtual modelling and testing is used in industry. Where possible, try to find examples of software that might be used to model and test products.

## Computational fluid dynamics (CFD)

**Computational fluid dynamics (CFD)** is a tool available in some 3D CAD packages; it simulates the flow of fluids or gases in or around a product. For example, a vehicle design can be tested in a simulated wind tunnel to evaluate the drag created by air flow over the external surfaces. Another example might be a design for a boat that could be tested in a simulated wave tank to evaluate how efficiently water flows around the surfaces of the boat.

By using CFD, designers can save time and money that would be needed to produce physical models and prototypes, and the expense of using specialist wind tunnels or wave tanks.

## Finite-element analysis (FEA)

**Finite-element analysis (FEA)** uses computer modelling to conduct virtual testing. A designer or engineer can use FEA software to simulate things like vibration or shock loads on products or components they have drawn. This can highlight any potential weak points in a product that might need further development before the design is actually manufactured. Using such software can save a lot of time and expense in having to make prototypes for physical testing.

## Rapid prototyping processes

A-level

### Fused deposition modelling (FDM; 3D printing)

**Fused deposition modelling (FDM)** machines build or 'print' a 3D model from 3D CAD drawings by using processing software that 'slices' the drawing and guides an extruder in paths to build the product from the bottom up, layer by layer (Figure 1.7.8).

FDM rapid prototyping machines soften a thermoplastic filament and extrude it to build the model. They will also use a support material that acts like a scaffold while the modelling material hardens. The support material, which is less dense, is broken away when the model is finished.

Rapid prototyping allows products to be modelled quickly, accurately and cheaply. Such models can be used to show clients and potential consumers what the product will look like to obtain feedback. If made full size, rapid prototype models can be used to make moulds for casting and making production dies.

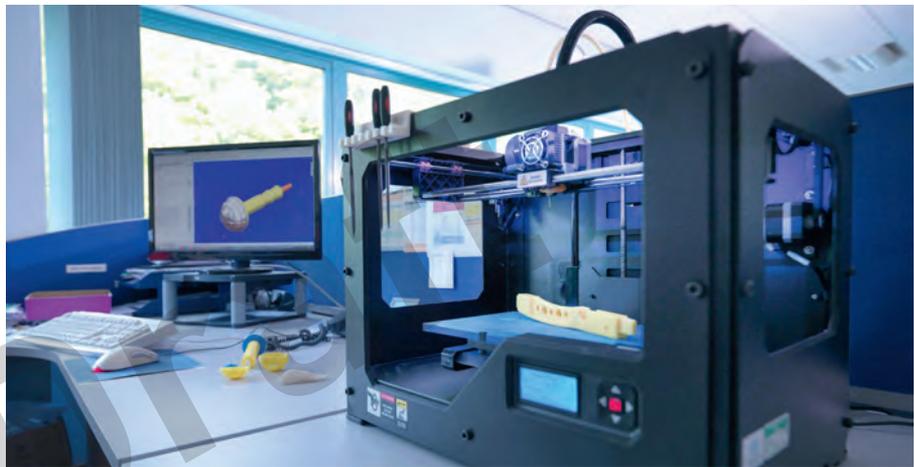


Figure 1.7.8 FDM machines print 3D models from 3D CAD drawings.

#### ACTIVITY

Make notes on why rapid prototyping might be used to model the following products:

- a handle to be used on cutlery by someone with arthritis
- a prototype mobile phone.

## Electronic Point of Sale (EPOS)

A-level

Electronic Point of Sale or EPOS is a system of capturing data when consumers purchase goods. Many items are labelled with bar codes, and when they are scanned at the till, the details of the sale are recorded. This information is normally used to control stock levels and 'limits' can be set where replacement stock will be re-ordered from distributors when a certain number have been sold. In turn, as distributors remove stock from warehousing, replacement products will be re-ordered electronically from the manufacturers. In addition to controlling stock, the data is used by sales and marketing teams to monitor how many items are being sold. They can then use this information to target their marketing of products to help improve sales or even determine if a new or improved product has to be launched if existing products seem to be in the decline stage of their lifecycle. Sometimes, when consumers purchase goods at the till, they may be asked to provide some details such as an email address. This will be used to send the consumer a receipt but it can also be used to advertise additional products to the consumer.

**KEY TERMS**

**Computer-aided design (CAD):** Using computers to draw in two or three dimensions and develop products

**Computer-aided manufacture (CAM):** Using computer-controlled equipment to machine materials

**Computer numerical control (CNC):** A program using code converted from CAD drawings to drive CAM equipment

**Computational fluid dynamics (CFD):** Using software to virtually test products in liquids or gases

**Finite-element analysis (FEA):** Using software to test products and identify potential stress or weak points

**KEY POINTS**

- CAD software is used to quickly produce accurate 2D and 3D drawings.
- CAM equipment is used to accurately manufacture products directly from CAD drawings.
- Virtual modelling allows products to be tested before they go into manufacture.
- Computer software can be used to test products virtually to simulate loads and stresses.
- Rapid prototyping is used to produce 3D models of products, directly from CAD drawings.

**Check your knowledge and understanding**

- 1 What are the benefits of using computer aided design in the development of products?
- 2 Explain how 3D printing can be used to speed up the development of new designs.
- 3 How can finite element analysis be used in preventing product failure?
- 4 Explain why Computational Fluid Dynamics (CFD) might be used in developing products such as high performance racing bikes or competition sailing boats and kayaks.
- 5 What are the benefits of machining using computer aided manufacturing equipment when compared to machining items on manually controlled equipment?

**Further reading**

*Introduction to solid modelling using Solidworks 2016* by William E Howard and Joseph C Musto. An introductory course presenting solid modeling as a communication tool and integral part of the design process.

*SketchUp 2014 for Dummies* by Aiden Chopra. User-friendly guide to 3D modeling using SketchUp.

*Solid Edge ST7 Basics and Beyond* by Online Instructor. Explanations and tutorials to learn Solid Edge.

# 1.4

## Forming, redistribution and addition processes

### LEARNING OUTCOMES

By the end of this section you should have developed a knowledge and understanding of:

- the ways that paper and board can be shaped into different products such as packaging
- how polymers, metals and timber can be formed into 3D products
- joining methods for metals and timber
- wasting processes for metals
- the use of adhesives and fixings
- how jigs and fixtures can be used to aid the manufacture of products

### The use of adhesives and fixings

Adhesives are substances used to stick materials together in order to bond them to each other. Different types of adhesives are used for different materials and applications.

#### PVA (polyvinyl acetate)

PVA is commonly used to bond most timbers together (Figure 3.3.1). It is a water-based adhesive which is white in colour. PVA soaks into the surface of the timber and sets once the timber has absorbed the water content. PVA is not usually a waterproof adhesive, although some PVA adhesives have been developed which are water-resistant.



**Figure 1.4.1** PVA is a water-based adhesive used to bond timbers together.



**Figure 1.4.2** Contact adhesive is used to join large areas such as sheet material together.

## Contact adhesives

Contact adhesive is used for large areas such as sheet material (Figure 1.4.2). It can be used to join the same or different materials together such as timber sheet to timber sheet, metal sheet to timber sheet, metal sheet to polymer sheet, etc. The two surfaces to be joined are coated in contact adhesive and left for approximately 10 minutes or until the adhesive feels 'tacky'. On contact with the other surface, adhesion is instant.

## UV hardening adhesives

UV hardening adhesive is a clear liquid which 'cures' to form the bond when exposed to ultraviolet light. UV hardening adhesive contains a photoinitiator which means as it absorbs the UV light wavelength it begins to cure and set to a solid bond. It has numerous applications and can be used to join metal, glass and polymers. It is often used for workshop projects made from polymers such as lighting as well as desk top stationery holders fabricated from parts. Many glass furniture products such as tables constructed from toughened sheet glass will make use of UV hardening adhesive to form the joints. The advantage of UV hardening adhesive is that any excess adhesive can be wiped away with a cloth prior to being exposed to UV light, thus giving a solid and clean joint. It has a fast curing time and unlike adhesives such as epoxy resin, there is no need to mix the adhesive and hardener prior to application, the hardening aspect is an integral part of the adhesive.

## Epoxy resin

Epoxy resin comes in two parts: resin and hardener. It is used to join different materials together, such as timber to metal, metal to polymer, polymer to timber (Figure 1.4.3). Equal amounts of resin and hardener are mixed to form the adhesive which then takes a time to fully set.



**Figure 1.4.3** Epoxy resin is used to join different materials together.



**Figure 1.4.4** Solvent cement is used to join polymers such as acrylic, ABS and PVC.

## Solvent cements

There are many types of solvent cement; examples are acrylic cement or Tensol 12. Solvent cement is most commonly a clear liquid called dichloromethane and is used to join polymers such as acrylic, ABS and PVC (Figure 1.4.4). Solvent cement works by softening the surface of the polymers to be joined, allowing them to fuse together.

### ACTIVITY

Make a list of all the adhesives available in your school or college workshop. Note what material(s) each adhesive is used for and how it is applied.

### KEY POINTS

- PVA is a white water-based adhesive used to bond most timbers together.
- When using contact adhesives the two surfaces to be joined are coated and left for 10 minutes. On contact with the other surface, adhesion is instant.
- UV hardening adhesive is a clear liquid which cures to form the bond when exposed to ultraviolet light.
- Epoxy resin mixes equal amounts of resin and hardener to join different materials together (e.g. timber to metal, metal to polymer, polymer to timber). It takes a time to fully set.
- Solvent cement is used to join polymers. It works by softening the surface of the polymers to be joined, allowing them to fuse together.

## Check your knowledge and understanding

- 1 Name a suitable adhesive for the following applications:
  - (a) melamine formaldehyde sheet to chipboard sheet
  - (b) veneered oak MDF to a section of solid oak
  - (c) acrylic sheet to acrylic round tubing.
- 2 What ratio of adhesive to hardener is used when mixing epoxy resin?
- 3 Give a specific application for UV hardening adhesive and give two advantages offered by the use of UV hardening adhesive.

## Further reading

<http://www.basaonline.co.uk> Further information on adhesives, including developments in adhesive sustainability and environmental issues.

<http://www.explainthatstuff.com/adhesives.html> How forces make things stick, how adhesive products work and why adhesives do not stick to the container.

# 2.9

## Design for manufacture and project management

### LEARNING OUTCOMES

By the end of this section you should have developed a knowledge and understanding of:

- the importance of planning for accuracy when making prototypes and making recommendations for small, medium and large scale production.
- quality control.

If you are studying at A-level you should also have developed a knowledge and understanding of:

- the procedures and policies put in place to reduce waste and ensure manufactured products are produced accurately and within acceptable tolerances, including quality assurance systems.

A-level

### Quality assurances

Effective project management is essential in all design and manufacture activities. The main aim of these procedures is to improve efficiency and reduce waste.

Within industry there are several different systems used, although the overall aim is largely the same.

### Critical path analysis (CPA)

**Critical path analysis (CPA)** is a project management method used to analyse all individual stages within a project and plan the effective and time-efficient completion of each element within the desired schedule.

To complete a CPA several elements are required:

- 1 a list of all activities within the project
- 2 an estimate of the time each stage will take
- 3 an understanding of how each stage relates/depends on the completion of other stages in the plan (dependencies)
- 4 specific deadlines for individual stages/items.

The overall aim of critical path analysis is to enable the completion of a project in the least possible time. To do this you need to produce a **critical path network (CPN)**, which shows each individual stage and its relationship to all other stages within the project.

### How to construct a critical path network (CPN)

Using a task analysis the project/process can be split down and each individual element can be arranged in time order, the basic order will be sequential with each element being completed one after the other.

This method will often identify waste time within the process where the individual completing the process will be waiting unnecessarily to complete the next task.

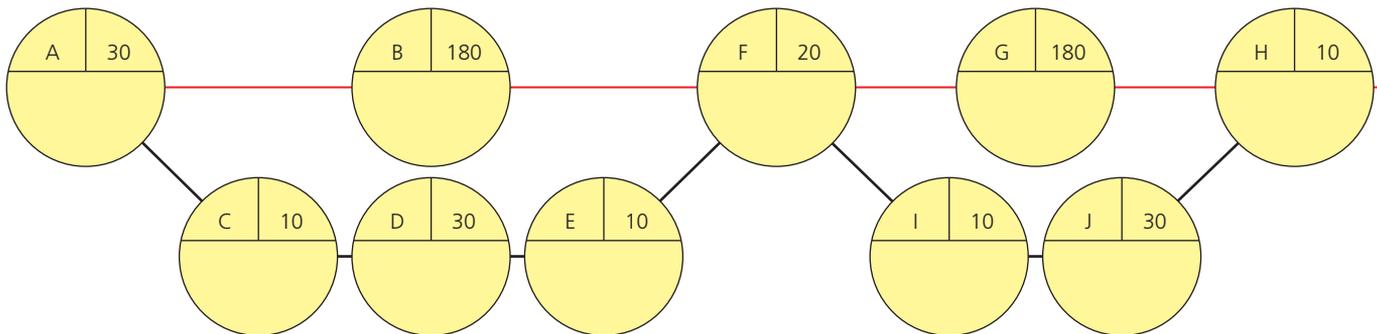
By analysing dependencies the process time can be reduced. Here is an example CPA based on the process of making a cup of tea.

**Table 2.9.1** List of tasks for making a cup of tea

Task	Time (Seconds)	Dependent on
<b>A</b> Fill Kettle with water	30	
<b>B</b> Boil Water	180	A Filling kettle with water
<b>C</b> Place teabag in Teapot	10	
<b>D</b> Retrieve milk from fridge	30	
<b>E</b> Choose cup	10	
<b>F</b> Add boiled water to teapot	20	B Boil water
<b>G</b> Let tea brew in pot	180	F Add boiled water to teapot
<b>H</b> Pour tea into cup	10	G Let tea brew in pot
<b>I</b> Add milk to cup	10	H Pour tea into cup
<b>J</b> Return milk to fridge	30	I Add milk to cup
Total time:	510	

It is clear from the list of tasks that if all tasks are completed one after the other (sequentially) there would be a lot of wasted time.

By reorganising the tasks using the dependencies to structure the process then the overall time required to make the tea could be shortened considerably.



**Figure 2.9.1** Critical Path Analysis of making a cup of tea

Figure 2.9.1 shows the tea making process with the critical path (longest time path) shown in red. This shows that the minimum time required to make the cup of tea is 430 seconds, a saving of 80 seconds in comparison to the sequential process shown in the table above. This is because of using parallel processing where two tasks are undertaken at the same time.

As making a cup of tea will only ever need one person parallel processing can only happen while waiting for the kettle to boil or the tea to brew.

In industry, where there are many people working on a single project tasks can be processed simultaneously (in parallel) more easily, in the manufacture of products this can be aided by the creation of sub-assemblies, where sections of a product can be assembled and then brought together on the final product. If we consider a simplified example of the mobile phone this can be split into several sub-assemblies:

- 1 The electronics Printed Circuit Board (PCB) and Central Processing Unit (CPU)
- 2 The screen
- 3 The external case
- 4 The battery.

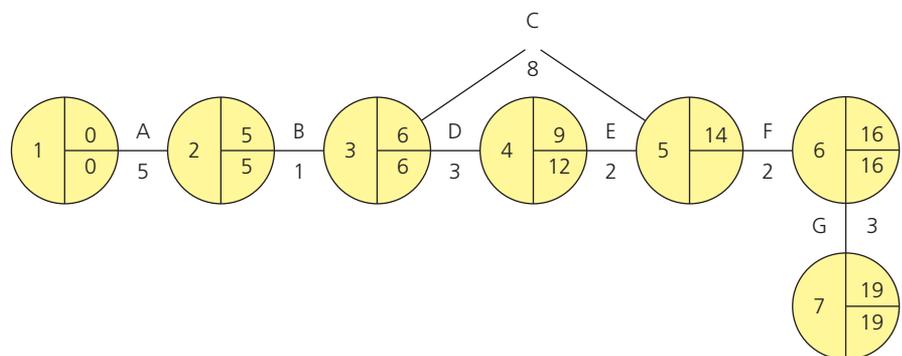
Each of these sub-assemblies can be created separately at the same time and then the final assembly of all four elements.

Here is an example CPA based on the production of a table lamp base.

**Table 2.9.2** CPA elements for the production of a table lamp base

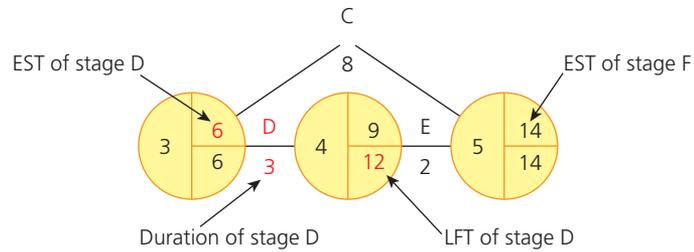
Stage	Description	Dependent on	Duration (hours)
A	Production of dimensioned drawings for each component	Starting activity	5
B	Order materials for individual components	Completion of stage A	1
C	Prepare mould for concrete base	Completion of stage B	8
D	Cut and weld mild steel cage	Completion of stage B	3
E	Drill and prepare mild steel cage	Completion of stage D	2
F	Assemble finished mild steel cage within mould for base	Completion of stages C and E	2
G	Cast concrete base	Completion of stage F	3

Each activity/stage is given a letter. In Figure 2.9.2, circular nodes represent the start or end points of stages, with the stage letters shown above the joining lines and the time of each stage shown below the line.



**Figure 2.9.2** CPA for the production of a table lamp base (Table 2.10.2)

The left-hand side of each circle shows the node number. The upper right quadrant of each circle shows the earliest start time (EST) in hours from the beginning of the project. The lower right quadrant shows the latest finish time (LFT) for the previous stage so as not to impact on the overall finish time.



**Figure 2.9.3** Each node shows the earliest start time (EST) and the latest finish time (LFT) for the previous stage

As you can see from Figure 2.9.2, the only time where the EST of one stage and LFT of the previous stage differs is in node number 4. This is due to stage C taking longer than the combination of stages D and E. As stage E must be completed by the same time as stage C then it must be started no later than 2 hours before the earliest start time of activity F.

**Table 2.9.3** Stages showing slack do not lie on the critical path

Stage	LFT	Duration	EST	Slack
A	5	5	0	0
B	6	1	5	0
C	14	8	6	0
D	12	3	6	3
E	14	2	9	3
F	16	2	14	0
G	19	3	16	0

The critical path is determined as the path that takes the longest time to complete. As stage C takes longer than stages D+E, this is the critical path within the lamp base project. The two stages showing slack in Table 2.10.3 can be delayed without affecting final project completion, and therefore do not lie on the critical path.

## Six Sigma

**Six Sigma** refers to a target within process design to minimise defects. The process was developed at Motorola in the 1980s. The aim of the system is to reduce the number of defective products produced to less than 3.4 in every million. The system requires the implementation of a **DMAIC (define, measure, analyse, improve, control)** procedure to assess and improve each stage of the design and manufacture activity.

### The key stages of Six Sigma (DMAIC)

- **Define:** What is the issue within the process?
- **Measure:** Take steps to measure the extent of the issue.
- **Analyse:** Determine where the issues measured occur.
- **Improve:** Introduce procedures to rectify the issues identified.
- **Control:** Ensure the modified procedures are implemented and maintained through effective quality assurance.

## Lean Six Sigma

Within design and manufacture, the combination of Six Sigma with lean manufacture systems has led to the term 'Lean Six Sigma'. The aim to reduce errors within product manufacture and improve efficiency in production methods also utilises critical path analysis to ensure that all elements of 'waste' are removed.

Within this context the term 'waste' (also known as '**MUDA**' within lean manufacturing) has seven different aspects.

- 1 **Transport:** When a product is being transported it is at risk of damage or loss. By reducing the distance a product is transported you reduce these risks and the chance of production being delayed due to traffic issues, etc.
- 2 **Inventory:** The main aim of just-in-time (JIT) manufacture is to reduce the inventory (raw materials and finished goods) on site at any time. Any stock held on site is again at risk of damage and loss in value, and may delay final sales.
- 3 **Movement:** Unlike transport, movement refers to employees and their equipment. When assembling products any unnecessary movement increases the production time and should be minimised.
- 4 **Waiting:** If processes within the manufacture are not split evenly in regards to time, then products or workers may be waiting as others catch up.
- 5 **Over-production:** Again a major part of JIT manufacture is the lack of storage requirements necessary. If a manufacturer was to over-produce products 'just in case', extra storage would be required and the excess products may never be required for sale, wasting investment in materials and production.
- 6 **Over-processing:** It is essential that the correct equipment is used for each manufacturing process. If a company invests heavily in machinery, this investment must be justified. This can be likened to the purchase of a new smartphone: if the user is not going to use all the functions available on that particular model, then a cheaper version would be sufficient.
- 7 **Defects:** Any defective products must be removed; this is key within Six Sigma and relies on effective procedures for quality control and assurance.

### ACTIVITY

- 1 Using critical path analysis, produce a time plan for a project you are completing.
- 2 Analyse how the manufacture of your final project could be modified to reduce the seven wastes covered in Lean Six Sigma. Produce a modified manufacture plan for your project if it were to be produced in a volume in excess of 50,000 units.

### KEY TERMS

- Critical path analysis (CPA):** A project management method used to analyse stages in a project in order to plan time-efficient completion within the desired schedule
- Critical path network (CPN):** A diagram which shows each individual stage and its relationship to all other stages within the project
- Six Sigma:** A target within process design to minimise defects
- DMAIC (define, measure, analyse, improve, control):** A procedure to assess and improve each stage of the design and manufacture activity
- MUDA:** 'Waste' in lean manufacturing
- Lean Six Sigma:** The combination of Six Sigma with lean manufacture systems to reduce errors within product manufacture and improve efficiency in production methods

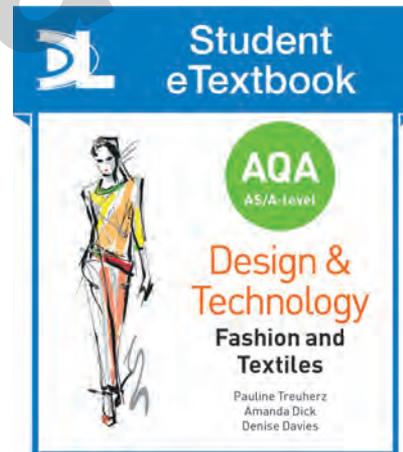
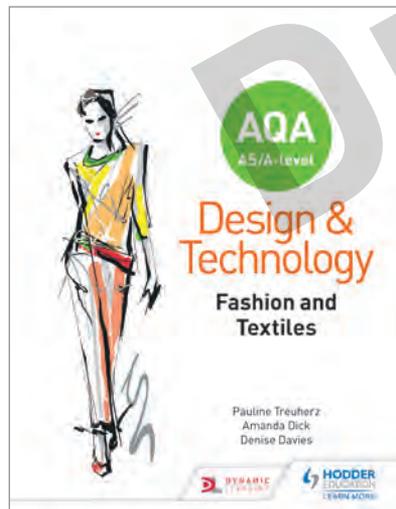
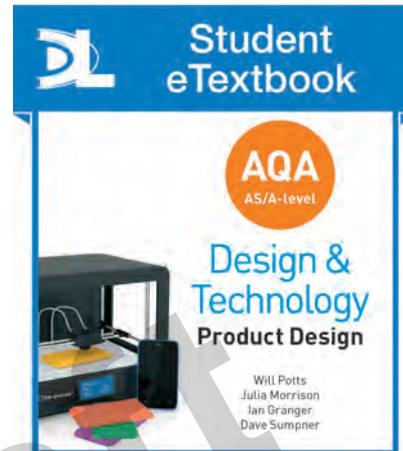
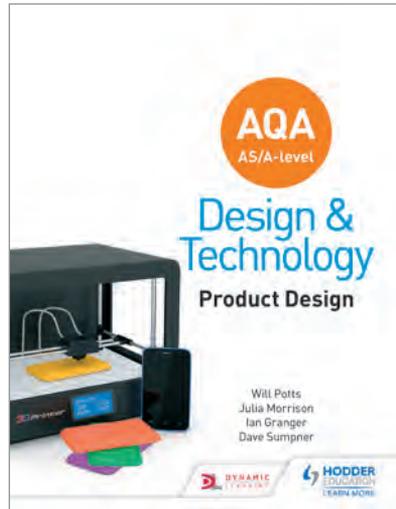
### KEY POINTS

- When producing a prototype product it is essential that you plan for accurate production; this requires effective research and development prior to investing time in the final manufacture.
- The development of the design must allow the concept to be tested against key specification criteria.
- Modelling strategies possibly including virtual CAD simulations and full sized block models.
- Manufacturing procedures must be evaluated for suitability and the achievable level of accuracy.
- By using effective QA procedures a manufacturer is aiming to produce products 'right first time and every time'.
- Prior to production, designers and engineers can model production procedures using CAD and CAE technologies to ensure that products are produced accurately first time.
- Effective project management is essential in all design and manufacture activities to ensure that they are completed to budget and within the agreed time scales.
- Quality control inspection checks take place throughout the production process and are performed in conjunction with strict guidance documentation produced by the company and the client.
- Dimensional accuracy checks may be carried out with flexible measuring equipment, such as a digital Vernier calliper or micrometer, where a range of measurements can be checked and exact readings can be recorded.
- When checking dimensional accuracy on a production line a specific measuring instrument is often used, such as a go-no-go gauge, which checks whether a single measurement fits within a tolerance range, giving a simple pass/ fail reading.
- Non-destructive testing (NDT) refers to methods used to check the internal structure of materials often after joining through processes such as welding.

### Check your knowledge and understanding

- 1 How many defects per million products produced would be acceptable for a Six Sigma compliant process?
- 2 What are the seven wastes associated with lean manufacture?
- 3 What is meant by the term 'critical path'?
- 4 Which of the seven wastes deals with the most efficient cutting path for a CNC laser cutter?

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