MET IIB Paper-1 2019
Crib

Question 1

a) What is a 'high specification' ceramic? Give the reasons why manufacturing industries are increasingly turning towards these materials in comparison with conventional structural materials such as metals and polymers.

[20%]

b) Discuss the range of ceramic materials that are currently available and highlight their particular characteristics.

[20%]

c) Outline the general processes used to manufacture high performance ceramic components.

[40%]

d) Describe three example applications in which ceramic materials are applied over conventional materials. In each case highlight the benefits of using ceramics.

[20%]

Question 2

a) Define a 'composite material' and give suitable examples to illustrate your answer.

[10%]

b) Why are carbon fibre composite materials increasing in popularity across a range of industrial sectors? Discuss the types of carbon fibre composites that are available including their general characteristics and major advantages. How does the magnitude of global carbon fibre production compare with steel and concrete?

[35%]

c) What is a carbon fibre 'Prepreg'? Describe the basic process of Prepreg manufacturing and the major benefits of their application.

[35%]

d) Formula 1 racing teams have applied carbon fibre composites in the production of a number of vehicle components. Describe two components in which traditional manufacturing materials have been replaced with carbon fibre composites and state the reasons why.

[20%]

Question 3

A small job shop manufacturing company is bidding for a contract to produce a critical component for the Bloodhound Supersonic Car. A major criterion for selecting the winning bid, besides low cost, is the time required to produce the part. However, if the company is awarded the contract, it will be held strictly to the completion date specified in the bid, and any delays will result in a penalty of £200,000 in addition to the loss of the contract. In order to determine the completion time and price to put in its bid, the company has identified the activities, precedence relationships, activity times, costs and daily resource requirements as shown in Table 1. In order to develop a competitive bid, the company decided to specify a contract price of £125,000 and a manufacturing time of 25 days.

Table 1

Activity	Predecessor	Time estimate (days)			Expected Cost of activity (£)
		Minimum	Most Likely	Maximum	
A	-	5	8	11	10000
B	-	7	9	17	18000
C	A	3	5	7	17500
D	A	3	5	13	30000
E	B, C	4	6	8	12000
F	B, C	4	5	6	2500
G	D, E, F	3	4	5	10000

(a) Prepare a Gantt Chart for the project. [20%]

(b) Which activities should the company be particularly diligent in monitoring for any delays? Explain the rationale for your answer. [10%]

(c) Has the company specified a reasonable price and time frame for the contract? Explain the rationale for your answer. [30%]

(d) The bid was successful, and the progress of the project in the first 15 days is shown in Table 2.

(i) Carry out an Earned Value Analysis and calculate the schedule variance and cost variance on Day 15. Assume that the activity costs are evenly distributed across its duration.

(ii) Comment on the progress of the project and suggest any corrective actions that are necessary. [40%]

Table 2

Day	Activity							
	A	B	C	D	E	F	G	Expenditure to date (£)
1	Started	Started	-	-	-	-	-	3,200
3	Ongoing	Ongoing	-	-	-	-	-	9,600
6	Completed on Day 5	Ongoing	Started today	-	-	-	-	20,900
9	-	Ongoing	Ongoing	-	-	-	-	35,300
12	-	Ongoing	Completed on Day 10	Started today	-	-	-	58,000
15	-	Completed today	-	Completed today	-	-	-	78,000

Question 4

As a manufacturer of a high-volume consumer product, such as a 3-pin electrical power socket, it is critical that the manufacturing processes chosen allow individual components and their assemblies to be produced whilst meeting market demands.

a) Injection moulding is commonly used to produce the main housing. Describe the basic principles of this process, the main operating parameters, and the common defects that affect the quality of the parts produced.

[50%]

b) Discuss the range of mechanical assembly and automation methods that could be applied during the lifecycle of the product, and the factors that influence their selection.

[50%]

Question 5

a) What are bio-based polymers? For one specific material, describe briefly a typical manufacturing route for the polymer and suggest two applications for the material. For which petroleum-based polymer would this material provide a substitute? What end-of-life processes are appropriate for bio-based polymers?

[25%]

b)

(i) What are the functions of food packaging, and what properties of the polymer are being used?

[20%]

(iii) How would you assess the environmental impact of polymers for food packaging? Discuss the factors that should be included in this assessment and explain how the system boundary should be defined. What would you expect your analysis to reveal for packaging for the three different food types: meat, cheese, salad?

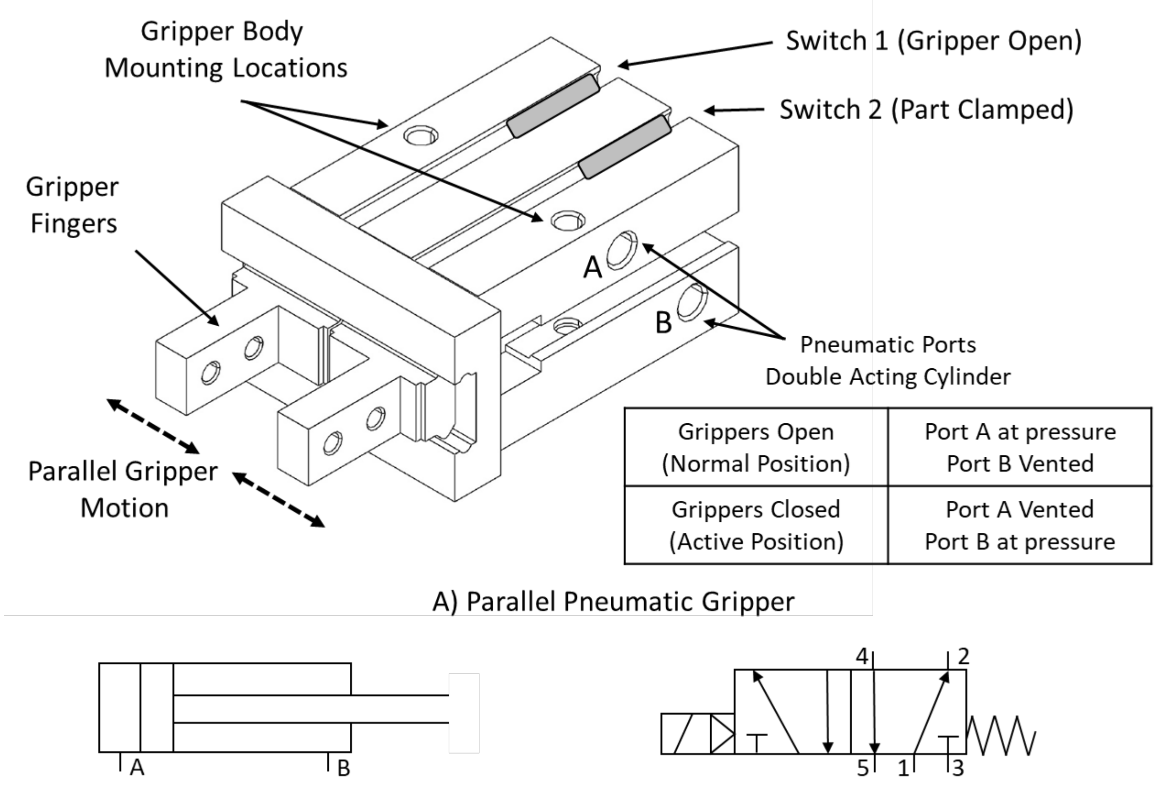
[35%]

(iv) Bio-based polymers are being promoted as an environmentally beneficial solution for future food packaging, substituting for petroleum-based polymers. Discuss the validity of this claim. What are the prospects for the future of bio-based polymers?

[20%]

Question -6

A system integrator has been tasked with developing a new pick and place solution using a SCARA robot fitted with a parallel pneumatic gripper. The pneumatic gripper has an integral double-acting cylinder that opens and closes the gripper fingers symmetrically around a centre location. The gripper is also fitted with two magnetic switches. Switch 1 has a closed circuit state when the gripper fingers are in a fully open position. Switch 2 has a closed circuit state when the gripper fingers are at a part clamped position. Details of the pneumatic components can be seen in Fig 1. (A – The physical configuration of the parallel pneumatic gripper and associated cylinder logic, B – The ISO symbol for a double acting cylinder and C – The ISO symbol for a 5 Port / 2 Position valve with spring return and electrical coil operation).



Grippers Open (Normal Position)	Port A at pressure Port B Vented
Grippers Closed (Active Position)	Port A Vented Port B at pressure

A) Parallel Pneumatic Gripper

B) ISO Double Acting Cylinder

C) ISO 5 Port/2 Position– Mono Stable Valve

Figure 1.

a) Design a pneumatic circuit that will enable the parallel gripper to be controlled using a 5 port / 2 position valve. Include in your design the components required to vary the speed of both the gripper's opening / closing motions and the force that it will be applied to components being gripped. Justify your selections.

[40%]

b) Draw a flowchart that depicts the high-level logic required to control the operation of the robot and the parallel gripper when performing a pick and place operation. The flowchart should include the following robot motions: initial position; pick location; place location; and continued operations via the pick location. For each of these motions provide details around the operation of the 5 port / 2 position valve and the switches used to sense gripper position. State any assumptions you make.

[40%]

c) The finished system will be delivered to a new company location. Describe the infrastructure components that should be installed to ensure safe operation of the robot and provide compressed air services to the pick and place production system.

[20%]

Question-1 Crib

a) A high specification ceramic, is a type of ceramic exhibiting a high degree of industrial efficiency. A type of ceramic used in specialized, recently developed applications. They often have simple chemical compositions, but they are difficult to manufacture. In comparison with the conventional construction materials such as metals and polymers, ceramics show some considerable advantages:

- low density compared to metals
- high hardness
- high thermal and chemical stability
- strength at very high temperatures
- high resistance to wear and corrosion
- electrically and magnetically neutral
- increased service life compared to conventional materials

On the other hand, severe disadvantages (for certain ceramics) have to be considered:

- low strength at ambient temperature
- high brittleness
- high costs (for powders and components)

b)

There area number of ceramic materials the most important being.

Silicon Carbide. This is exceedingly hard, synthetically produced crystalline compound of silicon and carbon. Its is extremely resistant against high temperature, abrasion and corrosion. It has a high thermal and variable electrical conductivity.

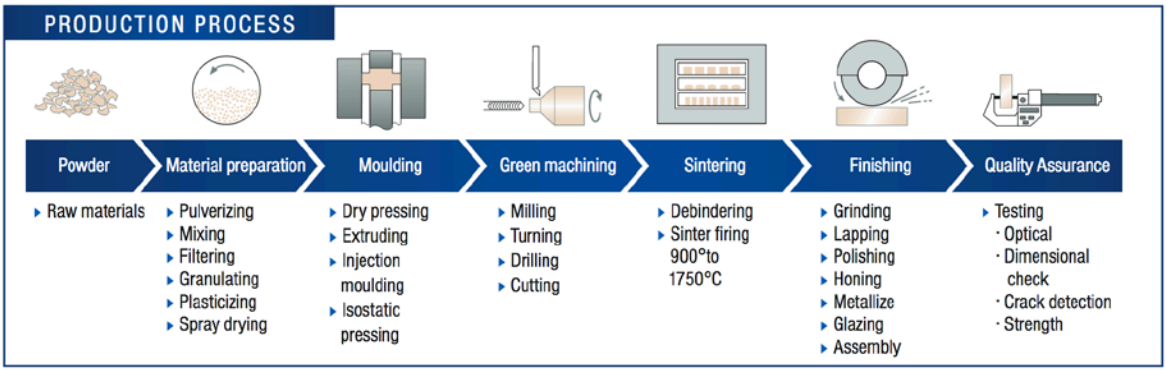
Silicon Nitride. Silicon nitrides (Si3N4) feature an excellent combination of material properties. They are nearly as light as silicon carbide (SiC), but their microstructure gives them excellent thermal shock resistance and their high fracture toughness makes them resistant to impacts and shocks.

Aluminium oxide. Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula Al_2O_3. It is the most commonly occurring of several aluminium oxides. It is commonly called alumina, and is an exceptionally hard, strong, sharp abrasive.

Zirconium dioxide. Unlike other ceramic materials, zirconium oxide (ZrO_2 –also known as zirconia) is a material with very high resistance to crack propagation. Zirconium oxide ceramics also have very high thermal expansion and are therefore often the material of choice for joining ceramic and steel.

c)

The following steps are employed in the production of ceramic components



Material Preparation:

Most ceramic products are made by the agglomeration of particles. The raw materials for these products vary, depending on the required properties of the finished ceramic part. The particles and other ingredients such as binders and lubricants may be blended wet and dry.

Forming:

Pressing into a 'green' part– ceramic particulate raw materials can be pressed in the dry, plastic, or wet condition into a die to form shaped products.

Types of Pressing:

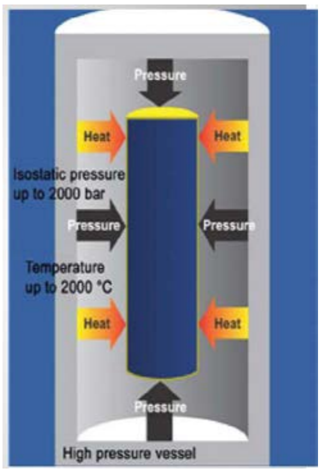
1. Dry Pressing
2. Isostatic Pressing
3. Hot Pressing

<u>Dry pressing</u>

Dry Pressing is used commonly for products such as structural refractories (high heat-resistant materials) and electronic ceramic components. Defined as the simultaneous uniaxial compaction and shaping of a granular powder along with small amounts of water and/or organic binder in a die. Used extensively because it can form a variety of shapes rapidly with uniformity and close tolerance.

<u>Isostatic Pressing</u>

Ceramic powder is loaded into a flexible (usually rubber), airtight container (called a bag) that is inside a chamber of hydraulic fluid to which pressure is applied. After cold isostatic pressing, the part must be fired (sintered) to achieve the required properties and microstructure. Examples ceramic products manufactured are: refractories, bricks and shapes, spark plug insulators, carbide tools, crucibles, and bearings.



Hot Pressing

Ceramic parts of high density and improved mechanical properties are produced by combining the pressing and firing operations. Both uniaxial and isostatic methods are used.

Green Machining.

The machining of a ceramic in the unfired state is called green machining. Green machining of ceramics is done whenever possible since the machining of ceramics after firing is very costly. However, the extremely abrasive nature of ceramics requires the use of carbide and PCD tools and abrasive wheels.

Sintering.

In order for ceramic to be hard and dense, they must be "sintered", or fired to high temperatures for prolonged periods of time in gas or electric kilns. Typical firing temperatures for alumina ~ 1750 ^{o}C, and zirconia can reach 2500 °C with firing cycles ranging from 12 - 120 hours depending upon the kiln type and product. Ceramics shrink approximately 20% during the sintering process. Non-uniform shrinkage as a result of standard forming and machining processes can cause deformation of the ceramic. Specific machining and firing methods to help limit these effects.

Grinding:

Diamond Grinding - Post firing machining may be required to achieve tight tolerances, and surface finishes. At this stage ceramic can only be machined with diamonds, so tooling can be costly. Standard machine shop equipment can be modified with diamond plated or impregnated wheels, drills and assorted tools, as well as necessary recirculating and filtered coolant systems.

d) there were many examples given in the lectures. Examples could include:

Metal forming: Extrusion dies for copper and brass industries. Conventional metal dies produce an average of 80 extrusions. Ceramic dies produced 600-800 extrusions. Other benefits include smoother surface finish and a more consistent diameter.

Refinery: Conventional nozzles in fluidised bed of Cat Cracker use a range of materials with a 3-5 year of lifetime between refurbishments. Ceramic nozzles offer 3 times the life at 2.5 times the cost.

Pumps: Setllite components in a gear pump suffer from corrosion and wear, with replacements required every 6 months. Ceramic replacements cost twice the price but last 6 times longer, saving the customer £7m over 8 years.

Wire industry: Ceramic rolls, cones and guides. Ceramic replacements over high speed steel lasted 20 times longer for 4 times the cost. Giving consistent wire surface quality, improved production rates and improved reliability.

Question-2 CRIB

a) A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components

The individual components remain separate and distinct within the finished Structure. The new material may be preferred for many reasons: common examples include materials which are stronger, lighter, or less expensive when compared to traditional materials.

Typical examples of composite materials include:

- Reinforced concrete and masonry
- Composite wood such as plywood
- Reinforced plastics, such as CFRP and GFRP
- Ceramic matrix composites
- Metal matrix composites

b)

i)

Carbon fibre composites have the following properties

- High in stiffness
- High in tensile strength
- Has a low weight to strength ratio
- high in chemical resistance
- Is temperature tolerant to excessive heat
- Has low thermal expansion

The biggest advantage of modern composite materials is that they are light as well as strong. By choosing an appropriate combination of matrix and reinforcement material, a new material can be made that exactly meets the requirements of a particular application. Composites also provide design flexibility because many of them can be moulded into complex shapes. The downside is often the cost. Although the resulting product is more efficient, the raw materials are often expensive. Carbon fibre composites are very popular in many industries such as aerospace, automotive, military, and recreational applications.

Carbon fibre is a very strong material that is also very lightweight. Carbon fibre is five-times stronger than steel and twice as stiff. Though carbon fibre is stronger and stiffer than steel, it is lighter than steel; making it the ideal manufacturing material for many parts. These are just a few reasons why carbon fibre is favoured by engineers and designers for manufacturing.

ii)
Carbon fibre is made of thin, strong crystalline filaments of carbon that is used to strengthen material. Carbon fibre can be thinner than a strand of human hair and gets its strength when twisted together like yarn. Then it can be woven together to form cloth and if needed to take a permanent shape, carbon fibre can be laid over a mould and coated in resin or plastic.

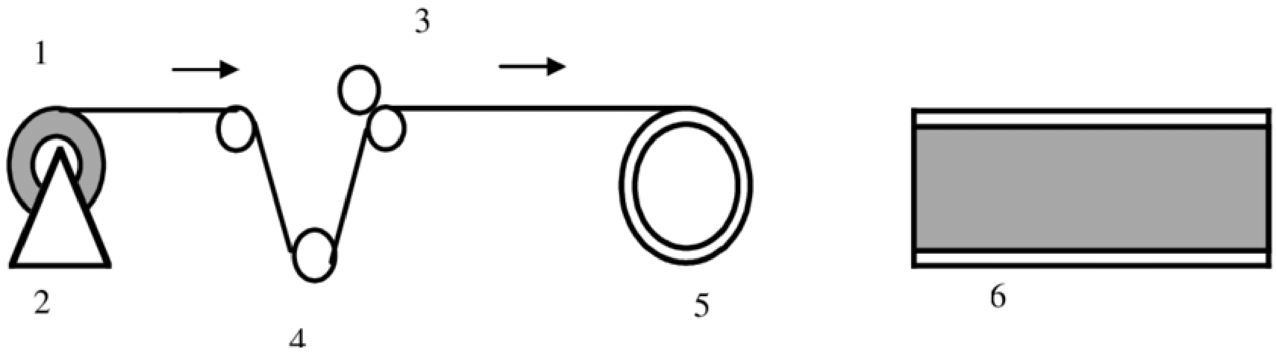
There are two types of resins that can used as matrices to make carbon fibre composites. **Thermoset polymers** are polymers that are cured into a solid form and cannot be returned to their original uncured form. Composites made with thermoset matrices are strong and have very good fatigue strength. They are extremely brittle and have low impact-toughness. They are commonly used for high-heat applications because the thermoset matrix does not melt like thermoplastics. Thermoset composites are generally cheaper and easier to produce because the liquid resin is very easy to work with. Thermoset composites are very difficult to recycle because the thermoset cannot be remoulded or reshaped; only the reinforcing fibre used can be reclaimed.

Thermoplastic polymers are polymers that can be moulded, melted, and remoulded without altering its physical properties. Thermoplastic matrix composites are tougher and less brittle than thermosets, with very good impact resistance and damage tolerance. Since the matrix can be melted the composite materials are easier to repair and can be remoulded and recycled easily. Thermoplastic composites are less dense than thermosets making them a viable alternative for weight critical applications. The thermoplastic composites manufacturing process is more energy intensive due to the high temperatures and pressures needed to melt the plastic and impregnate fibres with the matrix. The energy required makes thermoplastic composites costlier than thermosets.

iii)
Global carbon fibre production at around 100,000 tons is dwarfed by steel at 1 billion tons, and concrete at 3.3 billion tons per year. Very complex production methods. High energy consumption, reliant in oil based feedstocks, low take-up rate restricts growth of production facilities.

c) Prepreg is the common term for fibre reinforcement that has been pre-impregnated with a resin system. The resin system is typically an epoxy and already includes the proper curing agent. As a result, it's ready to lay into a mould without the addition of resin or the steps required of a typical hand lay-up.

The basic process sequence for Prepreg manufacture is shown below..



Schematic diagram of manufacture process of carbon fibre/epoxy prepreg cloth: (1) carbon fibre, (2) bracket, (3) nip rollers, (4) resin impregnation bath, (5) take-up roller, (6) expanding prepreg cloth.

The major advantages of using prepregs are listed below:

Ease of use
Low void content
Good fatigue resistance
Control of laminate thickness
Good environmental and corrosion resistance
Control of fibre volume fraction
Clean process
Better conformity and quality
High specific modulus and strength
Very low thermal expansion coefficient
Enhanced vibration damping characteristics

d) Examples of F1 carbon fibre applications

Monocoque lay-up
Carbon moulds are employed; chassis made in two halves and bonded together. Typical chassis laminate is 1-3 mm on honeycomb core. Monocoques made in this way have considerably more impact energy absorbing characteristics than conventional metals or glass fibres.

Suspension
Front and rear suspension made from CFC materials, which are much lighter and stiffer than traditional steel suspension, although less damage tolerant. The materials offer shorter manufacturing lead-times, and offers more aerodynamic shapes than steel.

Wings and body work.
Wings need to be very strong as they generate heavy down forces. They need to be stiff to maintain aerodynamic profiles. Complex shapes can be made. Bodywork needs to be stiff and strong enough to last several races.
Composite transmission maincase.

Traditionally manufactured in al/Mg/ or Ti alloy castings. CDC offers high stiffness to weight ratios, higher strength, increased fatigue life

Question – 3 Crib

(a)

Using the time estimates given, the expected (mean) duration of each activity and its variance can be calculated using the following formulae:

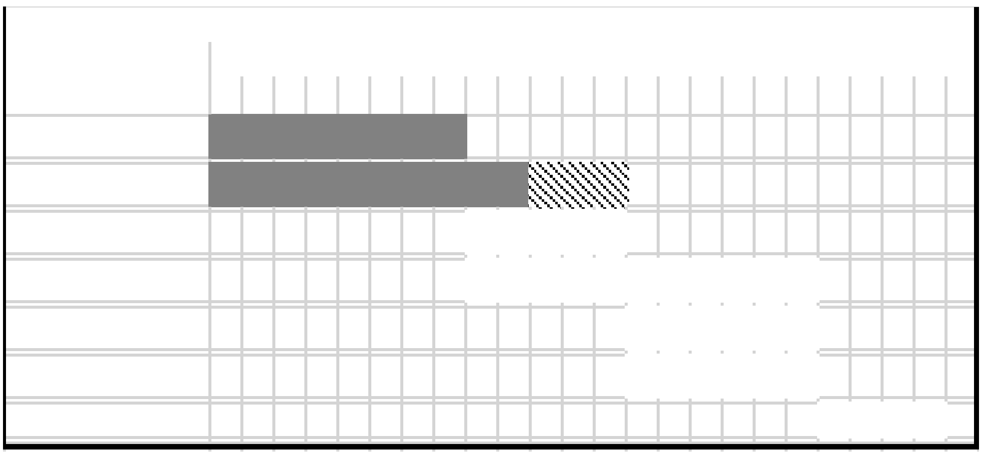
$$Mean = \frac{t_{minimum} + 4 * t_{most\ likely} + t_{maximum}}{6}$$

$$Variance = \frac{(t_{maximum} - t_{minimum})^2}{36}$$

Using the mean durations, the earliest start and finish time, latest start and finish times, and slack can be calculated as shown in the table below

Activity	Time estimate			mean	variance	ES	EF	LS	LF	Slack
	Minimum	Most Likely	Maximum							
A	**5**	**8**	**11**	**8.00**	**1.00**	**0**	**8.00**	**0.00**	**8.00**	**0.00**
B	7	9	17	10.00	2.78	0	10.00	3.00	13.00	3.00
C	**3**	**5**	**7**	**5.00**	**0.44**	**8.00**	**13.00**	**8.00**	**13.00**	**0.00**
D	3	5	13	6.00	2.78	8.00	14.00	13.00	19.00	5.00
E	**4**	**6**	**8**	**6.00**	**0.44**	**13.00**	**19.00**	**13.00**	**19.00**	**0.00**
F	4	5	6	5.00	0.11	13.00	18.00	14.00	19.00	1.00
G	**3**	**4**	**5**	**4.00**	**0.11**	**19.00**	**23.00**	**19.00**	**23.00**	**0.00**

The corresponding Gantt chart is shown below (assuming all activities start at their earliest possible time). The shaded cells denote the slack of each activity (candidates are not required to note this).



(b)

Activities A,C,E and G are on the critical path since they have no slack. The company should be particularly diligent in monitoring these activities since any delays in these activities will delay the project. In addition, activities B and D also need to be monitored carefully. Although these activities do not appear to be on the critical path, their variance are very high. In particular, if they get delayed and reach (or exceed) their maximum estimate, they will in fact be on the critical path.

(c)

In order to answer this question, we need to compute the *expected value* of the contract considering the risks of incurring the penalty and the expected profit.

The mean duration (μ) of the project is 23 days (total duration of the critical path activities) and the project variance (σ^2) is 2 days (sum of variances of the critical path activities). The following normal probability distribution describes the probability analysis.

$$Z = \frac{x - \mu}{\sigma}$$

where x is the target duration, which is 25 days.

The Z value is approximately 1.414, which gives a probability of approx. 0.92 for project completion on target (this is obtained from the normal distribution table). Therefore, there is a probability of 0.08 that the company will miss the deadline specified in the bid. In this event, the loss to the company will be £200,000 in penalty plus £100,000 in sunk costs of the contract = £300,000. Hence the risk to the project is 0.08*300000 = £24000. On the outset, the company's bid price seems to cover this risk.

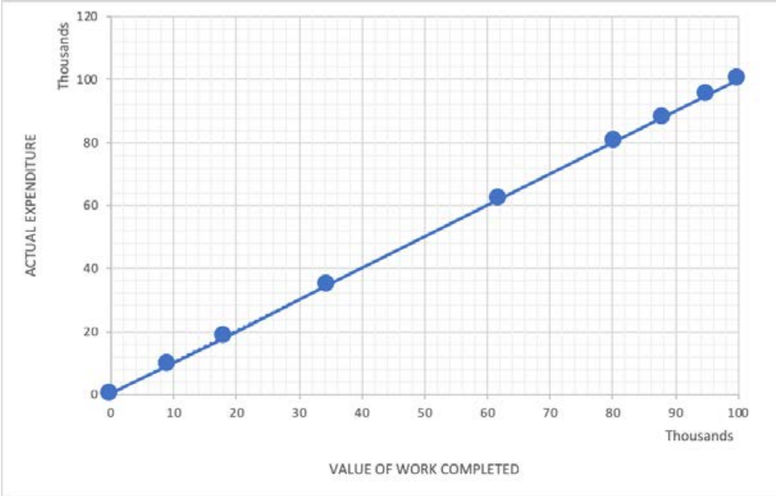
However, looking into the expected value of the contract further, the total cost of the project is £100,000 (sum of the costs of all project activities) and the bid price is £125,000. Therefore, if the company delivers the component on time, it will reap a profit of £25,000. However, note that the probability of on-time delivery is 0.92.

Hence, the expected value of the contract is:

0.92*25000 – 0.08*300000 = – £1,000 [An expected loss of £1,000].

Therefore, the company must either increase their bid price to compensate for the penalty risks or extend the time frame to reduce the probability of delays. However, note that the above calculation is based on the assumption that the decision-maker is "rational". A risk-seeking manager may go ahead with the bid in order to make it competitive – especially considering the possibility of future contract awards. The manager then has to monitor and control the project rigorously to ensure there are no delays and cost overruns.

(d) (i) The ideal earned value analysis chart is shown in figure below (candidates are not required to draw this):



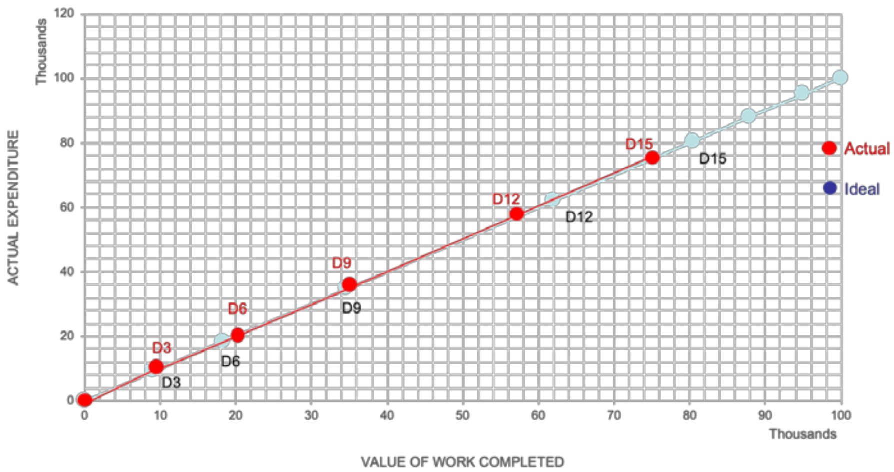
Comparing the project progress table with the Gantt chart, it can be seen that all the tasks due to be completed by day 15 has been completed. None of the other activities have started.
Therefore, the budgeted cost of the work performed (A, B, C and D) = £75,500 (BCWP).
The actual cost of work performed (given in the question) = £78,000 (ACWP).

Examining the Gantt Chart, by day 15, activities E and F should have started two days ago.
The budgeted cost for two days of activity E = £4000.
The budgeted cost for two days of activity F = £1000.

Therefore, the budgeted cost of work scheduled = £75500 + £5000 = £80,500 (BCWS).

Hence:
Cost Variance = ACWP – BCWP = £2500.
Schedule Variance = BCWS – BCWP = £5000.

(ii) The EVA chart of the project so far is shown in figure below (candidates are not required to draw this):



The project started off at a good speed, with activity A completed in the minimum time possible (5 days). The project manager started off C as soon as A was completed, which was a good idea considering that C is on the critical path. However, activity B was delayed beyond the "mean time" and took 15 days instead of 10. This was due to the high variability of that task (as expected). Perhaps in his hurry to finish the critical tasks (A and C) before time, not enough attention was paid to task B. By day 15 the project overall seems to be nearly on budget, but behind schedule.

The delay in activity B meant that tasks E and F, which was scheduled to start on day 13 were delayed (these can now start on day 16). This means that task B accidentally became a critical path activity. Now, since task E (which was critical) has been delayed by two days, the whole project is likely to be delayed by that duration. Since the bid specified a completion date of 25 days, the project should technically be on track for a completion within the specified time.

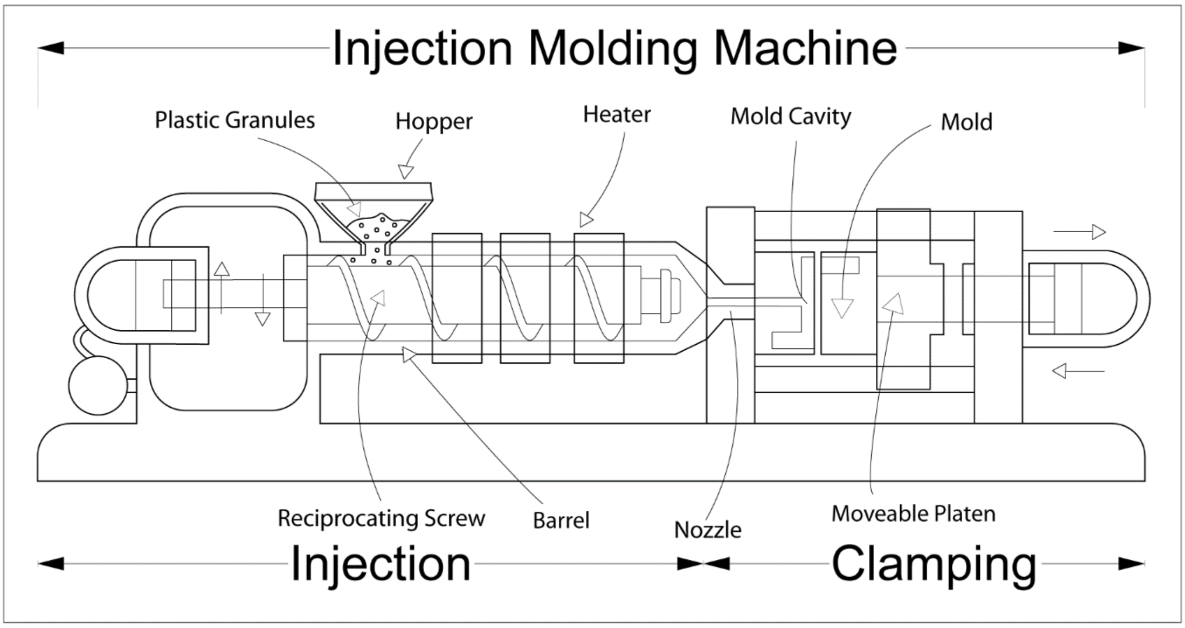
However, any further delays would result in a penalty which needs to be avoided if possible. Considering that the project has so far been on budget, in order to avoid the heavy penalty, the project manager could consider crashing activities E and G (critical path activities). Activity F has a slack of one day, and its variance is low – hence it should be safe. In any case the manager should monitor the project very closely until completion.

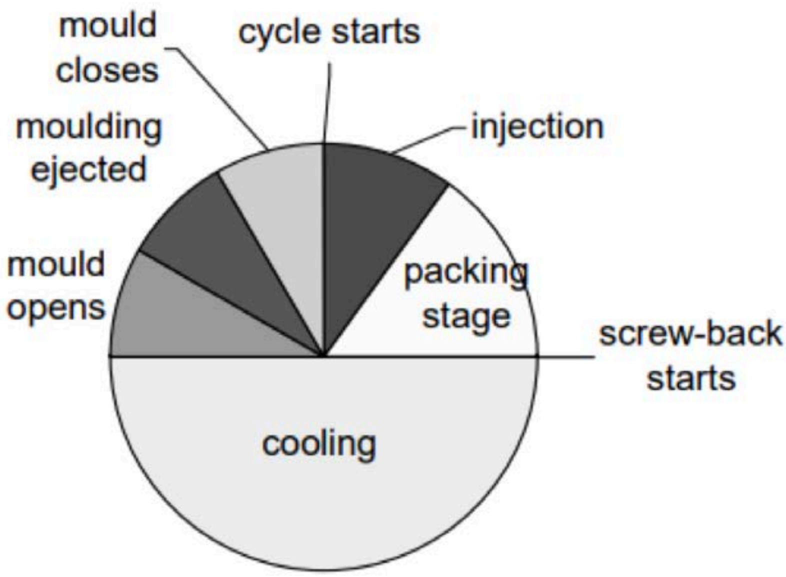
[Note: Excellent responses will have clearly articulated arguments with clear analysis and useful recommendations. Good answers on the other hand will only provide a concise answer (early/late) to the question.]

Question 4 Crib

a) Injection moulding is one of the prime processes for producing plastic articles. It is a fast process and is used to produce large numbers of identical items from high precision engineering components to disposable consumer goods.

Material granules for the part is fed via a hopper into a heated barrel, melted using heater bands and the frictional action of a reciprocating screw barrel. The plastic is then injected through a nozzle into a mould cavity where it cools and hardens to the configuration of the cavity. The mould tool is mounted on a moveable platen – when the part has solidified, the platen opens and the part is ejected out using ejector pins.





Process Parameters

Clamping force: Pressure to hold the mould together. Keep clamping force as low as possible (reduces wear and tear)

Injection pressure: max force for the plastic to be pushed in the mould cavity

Shot size: volume of the part and plus runners and gates. The shot capacity is the full amount as a weight or volume of material injected during moulding from the screw. It is the volume of the part plus runners, cold slug, sprue and gates

Closing force: force needed to hold the mould for packing and cooling

Defects

Flow Lines
Flow lines are streaks, patterns, or lines - commonly off-toned in color - that show up on the part as a consequence of the physical path and cooling profile of the molten plastic as it flows into the injection mold tooling cavity

Sink Marks
Sink marks are small craters or depressions that develop in thicker areas of the injection moulded part when shrinkage occurs in the inner portions of the finished product.

Voids
Voids are pockets of air trapped within or close to the surface of an injection moulded part.

Weld Lines

Short Shots
Short shots can be described as a situation where a moulding shot falls short. This means that the molten plastic for some reason does not fully occupy the mould cavity or cavities, resulting in a portion where there is no plastic. The finished product becomes deficient because it is incomplete.

Warping
Warping (or warpage) is the deformation that occurs when there is uneven shrinkage in the different parts of the moulded component. The result is a twisted, uneven, or bent shape where one was not intended

Flash
Flash is a molding defect that occurs when some molten plastic escapes from the mould cavity. Typical routes for escape are through the parting line or ejector pin locations. This extrusion cools and remains attached to the finished product.

b)
The range of mechanical and automation options for automating assembly covers:

- **mechanised methods**, in which machines / tools help people to do the job, reducing lifting tasks, helping alignment tasks and standardising work tasks.
- **hard automation**, in which machines do the same job every cycle, allowing high production rates to be achieved.
- **flexible automation**, in which robots and other software-driven machines do the jobs, which can be different each cycle, allowing mixed product production or different levels of product customisation.

Solely manual methods may also be considered, as these may be used for very low volume products and provide high levels of flexibility.

Mechanised methods make use of tools (eg powered screwdrivers), simple parts handling and orientation devices, but the human operator is at the centre of the assembly operation.

The important issue raised by the question and which candidates should consider, is the lifecycle of the product. This refers to the fact that any product is introduced to the market, may succeed and ramp up in volume, but will eventually decline in volume as it ages, becomes less attractive to buyers, and is possibly replaced by a new model or simply discontinued. There are also premarket aspects to the lifecycle, when development and prototyping are under way. The means of mechanical assembly needs to be appropriate to the point in the lifecycle at which it is used -which means that they may need to change over the lifecycle.

A combination of product and market attributes governs the way assembly is carried out. Candidates may refer to the 'Puttick Grid', which categorises products according to production and market certainty on one axis, and product complexity/variety on the other axis. The resulting four quadrants on this grid depict commodity products, consumer durables, jobbing/fashion products and capital equipment (super value goods). Each quadrant has its own distinctive characteristics in terms of manufacturing system requirements. The electrical socket was a consumer durable when first introduced, but with growth in volume and reduction of price in the market, has become a commodity.
Factors to take into account when choosing assembly method include: flexibility, reliability, quality, speed, capital investment, running costs, volume growth and lifecycle of the product, hazards (to assembly operators). Component and task variability are also important considerations. Automated systems have difficulty with high variability, whereas human operators are very flexible and adaptable, and may even enjoy such variety.
From these factors, students should also consider whether manual assembly, hard or soft (flexible) automation is appropriate.

Note: Given the expected high volumes and low customisation of a consumer electrical product such as a 3-pin electrical power socket, the most appropriate choice would be hard automation.

Question 5 Crib

(a)

i) Bio-based polymers are derived from bio-based renewable feedstock. They are not necessarily biodegradable.

ii) PLA, PHA and other starch-based bio-based polymers are made from corn (maize), typically by wet milling followed by fermentation and polymerisation.

Applications of PLA: degrades by hydrolysis, so suitable for food packaging and biomedical applications such as sutures.

iii) Substitute for: PS, PP, PE depending on properties (determined by different manufacturing routes).

iv) End-of-life: Biodegradable polymers mostly degrade under aerobic conditions (e.g. composting), but do so more slowly than foods, are not currently be suitable for domestic composting and may be too slow for commercial composting. It is very important that biodegradable polymers do not enter conventional polymer recycling streams, because they will degrade and contaminate them.

Non biodegradable biopolymers (e.g. biopolyethylene) could be recycled by conventional mechanical recycling processes, but are not available in sufficient quantities to constitute a separate waste stream.

(b) (i) Packaging increases the shelf life of food by providing different types of protection. Mechanical protection (e.g. rigidity in egg boxes; surface damage prevention such as tough polymer films); environmental barrier (e.g. oxygen impermeability in film preventing degradation; water barrier so food doesn't dry up); handling (e.g. liquids, powders: strength and toughness). Also provides information (print on polymer - may or may not be possible, may need second material as label); marketing (attractive appearance, colouring, surface texture); tamper-evidence (e.g. break-off tabs: more design than material).

(ii) Important to consider the whole lifecycle of the food plus packaging. Packaging typically has less than 5% of the environmental impact of the food it protects, and may reduce food wastage by orders of magnitude.

Impact may be assessed by eco-audit or by full LCA.

Eco-audit looks only at energy consumption or carbon footprint; LCA looks at other factors including water, chemical inputs and pollution. Because of the complexity of agricultural processes and the number of factors involved in food packaging, LCA is most appropriate for food packaging.

For agricultural processes, defining the system boundary is often not done systematically. It should include all inputs required to grow, harvest, transport and process the crop. For LCA, allocation of the factors between the different products can lead to disparate answers.

Meat is very resource-intensive to produce. Packaging to reduce wastage has huge environmental benefits, so the impact of the packaging itself as assessed by carbon footprint is negligible. However, there may be other impacts (from uncontrolled disposal of waste).

Cheese is less energy-intensive, but the packaging is still negligible compared with food production.

Salad is low-energy to produce. The packaging may be comparable. However, the packaging increases the shelf-life by an order of magnitude at minimum, so has significant positive benefits.

(iii) Bio-based polymers are mostly produced by industrially intensive agricultural processes. Their eco-impact, particularly when assessed by LCA, can easily exceed that of petroleum-based polymers. There is also concern about competition with food crops.

Bio-based polymers are currently produced in small quantities - world capacity is less than 5% of that for conventional polymers. Current projections do not suggest that production could reach levels that will allow them to take over the current food packaging market. Packaging usage would need to be reduced significantly for bio-based packaging to be realistic.

The disposal aspect is problematic: biopolymers mostly do not enter biodegradable waste streams. They are used for energy-from-waste, or in many places they go to landfill. This is contrary to public perception, and is environmentally much inferior.

For the future: bio-based polymer production will increase; technologies will develop; there is likely to be a move away from agricultural crops. Current trends are aimed at reducing the amount of single-use polymer packaging (whether bio-based or otherwise): if this can be made to happen, then bio-based polymers could dominate a smaller food packaging market.

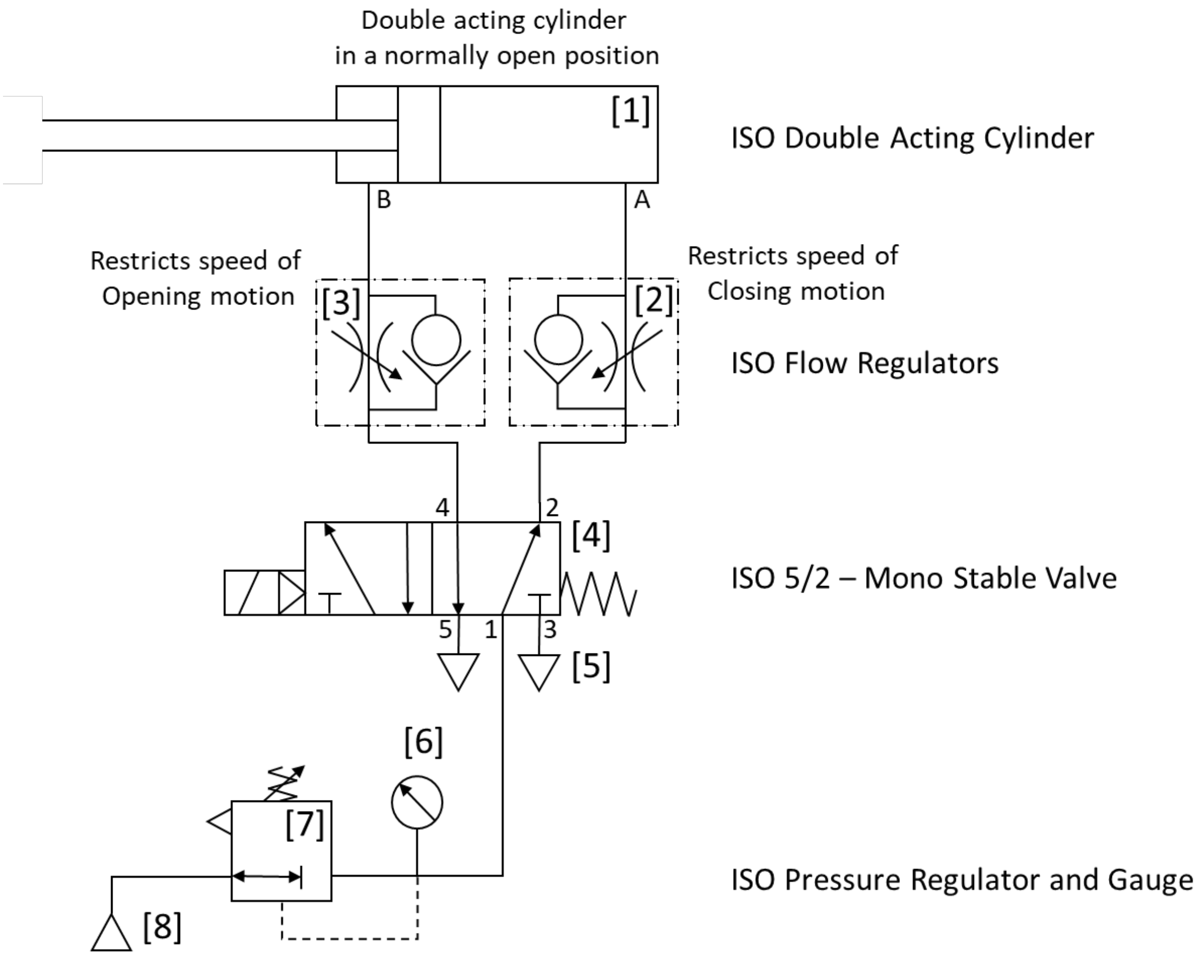
Excellent answers will consider all the factors mentioned, and will provide critical analysis of their relative impact. Strong insight into a wide range of environmental factors is expected, with nuanced solutions to problems.

A good answer will provide a reasoned account covering most factors, and will make sensible proposals based on a spread of information.

Weak answers may focus on only part of the topic, so leaving significant gaps in coverage. Arguments may be specious, or based on too little knowledge or understanding to have much validity.

Question 6 Crib

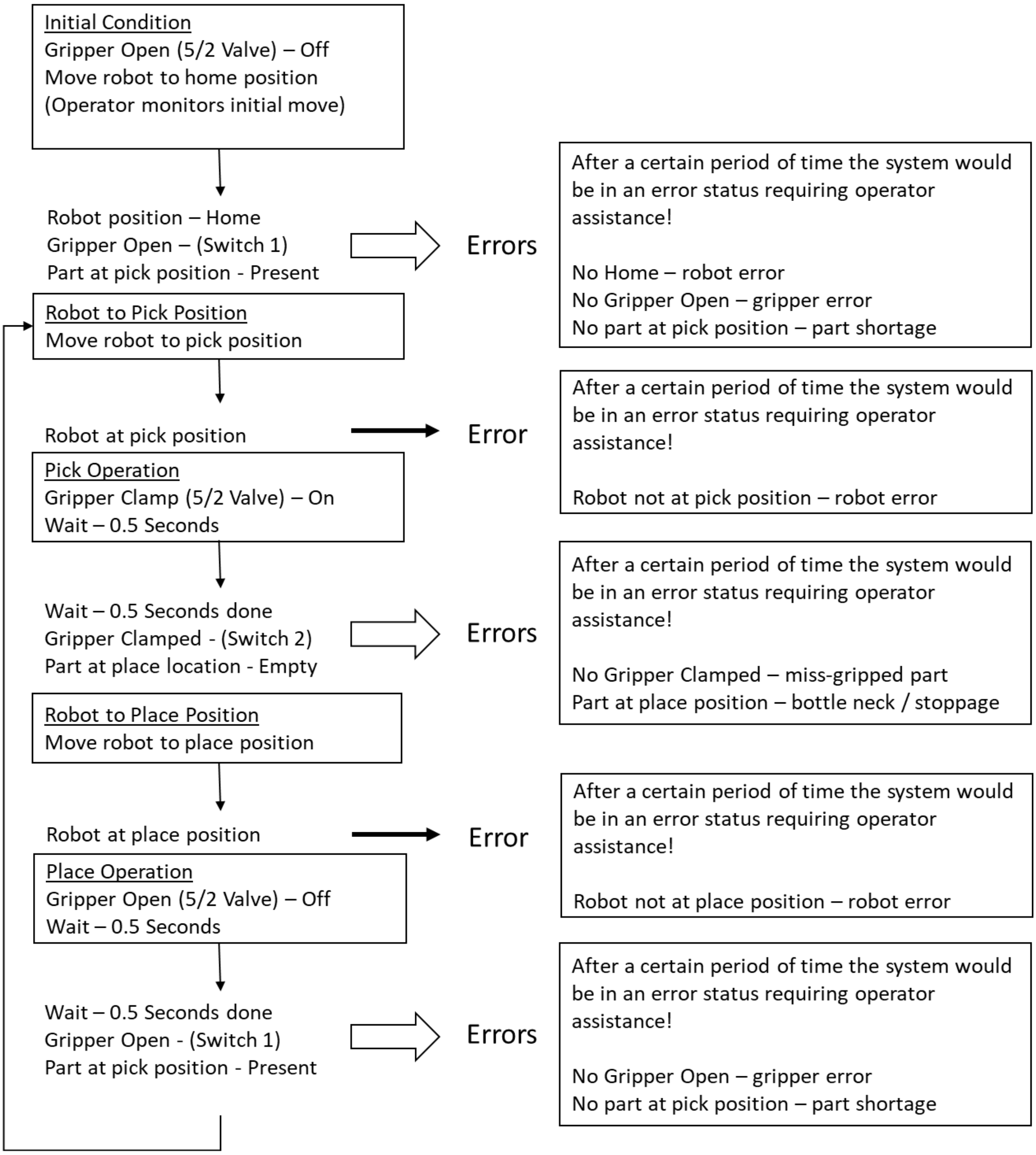
a) The following pneumatic circuit is to control the operation of a double acting cylinder using 5 port / 2 position valve. The circuit incorporates the use of flow regulators to control the opening and closing of the cylinder. It also includes the use of the pressure regulator to limit the clamping forces.



Component [No.]	Description
1	Double acting pneumatic cylinder

2	Flow restrictor (Restriction is applied to exhaust cycle – Closing)
3	Flow restrictor (Restriction is applied to exhaust cycle – Opening)
4	5 Port/2 Positon valve (Sprung return to normal position and is actuated via an electrical coil)
5	Local exhaust port (This is to allow venting to atmospheric pressure)
6	Gauge component of an air pressure regulator
7	Variable air pressure regulator
8	Compressed air source (Typically from a compressor, reservoir and dryer system)

b) The following flow chart depicts the high level logic required to control the operation of the robot and the parallel gripper when performing a pick and place operation.



c) The following table lists and describe the infrastructure components that should be installed to ensure safe operation of the robot and provide compressed air services to the pick and place production system.

Components	Description

Safety Guarding	The pick and place system should have appropriate guarding to ensure people can't be hit by fast moving machinery / components or get crushed between equipment in a trapping zone. Typically guarding is used as physical barrier to stop inappropriate access and is supplied either as wire mesh or Perspex panels.
E – Stop System	E-Stop systems are robust dedicated control systems (safety relay / PLC) that are used to control the mode of equipment operation within a production environment. Typical modes of operation include (Maintenance, Teach and Auto). The E-Stop system monitors the status of E-Stop buttons, safety pull cords and guard access points and limits the operational performance of the equipment appropriately. (Stopping equipment, Reducing maximum motion speeds or requiring addition safety interlocks such as dead manhandles to be used.)
Fortress Lock Access Control	A fortress lock is a key interlock system that is used to gain access to the production equipment through access points in the safety guards. The locks can be found in pairs, one external to the access point and one internal to the access point. A pair of locks has only one key and location of the key changes the operational mode of the system. If the key is external to the access point, the system will run at full speed automatically. If the key is internal to the access point, the system will run at a reduced speed requiring addition safety interlocks. If the key is not present in either lock, the system will not run.
Air Compressor	The air compressor is a piece of equipment that is used to compress air to storage pressure. There are three types of compressor that are in common use; Wale, Rotary Vane and Screw. Compressors typically need a three phase mains supply.
Air Tank	Once the air has been compressed it needs to be stored. The air tank provides this storage reservoir. The tank should be fitted with a safety relieve valve to ensure that the stored air pressure never exceeds the limits of the tank.
Main Line Filter	Removes contaminates from the compressed air supply passing through the element to a nominal size dependent upon that element (0.01 to 5 micron depending upon the element)
Air Dryer	The air dryer is used to reduce the amount of water vapour in the compressed air. Air after compressing can be hot and hold more moisture than when it is cold. Often air dryers include a chiller function.
Filter Regulator	This is a single unit that provides a filtering and pressure regulation function. The filter reduces contaminates and condensate from the air stream and the pressure regulator reduces the pressure to a working level.
Air Lubricator	Not commonly used today but this allows lubricants to be added to the air flow. (Still need when operating air motors)
Isolation Valve	Isolation valves can be used to isolate the air supply and dump air in the system to atmosphere. They also provide a Lock Out Tag Out (LOTO) mechanism, effectively allowing the isolator to be locked while maintenance work is in progress.