CRIBS

Question 1

(a) A typical definition would describe welding as an operation in which two or more parts are joined by means of heat or pressure or both, in such a way that there is continuity in the nature of the material between these parts.

Some advantages include:

- **Complex structures** can be fabricated from simple parts.
- Welded structures are **usually lighter than** mechanical joints.
- **High strength** joints can be produced.
- Welded structures **are more rigid** than mechanical joints.
- **Alterations/additions/repairs** can be made on existing structures.
- Welding does **not require exact fit-up**.
- Welded structures are **more economical** than mechanical joints.
- **Manually or fully automated** assembly
- **Wide range of techniques** to choose from

Some disadvantages include:

- Welded joints are **more brittle** and therefore their **fatigue strength is less** than the base materials being joined.
- Due to uneven heating & cooling of the structures during welding, the components **may distort** resulting in additional stresses.
- **Skilled labour** is required for welding.
- The **inspection of welding work is more difficult and costlier** than mechanical joining.
- **Defects** like internal pores, slag inclusion and incomplete penetration are difficult to detect.
- Welded joints cannot be assembled and reassembled **after operation.**

(b) Starting with arc welding, some example characteristics include:

- Arc welding is one of several **fusion processes** for joining metals.
- By applying **intense heat**, metal at the joint between two parts is **melted and caused to intermix - directly**,
- or more commonly, with an **intermediate molten filler metal**.
- Upon **cooling** and solidification, a **metallurgical bond** is created.
- In arc welding, the intense heat needed to melt metal is **produced by an electric arc**.
- The arc is formed between the **actual work and an electrode (stick or wire)** that is manually or mechanically guided along the joint.
- The electrode can either be a rod with the purpose of **simply carrying the current** between the tip and the work.
- Or, it may be a specially prepared rod or wire that not only conducts the current but also **melts and supplies filler metal to the joint**.

Some example characteristics of laser welding include:

- Laser welding is a **line-of-sight, single-sided, non-contact** joining process.
- Laser beams can be focused in **to sub millimetre-sized diameter spots**, enabling **power densities of the order of 10^6 W/cm^2 to be applied to the joint**.
- These power densities are sufficient to form a **'keyhole' weld** below the laser beam impingement point.
- It is characterised by its **high focused energy density**, which is capable of producing **high aspect ratio welds** (narrow weld width: large weld depth) in many metallic materials.
- It can be performed **at atmospheric pressure**, although **inert gas shielding is required for more reactive materials**.
- Furthermore, laser welding is of a **relatively low heat input**, especially when compared with arc welding processes.
- Laser welding delivers **fast processing** speeds compared to arc welding.

Some example characteristics of friction welding include:

- Friction Welding (FW), overcomes many of the problems associated with traditional joining techniques.
- FW is a **solid-state process** that produces welds of high quality in **difficult-to-weld materials such as aluminium, magnesium and titanium**.
- The process produces **coalescence of materials under compressive force** contact of workpieces rotating or moving relative to one another to produce heat.
- The frictional heat causes a **plasticised zone to form** between the materials and on cooling a **consolidated solid-phase joint** is formed.
- FW being a solid-state process **eliminates many of the defects** associated with fusion welding techniques such as **shrinkage, solidification cracking and porosity.**
- FW **requires low-energy-input** and is a repeatable mechanical process capable of producing **very high-strength** welds in a **wide range of materials**.

These are not complete lists and there are additional points that were noted in the lectures regarding quality, standard thicknesses, cost, etc. that were also acceptable characteristics.

c) Process choice should be based on an assessment of a range of factors. Excellent answers consider such factors as well as then choosing the correct technique. If the final decision was incorrect, there are still marks for considering the relevant factors. Examples include:

- nature of the materials to be joined
- mechanical properties required
- expected production volumes

- likely process cost
- accuracy of the final assembly
- likely production rate
- environmental effects

The three scenarios are summarised below:

i) In this case the materials to be joined are **dissimilar materials** and fusion based welding is likely to produce brittle welds which would reduce the **strength of the joint.** As it is an automotive application, the likely **production volumes will be high** and the associated **costs must be low**. An automotive engine valve will require a **precision joint**, which may or may not require post machining. In this case the ideal process choice would be **rotary friction welding**. **Burrs** produced during welding could be minimized through careful selection of process parameters or removed through grinding. The process offers **low electrical power consumption**, **low cost**, **high process speed** and **high yield**.

ii) In this case the plates are **made of the same materials** and so fusion based welding is appropriate. The **properties of the weld will be similar to those of the base materials.** Large structures suggest **medium production volumes** and **low to medium production costs**. The **accuracy of the final assembly is likely to be moderate** with low production rates. The **thickness of the plates** is at the upper end of laser welding capabilities and the **costs through this route are likely to be high** since the capital equipment costs of laser welding are high. The best choice of process in this case would be **arc welding,** most likely **MIG welding with flux coated filler wire** to protect the weld bead from the oxidation effects of the environment. This will **require multiple passes** with good joint preparation using the **'single-V butt joint'** approach.

iii) In this case the **materials are the same**, although they offer particular **challenges in terms of environmental protection** during welding. The **properties of the weld zone must be as close to the base materials** as possible. This rules out fusion based processes. **Linear friction welding** is the ideal choice since it is **most suited to the joining of high value-added components where the significant machine and associated tooling costs can be justified**. For large 'BLISK' manufacture this approach is considered more cost-effective than machining the form from a solid forging. In the case of **titanium alloys, microstructural refinement by dynamic re-crystallisation and phase transformation takes place about the bond line in the thermo-mechanically affected zone**. Welds of this type generally have excellent metallographic quality.

(d) Ultrasonic welding is the **joining or reforming of materials** through the use of **heat** generated from **high-frequency mechanical motion**. It is akin to friction welding accomplished by converting **high-frequency electrical energy** into **high-frequency mechanical motion**. That mechanical motion, along with applied force, creates frictional heat at the components' mating surfaces (joint area) so the materials bond between the parts.

The horn (which **delivers the acoustic energy and load** to the mating parts) is vibrated vertically **20,000 (20 kHz) to 120,000 (40 kHz)** times per second, at **distances measured in microns**, for a predetermined amount of time. Through careful part design, this vibratory mechanical energy is **directed to limited points of contact** between the two parts.

Applications include but are not limited to the following:

Plastic Welding: The mechanical vibrations are transmitted through the **thermoplastic** materials to the joint interface to create frictional heat. When the temperature at the joint interface reaches the melting point, plastic melts and flows, and the vibration is stopped. This allows the melted plastic to begin cooling. For automobiles, ultrasonic welding tends to be used to assemble large plastic components such as instrument panels, door panels, lamps, air ducts, steering wheels, upholstery and engine components.

Electrical Connections: In the electrical and computer industry ultrasonic welding is often used to **join wired connections** and to **create connections** in small, delicate circuits. Semiconductor devices, transistors and diodes are often connected by **thin aluminium and gold wires** using ultrasonic welding.

Thin gauge metals: Ultrasonic welding is generally utilized in the aerospace industry when joining **thin sheet gauge metals** and other lightweight materials. Aluminium is a difficult metal to weld using traditional techniques because of its high thermal conductivity. However, it is one of the easier materials to weld using ultrasonic welding because it is a softer metal and thus a solid-state weld is simple to achieve.

Applications in packaging: Packaging is an application where ultrasonic welding is often used. Many common items are either created or packaged using ultrasonic welding. **Sealing containers**, **tubes** and **blister packs** are common applications.

Question 2

(a) In lectures, the theory of adhesion was introduced in terms of (a) preparation of surface and pre-treatment, (b) design of the joint, (c) underlying surface and conditions once the part is in service and (d) the details of the adhesive chemistry. These all have to be considered prior to choosing the correct adhesive.

In terms of the properties of the adhesive prior to bonding, notes should include points such as the importance of choosing the correct viscosity for the application. A high viscosity adhesive can be difficult to remove from the container and apply but will stay in a thicker bondline. Low viscosity materials can flow too much and run off the surfaces, however they can penetrate and seal cracks. It is also important to note the role of thixotropy. This is a material's change (usually lowering) in apparent viscosity over time while under stress and relates to the ability to fill gaps between substrates and resist sagging on vertical surfaces. The change in apparent viscosity is an important consideration prior to complete curing of the adhesive. Some candidates noted the drip test, described in lectures, as a way of identifying thixotropic behaviour.

Application-specific considerations may include adequate surface preparation. Removal of grease or contamination layers ensure good contact between the adhesive and the structure. One example included the peel ply of carbon fibre composite sheets that gives the clean surface with the correct texture for bonding.
The gel time/work life/pot life was also noted by most candidates, which is the amount of time from initial mixing until the mixture can no longer be stirred. This can be increased or decreased by cooling or heating the resin and/or hardener depending on the ease of application and time required for the application. This can be linked to the ease (or difficulty) of application. For particularly large or difficult to access components, a longer pot life may be required.
It is essential to consider the in-service environmental conditions when choosing a structural adhesive. The expected harsh environment from this example was noted by a number of candidates. It was also noted that the maximum service temperature of an adhesive is calculated using the glass transition temperature.

Validation considerations for structural adhesives should include:
Carrying out standardised tests on relevant materials to look at, for example, the lap shear strength, a measure of the ultimate load. It is also worth identifying if the adhesive fails by cohesive or adhesive failure modes.
The peel strength may also be mentioned, which is a measure of a material's ability to withstand vibration and stretching without deforming or breaking.
The mechanical properties of the adhesive should be considered in terms of the likely conditions experienced during its use and so load cycle tests, elongation or maximum load testing are all valid.

There are additional points in the lectures that are also valid, such as the shrinkage of the adhesive, the cost and the health and safety considerations.

Cribs Part (b)

Industry trends include:
From the lectures, there were examples where carbon fibre composites have displaced traditional materials, with examples such as ski manufacturing, in the wing box of planes (in general replacing aluminium in some aspects of aerospace applications) as well as much of the plane interior, in wind turbine blade manufacture. It was an important point that industry was trying to move to lighter materials that maintained the necessary mechanical properties. There is currently a trend towards more automation due to the poor volume throughput compared with traditional materials. A significant trend is tackling the current restriction in waste management. There is no feasible recycling route for carbon fibre composites, which is very costly with 25-40% waste noted in some applications. Also, the current step of fabricating the pre-preg involves very large volumes of solvent evaporation and re-capture, which is a very inefficient process. There is a noted trend that carbon capacity is going up rapidly up and the price is reducing. Designers are taking advantage of composite manufacturing possibilities but it was noted by visiting lecturers that it is not understood yet precisely what the limits to industrial growth will be.

Material challenges include:
Some challenges include the non-isotropic nature of the materials, their challenging compatibility with fastening to metal structures (bolts/rivets).
Improved delamination and fatigue properties also need to be considered.
Currently relatively expensive and slow to make parts at larger throughput.
The ability to predict and model material behaviour is still lacking and so the material input, processing and the output all need to be qualified.
The matrix also needs to be considered as it is a critical part of the composite and the challenges of choosing between thermoset and thermoplastic can also be mentioned in this context in terms of the tradeoff between mechanical properties and cost/volume.
At the moment it is not feasible to predict performance based on molecular structure, which can limit design.

Production technology challenges include:
The manufacturing process to make the precursor material (Polyacrylonitrile) is very energy intensive and requires significant solvent recycling.
When making the carbon fibre reels, disposal of waste material is also a challenge, both in terms of solvent capture, waste product capture and also end-of-use recycling.
One answer to throughput challenges is Automated Fibre Placement, which can place material onto concave and convex tooling, combined with developed and non-developed surfaces. Also Automated Tape Layup is being used to fabricate large flat panels. Examples were given in lectures.

Techniques for handling large volumes and making parts faster are improving rapidly. The time required to make parts is still comparatively slow. Metal takes seconds to turn into final form, carbon composite can take weeks.

Other growth opportunities in terms of the business that were mentioned for carbon fibre composites include:
Creating wider rolls
-Identifying single product demand to reduce the need for flexibility
-Improvement in product defect occurrences.
Decreasing process time
Delivering new and heavier products with thicker filaments or more filaments per tow. Either option is currently facing significant challenges, either due to poor uniformity or the challenge of oxygen diffusion respectively.
Compromising on alignment may allow more rapid manufacturing at the cost of reducing the mechanical performance.

Examiner's Comments:
Question 1:
This was a popular question choice, taken by about half of the group. Most candidates showed good or excellent knowledge and understanding of at least some parts of the first question. There were some detailed and impressive answers. There were very few candidates who had not engaged with the material.

(a) This first part was very well tackled by the majority of the candidates that chose the question, with half receiving more than 70%. This showed very good understanding of the fundamentals of welding.

(b) This second part was divided into three sub-units, describing each of the noted welding technologies. This was in general answered very well, with half of the class giving very good or excellent answers. While excellent answers were given about arc welding, the candidates struggled a bit more discussing laser and friction welding.

(c) The third part was the section that proved the most challenging. While only a few candidates correctly identified the welding routes required, there were marks awarded for the process of identification, where some candidates showed a very good qualitative and quantitative understanding of the considerations.

(d) This final part was answered very well indeed with the candidates again showing an excellent appreciation for the features of the welding technique as well as its applications.

Question 2:
This was not a popular question to attempt, with only approximately a quarter of the group answering. Part (a) was answered very well by the majority of students that chose this section. Some candidates showed an excellent breadth of knowledge on the topic. The differentiation between the very good and excellent answers was often due to the level of detail given for each point. The question asked to discuss in detail and so memorised lists and bullet points were not sufficient and needed to be backed up with notes that convey the underpinning message.

Question 2, Part (b) was a more integrative question, combining elements of the lectures on carbon fibre pre-preg production, applications in Formula 1 and some *future work with advanced carbon fibres and nanotubes. There was a variety of answers drawing upon different aspects of the lectures noted above. Most candidates noted the key industrial trends, the challenge of the cost and feasible manufacturing volumes at the moment as well as the challenge of lay-up of pre-preg. Also, the majority of answers covered the challenge of recycling and waste management. There are a large variety of challenges and this was reflected in the varied answers. Excellent answers noted both the wide variety of challenges and also gave a more detailed description to convey a clear understanding.*

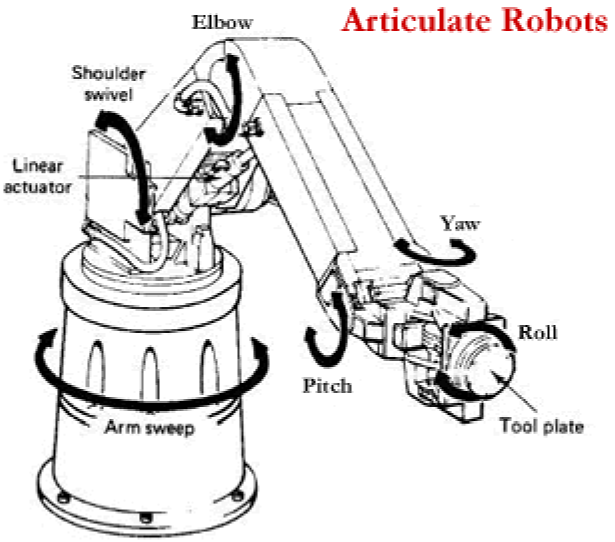
METIIB Paper 1 – Question 3 Robotics question

Form of Answer

Part a)

Articulated anthropomorphic robots are formed with a series of rotary joints, which can have non parallel axes. Many joints gives many degrees of freedom leading to great versatility in the positioning of end effectors. Can mimic human motion hence suitable for wide range of tasks including complex motion, eg spray painting, weldings, fettling

Disadvantages: less rigid than design such as SCARA or coordinate, hence slower and potentially less accurate. More expensive than many designs for equivalent payload



The **SCARA** acronym stands for **Selective Compliance Assembly Robot Arm** or **Selective Compliance Articulated Robot Arm**.

SCARA robots are formed with arms and rotary joints. All joint axes are parallel and in the z direction. Therefore the arm is slightly compliant in the X-Y direction but rigid in the 'Z' direction, hence the term: Selective Compliant. This is advantageous for many types of pick and place or vertical stacking assembly operations, i.e., inserting a round pin in a round hole without binding.

Disadvantages: limited versatility, restricted access to workspace

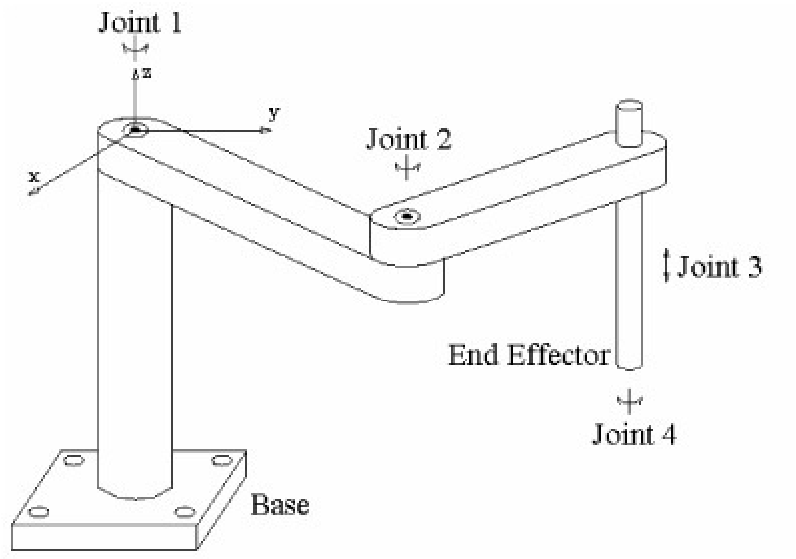
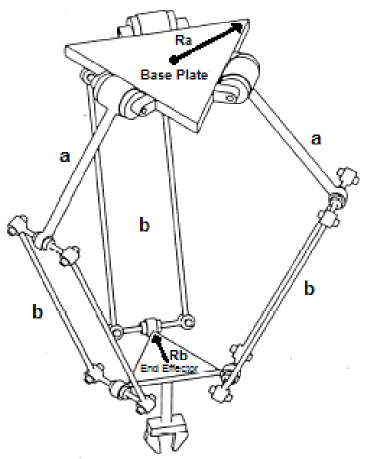


Figure 5. SCARA - Selective Compliance Assembly Robot Arm.

The delta robot is a parallel robot i.e. it consists of multiple kinematic chains connecting the base with the end-effector. The robot can also be seen as a spatial generalisation of a 4-bar linkage.



The key concept of the delta robot is the use of parallelograms which restrict the movement of the end platform to pure translation, i.e. only movement in the X, Y or Z direction with no rotation.

The robot's base is mounted above the workspace and all the actuators are located on it. From the base, three middle jointed arms extend. The ends of these arms are connected to a small triangular platform. Actuation of the input links will move the triangular platform along the X, Y or Z direction. Actuation can be done with linear or rotational actuators.

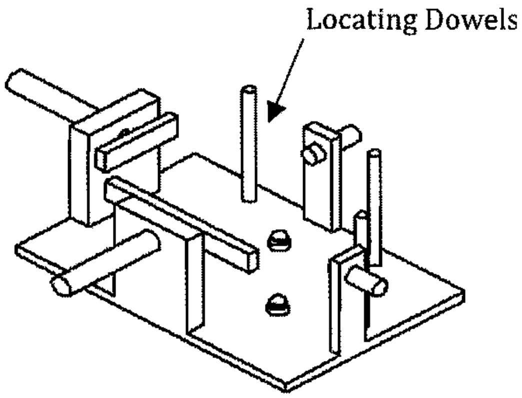
Since the actuators are all located in the base, the arms can be made of a light composite material. As a result of this, the moving parts of the delta robot have a small inertia. This allows for very high speed and high accelerations. (up to 100g)

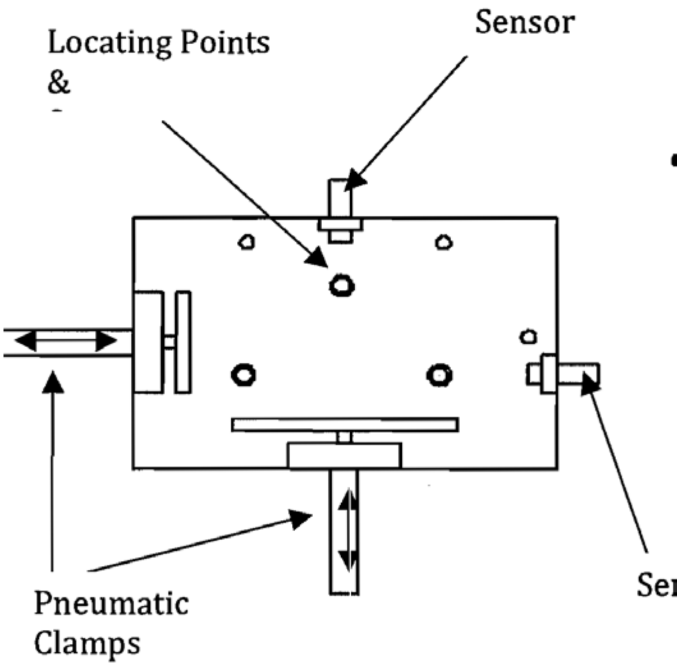
Having all the arms connected together to the end-effector increases the robot stiffness, but reduces its working volume.

Can be used for very high speed pick and place.

Limited payload compared to other designs

Part b)





The fixture above is designed with kinematic principals in mind. Three spherical points of contact supporting the base of the product and define a z plane. Three points of contact on the sides of the box to locate it in the XY Plane.

Pneumatic clamps have been positioned centrally to push the part against the location points. The status of the of the clamps would be detected by sensors. This would let you know if they are extended or retracted. Sensors are also situated XY fixture points to ensure that you know that the box has been clamped into a known position.

A SCARA robot with end effector comprising vacuum gripper and screwdriver would be used for the material handling solution.

Reason: This is a typical vertical stack assembly and screwing operation. Thus 3 dof is adequate. A SCARA construction gives a cheap, vertically rigid construction which could cope well with an end effector that is quite heavy due to the dual roles it performs.

Errors and Sensing

Robot – parts not picked up - vacuum sensor on gripper

Robot - Lid incorrectly positioned – high accuracy diffused optical sensor on z axis

Robot - out of screws – inductive sensor on screw driver

Robot - screwing errors:

Cross thread – torque sensor (ON) AND Screw driver lower Z position inductive sensor (OFF)

Stripped thread – torque sensor (OFF) AND Screw driver lower Z position inductive sensor (ON)

Fixture – box incorrectly clamped – Clamp extended sensor (ON) AND box location sensor (OFF)

Clamp extension sensors can be (Inductive, optical diffused or magnetic depending on cylinders)

Box location sensors can be (Capacitive, optical diffused)

MET IIA Paper 1 – Question 6 - ISOS

SOLUTION

(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.

	Time estimate									
Activity	Minimum	Most Likely	Maximum	mean	variance	ES	EF	LS	LF	Slack
1	**5**	**8**	**17**	**9.00**	**4.00**	**0**	**9.00**	**0.00**	**9.00**	**0.00**
2	7	10	19	11.00	4.00	0	11.00	3.00	14.00	3.00
3	**3**	**5**	**7**	**5.00**	**0.44**	**9.00**	**14.00**	**9.00**	**14.00**	**0.00**
4	1	3	5	3.00	0.44	9.00	12.00	17.00	20.00	8.00
5	**4**	**6**	**8**	**6.00**	**0.44**	**14.00**	**20.00**	**14.00**	**20.00**	**0.00**
6	3	3	3	3.00	0.00	14.00	17.00	21.00	24.00	7.00
7	**3**	**4**	**5**	**4.00**	**0.11**	**20.00**	**24.00**	**20.00**	**24.00**	**0.00**

Activities 1, 3, 5, 7 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, activity 2 also need to be monitored carefully. Although this activity does not appear to be on the critical path, its variance is very high. In particular, if it gets delayed and reaches (or exceeds) its maximum estimate, it will in fact be on the critical path.

[Note to the examiner: Most candidates will perform these calculations correctly and will suggest activities 1,3,5,7. It is likely that many candidates will miss out activity 2 as a potential activity to be monitored.]

(b) The mean duration (μ) of the project is 24 days (total duration of the critical path activities) and the project variance (σ^2) is 5 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.

The Z value for a probability of 0.9 is approximately 1.29 (this is obtained from the normal distribution table).

Substituting the values in the above formula, we get $x \approx 27$days. **The company should specify a duration of 27 days in the bid to be 90% certain that it will be deliver the component without delays.**

[Note to the examiner: Slight variations to the answer is allowable as some candidates might try to provide a more precise calculation.]

(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 total cost of the project is £100,000 (sum of the costs of all project activities) and the bid price is £120,000. Therefore, if the company delivers the component on time, it will reap a profit of £20,000. [Note that on the outset this appears to be a very healthy profit margin, considering that the aerospace industry normally operates at less than 10% profit margin].

However, note that the probability of on-time delivery is 0.9. There is a probability of 0.1 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 expected value of the contract is

0.9*20000 – 0.1*300000 = – £12,000 [An expected loss of £12,000].

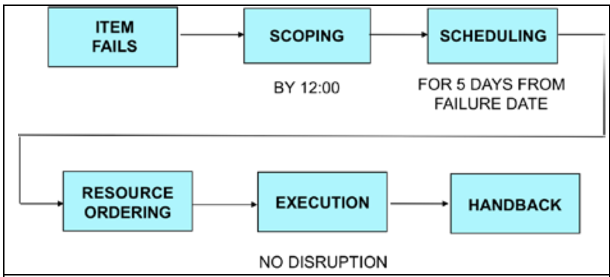
Therefore, the company must either increase their bid price to compensate for the penalty risks or extend the time frame to reduce the probability of delays. However, note that the above calculation is based on the assumption that the decision-maker is "rational". A risk-seeking manager may go ahead 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.

[Note to the examiner: Some candidates might forget to include the sunk project costs in this calculation. Even in this case, the expected value of the project will be a loss of £2000, leading to the same conclusion. The response to this question may vary between candidates. Credit should be given where the response is clearly presented and argued.].

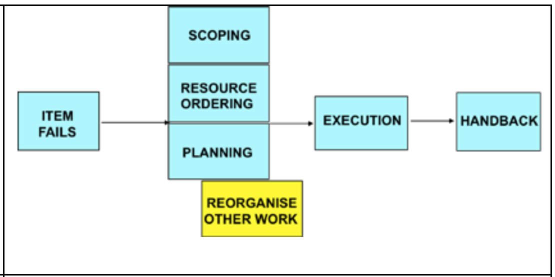
MET IIA Paper 1 – Question 4 - ISOS

SOLUTION

(a) (i) Standard and imperative response can be described by the following figures:



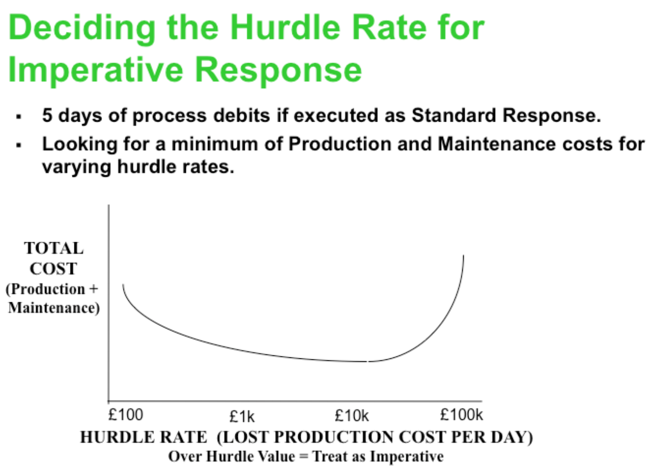
Standard response



Imperative Response

Standard response: when an item fails, engineers go and establish the scope of the problem and needed response, and produce a scoping report, by mid-day on the day of the failure. They then schedule the repair for 5 days from the failure date, and order the necessary resources to do the repair. On the repair date the repair team execute the repair with no disruption. The plant is then handed back to operation.

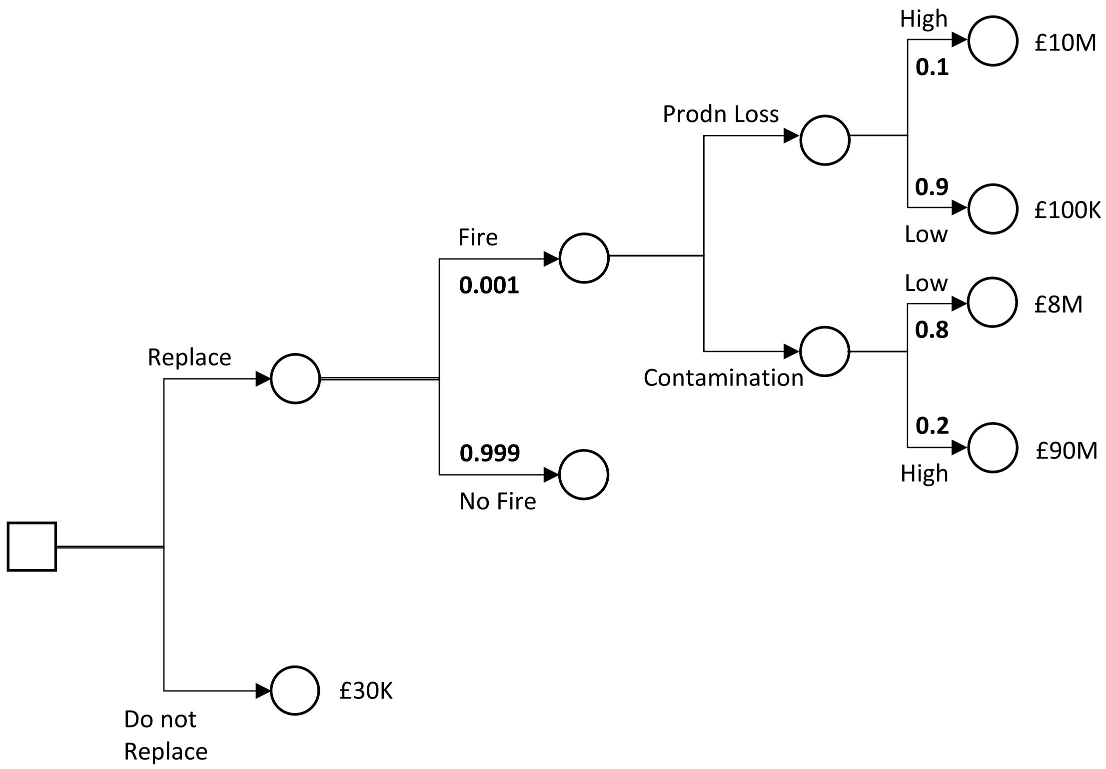
Imperative response is still planned before execution begins. When an item fails, the work is scoped, the resources are ordered and the repair is planned, but an imperative response is allowed to override other work to draw people to complete it in faster than the 5 days of the planned response work.



The decision between the two responses is made by
- comparing the cost of "creative maintenance", i.e., extra cost incurred in speeding up the maintenance process to the total cost of production + maintenance.
- Other considerations include environment and safety issues.

[Note to examiner: Excellent responses will discuss the concept of hurdle rate clearly and will describe how the hurdle rate is obtained, and also provide examples for each. Poorer responses will simply state what has been presented to them in the lecture.]

(b) (i) The approach to be taken is to calculate the risk of not replacing the equipment against the cost of replacing it. A decision-tree maybe used to aid in the calculation. The figure below shows the decision tree for this problem.



The cost of replacing the equipment is £30K. Rolling back the probabilities and consequences in the decision tree, the risk of not replacing the equipment is found to be £26300. **On an economic basis, the company should not replace the equipment since the cost of replacement outweighs the risks.**

[Note to examiner: Marks should be allocated for the correct approach (decision tree), formulation of the decision tree correctly, and for correct calculations.]

(ii) This part of the question requires candidates to draw on wider lectures on risk analysis. Although the economic analysis shows that the equipment should not be replaced, a number of factors must be taken into account when making this decision:

- The gap between cost and risk is small. Note that this is a typical high-impact-low-probability event. The actual cost incurred if a fire happens is very large. For such risks, a purely economic calculation might not be the best way to make a decision.
- A number of risk factors are not considered in this decision such as reputational impact on the company due to such an incident, possible loss of customers, possible further lawsuits etc. Consideration of such risks may in fact change the decision.
- The risk analysis currently only considers the financial impact of environmental damage through penalties etc. However, the actual environmental impact itself is not considered – linking to sustainability. Typically, companies (e.g., Exxon) considers environmental (and safety) risks from a non-financial perspective.

Considering the difference between the cost and risk, it would therefore be prudent to replace the equipment.

[Note to examiner: Candidates can respond to this question either way (yes or no), but need to present their arguments clearly. There is a stronger argument for replacing the equipment in the overall context of risk. Excellent responses will recognise this and will present several arguments, with examples, for going against the economic choice.]

METIIB Paper 1 – Question 5 *Crib*

(a) Barrier function can prevent chemicals from leaving a product, or prevent chemicals from outside from reaching the product. In many food applications the barrier is selective to particular molecules. Typically makes use of variable permeability of polymer film to different molecules. Enhanced barrier function can be gained by incorporating a thin layer of aluminium (10 micron) sandwiched between polymer film layers.

Examples:

Inert atmosphere (e.g. nitrogen) around bagged prepared salad: low permeability to nitrogen, but also low permeability to oxygen ingress.

PET bottles for carbonated drinks: low permeability to CO2.

Cheese packaging: allows egress of CO2 as cheese ripens, but does not allow excessive loss of water or smells. Low permeability to oxygen ingress.

(ii) Environmental impacts: Product life increased by orders of magnitude, so (simplistically) reduces wastage. But the lengthening of the supply chain promotes globalisation of food production, with both positive and negative environmental consequences (factors include transport, agricultural policies and impacts). The complexity of packaging material may in some cases be increased if a barrier function is included (e.g. as an additional polymer layer in cheese packaging, or with metallised films), reducing recyclability.

Considering packaged food as a whole, the environmental impact of the food production hugely dominates the total impact. So the impact of the packaging itself is normally considerably less than 5% of the total impact, and any end-of-life considerations are (in terms of energy or carbon footprint) negligible.

(b) A system boundary is used to define what should be included for a particular environmental analysis. For this case, the following factors should be considered:

Packaging: Material production, manufacturing process, transport between different stages. End-of-life disposal.

Supply chain issues: The weight and volume of the packaging and how it affects the density with which the product can be packed for transport.

The analysis is of the packaging, so the production of the product being packaged (cheese) is outside the boundary. Nevertheless, the effectiveness of the packaging has implications for the shelf-life (lifetime) of the product.

(c) User inputs include Bill of materials, shaping processes, transport needs, duty cycle. The Eco database is used to generate embodied energies, process energies, CO2 footprints, unit transport energies etc. The eco-audit can be facilitated using CES. Assumptions may typically include details of the materials used.
Outputs include a bar-chart showing impact of the four lifecycle phases: material, manufacture, transport and use, plus end-of-life.
The analysis should be used to identify the phase with the greatest impact, and to focus on this for action.
Additional factors: In assessing the wider environmental consequences of food packaging, the domination of the food production aspect should be remembered. Not specifically mentioned are the factors associated with the function of food packaging in reducing food wastage, including the barrier function described under (a) (ii).

(d) Discussion of biopolymers would be appropriate here, including environmental impacts of the production and end-of-life aspects. PLA would be a good material to consider.