Version WON/03

MET 3

MANUFACTURING ENGINEERING TRIPOS PART IIB

Tuesday 23 April 2024 9.00 to 12:10

Paper 1

Answer not more than ***four*** *questions.*

Answer each question in a separate booklet.

All questions carry the same number of marks.

The ***approximate*** *percentage of marks allocated to each part of a question is indicated in the right margin.*

Write your candidate number <u>*not*</u> *your name on the cover sheet on each booklet.*

STATIONERY REQUIREMENTS

8 page answer booklet x 4
Rough work pad

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM

CUED approved calculator allowed
Engineering Data Books

10 minutes reading time is allowed for this paper at the start of the exam.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

You may not remove any stationery from the Examination Room.

Question 1

(a) You are given the task of manufacturing a custom orthopaedic implant, specifically a hip joint replacement. This implant requires biocompatible material, tailored to fit the patient's unique anatomy. The design includes complex, organic shapes, and a porous surface structure to promote bone ingrowth. The material selected for this implant is a titanium alloy, known for its strength, biocompatibility, and compatibility with Additive Manufacturing (AM) processes.

(i) Choose the most suitable additive manufacturing process for this orthopaedic implant. Provide a description of the process and justification for your choice, focusing on factors such as the material's properties, the complexity of the design, the required precision, and the biological considerations of the implant.

[20%]

(ii) Outline any necessary post-processing steps that would be required for the implant after manufacturing. Explain how these steps are crucial to ensure the implant's functionality, safety, and compliance with medical standards.

[20%]

(iii) Describe how your chosen AM process might influence the cost and production time of the implant. Discuss the suitability of the process for customised, single-unit production versus mass production.

[20%]

(b) Briefly discuss two alternative AM processes that could potentially be used to manufacture this implant. Compare the advantages and disadvantages of these alternatives to your chosen process.

[20%]

(c) Suggest three areas where AM technologies will likely develop further and describe how these may impact the manufacture of medical implants.

[20%]

Question 2

(a) Resin is an important component in many composite materials. Describe any two such composite materials used to fabricate large structures. Include in your description of each composite an example application, the main manufacturing steps of the composite, the role of the resin and any properties you think are important when selecting the resin.

[30%]

(b) An epoxy resin manufacturer supplies material to the composite materials sector, with one of their resins being used in a composite for the fabrication of F1 cars. In a recent innovation, they will include carbon nanotubes as an additional ingredient in this resin.

(i) Describe the potential benefits you would anticipate if incorporating carbon nanotubes into a resin considering this end application.

[10%]

(ii) What challenges would the epoxy resin manufacturer face when integrating this new ingredient into their process? In your answer consider challenges that relate to the new ingredient and to the need to update the chemical process.

[20%]

(c) (i) Explain what is meant by the terms;

- *High Performance Materials*, and
- *Biomimetics*.

[10%]

(ii) Explain how glass can be made into a high performance material through a chemical treatment.

[15%]

(iii) Explain how you would approach making a high performance glass using biomimetics.

[15%]

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Question 3

A food manufacturing company needs to update its product labelling capability to meet food standard requirements. The product is a plastic bottle filled with non-transparent liquid. The product labels are adhesive backed glossy paper held on a semi translucent plastic backing film. The existing labelling and reject station can be seen in plan view in Fig 1. The labeller operates by unrolling / feeding backing material with sticky labels attached around a label separator. This causes the labels to peel from the backing material. A section of the sticky label is positioned in front of the label applicator belt, with the sticky side of the label exposed to an oncoming product. When the product contacts the label, Sensor C is triggered, and the remainder of the label is fed forward. The feed rate of the label and the label applicator belt are matched to ensure smooth operation as the product is rolled into contact with the label. Used backing material is rolled up onto a backing reel for disposal when label reels are changed. Sensors D and E check that a label has been correctly applied onto the product. Correctly labelled products continue down the main conveyor while mislabelled products are deflected by a pneumatic reject arm onto a scrap conveyor. Table 1 provides details about the different sensors used within the labeller and reject station to check for correct or incorrect labelling.

The labeller and reject station are currently controlled by a modular Programmable Logic Controller (PLC), with digital I/O for sensors and actuators and servo driven motors to control the motion of the label reels and conveyors. It also has mounting locations for an optional ink jet printer to be installed. The optional printer requires Ethernet for data communications and an I/O signal from the PLC to trigger print operations.

Sensor Identifier	Type of Sensor	Possible Issues
Sensor A	Optical Diffused Sensor	Missed Labels
Sensor B	Optical Diffused Sensor	Missed Labels
Sensor C	Mechanical Switch (Lever Arm)	Non Operational / Lever Arm Deforms
Sensor D	Optical Through Beam	Missed Correctly Labelled Product
Sensor E	Optical Through Beam	Missed Correctly Labelled Product

Table 1

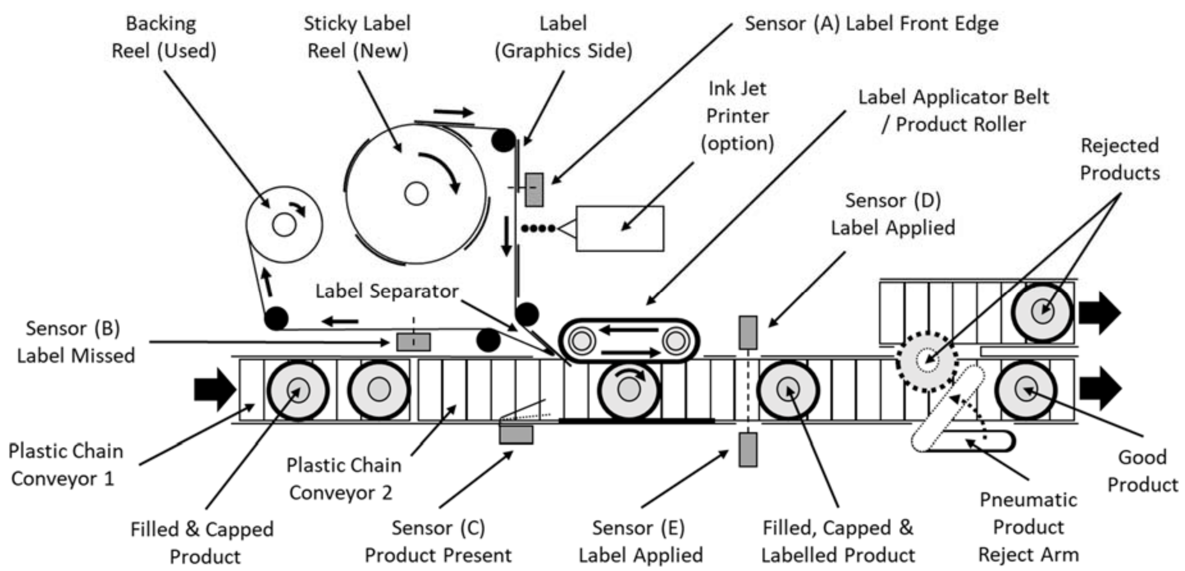

Fig 1

(a) The food standards agency requires product traceability information to be printed onto the product labels. The label information must be verified (human readable) once applied to the product. This information will include the products use by date and the products manufacturing batch number.

(i) Draw a multi-level system architecture diagram for the updated solution, showing *Data Systems*, *Hardware Components* and *Networks* that can be used in delivering the new capability. Explain your reasoning and reference typical industrial systems architecture standards.

[20%]

(ii) Identify additional hardware to be installed on the line to achieve the new traceability requirements and list their specific features that make them suitable for the task. Draw a sketch showing the location of this additional hardware.

[25%]

(iii) The maintenance team have had problems with erratic sensor operations within the labeller and reject station. Describe why the different sensors and/or sensor implementation may be causing operational issues. Suggest appropriate sensors, sensor technologies and implementation methods to improve the reliability of the line.

[15%]
(cont.

(b) It is proposed to upgrade the capabilities of the existing modular PLC with additional hardware modules and software functions. Describe tests that should be carried out to determine the performance limits of the updated solution. Include any assumptions made about the operation of the system.

[30%]

(c) The production manager has recently seen examples of low-cost automation solutions using Raspberry Pi controllers and camera technologies. Briefly discuss their limitations that may make them unsuitable in this application.

[10%]

Question 4

(a) Compare and contrast the logistics systems of *service companies* and *manufacturing companies*.

[20%]

(b) A group of researchers at Cambridge are testing an electric bus pilot in West Cambridge. The route of this bus starts at a bus depot, calling at four stops, and returning to the depot. Due to limited battery capacity, the researchers need to identify the shortest route for the bus so that the number of trips that can be made with a single battery charge can be maximised. The distances between the various stops in the route are shown in the matrix in Table 2, where 'D' indicates the depot.

		To				
		D	**1**	**2**	**3**	**4**
From	**D**	-	200	300	100	110
	1	150	-	140	100	110
	2	300	220	-	200	140
	3	190	160	190	-	130
	4	160	140	170	160	-

Table 2

Use the *Branch and Bound algorithm* to determine the shortest route that the bus must take to pass through all the stops. The bus route must start and end at the depot 'D'. Explain your approach.

[35%]

(c) Given the success of the pilot, the researchers have been asked by the city council to extend the bus network to cover six stops in the Greater Cambridge area with provisions for wheelchair access. The additional space required for wheelchairs poses an additional constraint on the buses as they can each carry only a maximum of 14 passengers. Given the historical data, it is estimated that the maximum number of passengers boarding at the stops are 4, 6, 3, 5, 3, and 6 at stops 1, 2, 3, 4, 5, and 6 respectively. The distance matrix between the various stops is shown in Table 3.

(TURN OVER

		To						
		D	**1**	**2**	**3**	**4**	**5**	**6**
From	**D**	-	2000	1800	1400	1600	1200	1900
	1	2000	-	2200	1800	3000	2600	2800
	2	1800	2200	-	3200	2000	2200	2100
	3	1400	1800	3200	-	2000	2200	2100
	4	1600	3000	2000	2000	-	3000	2200
	5	1200	2600	2200	2200	3000	-	3600
	6	1900	2800	2100	2100	2200	3600	-

Table 3

(i) Evaluate the minimum number of buses required and the corresponding bus routes that minimise the overall distance travelled. Ensure the estimated maximum number of passengers can be picked up at each stop. Assume that all passengers at each stop board the bus together at the same time. Explain your approach.

[30%]

(ii) Describe how you would evaluate the solution if the passengers do not necessarily board the bus together.

[15%]

Question 5

Cymba-Tech produces sound systems with an annual profit approaching £20 million. The company has been developing a new sound amplifier. The demand for the amplifier has been hard to assess. If there is high demand, the company estimates cashflows with a Net Present Value (NPV) of £800,000. Under medium demand an NPV of £150,000 is estimated. If demand is low, the launch of the amplifier can result in a negative NPV of £600,000, due to high production costs. Abandoning the launch would result in a zero NPV. The marketing team advised that the probabilities of high, medium or low demand are 0.2, 0.4 and 0.4 respectively. There is an option for undertaking further market research from an external company, Resi, to determine demand at a cost of £50,000.

(a) Assuming further market research is not conducted, determine which option should be chosen by Cymba-Tech.

[20%]

(b) Assuming the information provided by Resi about demand for the new product is perfect, what is the maximum amount Cymba-Tech should pay for market research?

[30%]

(c) If undertaken, the outcome of the market research would be a positive or negative recommendation. Based on the previous success record of the marketing department, Table 4 provides probabilities of a positive or negative recommendation, given actual demand. For example, if demand is high the probability of a positive recommendation is 0.8. Should Cymba-Tech use the services of Resi?

[50%]

	Actual Demand		
	High	Medium	Low
Positive	0.8	0.5	0.1
Negative	0.2	0.5	0.9

Table 4

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Question 6

Due to the rise of portable electronics, there has been an increasing demand for lithium for use in rechargeable batteries. However, these batteries must be disposed of at their end-of-life. Globally, the recycling rate of lithium-ion (Li-ion) batteries is relatively low, with around 5% of batteries estimated to be recycled. Li-ion batteries which are not recycled usually end up in landfills. Furthermore, there are resource limit constraints on the amount of lithium available to mine for batteries and the rate of lithium production.

(a) How would you assess the environmental impact of Li-ion battery production and usage? Discuss the factors that should be included in this assessment and explain how the system boundary should be defined.

[25%]

(b) What difficulties and challenges must be considered when attempting to recover and recycle the lithium from Li-ion batteries? What are the benefits?

[25%]

(c) Other than conventional recycling, what are the alternative approaches for Li-ion batteries that could reduce their environmental impact? Discuss the relative environmental impact of these alternatives in relation to current end-of-life practices for Li-ion batteries.

[25%]

(d) What technologies are being developed for using alternative materials and designs for Li-ion batteries? Your answer should include discussion of any alternative chemistry that is being developed, the timescales involved and the barriers to implementation. What might be the environmental implications of alternative technologies compared to those of existing Li-ion systems?

[25%]

END OF PAPER