Version SWP/8

MET3
MANUFACTURING ENGINEERING TRIPOS PART IIB

Tuesday 27 April 2021 9.00 to 12.10

Paper 1

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

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 **not** your name on the cover sheet and at the top of each answer sheet.*

STATIONERY REQUIREMENTS
Write on single-sided paper.
You may type your answers.

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed.
You are allowed access to the electronic version of the Engineering Data Books.
Probability Table for Question 6.

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

The time taken for scanning/uploading answers is 30 minutes.

Your script is to be uploaded as a single consolidated pdf containing all answers.

1 (a) High-power lasers have experienced a steady increase in use over the past 50 years. List three manufacturing sectors that apply high-power lasers. For each sector, give a specific example of a laser application and state the benefit of adopting lasers in that application. [15%]

(b) The industrial fibre laser has come to dominate the laser materials processing market over the past 20 years.

(i) Briefly describe the operating principles of an industrial fibre laser. [15%]

(ii) What are its main advantages over other forms of laser? [10%]

(c) A company wishes to manufacture a titanium component as shown in Fig. 1. It is a disk with an outer diameter of 10 mm, thickness 5 mm, with six through holes each of diameter 1.5 mm. The tolerances of each dimension are +/- 10%. The batch size of the component is 500.

(i) Describe a laser-based approach for manufacturing this part. Your answer should include a review of the part and its suitability for laser processing, brief details of the laser processes to be employed and reasons for their choice. [40%]

(ii) Suggest an alternative approach to laser-based manufacturing. Compare the two in terms of productivity, cost, and precision. [20%]

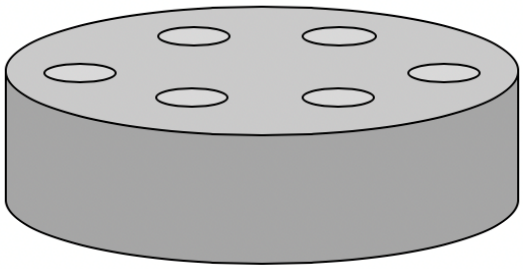

Fig. 1

2 A manufacturing company is developing a new epoxy adhesive that will be used for joining parts in the automotive sector. Market research suggests the demand for the new adhesive will be intermittent and the company will need to customise its formulation for each customer.

(a) Should the company invest in constructing a continuous process or a batch process to create the product above? Explain your reasoning. [15%]

(b) It has been suggested that a Hazard and Operability (HazOp) study should be completed for the new process. Explain why a HazOp study would be recommended and how such a study is normally carried out. [20%]

(c) Describe how you would test if the company's new epoxy adhesive is suitable for the target market. [25%]

(d) After 6 months of successful production of the new epoxy adhesive, customer complaints identify that there has been a drop in performance of the adhesive in batches manufactured most recently. The adhesive, which is a crosslinking polymer system, is taking a lot longer to set and it fails at a lower temperature than in the specification. Describe how you would find out what has gone wrong in the recent batches. [25%]

(e) Describe any two trends in the chemical process industry that may affect the production of epoxy adhesives. [15%]

3 A computer company is developing a new all-in-one computer. A single model will be produced initially, with two further models being produced as enhanced computer modules become available. A new production line will cater for all three models, supporting mixed production requirements. The assembly process will require a computer module comprising of a Liquid Crystal Display (LCD), a single board computer and power supply to be positioned screen down within the plastic front facia of the computer. The back case of the computer can then be fitted to the front facia. This requires the back case to be held at an angle, allowing alignment clips along the lower edge of the front facia to mate correctly before the case is rotated flat, closing the gap between the facia and the case. The assembly is then fastened together with six screws. Fig. 2 provides an exploded assembly drawing of the initial model.

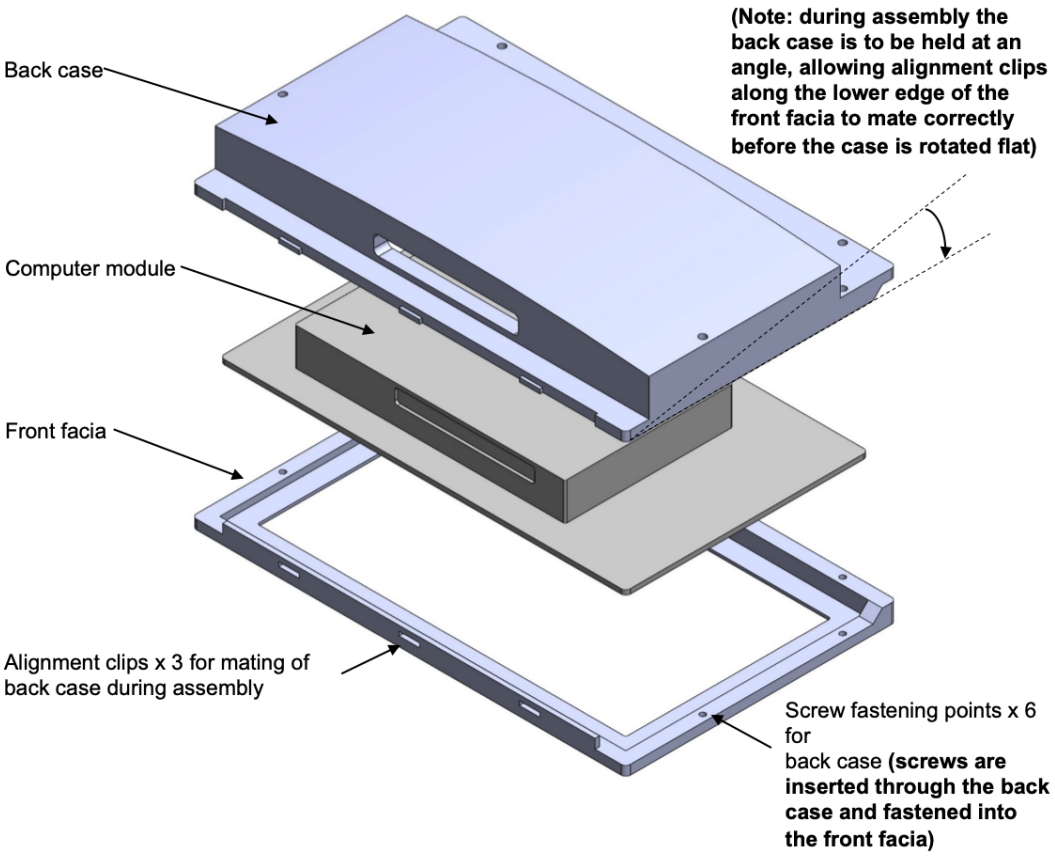

Fig. 2: Exploded assembly drawing of the all-in-one computer.

A limited list of hardware is available to automate this task as shown in Table 1:

(cont.

No. of Parts	Available Hardware	Operational Process Times (Seconds)
1	4-Axis SCARA robot	Loading any part from a conveyor shuttle to an assembly fixture (2 s) Unloading any assembly from a fixture to a conveyor shuttle (2 s) Collection and fastening of 1 screw (4 s)
1	5-Axis anthropomorphic robot	
1	Bowl screw feeder	Negligible
1	Programmable rotary turntable (1 degree resolution) maximum 4 stations	360 degree rotation (6 s)
1	Electric screw driver, with a vacuum system for picking up individual screws	Negligible

Table 1: Available hardware and associated operational process times.

(a) You have to design an automated system that will perform the final assembly of the initial model.

(i) Draw the floor layout of the new automated production system making use of the available hardware in Table 1. The design should include any additional conveyor systems and kitting trays for transporting parts in and out of the system. Describe the overall operation of the system, listing the specific features of the hardware components that make them suitable for the task. [40%]

(ii) Noting the operational process times provided in Table 1, describe ways in which you could upgrade your production system to achieve increased throughput. List additional hardware you would need to purchase and describe how it would be integrated with your original system. [30%]

(b) Describe technologies and control strategies that are required to support the mixed production of the initial model and the two subsequent computer models. Illustrate how this could be applied in the case of the final assembly system you have designed in part a) of this question. [30%]

4 A small machining and fabrication company would like to explore improvements that can be made through the introduction of automation. The company is categorised as a Small to Medium-sized Enterprise (SME), but over the last two years has had a 20% growth in staff. 40% of the company's revenue comes from manual job shop fabrication of one-off products, but the remaining and growing area of revenue is from the company's mechanical ventilator product used in the medical sector. This product has been developed in-house.

(a) Considering the company's operations and product portfolio, describe both the benefits and challenges that automation solutions could bring to this company. [40%]

(b) The company is considering introducing a collaborative robot (cobot) for machine tool loading and unloading. This includes the loading of castings and the unloading of machined parts. Currently these operations are performed manually. What are the benefits and limitations of using cobots? Hence what issues should the company consider when investigating cobots for this type of operation? [30%]

(c) The company has received information promoting the use of automation solutions based on computing, controller and vision systems that are low-cost and off-the-shelf. Noting the potential limitations of such solutions, what types of applications within the company's operations might these low-cost solutions be appropriate for? Justify your selections. [30%]

5 International concern about the environmental impact of waste plastics has brought polymer-based food packaging under scrutiny, with particular emphasis on what happens to packaging at end-of-life.

(a) Mechanical recycling is regarded as the most promising long-term solution for end-of-life thermoplastic polymers. The output of a mechanical recycling process is typically polymer granules that are then used as the input material for manufacturing new articles by standard polymer manufacturing processes. An economically viable recycling process needs to be able to deliver clean, single-material polymer as its output. This is particularly challenging for polymer food packaging reclaimed from the domestic waste stream, and current mechanical recycling rates are low.

(i) Explain what is meant by describing a polymer as *clean* and *single-material*. [5%]

(ii) The requirement for the mechanically recycled polymer to be clean and single-material arises from a range of considerations including economic and technological factors. Explain the significance of the main factors, commenting on their relative importance in terms of achieving a viable recycling operation. For each factor, discuss whether the main barriers to improving yield of high-quality material are economic or technological, or whether other issues are significant, and suggest how improvements may be made. [40%]

(iii) In response to pressure to reduce plastic food packaging, the following changes have been proposed. In each case, discuss the positive and negative environmental implications of the changes, looking at the full lifecycle of the product as well as the packaging.

- Replace PET clamshell packages for bakery products with cardboard boxes;
- Replace PET bottles for carbonated drinks with glass bottles;
- Remove all packaging (shrink-wrap film) from cucumbers to be sold in supermarkets. [30%]

(b) A container made from poly-lactic acid (PLA), derived from maize, is being promoted as a 'green' packaging solution for takeaway meals. PLA is biodegradable. Discuss the extent to which this packaging solution can be described as environmentally beneficial. [25%]

6 (a) (i) State the different ways in which constraints can be set in optimisation problems. [10%]

(ii) Briefly describe the different approaches for optimising more than one objective. [10%]

(iii) Discuss how the performance of heuristic optimisation approaches can be evaluated. [10%]

(iv) What is the role of *archiving* in multi-objective optimisation approaches? Briefly discuss different approaches to archiving. [15%]

(b) Kelly's Wheels is a bicycle supplier and has obtained data related to predicting their *Sales* from a survey of customers. Kelly's Wheels thinks that the most significant factors affecting *Sales* are the following:

- *Price level*, which is the perceived level of price charged by product suppliers;
- *Overall service*, the overall level of service necessary for maintaining a satisfactory relationship between supplier and customer;
- *Product quality*, the perceived level of quality of a particular product.

Respondents to the survey provided a numeric rating between 0 and 10 to each of the factors above, with 0 being 'poor' and 10 being 'excellent'. Based on the data, Kelly's Wheels developed a multiple regression model for predicted *Sales level*, for which the summary output is shown in Fig. 3.

Regression Statistics	
Multiple R	0.773
R Square	0.598
Adjusted R Sq.	0.585
Standard Error	5.79
Observations	100

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	4781.700	1593.900	47.541	6.40E-19
Residual	96	3218.556	33.527		
Total	99	8000.256			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	19.475	4.048	4.811	0.000	11.439	27.511
Price level	-3.083	0.697	-4.426	0.000	-4.466	-1.700
Overall service	10.944	0.980	11.163	0.000	8.998	12.890
Product quality	0.288	0.452	0.638	0.525	-0.609	1.185

Fig. 3: Summary output.

(cont.

(i) Based on the summary output, estimate *Sales level* of a particular customer who has rated *Price level*, *Overall service*, and *Product quality* as 3, 4, and 5 units, respectively. [5%]

(ii) Discuss whether this model is acceptable as a means of predicting *Sales level*. Explain the rationale for your answer. [10%]

(iii) What is the impact of an increase of two units in *Product quality* on the *Sales level*? [10%]

(iv) Can the relative importance of explanatory variables be established from the coefficients in this model? Is your answer applicable to any regression model? [15%]

(c) The financial return of a new product development project is believed to be normally distributed with a mean of 1% and standard deviation of 2%. Find the probability that the return will be at least 3%. [15%]

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Probability table for Question 6

Common values for Standard Normal	
Confidence Level	**Z between**
19.7%	[-0.25, 0.25]
38.3%	[-0.50, 0.50]
54.7%	[-0.75, 0.75]
68.3%	[-1.00, 1.00]
78.9%	[-1.25, 1.25]
86.6%	[-1.50, 1.50]
92.0%	[-1.75, 1.75]
95.4%	[-2.00, 2.00]
97.6%	[-2.25, 2.25]
98.8%	[-2.50, 2.50]
99.4%	[-2.75, 2.75]
99.7%	[-3.00, 3.00]