Version WON/03

MET 3

MANUFACTURING ENGINEERING TRIPOS PART IIB

Tuesday 29 April 2025 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 not 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 Book

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) Describe the operating principles of a *laser* and the characteristics of the light that it produces.

[20%]

(b) The fiber laser has dramatically advanced the state of laser-based manufacturing due to its simplicity, cost and reliability.

(i) Describe the basic design of a fiber laser, using sketches where appropriate to support your answer.

[20%]

(ii) Identify and describe three manufacturing processes that have been replaced by fiber lasers. For each process, explain the original method replaced, and discuss the new capabilities offered by fiber lasers.

[20%]

(c) A manufacturing firm is considering transitioning from traditional CO_2 lasers to fiber lasers for their sheet metal cutting operations. Discuss the potential benefits and challenges of this transition, focusing on aspects such as energy efficiency, operational cost, material compatibility, and maintenance. Provide a reasoned conclusion on whether the transition is justified.

[20%]

(d) Discuss three ways in which fiber lasers can reduce the environmental impact of manufacturing processes, providing specific examples.

[20%]

Question 2

Silicon chip manufacturing has been central to technological advancement by adhering to *Moore's Law*, which predicts a doubling of transistor density approximately every two years. However, maintaining this trend has become increasingly challenging.

(a) Explain the fundamental steps involved in silicon chip manufacturing, highlighting the key processes used to achieve miniaturisation and precision.

[25%]

(b) Discuss the limitations of silicon chip manufacturing that make it challenging to maintain Moore's Law. Your answer should address physical, economic, and technological barriers.

[25%]

(c) Identify and evaluate *two* emerging manufacturing solutions that could address the challenges of maintaining Moore's Law.

[25%]

(d) Describe the negative environmental impacts of silicon chip manufacturing. Suggest strategies to mitigate these impacts while ensuring sustainable growth in the semiconductor industry.

[25%]

(TURN OVER

Question 3

(a) In the context of industrial logistics, explain the term *double marginalisation* and provide a suitable example.

[15%]

(b) State three differences in the logistics operations of a high-end consumer electronics manufacturer versus that of a low-priced clothing manufacturer.

[20%]

(c) Fig 2 shows a logistics network with the nodes representing various facilities and the edges representing the paths that exist between the facilities. The weights on the edges show the time taken to travel between the facilities. Identify the quickest path starting from location A, noted with *, to all other locations in the graph shown in Fig 2.

[25%]

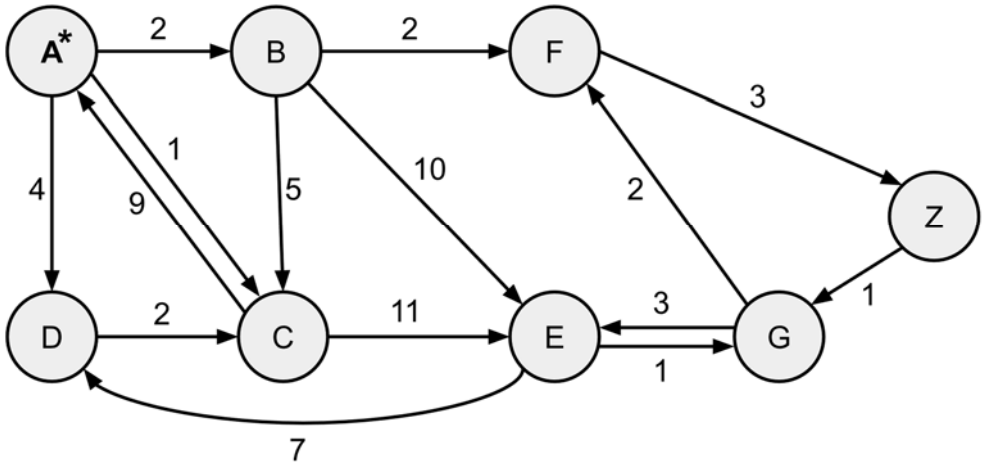


Fig 2

(d) A company plans to open a series of low-capacity or high-capacity warehouses in Glasgow, Leeds, and Plymouth that will collectively serve the London, Manchester, Glasgow and Birmingham markets. The transportation cost per unit between the different warehouse locations and the demand points are provided in Table 2. The warehouse capacities and the fixed cost of

operations for the low and high-capacity warehouses are presented in Table 3. The market demand at London, Manchester, Glasgow and Birmingham are 20, 30, 20 and 18 respectively. The company wants to optimise the number of low-capacity and high-capacity warehouses to open at the different locations, and the number of products that will be delivered across the corresponding markets and warehouses.

(i) Formulate an appropriate *Linear Programming Problem* to minimise the cost of warehousing and transportation. Clearly explain your formulation.

[20%]

(ii) Assuming that the selling price is the same across all the markets, formulate an appropriate *Linear Programming Problem* to maximise the company profit. Clearly explain your formulation.

[20%]

Transportation cost per unit				
Markets / Warehouse locations	London	Manchester	Glasgow	Birmingham
Glasgow	81	92	101	130
Leeds	117	77	108	98
Plymouth	102	105	95	119

Table 2

Warehouse locations	Low-capacity warehouse		High-capacity warehouse	
	Capacity	Cost	Capacity	Cost
Glasgow	30	6000	50	9000
Leeds	30	4500	50	6750
Plymouth	30	6500	50	9750

Table 3

Question 4

(a) Answer the following questions.

(i) Describe the main elements of an optimisation problem.

[10%]

(ii) Describe the three approaches for optimising more than one objective function. State the advantages and disadvantages of each approach.

[10%]

(iii) Discuss ways in which the performance of heuristic optimisation approaches can be evaluated.

[10%]

(b) At the beginning of every month, a city council must make decisions on allocating budget to different maintenance, repair, and rehabilitation (MR&R) projects to maintain public assets in satisfactory condition. To make projects comparable, the council converts the outputs of these projects into a commensurable utility value. The council has a given budget each year. Ten MR&R projects were identified. Each project has a cost and utility value assigned to it.

(i) Describe two ways in which the above problem could be formulated as an optimisation problem to help the council increase the utility value of as many public assets as possible, given its budget.

[20%]

(ii) For each of the formulations proposed in (b)(i) which stochastic optimisation algorithm(s) would you choose and why?

[15%]

(iii) The council realises that there are shared resources among two specific projects, which means they cannot be chosen at the same time. Moreover, it has been found that at least one of three other specific projects must be selected. Formulate a single-objective optimisation problem to impose these additional conditions and maximise the utility value.

[15%]

(iv) The council's engineers discover that the commencement of one of the projects depends on the completion of another specific project. Incorporate this additional condition into the problem formulated in part (b)(iii) and reformulate the optimisation problem to maximise the utility value.

[10%]

(v) An environmental protection agency offers an award for a council endorsing sustainable communities. This award is given to a council that can maintain water infrastructure in a desirable condition. To be eligible for this award, the council needs to achieve a minimum utility value for three specific projects. Incorporate the information on this award into the problem formulated in (b)(iii).

[10%]

Question 5

A CNC lathe carries out two turning operations, OP1 and OP2 on a component. The company wants to implement an automated part loading/unloading solution for a single spindle CNC lathe using a robot.

The operation is currently performed manually by the operator in the following way. Materials are stored in totes that are picked by the operator, with each tote holding up to forty jumbled castings for a single component type. Finished components are stored on kitting trays within one of twenty location wells on each tray. Complete kitting trays are moved manually to the assembly area at the end of shifts. Totes and kitting trays are specific to component types. A full listing of part loading/unloading, and machine cycle executions is shown in Table 1.

Task	**Description of current operator tasks**
1	Determine component type and batch size to be made from the daily operations schedule.
2	Pick raw material totes and finished component kitting trays. Verify contents.
3	Orientate and load a single casting into CNC lathe chuck for OP1 and run OP1.
4	Support operations in assembly area (Secondary task for operator, during CNC OP1).
5	OP1 finished, turn semi-finished component around in the chuck for OP2 and execute OP2.
6	Support operations in assembly area (Secondary task for operator, during CNC OP2).
7	OP2 finished, unload finished component from chuck and store in kitting tray well.
8	Repeat cycle until batch is complete, restocking totes and kitting trays as required.

Table 1

(Cont.

(a) Stating any assumptions you make,

(i) Identify all hardware components that would be required for automating handling of parts, totes, and kitting trays. Also identify any control and sensory components required to enable fully automated operations. Include any additional features or modifications that would be required on the CNC lathe.

[30%]

(ii) For each of the hardware components, specify capabilities that make them suitable for the part loading / unloading solution.

[20%]

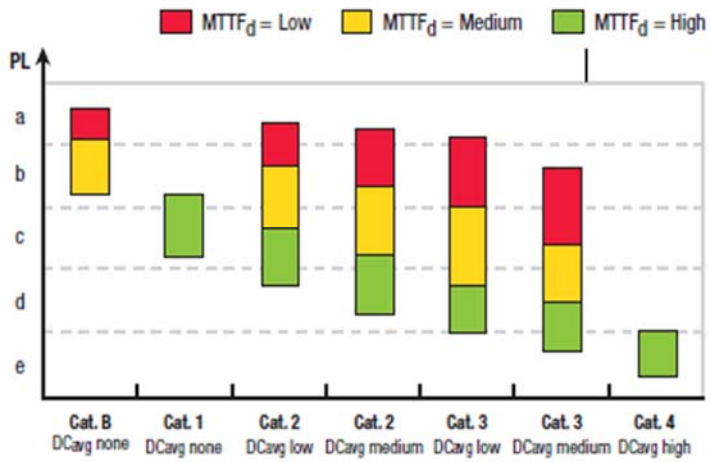
(iii) Draw a floor layout showing all the hardware components required for the robot part loading / unloading solution to run automatically. Justify the layout you are proposing.

[20%]

(b) The industrial robot chosen for part loading/unloading the CNC lathe has a suitable work envelope and can achieve the required pick and place cycle times. The operations team has performed a risk assessment and determined that a safety system meeting ISO13849 Performance Level - d is required. Determine the appropriate category of safety system architecture that should be implemented using details provided in Fig 1. Discuss how the quality of components used, and features of the safety system architecture will affect the performance of the system.

[30%]

(Cont.



MTTFd
(Mean time to Dangerous Failure)

DCavg
(Diagnostic Coverage)

PL
(Required Performance Level)

Cat. - Category
(Safety System Architecture)

Fig 1

Question 6

Modern products are heavily dependent on a class of materials known as *critical metals* in order to function.

(a) What is a critical metal? Include three examples of critical metals in your answer.

[15%]

(b) What challenges must be addressed when attempting to recover and recycle critical metals from products? What are the benefits?

[35%]

(c) How would you evaluate the *relative environmental impact* of using an alternative to a critical metal in a product? Discuss the factors that should be included in this assessment and explain how the system boundary should be defined.

[25%]

(d) A company is attempting to reduce its use of critical metals, with one of the aims being to reduce the *lifetime environmental footprint* of its products. For the factors identified in Part (c), discuss what should be considered when deciding whether to recover and reuse critical metals from products at end-of-life, or whether to use an alternative to the critical metal.

[25%]

END OF PAPER

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