Version POK/3

EGT2
ENGINEERING TRIPOS PART IIA
EGT3
ENGINEERING TRIPOS PART IIB

Wednesday 3 May 2023 14:00 to 15:40

Module 4C4

DESIGN METHODS

*Answer not more than **three** 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.*

STATIONERY REQUIREMENTS
Single-sided script paper

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.

1 Filled bottles of shower gel are weighed to check that the correct volume of product is present. The filled bottles are to weigh 550 g ± 5 g. The filling equipment is able to dispense the required volume of gel to within 0.5% whilst the weighing equipment is accurate to within 1%.

Table 1 shows equations for the approximate combination of probabilities. Assume that all probability distributions are normal and independent, the range from minimum to maximum is equivalent to two standard deviations, and that in this case the product of two random variables is approximately normal.

(a) For the initial design the weight of an empty bottle is 50 g ± 0.5 g. Calculate how many filled bottles will be rejected after weighing. [40%]

(b) Suggest three ways to reduce the rejection rate. Discuss the practicality of each solution, using your calculation above to estimate the relative effectiveness of each solution. [30%]

(c) The filling valve sub-system controls the amount of liquid deposited into each bottle by adjusting the time the valve is open. Undertake a Failure Mode and Effects Analysis (FMEA) of the filling valve subsystem, describing four possible failure modes. Indicate which failure modes can be identified by weighing the filled bottle. Provide two additional risk minimising actions for each failure mode. [30%]

y	μ_y	σ_y^2
$x + a$	$\mu_y + a$	σ_x^2
ax	$a\mu_x$	$a^2\sigma_x^2$
$a_1x_1 + a_2x_2$	$a_1\mu_1 + a_2\mu_2$	$a_1^2\sigma_1^2 + a_2^2\sigma_2^2$
x_1x_2	$\mu_1\mu_2$	$\mu_2^2\sigma_1^2 + \mu_1^2\sigma_2^2$
x_1/x_2	μ_1/μ_2	$(\mu_2^2\sigma_1^2 + \mu_1^2\sigma_2^2)/\mu_2^4$

Table 1

2 A life-logger is a wearable system worn around the user's neck. The purpose of a life-logger is to serve as a memory aid for users with amnesia. A life-logger uses sensor data to automatically capture photographs of the user's everyday activity. A software application allows the user to view these photographs at a later stage.

(a) Provide a solution-neutral problem statement for the life-logging problem, as described above, at an appropriate level of abstraction. [10%]

(b) Identify and draw the overall function structures, including their functional elements and the flow of energy and signals. Briefly explain the role of the function structures. [20%]

(c) Create a morphological chart that maps each of five functions in (b) to three function carrier candidates. [25%]

(d) Identify five key evaluation criteria for a life-logger. [25%]

(e) Propose a preferred conceptual design and briefly explain your motivation for this choice. [20%]

3 An organisation plans to introduce a new paperless expense claim process, which will allow employees to make a claim for incurred expenses. This process includes capturing information about receipts and job numbers, approving the documentation, and reimbursing the expenses. A job number identifies an account that will be charged for the expense. A review of the existing expense claim process reveals the activities and people involved in a typical claim:

- the employee making a claim, the Claimant, scans purchase receipts into the software
- the Accounts Team extracts purchase information from the credit card bill
- the Claimant matches purchase receipt scans to a line item from the credit card bill
- the Claimant adds supporting information and assigns job numbers to each line item
- the Claimant submits the expense claim to the Supervisor
- the Supervisor checks the expense claim for valid expenses
- the Supervisor submits approved expense claims to the Accounts Team
- the Supervisor returns unapproved expense claims back to the Claimant, noting issues
- the Accounts Team checks that line items have the correct information and job number
- the Accounts Team submits acceptable expense claims to the Payroll Team
- the Accounts Team returns unacceptable expense claims back to the Claimant, noting issues
- the Claimant makes corrections and resubmits the expense claim to the Supervisor
- the Payroll Team reimburses the claimant for the amount shown from the job number.

(a) Provide a solution-neutral problem statement for the expense claim process as described above, at an appropriate level of abstraction. [10%]

(b) Draw a swim-lane flow diagram to represent activities in a typical expense claim. [30%]

(c) Draw a Multiple-Domain Matrix (MDM) to show the activities and people in a typical expense claim, with the activity-based Dependency Structure Matrix (DSM) in the partitioned form. [30%]

(d) It is discovered that the new paperless expense claim process increases the average process time for each expense claim from four weeks to eight weeks. Discuss possible causes for this time increase and suggest ways to address it. [30%]

4 A power plant's safety system relies on a set of n individual components that have individual and independent probabilities of failure.

(a) Assume each component has a constant failure rate and the probability of failure of each component is the same. The mean time between failures for a component is 50,000 hours.

(i) Find expressions for the probability of a failure in the safety system within a three-year period assuming the system has either (1) series redundancy; or (2) parallel redundancy. [10%]

(ii) Assuming $n = 3$, calculate the gain in value provided by the redundancy solution resulting in the lowest probability of failure. [10%]

(b) An alternative solution is proposed in the form of a k-out-of-n system.

(i) Find expressions for the probabilities of failure when $k = n$ and $k = 1$. [10%]

(ii) It is decided to set $k = 2$ and $n = 3$. Let $\mathbf{x}$ denote the system state vector. Derive an expression for the reliability structure function of this system and provide a block diagram illustrating this function. [20%]

(iii) Assuming the probability of failure of an individual component is the same as in (a)(i), compare the gain in value between the 2-out-of-3 system in (b)(ii) with the system resulting in the highest probability of failure in (a)(ii). Briefly comment on this result. [30%]

(c) Changing the redundancy in the power plant's safety system is estimated to require a six-month development programme. The quality of carrying out this work is 0.9 and the rework discovery time is two months. By how much will this programme overrun? [20%]

END OF PAPER

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