Version JMC/3

EGT2
ENGINEERING TRIPOS PART IIA
EGT3
ENGINEERING TRIPOS PART IIB

Wednesday 2 May 2018   14 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.

1 A new 12-sided £1 coin was introduced to the UK as legal tender in March 2017. The old round £1 coin lost its legal tender status in October 2017. Fig. 1 shows both coins. During the transition period of roughly six months, coin counting machines (which work by weighing coins) were sometimes forced to deal with both types of coin.

Table 1 shows the dimensions of the new and old coins. Table 2 shows equations for combining probabilities. Assume that all probability distributions are normal and that the range from minimum to maximum is equivalent to six standard deviations.

(a) Coins are machined to a tolerance of ±0.001 mm, for both the thickness and diameter. For each coin, calculate the standard deviation relating to the coin weight. Ignore the effect of any embossing on the coin surfaces and assume the coin is a smooth disc. The area of a 12-sided dodecagon equals $\frac{3}{4}D^2$, where D is the circumscribed diameter. [20%]

(b) The new coins are weighed to ensure quality control. The weigh-scale is accurate to within 0.1% and coin weight is required to be within ±0.01 g. For each coin, calculate the percentage of coins which will be rejected. Which coin has the lowest rejection rate? [20%]

(c) New £1 coins are collected by retailers in plastic bags and counted at the bank. Each bag of coins is weighed to determine the number of coins in the bag, and thus calculate the monetary value. The bank's weigh-scales are accurate to within 1%. Using the answer from (a), calculate how many new 12-sided coins can be in a bag before there is a 5% chance of the bag count being incorrect. Assume the weight of the bag is negligible. Would you expect this answer to differ for a bag of old round coins? Explain your reasoning. [30%]

(d) What other factors might affect the measured weight of a bags of coins? Can the weigh-scale method cope with bags containing both new and old coins? Suggest alternative methods for counting coins and comment on the expected performance, accuracy and costs of these methods. [30%]

Fig. 1

	Old round coin	New 12-sided coin
Diameter	22.5 mm	23.43 mm*
Thickness	3.15 mm	2.8 mm
Weight	9.5 g	8.75 g

Table 1: Properties of the new and old £1 coins. * the maximum diameter circumscribed for the 12-sided coin.

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 2: Equations for combining probabilities, where y is a function of independent variables x_n, a is a constant, μ is the mean and σ is the standard deviation.

2 Falls are a common and often serious cause of injury. Your company has been asked to reduce injuries due to falls in a hospital environment.

(a) One solution strategy for the above problem is to change the hospital environment to prevent falls. Explain how to elicit requirements for such a solution strategy. [20%]

(b) An alternative, or complementary, solution strategy for the above problem is to devise a fall-detection system that can automatically detect a fall and immediately notify staff. List key requirements for such a system. [30%]

(c) Identify a solution-neutral problem statement for the overall function of the system in (b) and design the main function structures. [30%]

(d) Discuss how the system in (b) can be verified and validated. [20%]

3 A system consists of n identical components configured for parallel redundancy.

(a) Give a definition of the hazard function and explain why it is a conditional failure rate. [20%]

(b) Assume each component has hazard function $h(t) = \lambda$, where λ is the failure rate. Derive an expression for the probability of a system failure in time t. [30%]

(c) Show that the hazard function $h(t)$ can be expressed as $h(t) = -\frac{d}{dt} \ln R(t)$, where $R(t)$ is the reliability function. [20%]

(d) Now assume the n components of the system are changed into a different set of n identical components where each component has an identical hazard function that varies linearly with time with an intercept of zero. Derive an expression for the probability of a system failure in time t. [30%]

4 A manufacturer of forged steel parts undertakes a review of energy efficiency and material across their site to identify any opportunities to improve their profitability and environmental performance. An assessment of the major energy using equipment (furnaces, forge presses, machine shop equipment) shows that only small efficiency gains (up to 5%) can be achieved, as the equipment is up-to-date and in good condition. Similarly, an assessment of waste across the site shows 99% of all materials entering the site end up in a saleable product. In 2017, the site produced 5,000 tonnes of steel products and used 160 TJ (terajoules) of energy in the melting furnaces. First appearances suggest that little can be done to improve the resource efficiency of the site.

(a) Provide a definition of a *system* and suggest how the application of *systems thinking* to the manufacturer's site might reveal further opportunities for resource efficiency savings. [20%]

(b) On further investigation it is found that for every tonne of product produced, four tonnes of steel are melted in the furnaces. Draw a diagram of the rework model for the furnaces and use the model to explain why the manufacturer's site might be less efficient than at first thought. [30%]

(c) Rework not only results in additional energy use but also affects the throughput of the site. A new order for 1,000 products is placed with the company and a decision is made to dedicate the entire manufacturing capacity to this run. The production process is found to take 10 days: from casting, through forging and machining, to final quality testing.

(i) Calculate how many rework cycles, and thus how many days, it will take to complete 95% of the order.

(ii) Calculate how many rework cycles and how many days are required to complete 95% of the order, if the quality of work is tripled and the rework discovery time is halved. [30%]

(d) Draw sketches of *work done* versus *perceived work done* for the calculations in (c) showing how uncertainty in the work progress changes between the two cases. [20%]

END OF PAPER

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