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2.830J / 6.780J / ESD.63J Control of Manufacturing Processes (SMA 6303)
Spring 2008

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Massachusetts Institute of Technology
Department of Mechanical Engineering
Department of Electrical Engineering and Computer Science
2.830J/6.780J Control of Manufacturing Processes
Spring 2008

Quiz #1
Thursday – March 13, 2008

In all problems, please show your work and explain your reasoning. Statistical tables for the cumulative standard normal distribution, percentage points of the χ^2 distribution, percentage points of the t distribution, percentage points of the F distribution, and factors for constructing variables for control charts (all from Montgomery, 5th Ed.) are provided.

Problem 1 [35%]

Part (a)* [10%]

Control charts for \bar{x} , R , and s are to be maintained for the threshold voltage of short-channel MOSFETs using sample sizes of $n = 10$. It is known that the process is normally distributed with $\mu = 0.75$ V and $\sigma = 0.10$ V. Find the centerline and $\pm 3\sigma$ control limits for each of these charts.

* May & Spanos, Problem 6.6.

Problem 1, cont'd.

Part (b)[†] [10%]

Repeat part (a) assuming that μ and σ are unknown and that we have collected 50 observations of sample size 10. These samples gave a grand average of 0.734 V, and average s_i of 0.125 V, and an average R_i of 0.365 V.

[†] May & Spanos, Problem 6.7.

Problem 1, cont'd

Part (c) [15%]

The specification limits for MOSFET threshold voltage in this process is $x = 0.7 \pm 0.05$ V. What is the Cp and Cpk for this process? Assuming the process as specified in part (a) is in control, what is the fraction of MOSFETs that are nonconforming? If the process in part (a) was recentered such that μ_x is on target at 0.7 V, what would the fraction be of MOSFETs that are nonconforming?

Problem 2 [30%]

Part (a) [10%]

Based on a fairly large historical sample of gate oxide thicknesses consisting of 61 samples, an average oxide thickness of 96.5 \AA is observed, with a variance of 6 \AA^2 . What are your best estimates, and 95% confidence intervals, for the process mean and process variance?

Part (b) [10%]

A change is proposed to increase the gate oxide thickness. Using the modified process, 11 samples are taken, with observed sample mean of 100 \AA and sample variance of 20 \AA^2 . What are your best estimates, and 95% confidence intervals, for the new process mean and process variance?

Part (c) [10%]

To 95% confidence, has the modification resulted in a process with a different mean than in part (a)? To 95% confidence, has the modification resulted in a process with a different variance than in part (b)?

Problem 3 [35%]

You are in charge of a process manufacturing parts whose key output parameter, x , is known to be normally distributed. When the process is in control, the mean value of x is known to be μ and its standard deviation σ .

Unfortunately, the supplier of an important input material for this process is rather unreliable, and every so often they inadvertently supply a large batch of material whose properties cause the mean of x to shift to $\mu + k\sigma$, with the standard deviation of x remaining unchanged.

When this mean shift occurs, you want to be able to identify it as quickly as possible. Your metrology staff tells you that they can currently measure at most a fraction f of parts produced, although you are free to choose how this measurement budget is apportioned: *i.e.* you can dictate any n , where samples of n parts are taken at intervals of n/f parts.

Part (a) [3%]

Write down, in terms of μ , σ and n , expressions for $\pm 3\sigma$ control limits for an \bar{x} control chart monitoring this process.

Part (b) [5%]

Write down an expression for the probability, β , that the mean, \bar{x} , of any given sample of size n from an out-of-control process with mean output $x = \mu + k\sigma$, will *not* fall outside the control limits.

Problem 3, cont'd.

Part (c) [10%]

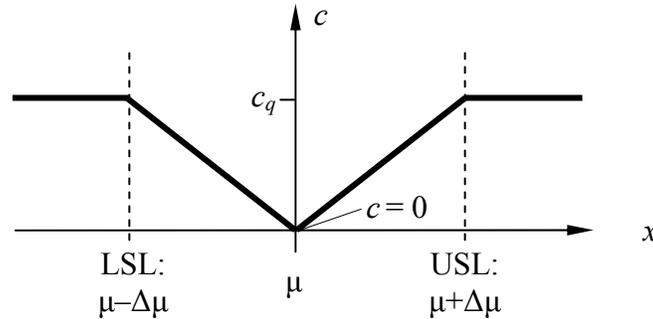
Derive, in terms of n , f , and β , an expression for the average number of parts, P , that will be produced after a mean shift occurs and before a sample falls outside the range (LCL, UCL).

We *could* use the expression that you have just derived to choose a value for n that minimizes P for a given f (do *not* attempt to choose n now). Suggest one other consideration that would feature in the selection of sample size and sample frequency.

Problem 3, cont'd.

Part (d) [10%]

Now suppose that you are told that the quality loss function for the process is defined as follows:



Here, c is the cost penalty associated with producing a part with a particular x . Write down an expression for the expected cost penalty $E_k[c]$ for a part produced when the process output is $x \sim N(\mu + k\sigma, \sigma^2)$. (Hint: your answer should be expressed as a sum of integrals; do not attempt to evaluate the integrals.)

Note: the probability density function of $x \sim N(\mu, \sigma^2)$ is given by $\frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$.

Problem 3, cont'd.

Part (e) [7%]

With the above information in mind, you now want to investigate whether you should install more metrology equipment so that the fraction of parts measured, f , can be increased. Suppose that measurement costs can be completely described by an incremental cost c_m per part measured.

Write down, and briefly explain, a cost expression that should be minimized when selecting an optimal value for f . Your answer should be given in terms of the following parameters:

- n sample size
- c_m cost of measuring one part
- f fraction of all parts produced that are measured
- $E_k[c]$ expected cost penalty for a part produced when the output is $x \sim N(\mu + k\sigma, \sigma^2)$
- $E_0[c]$ expected cost penalty for a part produced when the output is $x \sim N(\mu, \sigma^2)$
- β your answer to part (b)
- d the frequency (in parts⁻¹), on average, with which the material supplier delivers a defective batch of material (e.g. if $d = 10^{-5}$ parts⁻¹, the supplier would deliver a defective batch for every 10^5 parts produced by the process. Hopefully, not much of the batch will be used before the problem is noticed!)

What other factors should be considered when choosing f ?