

1. *Briefly* describe the purposes of the following two types of measurement studies:

calibration experiment

gage R&R study

2. In a calibration experiment, $n = 10$ items are measured once each on both a "gold standard" measuring device and an "inexpensive/in-plant" measuring device, producing 10 data pairs (x, y) . (x is the "gold standard" measurement.) The 10 values x have mean $\bar{x} = 100$ and standard deviation $s_x = 20$. A plot of the (x, y) data pairs is approximately linear, and simple linear regression analysis produces the least squares line $\hat{y} = .01 + .99x$ and $\sqrt{MSE} = s = 5$.

Suppose that a new specimen is measured on the inexpensive device and $y = 105$ is obtained. Give approximately 90% two-sided confidence limits for the new specimen's "gold standard" measurement. (Plug in, but don't bother to simplify.)

3. Faust, Hensley and Thompson did a gage R&R study intended to assess the adequacy of electronic calipers for measuring a particular diameter of some nominally 5 inch paper disks. The $J = 3$ students each measured $I = 5$ different disk diameters $m = 2$ times. In the notation of the text, they obtained $\bar{R} = .0033$ inch and $\bar{\Delta} = .0092$ inch.

a) Find and interpret an estimated "repeatability" standard deviation for this device used to make such measurements.

Interpretation:

$\hat{\sigma}_{\text{repeatability}} = \underline{\hspace{2cm}}$

b) Find an estimated "reproducibility" standard deviation for this device used to make such measurements. Do you judge that there is important operator-to-operator variability here? Explain.

Discussion/Explanation:

$$\hat{\sigma}_{\text{reproducibility}} = \underline{\hspace{2cm}}$$

c) Specifications on the diameter of interest were $5 \pm .0625$ inch. Find and briefly interpret an estimated gage capability ratio for this device used to measure these diameters.

Interpretation:

$$\text{estimated } GCR = \underline{\hspace{2cm}}$$

4. Faust, Hensley and Thompson (who did the gage study referred to in question 3) worked with the company on process monitoring of diameters of these disks.

a) Suppose a single operator is going to do all the measuring of disk diameters. In \bar{x} charting of samples of $n = 5$ diameters measured with the electronic calipers, possible "standards given" control limits are

$$LCL_{\bar{x}} = 5 - 3 \frac{\hat{\sigma}_{\text{repeatability}}}{\sqrt{5}} \quad \text{and} \quad UCL_{\bar{x}} = 5 + 3 \frac{\hat{\sigma}_{\text{repeatability}}}{\sqrt{5}}$$

(for $\hat{\sigma}_{\text{repeatability}}$ from the gage R&R study). These limits may not work so well in this application. Why?

b) The machine that cuts/punches these disks from rolled paper has 3 heads (call them left, center, and right) that simultaneously cut 3 disks across an 18 inch width of paper. Do you suggest treating the 3 disks cut at the same time as a sample of size $n = 3$ for purposes of \bar{x} charting? Explain.

Yes? No? (circle one) Explanation:

Here is some information from 10 hourly samples of $n = 5$ measured disk diameters (in units of .01 inch above 5.00 inches) from the right head.

hour	1	2	3	4	5	6	7	8	9	10	
\bar{x}	.05	.14	.76	1.61	.92	1.23	1.56	.98	1.06	1.31	$\sum \bar{x} = 9.62$
R	2.80	2.25	2.20	2.90	1.10	.75	1.15	1.30	1.90	2.05	$\sum R = 18.40$

c) Considering first retrospective R charting, find control limits based on the values in the table, apply them to the sample ranges and comment on what that application suggests about process stability here.

d) Find an estimate (based on the sample ranges above) of a "process short term standard deviation."

e) Use your answer to d), a normal distribution assumption and the diameter specifications of $5 \pm .0625$ inch and find a "projected best possible fraction of diameter measurements inside specifications." How should this compare to a "projected best possible fraction of actual diameters inside specifications"? Explain.

Discussion:

projection = _____

f) Is there evidence in the sample means, \bar{x} , of process instability? (Show appropriate calculations and explain.)

5. In a p charting problem, a standard value for the fraction nonconforming is .001. Samples of size $n = 200$ will be used.

a) Find standards given control limits for \hat{p} .

b) Say, in as much detail as possible how you would find an ARL for the possibility that $p = .005$. (Tell me what binomial distribution to use in exactly what way in order to find this ARL. But you don't have to produce a numerical value here.)

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Professor Vardeman

Quality Culture Questions

1. For which of the following is there a single universally recognized "certifying" or "awarding" body? (Check all that apply.)

- Malcom Baldrige Award
- ISO 9000 Certification
- 6 Sigma Blackbelt Status

2. Which of these deal primarily with quality issues *prior to manufacturing* a product? (Check all that apply.)

- Quality Function Deployment
- Total Quality Management
- Robust Design

3. Match the quality topic/movement to the most closely associated guru or organization. (Draw a single line connecting each topic to a single guru or organization.)

Movement	Guru/Organization
6 Sigma-----	W. Edwards Deming
Malcom Baldrige-----	Genichi Taguchi
Quality Function Deployment	National Institute for Standards and Technology
Robust Design-----	International Organization for Standards
ISO 9000-----	Motorola Corporation
Total Quality Management---	Yoji Akao

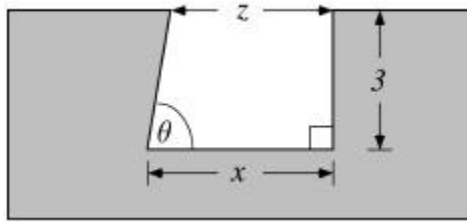
4. Proponents of various quality and management paradigms make claims like "42% of Japanese companies use our methods" or "US companies saved \$80 Million last year using our approach." We talked in class about measurement. In light of this, what problems do you see in producing such figures?

5. What is the relevance of the concept of "conflict of interest" to evaluating available material on quality and management paradigms?

6. General Electric is widely reputed to have the country's most effective "6 sigma" program. The company has its own proprietary training materials. Why do you not expect to see them soon at Waldenbooks?

Technical Questions

1. A groove is to be machined in metal block. A 2-dimensional schematic is below. We will assume that due to manufacturing variation, the dimension x and the angle θ are variable. The gap z is then variable, and in fact $z = x - 3\cot(\theta)$.



a) Suppose that x has $\mu_x = 2$ and $\sigma_x = .01$ (in cm) while θ has $\mu_\theta = \frac{\pi}{2}$ and $\sigma_\theta = .02$ (radians). Approximate the mean and standard deviation of the gap z . (By the way, $\frac{dz}{d\theta} = -3/(\cos^2(\theta) - 1)$.)

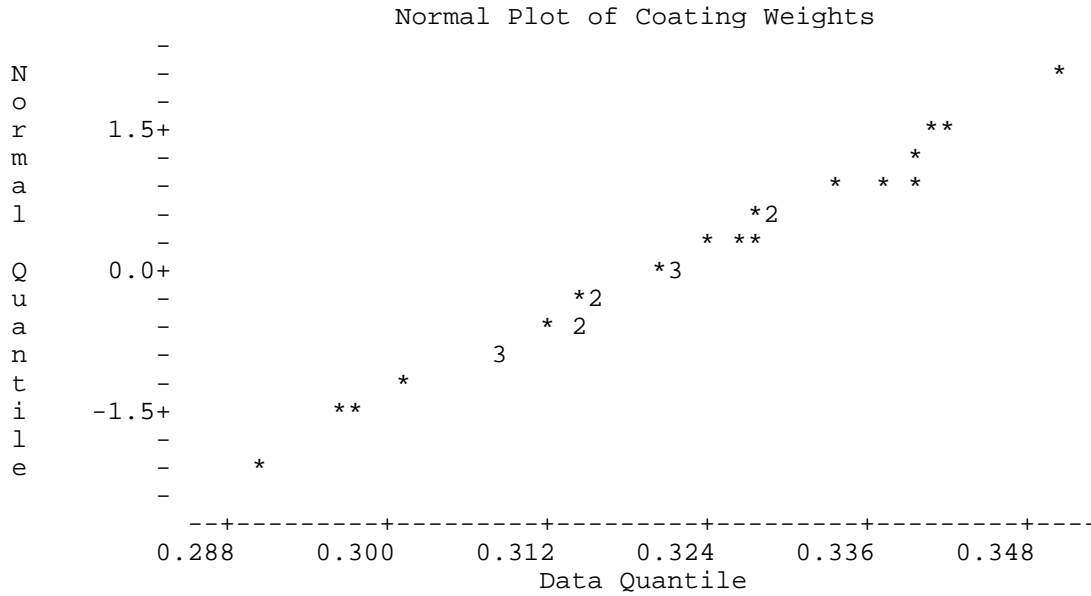
b) The kind of analysis you were asked to do in a) produces an approximate correlation between x and z of .164. Suppose that in monitoring the machining process I plan to sample 3 blocks per hour, measure both x and z on each one and compute \bar{x} and \bar{z} . I am worried about all of x , z and θ . Exactly how do you propose that I reduce \bar{x} and \bar{z} to a single value to plot on a Shewhart chart? What control limits do you suggest I use? (You may assume that the means and standard deviations from a) are standard values.)

What to plot:

Control limits:

2. Briefly contrast the industrial uses of SPC and what Vardeman has called EFC.

3. Below is a normal plot of weights of a sprayed industrial coating taken off 30 standard size targets. (Weights are in grams.)



a) Say what this plot indicates about the amounts of coating sprayed onto these targets.

As a matter of fact, the sample mean for the values represented above is $\bar{x} = .3210$ and the sample standard deviation is $s = .0148$, while specifications on the weight were $.320 \pm .030$.

b) Give 2-sided 90% confidence limits for the process capability (6σ) here.

c) Give an approximate 95% lower confidence bound for the process capability measure C_{pk} in this context.

- d) Give 95% two-sided tolerance limits for 99% of all coating weights under these process conditions.
- e) Suppose that one wishes to do monitoring of coating weights, based on \bar{x} 's for $n = 4$. Further, small changes in mean weight are of major concern, so either a CUSUM or EWMA chart will be used. An "all OK ARL" of 370 is desired. Use the mean and standard deviation from the previous page as standard values and set up either a two-sided CUSUM scheme or a EWMA scheme, if quickest possible detection of a change in mean weight of size .0074 is desired. Be sure to give all appropriate parameters. (λ , $EWMA_0$, UCL_{EWMA} and LCL_{EWMA} **or** k_1 , k_2 , U_0 , L_0 and h)
- f) Compute the values needed in order to enter some table to find the ARL if in fact the mean coating changes to .3100 while the standard deviation of weights increases to .0200. Say which table you would then use (but don't bother to actually look for the ARL).

1. ISU students Bauer, Brink and Fife studied the performance of 3 different copy machines available to ISU students. $m = 5$ copies of the same Auto Cad drawing were made on each machine for 3 different enlargement settings, and the length of a particular line segment on that drawing was measured. (All the measuring was done by a single student, and as a means of getting a handle on measurement precision, that student measured the line on the original drawing 10 times, obtaining lengths with sample mean 2.0058 inches and sample standard deviation .0008 inch.)

Sample means and standard deviations for the measurements on the copies are below.

		Enlargement Setting		
		100%	129%	155%
Copier	1	$\bar{y}_{11} = 2.0158$	$\bar{y}_{12} = 2.6058$	$\bar{y}_{13} = 3.1192$
		$s_{11} = .0028$	$s_{12} = .0024$	$s_{13} = .0018$
	2	$\bar{y}_{21} = 2.0134$	$\bar{y}_{22} = 2.5996$	$\bar{y}_{23} = 3.1038$
		$s_{21} = .0011$	$s_{22} = .0009$	$s_{23} = .0011$
	3	$\bar{y}_{31} = 2.0206$	$\bar{y}_{32} = 2.6098$	$\bar{y}_{33} = 3.1150$
		$s_{31} = .0011$	$s_{32} = .0022$	$s_{33} = .0007$

A pooled sample standard deviation computed from the 9 values s_{ij} is $s_P = .0017$.

(a) Are you surprised that $s_P = .0017$ is larger than the .0008 inch standard deviation obtained in the preliminary measurement study? (Say clearly YES or NO and then EXPLAIN why or why not.)

(b) The $m = 5$ measurements from Copier 1 at the 100% setting were in fact 2.014, 2.020, 2.017, 2.015 and 2.013. What are the values of the corresponding residuals?

(c) Say what the normal plot of the residuals for this study attached to this exam suggests about the appropriateness of "standard" kinds of data analyses here.

(d) If one wishes to attach $\pm \Delta$ precision figures (based on two-sided 95% individual confidence limits) to each of the sample means in the table on page 1, what Δ should be used? (No need to simplify.)

(e) Give two-sided 95% (individual) confidence limits for the difference in mean lengths of the line produced by copiers 1 and 2 on their 100% settings. (No need to simplify.)

(f) Give 95% individual two-sided confidence limits for the difference in copier 1 and 2 main effects, $\alpha_1 - \alpha_2$. (No need to simplify.)

(g) Four of the nine fitted Copier \times Enlargement Setting interactions are $ab_{11} = - .00296$, $ab_{12} = - .00142$, $ab_{21} = .00264$ and $ab_{22} = .00038$. Are ANY of the nine interactions statistically detectable (using, say 95% two-sided confidence limits as a basis of judging this)? Explain carefully.

2. Cooley, Franklin and Elrod in a 1999 *Quality Engineering* article describe a 2^3 factorial experiment aimed at understanding the effects of A-Hole Type (in the fan "spider"), B-Barrel Type (to which the fan "spider" was attached) and C-Assembly Method on the torque, y (in ft lbs), required to break some industrial fans (large y is good). $m = 8$ fans of each of the 2^3 types were tested. Below are estimated mean responses for each of the 2^3 combinations. (For all except combination **ac**, these are sample means, but a peculiarity of the data collection for that combination necessitates the use of something more complicated for **ac**. *But here ignore this issue and just treat the values below as if they were sample means of $m = 8$ torques.*)

comb	mean
(1)	53
a	105
b	44
ab	50
c	176
ac	197
bc	154
abc	166

(a) In the space above, use the Yates algorithm and compute the fitted effects for the "all high" treatment combination.

(b) Use 7.2 ft lbs as an estimate of the standard deviation of breaking torques for any fixed combination of Hole Type, Barrel Type and Assembly Method. (7.2 is not actually s_p in this problem, but treat it as if it were.) Which of the 2^3 factorial effects do you judge to be "clearly more than noise"? Show appropriate calculations to support your conclusion.

(c) Suppose that one somehow judges that the only effects of practical importance in this study were A, B and C main effects and the $A \times B$ interactions. What combination of Hole Type, Barrel Type and Assembly Method has the largest predicted breaking torque, and what is this predicted value, \hat{y} ?

3. Chowdhury and Mitra in their article "Reduction of Defects in Wave Soldering Process" that appeared in *Quality Engineering*, discuss a 2^{9-5} fractional factorial experiment run in an attempt to learn how to reduce defects on Printed Circuit Boards. The factors studied and their levels were:

A- Wave Height	11.0 mm (-) vs. 11.5 mm (+)
B- Flux Specific Gravity	.80 (-) vs. .78 (+)
C- Conveyor Speed	1.75 m/min (-) vs. 1.65 m/min (+)
D- Preheater Temp	80 °C (-) vs. 75 °C (+)
E- Solder Bath Temp	225 °C (-) vs. 230 °C (+)
F- Blower Heater Temp	215 °C (-) vs. 210 °C (+)
G- Foam Pressure	.20 kg/cm ² (-) vs. .15 kg/cm ² (+)
H- Direction of PCB	Reverse (-) vs. Existing (+)
J- Jig Height	High (-) vs. Low (+)

The Generators used to choose the combinations actually studied were:

$$E \leftrightarrow BC \quad F \leftrightarrow BD \quad G \leftrightarrow ACD \quad H \leftrightarrow AD \quad J \leftrightarrow AB$$

(a) How many different combinations of levels of factors A through I are possible? What number of combinations were actually run? What fraction of all possible combinations were actually run?

$$\# \text{ possible} = \underline{\hspace{2cm}} \quad \# \text{ run} = \underline{\hspace{2cm}} \quad \text{fraction run} = \underline{\hspace{2cm}}$$

(b) What levels of Factors E through J were run with the 2 combinations of A through D indicated below (fill in plus and/or minus signs).

<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>	<u>F</u>	<u>G</u>	<u>H</u>	<u>J</u>
+	+	-	-					
+	-	-	+					

(c) Each 2^9 factorial effect is aliased with (confounded with) how many other effects?

$$\text{number of aliases of a given effect} = \underline{\hspace{2cm}}$$

(d) Name 3 effects aliased with the A main effect in this study.

_____ , _____ , _____

One response variable, y , in this study was the total number of dry solder defects on 20 PCBs (10 of them "nonoxidized" and 10 of them "oxidized"), y . When the values of y obtained in the study are listed in Yates order for Factors A through D, and the Yates algorithm is applied, the results (again in Yates order) are:

$$92.00, 3.75, 1.25, -1.25, 0.00, -1.00, -0.75, -3.50 \\ -6.38, -10.13, 0.13, -1.88, 5.13, 0.13, -0.38, 1.88$$

(Read left to right, top to bottom.)

(e) The two largest (in magnitude) of the "fitted effects" computed by the Yates algorithm are -10.13 and -6.38 . Give the simplest possible interpretations of these quantities. (What are the lowest order effects they include?)

simplest interpretation of -10.13 _____

simplest interpretation of -6.38 _____

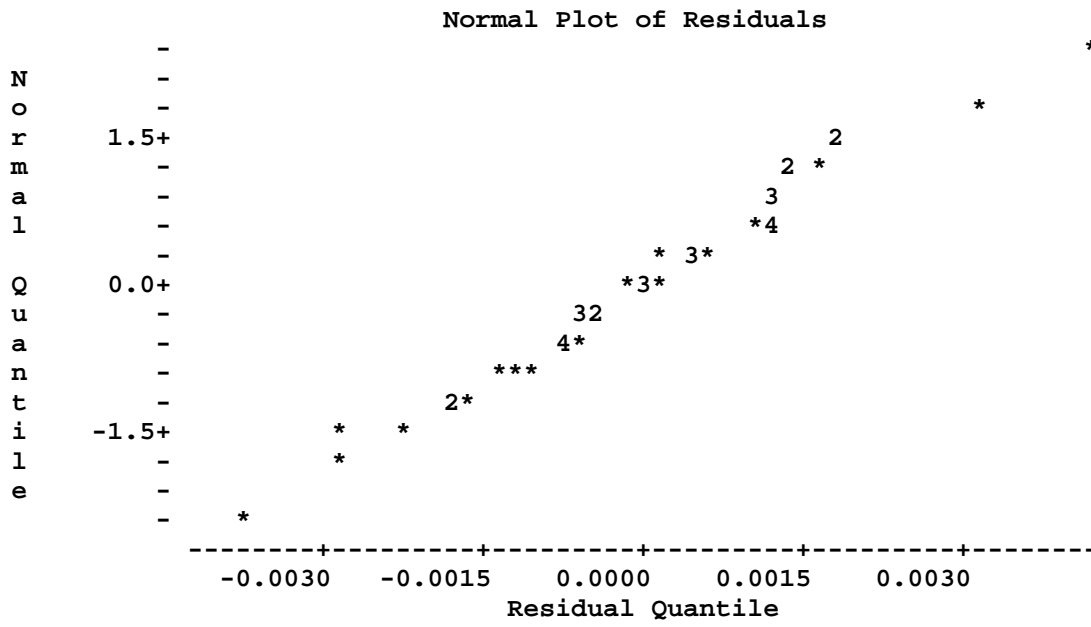
(f) Suppose that the effects mentioned in (e) are judged to be the only ones of importance in this study. What settings of Factors A through J should one use for minimum y , and what responses \hat{y} do you predict if your recommendations are followed?

A B C D E F G H J

$\hat{y} =$ _____

(g) A normal plot of the last 15 of the values computed by the Yates algorithm is given on the page of graphs attached to this exam. Interpret it in the context of this study.

Normal Plot of Residuals for Question 1



Normal Plot of Fitted Sums of Effects for Question 3

