

IE 361 Exam 1

October 7, 1996

Professor Vardeman

1. Below are some summary statistics from a gage R&R study conducted by IE 361 students Olsen, Hegstrom and Casterton. The figures are in mm and come from a study of Brinell hardness determination where each operator measured each part twice.

Part	Operator		
	1	2	3
1	$\bar{y}_{11} = 3.300$	$\bar{y}_{12} = 3.275$	$\bar{y}_{13} = 3.300$
	$R_{11} = 0$	$R_{12} = .050$	$R_{13} = 0$
2	$\bar{y}_{21} = 3.225$	$\bar{y}_{22} = 3.250$	$\bar{y}_{23} = 3.225$
	$R_{21} = .050$	$R_{22} = .100$	$R_{23} = .150$
3	$\bar{y}_{31} = 3.250$	$\bar{y}_{32} = 3.200$	$\bar{y}_{33} = 3.225$
	$R_{31} = .100$	$R_{32} = 0$	$R_{33} = .050$
4	$\bar{y}_{41} = 3.275$	$\bar{y}_{42} = 3.225$	$\bar{y}_{43} = 3.200$
	$R_{41} = .050$	$R_{42} = .050$	$R_{43} = 0$

a) Find an estimate of the "repeatability" standard deviation based on data from all 12 cells in the table. What does this figure measure?

b) Find an estimate of the "reproducibility" standard deviation based on data from all 4 parts. What does this figure measure?

c) If engineering specifications on this measurement are $3.250 \text{ mm} \pm .100 \text{ mm}$, what is an estimated gage capability ratio here? Interpret this figure in terms that a nonquantitative person can understand.

2. Below are some summary statistics from periodic measurement of the lengths of $n = 5$ sheets cut from rolls of paper on a drum cutter. The units are 64ths of an inch above nominal length.

sample	\bar{x}	s
1	12.2	.84
2	11.2	1.64
3	10.6	2.07
4	12.2	2.49
5	11.2	.84
6	12.6	1.82
7	12.2	2.95
8	13.6	1.67
9	12.2	1.30
10	10.4	1.52

$$\sum \bar{x}_i = 118.4 \quad \sum s_i = 17.14$$

a) Find retrospective control limits for s based on these values. Is there evidence in the sample standard deviations of change in the process short term variability?

b) Give an estimate of the process standard deviation σ based on the information in the table above.

c) Suppose that in the future one wants to do monitoring of ranges of lengths of samples of $n = 4$ sheets. Use your figure from b) and find appropriate control limits for R .

d) Find retrospective control limits for the sample means in the table. Is there evidence in the \bar{x} 's of process change?

e) If the drum used to cut these sheets had several blades on it and therefore cut several sheets each revolution, explain why one should be then be wary of control charts for \bar{x} and/or s that look "too good."

Return to an assumption (implicit in parts a) through d)) that the possible difficulty mentioned in part e) is not present (for example because the drum has only one blade).

f) Based on a normal distribution assumption about sheet length, your estimate of σ from part b) and \bar{x} used as an estimate of μ , about what fraction of sheet lengths do you estimate are below 10 (in the units of the table, namely 64ths of an inch above nominal)?

g) If it is possible (by, for example, changing the tension on the paper as it's fed through the cutting machine) to change the mean sheet length (without altering the standard deviation of sheet length) and you are concerned about the "give-away cost" associated with the mean sheet length being above nominal (but wish essentially all lengths to be at least nominal) what adjustment to the current mean length do you recommend? Explain.

3. Miscellaneous

a) If one wishes to set up an \bar{x} chart with $ARL = 200$ when the process mean and standard deviation are at their "standard" values, what "number of σ 's" should be used?

b) Consider u chart process monitoring with a standard nonconformance rate of $\lambda = .1$. Give control limits for an observed nonconformance rate \hat{u} based on $k = 2$ units inspected. What is the ARL for your chart if in fact the nonconformance rate is at its standard value?

c) A series of daily lots of castings is checked for cracks using a magnaflux inspection method. Below are lot sizes and numbers of cracked castings identified. Set up appropriate control limits and judge whether the process appears to have been stable over the study period.

sample size	50	100	50	100	50	100	50	100	50	100
number cracked	7	9	5	8	6	11	6	8	6	9

d) Consider the turning of steel shafts on a computer controlled lathe, where after turning a shaft can be placed into a gage and diameter measurement automatically fed to a computer that has the capability of signaling the lathe to change the tooling position for the next part turned. Briefly discuss the proper roles of "statistical process control" and "engineering control" in this context.

IE 361 Exam II

November 20, 1996

Professor Vardeman

1. Specifications on the hardness of a tablet produced by a pharmaceutical company are 17 ± 5 SCUs (standard Cobb units). Suppose that a sample of $n = 25$ tablets from a large lot has hardnesses with a reasonably linear normal plot, $\bar{x} = 16.5$ and $s = 1.5$.

a) Give an approximate 95% lower confidence bound for the process capability index C_{pk} .

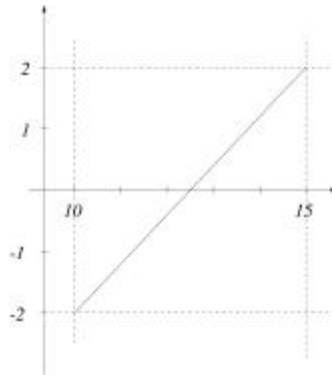
b) Give a 90% two-sided confidence interval for the process capability, 6σ .

c) Give a 90% two-sided prediction interval for the hardness of a single additional tablet drawn from this lot.

d) Suppose that the value 1.5 SCU referred to above is a good estimate of the process short term variability and from now on you wish to do process monitoring of tablet hardness based on means of samples of size $n = 4$. Set up a EWMA monitoring scheme with $\lambda = .1$ that on average will run about 100 periods between (false) alarms when "all is well" with this process. (Give a starting value and upper and lower control limits.)

2. Miscellaneous

a) Below is a schematic of a linear looking normal plot. Find graphical estimates of μ and σ based on this plot.



b) A production process is such that it is not safe to assume that even consecutively manufactured items come from the same process conditions. Nevertheless, one wishes to do the best job possible of estimating a "short term standard deviation" for a measured characteristic x . Below are 10 consecutive values of x listed in the order in which they were produced. Use them to make the best estimate of σ possible in this $n = 1$ situation.

19.8, 19.6, 21.3, 18.4, 20.8, 20.7, 18.2, 22.8, 20.6, 24.0

c) You are in charge of a metal cutting operation that simultaneously turns 4 cylindrical shafts on the 4 heads of a single machine. You wish to monitor shaft diameter and may either i) monitor the 4 heads separately using 4 different \bar{X} charts or ii) monitor all 4 heads at once on a single multivariate chart. Discuss circumstances under which the second possibility is preferable to the first.

d) The standard mean vector and variance-covariance matrix for the two variables x_1 and x_2 are respectively

$$\begin{pmatrix} 2 \\ 2 \end{pmatrix} \text{ and } \begin{pmatrix} 9 & -4 \\ -4 & 9 \end{pmatrix} .$$

Suppose measurements on 5 widgets give $\bar{x}_1 = 3$ and $\bar{x}_2 = 3$. Write (but don't bother to simplify) a matrix expression for a statistic you would compute to help you judge whether this outcome is "typical" or "atypical." Without doing the calculation, say what you expect the statistic to indicate and why.

3. In a study of the weight loss properties of some high temperature polymers, specimens of two different polymers placed at two different locations in an oven gave percent weight loss results summarized in the table below.

		Oven Position	
		1	2
Polymer	Avimid-N	$n_{11} = 1$ $\bar{y}_{11} = 8.90$	$n_{12} = 4$ $\bar{y}_{12} = 9.23$ $s_{12} = .71$
	PMR-II-50	$n_{21} = 2$ $\bar{y}_{21} = 29.80$ $s_{21} = 0$	$n_{22} = 3$ $\bar{y}_{22} = 26.20$ $s_{22} = 1.04$

a) What are the "standard" model assumptions under which one typically does statistical analysis of data like those represented in the table?

Henceforth operate under the standard model assumptions.

b) Estimate the standard deviation of % weight loss for specimens of a given polymer placed at a given position in the test oven.

c) Is there a statistically detectable difference between mean weight losses at the two different oven positions for the PMR-II-50 polymer? (Give an appropriate two-sided 95% confidence interval to support your answer.)

d) Make an interaction plot of the mean weight losses below. Does it suggest that the polymer \times position interactions are large in comparison to the main effects of polymer and of position? Explain.

e) If you were to enhance your plot from d) with error bars based on simultaneous 95% two-sided confidence limits for the 4 means, plus or minus values would be different for the 4 different means. Write out (but don't simplify) expressions for these 4 different plus or minus values.

f) Make a 90% two-sided confidence interval for the difference in position 1 and position 2 main effects on % weight loss.

IE 361 Exam 3

December 18, 1996

Prof. Vardeman

1. The paper "Achieving a Target Value for a Manufacturing Process," by Eibl, Kess and Pukelsheim, that appeared in *Journal of Quality Technology* in 1992 describes a series of experiments intended to guide the adjustment of a paint coating process. The first of these was a 2^{6-3} fractional factorial study. The experimental factors studied were as below (exact levels of these factors are not given in the paper, presumably due to corporate security considerations).

- A- Tube Height low (-) vs high (+)
- B- Tube Width low (-) vs high (+)
- C- Paint Viscosity low (-) vs high (+)
- D- Belt Speed low (-) vs high (+)
- E- Pump Pressure low (-) vs high (+)
- F- Heating Temperature low (-) vs high (+)

The response variable was a paint coating thickness measurement, y , whose units are mm. $m = 4$ workpieces were painted and measured for each of the $r = 8$ combinations of levels of the factors studied. The $r = 8$ samples of size $m = 4$ produced a value of $s_p = .118$ mm.

(a) Suppose that one wishes to attach a precision to one of the $r = 8$ sample means obtained in this study. This can be done using 95% two-sided confidence limits of the form $\bar{y} \pm \Delta$. Find Δ .

(b) Below are the mean thicknesses measured for the 8 combinations studied, *listed in Yates standard order as regards levels of factors A, B and C*. Use the Yates algorithm and find 8 estimated (sums of) effects.

A	B	C	\bar{y}
-	-	-	.98
+	-	-	1.58
-	+	-	1.13
+	+	-	1.74
-	-	+	1.49
+	-	+	.84
-	+	+	2.18
+	+	+	1.45

(c) Two-sided confidence limits based on the estimated (sums of) effects calculated in part (b) are of the form $\hat{E} \pm \Delta$. Find Δ if 95% confidence is desired.

(d) Based on your answer to (c), list below those estimates from part (b) that represent statistically detectable (sums of) effects.

In fact the experimental plan used by the investigators had generators $D \leftrightarrow AC$, $E \leftrightarrow BC$ and $F \leftrightarrow ABC$.

(e) Finish the table below specifying the 8 combinations (of the 6 experimental factors A, B, C, D, E and F) that were included in the experiment.

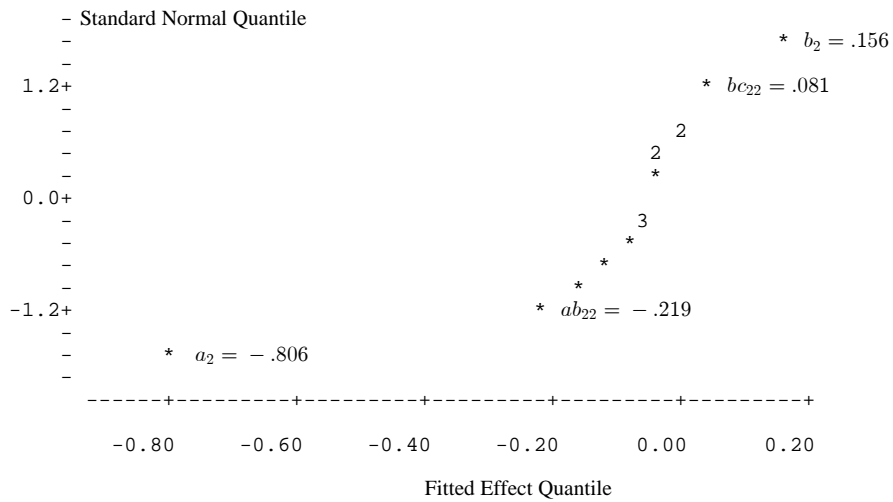
A	B	C	D	E	F
-	-	-			
+	-	-			
-	+	-			
+	+	-			
-	-	+			
+	-	+			
-	+	+			
+	+	+			

(f) Write out the whole defining relation for this study. (You will need to consider here not only products of pairs, but a product of a triple as well.)

I \leftrightarrow _____ \leftrightarrow _____ \leftrightarrow _____ \leftrightarrow _____ \leftrightarrow _____ \leftrightarrow _____ \leftrightarrow _____

(g) In light of your answers to part (d) and the aliasing pattern here, what is the simplest possible potential interpretation of the results of this experiment?

2. The plot below is a normal plot of 15 fitted effects $a_2, b_2, ab_{22}, \dots, abcd_{222}$ from an unreplicated 2^4 experiment. (The grand mean for the original data was $\bar{y}_{\dots} = 3.594$.)



(a) Interpret the normal plot above. Which factorial effects are "clearly" visible above the noise level in this experiment? If the object of experimentation is to find a way to make the mean response large, what has been learned from this study? Explain carefully your reasoning.

(b) In light of your analysis in (a) and the objective of *large* mean response, what levels of what factors do you suggest be used in the future? (Tell me where to set "knobs" A through D.)

(c) If your recommendations from (b) are followed, what mean response do you predict will be achieved? (Explain.)

3. Miscellaneous questions about sampling inspection.

(a) Your boss says "You've had a QC course ... can we reduce our inspection costs using acceptance sampling?" How do you reply?

(b) Consider an attributes acceptance sampling plan with $n = 10$ and $c = 2$. Write out completely, but do not do the arithmetic necessary to simplify values for the **type B** OC of this plan for **both** fraction nonconforming and mean defects per unit contexts with $p = \lambda = .1$. (Give two different numerical expressions.)

(c) Find an attributes single sampling plan (find n and c) whose operating characteristic curve "drops" in the vicinity of $p = .01$ and whose acceptance probability is around $Pa = .05$ when $p = .02$.

(d) Describe the operation of the Military Standard 105 switching system when applied to lots of $N = 500$, using an AQL of 1% and general inspection level II.