IE 361 Exam 1
Fall 2009

I have neither given nor received unauthorized assistance on this exam.

________________________________________________________

Name                Date
This exam consists of 20 multiple choice questions. There is a single best answer for each question. **Circle EXACTLY ONE response** for each question on this answer sheet.

<table>
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</tbody>
</table>
1. A two-part definition of "quality" that includes both "quality of design" and "quality of conformance"
   a) recognizes the roles of both product features/appropriateness and adherence to the engineering specifications established for the product.
   b) applies to both manufacturing and service contexts.
   c) can be thought of as an amplification of a "fitness for use" definition of quality.
   d) Exactly 2 of responses a) through c) are correct completions of the sentence.
   e) All of responses a) through c) are correct completions of the sentence.

2. The text's "6 Step Process Oriented Quality Assurance Cycle"
   a) is one formalization of a rational/scientific/data-based approach to business process improvement.
   b) is fundamentally opposed to most provisions of a corporate 6 Sigma program.
   c) provides an intellectual framework and outline for many business improvement projects.
   d) Exactly 2 of responses a) through c) are correct completions of the sentence.
   e) All of responses a) through c) are correct completions of the sentence.

3. Regarding simple qualitative principles of practical industrial process data collection,
   a) rational consideration of what sample size is appropriate involves assessment of both the variability one expects to encounter and the size of effect one hopes to be able to "see."
   b) the advent of large corporate data bases means that in most cases, all information necessary for guiding process improvement efforts can simply be queried from existing sources.
   c) the advent of modern digital measuring technology has removed the human element from industrial data collection and guarantees the collection of useful data.
   d) None of responses a) through c) are correct completions of the sentence.
   e) Exactly 2 of responses a) through c) are correct completions of the sentence.

For Problems 4 through 6, consider a situation in which small plastic bottles are filled with a dry spice and sold by weight of net contents. Net contents have a nominal value of 116 g. Bottle net contents weight can be measured with negligible bias and standard deviation \( \sigma \), and measurement errors are normal.

4. If \( \sigma = 1 \text{ g} \), a single actual net contents level, \( x \), must be at a minimum how much, if the bottle is to be 90% sure of being measured as containing at least 116 g (the label weight)?
   a) at least 114.35 g.
   b) at least 114.72 g.
   c) at least 116 g.
   d) at least 117.28 g.
   e) at least 117.65 g.

5. Reducing the value of \( \sigma \) (improving measurement precision)
   a) would reduce the correct answer to question 4.
   b) would leave the correct answer to question 4 unchanged.
   c) would increase the correct answer to question 4.
   d) would change the correct answer to question 4, but how can not be determined without knowing the new value.
6. The bottle filling process has its own inherent variability, measured by $\sigma_x$. Suppose that the spice company ships only bottles with net contents measured as at least 116 g and wants at most .1% of filled bottles to fail a weighing test. This requires setting the mean fill level, $\mu_x$, appropriately. (Note that increasing $\mu_x$ increases company costs.) Here

a) decreasing either $\sigma_{\text{device}}$ or $\sigma_x$ decreases the required mean fill level.
b) decreasing either $\sigma_{\text{device}}$ or $\sigma_x$ increases the required mean fill level.
c) decreasing $\sigma_{\text{device}}$ decreases the required mean fill level while decreasing $\sigma_x$ increases it.
d) decreasing $\sigma_{\text{device}}$ increases the required mean fill level while decreasing $\sigma_x$ decreases it.
e) none of the answers a) through d) is correct.

Problems 7-12 concern measurement of the widths of some mass-produced binder clips using a vernier micrometer. Fact: The upper 2.5% point of the $F_{6,6}$ distribution is about 5.82.

7. Two different operators measure the same clip $n_1 = n_2 = 7$ times each, with resulting means and standard deviations $\bar{y}_1 = 31.9487$ mm, $\bar{y}_2 = 31.9280$ mm, $s_1 = .0055$ mm, and $s_2 = .0043$ mm. Based on 95% confidence limits, one can conclude

a) that there is no clear difference in either operator biases or precisions.
b) that there is no clear difference in operator biases, but there is a clear difference in operator precisions.
c) that there is a clear difference in operator biases, but no clear difference in operator precisions.
d) that there are clear differences in both operator biases and in operator precisions.
e) nothing about comparison of operator biases or precisions from this information.

8. In the context of question 7

a) a clear difference between operator biases is reproducibility variation.
b) a clear difference between operator precisions is repeatability variation.
c) one can be sure that the operator with the best precision has the smaller bias.
d) none of responses a) through c) are correct completions of the sentence.
e) exactly 2 of the responses a) through c) are correct completion of the sentence.

9. Two different operators measure the same 3 clips once each, with the results below.

<table>
<thead>
<tr>
<th>Clip</th>
<th>Operator 3</th>
<th>Operator 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>32.002 mm</td>
<td>31.947 mm</td>
</tr>
<tr>
<td>3</td>
<td>31.914 mm</td>
<td>31.899 mm</td>
</tr>
<tr>
<td>4</td>
<td>31.963 mm</td>
<td>31.928 mm</td>
</tr>
</tbody>
</table>

Assuming measurement linearity, 95% confidence limits for the difference in biases for these 2 operators are

a) $0.0350 \text{ mm} \pm 4.303 \sqrt{0.0200} \text{ mm}$.
b) $0.0350 \text{ mm} \pm 4.303 \left( \frac{0.0194}{3} + \frac{0.0058}{3} \right) \text{ mm}$.
c) are $0.0350 \text{ mm} \pm 4.303(0.0200) \text{ mm}$.
d) possible to determine from the given information, but are not given in any of responses a) through c).
e) impossible to determine from the given information.
10. In the context of question 9, Operator 4 measured another clip (Clip 5) 10 times. The measurements obtained had sample standard deviation .0100 mm. Approximate 95% confidence limits for a clip-to-clip standard deviation of actual width
a) are .0098 mm to .6957 mm.

b) are .0108 mm to .7644 mm.

c) are .0000' mm to .0220 mm.

d) are .0000' mm to .0242 mm.

e) None of responses a) through d) is close to a correct completion of the sentence.

11. Below is part of a JMP report from the analysis of the data of question 7, that one might treat as a very small Gauge R&R study involving only I = 1 part and J = 2 operators.

| REML Variance Component Estimates |
|---|---|---|---|---|---|---|---|
| Random Effect | Var Ratio | Var Component | Std Error | 95% Lower | 95% Upper | Pct of Total |
| Operator | 8.6911764 | 0.0002111 | 0.00003034 | -0.0000384 | 0.00008058 | 89.681 |
| Residual | 2.4286e-5 | 9.9146e-6 | 1.2488e-5 | 6.6177e-5 | 10.319 |
| Total | 0.0002354 | | | | 100.000 |

95% confidence limits for the reproducibility standard deviation
a) are not available based on the given information.

b) are 0 mm to .00081 mm.

c) are 0 mm to .0284 mm.

d) are .0000125 mm to .0000662 mm.

e) are .0035 mm to .0081 mm.

12. The analysis provided by the JMP report in question 11 suggests

a) that one’s best guess is that reproducibility variation is a bigger contributor to measurement imprecision than is repeatability variation.

b) the precision with which one knows \( \sigma_{\text{reproducibility}} \) and \( \sigma_{\text{repeatability}} \) is poor enough that it is not possible to say definitively which is larger.

c) that increasing I to the value 10 common on corporate gauge R&R forms should greatly improve the quality of one's information about \( \sigma_{\text{reproducibility}} \).

d) Responses a) and b) are the only correct completions of the sentence.

e) Responses a) and c) are the only correct completions of the sentence.

Problems 13 through 15 concern an ANOVA analysis of a standard Gauge R&R data set obtained by using an optical gauge to measure a diameter for a certain injection molded plastic part. This study had I = 5, J = 4, and m = 3. Mean squares obtained were \( MS_{\text{Operator}} = 6.66 \times 10^{-5} \) in\(^2\), \( MS_{\text{Part \times Operator}} = 1.33 \times 10^{-7} \) in\(^2\) and \( MSE = 1.4 \times 10^{-6} \) in\(^2\). (As it turns out, these produce \( \hat{\sigma}_{\text{reproducibility}} = .0020 \) in, \( \hat{\nu}_{\text{reproducibility}} = 2.4, \hat{\sigma}_{R&R} = .0023 \) in, and \( \hat{\nu}_{R&R} = 4.4 \).) In fact, engineering specifications on the diameter in question were .502 in ± .002 in.
13. 95% confidence limits for the repeatability standard deviation
a) are impossible to determine here.
b) are $1.15 \times 10^{-6}$ in$^2$ to $1.791 \times 10^{-5}$ in$^2$.
c) are .0010 in to .0015 in.
d) are .0014 in to .0066 in.
e) None of responses a) through d) is a correct completion of the sentence.

14. Approximate 95% confidence limits for the reproducibility standard deviation
a) should employ $\chi^2$ percentage points, but the 2.4 value in the numerator under the root in the formula for confidence limits.
b) will be very widely separated because degrees of freedom will be small, following from the relatively small number of operators that were used in the study.
c) will be in the ratio of $\sqrt{7.378/.051} = 12.03$ to 1.
d) All of the responses a) through c) are correct completions of the sentence.
e) Exactly 2 of the responses a) through c) are correct completions of the sentence.

15. 95% approximate confidence limits for the PTR (precision to tolerance ratio) or GCR here
a) are impossible to determine from the information provided.
b) are about 2.1 to 9.9 and indicate that the measurement precision is not adequate for checking conformance to these specifications.
c) are about 2.1 to 9.9 and indicate that the measurement precision is adequate for checking conformance to these specifications.
d) are about 2.1 to 9.9 and because of the large difference between them prevent one from making definitive conclusions about the adequacy of the measurement precision.
e) None of the responses a) through d) is a correct completion of the sentence.

Below is part of a JMP report from the analysis of a calibration data set that was taken from an online MAE 334 Laboratory at the University of Buffalo. The lab concerns calibration of some thermocouples. Temperatures of cups of water, $x$, read from a dial thermometer and voltages, $y$, across the thermocouple were recorded in pairs. Use the report in answering questions 16 and 17.
\( x \) is in \(^\circ \text{C} \), the units of \( y \) are \( \mu \text{V} \), and the limits shown on the plot are 95\% prediction limits.

16. 95\% confidence limits for a repeatability standard deviation of voltages read on water of a fixed temperature are
a) 13.6 \( \mu \text{V} \) to 29.4 \( \mu \text{V} \).
b) 40.4 \( \mu \text{V} \) to 42.0 \( \mu \text{V} \).
c) \(-688.8 \mu \text{V} \) to \(-648.2 \mu \text{V} \).
d) impossible to determine from the given information.
e) None of the responses a) through d) is a correct completion of the sentence.

17. Tomorrow this thermocouple will be used to measure temperature.
a) If the voltage read on it is 0.0 \( \mu \text{V} \), one should estimate temperature to be 16.2 \(^\circ \text{C} \).
b) To the extent that one takes the dial thermometer as accurate, one may assume that today's temperatures obtained by converting voltages to temperatures have little bias.
c) If the test leads used today to connect the thermocouple to the lab analyzer and collect the calibration data should disappear from the lab and need to be replaced tomorrow, the calibration work may need to be redone.
d) Exactly 2 of responses a) through c) are correct.
e) All 3 of responses a) through c) are correct.

The final step in the production of some glass vials is a visual inspection carried out by human inspectors. 4 particular vials (marked in an "invisible" ink that can be seen only under ultraviolet light) are repeatedly run through the inspection process among a large number of newly produced vials. Each of 2 company inspectors sees those vials 10 times in a company study. Below are the rates at which the vials are identified as defective by the inspectors

<table>
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<tr>
<th>Vial</th>
<th>Inspector 1</th>
<th>Inspector 2</th>
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<tbody>
<tr>
<td>1</td>
<td>.9</td>
<td>.8</td>
</tr>
<tr>
<td>2</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>.7</td>
<td>.8</td>
</tr>
<tr>
<td>4</td>
<td>.8</td>
<td>.6</td>
</tr>
</tbody>
</table>

18. In this context, differences between operators in the long run frequencies with which they call a particular vial defective
a) are a kind of "reproducibility" variation.
b) are reflected in values of \( \hat{p} \) that differ across a row.
c) are only part of the variability in calls made across inspectors, as single inspectors are not completely consistent in how they call a given vial.
d) Exactly 2 of responses a) through c) are correct completions of the sentence.
e) All of responses a) through c) are correct completions of the sentence.

19. Approximate 95\% confidence limits for the difference in fractions of defective calls that the two operators would in the long run make on Vial 4 are
a) \( .2 \pm 1.96(.11) \).
b) \( .2 \pm 1.96(.20) \).
c) \( .2 \pm 1.96(.21) \).
d) \( .14 \pm 1.96(.21) \).
e) given in none of the above responses a) through d).
20. Approximate 95% confidence limits for the difference in long run fractions of defective calls that the two operators would make across *all vials*

a) are $.05 \pm 3.182(.13)$.

b) are $.05 \pm 3.182(.06)$.

c) rely for their practical validity on the model assumption that the 4 vials are a random sample of the vials the inspectors will face.

d) Both a) and c) are correct completions of the sentence.

e) Both b) and c) are correct completions of the sentence.
This exam consists of 20 multiple choice questions. There is a single best answer for each question. Circle EXACTLY ONE response for each question on this answer sheet.

1. A B C D E
2. A B C D E
3. A B C D E
4. A B C D E
5. A B C D E
6. A B C D E
7. A B C D E
8. A B C D E
9. A B C D E
10. A B C D E
11. A B C D E
12. A B C D E
13. A B C D E
14. A B C D E
15. A B C D E
16. A B C D E
17. A B C D E
18. A B C D E
19. A B C D E
20. A B C D E
1. "Special cause variation"
   a) is exactly that kind of process variation that control charting is meant to detect.
   b) must be eliminated by appropriate process intervention in response to "out of control" signals before it makes sense to think of a process as physically stable.
   c) is also known as "random" variation.
   d) All of responses a) through c) are correct completions of the sentence.
   e) Exactly 2 of responses a) through c) are correct completions of the sentence.

2. In a case where individual measurements \( x \) are to be plotted on a control chart (the plotted statistic is just \( \bar{Q} = x \))
   - standards given control limits should be based on engineering specifications.
   - one is essentially operating an \( \bar{X} \) chart with \( n = 1 \).
   - retrospective control limits should be set at the average measurement plus or minus three times the grand sample standard deviation of the measurements.
   - engineering specifications for \( x \) can be derived from the plotted values as long as no out-of-control signals are issued.
   a) None of the above is a correct completion of the sentence.
   b) Exactly one of the above is a correct completion of the sentence.
   c) Exactly two of the above are correct completions of the sentence.
   d) Exactly three of the above are correct completions of the sentence.
   e) All of the above are correct completions of the sentence.

3. Every morning before a day's work begins in a testing lab, the same standard specimen is tested on a particular laboratory instrument. The single measured value produced is then plotted on a control chart with control limits set at 
   \[
   \text{(true value for the standard specimen)} \pm 3 \sigma_{\text{measurement}}
   \]
   (the value of \( \sigma_{\text{measurement}} \) was derived from repeated measurement of the standard specimen in a single session). This practice
   - is a form of "measurement process" monitoring.
   - is primarily effective at detecting a change in the instrument's bias, but can be expected to also eventually detect a degradation in instrument precision.
   - could be made more practically useful by replacing standards-given charting with retrospective charting.
   - is intended to detect a change in behavior of the instrument.
   a) None of the above is a correct completion of the sentence.
   b) Exactly one of the above is a correct completion of the sentence.
   c) Exactly two of the above are correct completions of the sentence.
   d) Exactly three of the above are correct completions of the sentence.
   e) All of the above are correct completions of the sentence.

4. Large sample sizes in control charting
   a) allow relatively quick detection of relatively small process changes.
   b) are relatively expensive.
   c) are essential to guarantee high rates of conformance to engineering specifications.
   d) Exactly 2 of a), b), and c) are correct completions to the sentence.
   e) All of a), b), and c) are correct completions to the sentence.
Below are sample means and standard deviations from 10 samples of size \( n = 6 \). Use the information from these samples to answer questions 5 through 7.

<table>
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<tr>
<th>Sample</th>
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<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{x} )</td>
<td>4.20</td>
<td>4.62</td>
<td>3.27</td>
<td>6.27</td>
<td>4.96</td>
<td>7.31</td>
<td>6.77</td>
<td>6.99</td>
<td>5.58</td>
<td>8.41</td>
<td>58.38</td>
</tr>
<tr>
<td>( s )</td>
<td>1.64</td>
<td>1.26</td>
<td>.72</td>
<td>1.19</td>
<td>2.11</td>
<td>2.10</td>
<td>2.03</td>
<td>1.87</td>
<td>1.96</td>
<td>1.93</td>
<td>16.81</td>
</tr>
</tbody>
</table>

5. Consider standards given control charting for both \( \bar{x} \) and \( s \), with standards \( \mu = 5.0 \) and \( \sigma = 2.0 \).
   
   a) The \( \bar{x} \) chart and \( s \) chart both produce out-of-control signals.
   
   b) The \( \bar{x} \) chart produces out-of-control signals, but the \( s \) chart does not.
   
   c) The \( \bar{x} \) chart produces no out-of-control signals, but the \( s \) chart produces signals.
   
   d) Neither chart produces out-of-control signals.

6. Consider retrospective control charting for both \( \bar{x} \) and \( s \).
   
   a) The \( \bar{x} \) chart and \( s \) chart both produce out-of-control signals.
   
   b) The \( \bar{x} \) chart produces out-of-control signals, but the \( s \) chart does not.
   
   c) The \( \bar{x} \) chart produces no out-of-control signals, but the \( s \) chart produces signals.
   
   d) Neither chart produces out-of-control signals.

7. Ignore any lack of stability that you found indicated by the \( s \) values above and use these values to make an estimate of \( \sigma \). Based on this estimate, in turn set an upper control limit for future ranges (\( R \)) based on samples of size \( n = 4 \). (Remember that the samples represented in the table were of size \( n = 6 \).) This \( UCL_R \) is closest to
   
   a) 3.84
   
   b) 7.90
   
   c) 8.30
   
   d) 8.54
   
   e) 8.97

8. Below are some statements about various kinds of "limits" encountered in a course like IE 361. How many of them are true?
   
   • Statistical tolerance limits change when engineering specification limits change.
   
   • 95% confidence limits for a process mean are inside 95% prediction limits for a new individual value from the process.
   
   • Standards given control limits for an \( n = 5 \) sample mean can also be used to make 99% predictions for a new individual value from the process.
   
   • Control limits concern the establishment of process stability, while the use of statistical prediction and tolerance limits assumes that stability is present.

   a) All 4 are correct.
   
   b) Exactly 3 are correct.
   
   c) Exactly 2 are correct.
   
   d) Exactly 1 is correct.
   
   e) None is correct.
In a project intended to eventually improve the operation of a large heating, ventilation, and air conditioning (HVAC) system, the numbers of alarms issued by \( \text{CO}_2 \) sensors in the system are recorded for 10 consecutive weeks and are reproduced below. Use this scenario and these data to answer questions 9 through 11.

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Alarms</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>10</td>
<td>6</td>
<td>8</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>6</td>
<td>64</td>
</tr>
</tbody>
</table>

9. The data in the table
   a) provide no evidence of change over time (variation) in the \( \text{CO}_2 \) sensor alarm rate in the 10 week period.
   b) provide clear evidence that the system is not operating consistently at a designed-for-rate of 2 sensor alarms per week.
   c) are an example of "mean non-conformities per unit" data.
   d) Exactly 2 of a) through c) are correct completions of the sentence.
   e) All of a) through c) are correct completions of the sentence.

10. In this context, any lack of process stability identified by process monitoring
   a) is potentially attributable to sensor failure during the period of study.
   b) is potentially attributable to a poor Engineering Feedback Control system that fails to keep \( \text{CO}_2 \) levels consistent across the period of study.
   c) is potentially attributable to changes in weather or building use patterns across the period of study.
   d) Exactly 2 of a) through c) are correct completions of the sentence.
   e) All of a) through c) are correct completions of the sentence.

11. If rather than charting sensor alarms per one week, in the future one will chart rates of occurrence for two-week periods

\[
\text{rate} = \frac{\text{total sensor alarms in a two-week period}}{2}
\]

and using the data of the table above to set a standard occurrence rate, control limits for the future (two-week) rates
   a) can not be determined without some direct experience with two-week monitoring periods.
   b) are \( LCL_{\text{rate}} = 1.03 \) and \( UCL_{\text{rate}} = 11.77 \).
   c) are no \( LCL_{\text{rate}} \) and \( UCL_{\text{rate}} = 13.99 \).
   d) are \( LCL_{\text{rate}} = 2.07 \) and \( UCL_{\text{rate}} = 23.53 \).
   e) None of a) through d) is a correct completion of the sentence.
12. Suppose that under standard process conditions, drips have been appearing in the final painting of a type of large farm implement at a rate of about .3 drips per unit. 50 of these units are produced per day. One might consider control charting either

\[ X = \text{the number of units (out of 50) with at least one drip} \]

or

\[ Y = \text{the total number of drips on all 50 units} \]

Below are some statements about standards-given control charting for this painting process. How many of them are true?

- Charting for \( X \) is "np" charting.
- Charting for \( Y \) is "c" charting.
- A center line for charting with \( X \) should be at 12.96.
- A center line for charting with \( Y \) should be at 15.00.

a) All 4 are correct.
b) Exactly 3 are correct.
c) Exactly 2 are correct.
d) Exactly 1 is correct.
e) None is correct.

Problems 13 and 14 concern the cutting of rolled paper into sheets. Suppose that a single revolving cylindrical cutter with two blades on it as pictured below is used to slice the rolled paper into sheets as the paper passes below the rotating cutter.

Every hour, \( n = 10 \) consecutive sheets of paper are sampled from the cutting process and their lengths carefully measured for purposes of (cutting) process monitoring. Consider the possibility that the two blades are not perfectly positioned opposite each other (they are lined up with the cylinder axis, but are not exactly 180 degrees apart).

13. Below are several statements about this situation. How many of them are true in the event that there is important mis-positioning of the blades?

- Consecutive sheet lengths will tend to oscillate up and down.
- If the 10 sheets from any particular hour are treated as a single sample of size 10, this scenario is one involving "stratification."
- There is not really a single sheet cutting process at work, but rather two such processes.
- The practical difficulty of determining which of the two blades cuts a given sheet off the paper roll makes it practically impossible to separately monitor the operation of the two blades.

a) All 4 are correct.
b) Exactly 3 are correct.
c) Exactly 2 are correct.
d) Exactly 1 is correct.
e) None is correct
14. An engineer faced with this problem suggests breaking every set of 10 consecutive sheets sampled into *pairs of consecutive sheets* and for each pair computing both

\[ z = \text{the average of the two measured sheet lengths for the pair} \]

and

\[ w = \text{the range of the two consecutive sheet lengths} \]

In this context, one might consider control charting with samples of \((n = 5)\) \(z\)'s and samples of \((n = 5)\) \(w\)'s. Here

**a)** "\(\bar{x}\)" charting applied to \(z\)'s monitors the average amount of paper required to produce a sheet.

**b)** "\(\bar{x}\)" charting applied to \(w\)'s monitors one kind of inconsistency in sheet lengths.

**c)** "\(R\)" charting applied to the \(z\)'s monitors one kind of inconsistency in sheet lengths.

**d)** Exactly 2 of a) through c) are correct completions of the sentence.

**e)** All of a) through c) are correct completions of the sentence.

15. It is fashionable in "Six Sigma" circles to insist that a successful company's nonconforming rates should be small numbers of "parts per million" (for example, \(p = 1 \times 10^{-6}\)). Consider \(p\) charting based on the "large" sample size of \(n = 100\). You may take as given the facts that such a chart (with given standard \(p = 1 \times 10^{-6}\)) signals lack-of-control exactly when the sample contains at least one nonconforming item, and that the ARL for such a scheme is about 1000 if it is the case that \(p = 10^{-5}\).

**a)** These calculations suggest that only smaller (than the change to \(10^{-5}\)) changes from \(p = 10^{-6}\) will be quickly detected by attributes control charting.

**b)** These calculations indicate that a \(p\) chart for \(n = 100\) will be an effective tool for detecting a 10-fold multiplication of a "parts per million" fraction non-conforming.

**c)** These calculations suggest that process monitoring for "parts per million" rates based on attributes data and reasonable sample sizes is a hopeless proposition.

**d)** These calculations suggest nothing about the likely effectiveness of attributes control charting in parts per million contexts.

**e)** None of a) through d) is correct.

16. Process capability indices \(C_p\) and \(C_{pk}\)

- are both one-number summaries of the relationship between process parameters and the engineering specifications.
- are both typically poorly estimated/determined on the basis of small samples.
- are respectively measures of process potential and current process performance.
- both really only have natural/useful interpretations in cases where process output is normally distributed.

**a)** All 4 of these completions of the statement are correct.

**b)** Exactly 3 of these completions of the statement are correct.

**c)** Exactly 2 of these completions of the statement are correct.

**d)** Exactly 1 of these completions of the statement is correct.

**e)** None of these completions of the statement is correct.
17. Below is a normal plot of measured contamination levels from \( n = 120 \) chemical samples.

![Normal Quantile Plot](image)

- **a)** This plot suggests that the distribution of contamination levels is fairly symmetric.
- **b)** This plot suggests that the center of the contamination level distribution is around 10.
- **c)** This plot suggests that relative to the shape of the normal distribution, the distribution of contamination levels has fewer extreme values/lighter tails.
- **d)** All of statements a) through c) are correct.
- **e)** Exactly 2 of statements a) through c) are correct completions of the sentence.

Lengths (in cm) in a batch of \( n = 19 \) kitchen worktops have \( \bar{x} = 120.005 \text{ cm} \), \( s = .015 \text{ cm} \), \( \min x_i = 119.96 \text{ cm} \), and \( \max x_i = 120.04 \text{ cm} \). Specifications on this dimension of these worktops are \( 120.00 \pm .15 \text{ cm} \) and we'll suppose that the process used to make them is physically stable. Use these facts to answer questions 18 through 20.

18. How "sure" should one be that at least 90% of worktops will have lengths between 119.96 cm and 120.04 cm?

- **a)** 95%
- **b)** 90%
- **c)** 86%
- **d)** 58%
- **e)** None of the above are close to correct (say within 2% of the correct value).
19. Assuming worktop length to be normally distributed, 95% confidence limits for \(6\sigma\) for manufactured worktop length
   - **a)** are .68 cm and 1.33 cm and indicate that the process does not have the potential to meet specifications.
   - **b)** are .68 cm and 1.33 cm and indicate that the process has the potential to meet specifications.
   - **c)** are .068 cm and .133 cm and indicate that the process does not have the potential to meet specifications.
   - **d)** are .068 cm and .133 cm and indicate that the process has the potential to meet specifications.
   - **e)** tell one nothing about process capability.

20. Again assuming worktop length to be normally distributed, one can be 95% sure that the next worktop produced has length
   - **a)** between values \(120.005 \pm 2.101(.0034)\) cm.
   - **b)** between values \(120.005 \pm 2.101(.0150)\) cm.
   - **c)** between values \(120.005 \pm 2.101(.0154)\) cm.
   - **d)** between values \(120.005 \pm 2.793(.0150)\) cm.
   - **e)** None of the above are close to correct.
IE 361 Exam 3  
Fall 2009

I have neither given nor received unauthorized assistance on this exam.

__________________________________________________________
Name Signed                     Date

__________________________________________________________
Name Printed
This exam consists of 20 multiple choice questions. There is a single best answer for each question. 
Circle EXACTLY ONE response for each question on this answer sheet.

1. A  B  C  D  E
2. A  B  C  D  E
3. A  B  C  D  E
4. A  B  C  D  E
5. A  B  C  D  E
6. A  B  C  D  E
7. A  B  C  D  E
8. A  B  C  D  E
9. A  B  C  D  E
10. A  B  C  D  E
11. A  B  C  D  E
12. A  B  C  D  E
13. A  B  C  D  E
14. A  B  C  D  E
15. A  B  C  D  E
16. A  B  C  D  E
17. A  B  C  D  E
18. A  B  C  D  E
19. A  B  C  D  E
20. A  B  C  D  E
1. The method of "propagation of errors" or "statistical/probabilistic tolerancing" applied to
\[ U = g(X, Y, \ldots, Z) \]
- is useful for finding an approximate theoretical mean and an approximate theoretical standard
deviation for \( U \) based on the form of the function \( g \) and means and standard deviations for the
inputs \( X, Y, \ldots, \) and \( Z \).
- is an important data analysis method for decomposing observed variation in the output, \( U \), into
parts attributable to several factors.
- can be a design tool for setting engineering tolerances on various inputs that impact a critical
product characteristic.
- can help identify which input \( X, Y, \ldots, \) or \( Z \) is the most important contributor to variation in
the output \( U \).

a) None of the bullets above is a correct completion of the sentence.
b) Exactly 1 of the bullets above is a correct completion of the sentence.
c) Exactly 2 of the bullets above is a correct completion of the sentence.
d) Exactly 3 of the bullets above is a correct completion of the sentence.
e) All 4 of the bullets above are correct completions of the sentence.

2. Below are some statements about sample sizes in experimentation. How many of them are true?
- Large sample sizes provide the ability to see small experimental effects.
- "Balanced data" are data where sample sizes are all the same across the whole set of
experimental conditions.
- It is very important that some samples sizes(s), \( n \), in an experiment be larger than 1.
- Constant sample sizes across the set of experimental conditions provide relatively simple/clean
formulas for data analysis, but are in no other way essential to good experimentation.

a) None are true,
b) Exactly 1 is true
c) Exactly 2 are true.
d) Exactly 3 are true.
e) All 4 are true.

3. In an experimental study where \( n \) observations are made overall for the comparison of \( r \) different
experimental conditions, the pooled sample standard deviation, \( s_{pooled} \)
- serves as a measure of "background noise" for the study and a basic ingredient of measures
against which observed differences in responses for the experimental conditions can be judged.
- has \( n - 1 \) associated degrees of freedom.
- is unaffected by measurement noise and quantifies only item-to-item variation.
- is an estimate of the variability in response for any fixed one of the experimental conditions.

a) None of the bullets above is a correct completion of the sentence.
b) Exactly 1 of the bullets above is a correct completion of the sentence.
c) Exactly 2 of the bullets above is a correct completion of the sentence.
d) Exactly 3 of the bullets above is a correct completion of the sentence.
e) All 4 of the bullets above are correct completions of the sentence.
4. Below are some statements about experimental design and analysis. How many of them are true?
   - A standard gauge R&R study is a balanced $I \times J$ two-way factorial study.
   - A $3^4$ factorial experiment studies 3 factors, each at 4 levels.
   - Interactions in a two-way factorial study are measures of lack of parallelism for plots of means versus level of Factor A (with means for a given level of B connected by line segments).
   - Full factorial experiments are a practical way of learning about the impact of many factors on a response variable, $y$.

   a) None are true,
   b) Exactly 1 is true
   c) Exactly 2 are true.
   d) Exactly 3 are true.
   e) All 4 are true.

5. Below are some statements about factorial experimental design and analysis. How many of them are true?
   - Two-way interactions in a two-way factorial measure what part of mean response cannot be accounted for by an overall mean and factors A and B operating separately on the response variable.
   - Two-way $A \times B$ interactions in a three-way factorial are averages across levels of C of what one would call $A \times B$ interactions looking at one level of C at a time.
   - Two-way $A \times B$ interactions in a three-way factorial are two-way interactions computed on a two-way table of means produced by averaging mean responses across levels of C.
   - Three-way interactions in a three-way factorial measure differences in what one would call $A \times B$ interactions looking at one level of C at a time.

   a) None are true,
   b) Exactly 1 is true
   c) Exactly 2 are true.
   d) Exactly 3 are true.
   e) All 4 are true.

6. Below are some statements about fractional factorial experimental design and analysis. How many of them are true?
   - A virtue of good fractional factorial experimentation is that it guarantees that high-order interactions will not be present in a many-factor system.
   - A virtue of good fractional factorial experimentation is that it allows at least some information to be gathered on the pattern of joint action of many factors on a response variable.
   - In "many-factor" contexts, small fractions of full factorials almost always produce complete understanding of dependence of system response on the many factors.
   - Data from essentially any set of half of all $2^p$ combinations of levels of $p$ two-level factors will provide the same level of insight into system reaction to changes in levels of the factors.

   a) None are true,
   b) Exactly 1 is true
   c) Exactly 2 are true.
   d) Exactly 3 are true.
   e) All 4 are true.
An optical measuring system makes use of "triangulation" to determine distances. A schematic for using triangulation to determine the 2-d distance of a point to a line is below.

Simple trigonometry shows that the perpendicular distance $D$ from the point $C$ to the line through points $A$ and $B$ is (in terms of the distance $L$ from $A$ to $B$ and the positive angles $\alpha$ and $\beta$)

$$D = L \cdot \frac{(\sin \alpha)(\sin \beta)}{\sin(\alpha + \beta)}$$

Suppose that the distance between $A$ and $B$ can be measured with standard deviation $10^{-3}$ meter, and angles can be measured with standard deviation $0.01$ radian. As it turns out

$$\frac{\partial D}{\partial \alpha} = L \cdot \frac{\sin^2(\beta)}{\sin^2(\alpha + \beta)} \quad \text{and} \quad \frac{\partial D}{\partial \beta} = L \cdot \frac{\sin^2(\alpha)}{\sin^2(\alpha + \beta)}$$

7. For an instance of the use of such an optical measuring device (with the indicated precisions of measurement of distance $A$ to $B$ and angles) the standard deviation associated with measurement of $D$ if the distance from $A$ to $B$ is $L = 1$ meter and $\alpha = \pi / 4$ and $\beta = \pi / 4$

a) is $0.00005$ meter.

b) is $0.00709$ meter.

c) is $0.01003$ meter.

d) is $0.01005$ meter.

e) None of a) through d) is a correct completion of the sentence.

8. For a set-up of an optical measuring device where the distance from $A$ to $B$ is $L = 1$ meter and in fact $D = 0.5$ meter, consider the two possibilities that

1. C is horizontally positioned half way between A and B (the perpendicular from C to the line through A and B bisects the line segment AB)

2. C is horizontally positioned as opposite B (the perpendicular from C to the line through A and B intersects the line at point B)

For which of the possibilities is measurement of $D$ most precise?

a) Measurement of $D$ is most precise under possibility 1.

b) Measurement of $D$ is most precise under possibility 2.

c) Measurement of $D$ is equally precise under the two possibilities.

d) It is not possible to say which possibility gives the most precise measurement of $D$ based on the given information.
An example in the book *Testing 1,2,3: Experimental Design in Marketing and Service Operations* by Ledolter and Swersey concerns a study made to identify causes of cracking in ceramic flower pots produced by Company X. Three factors potentially affecting both the fraction of pots that crack in firing and the cost of making those pots were

<table>
<thead>
<tr>
<th>A- Cooling Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>B- Peak Kiln Temperature</td>
</tr>
<tr>
<td>C- Clay Mix</td>
</tr>
</tbody>
</table>

The following series of questions is not necessarily true to the scenario developed in the book, but take their motivation from the example and data there.

A company standard production method and 3 others were suggested for study by a Company X analyst (who had not taken IE 361). The 3 new methods involved changing level of only one of the three factors A, B, or C. Two production runs were made for each method and the response variable $y$ = percentage of pots produced that were cracked was observed for each. Some summary statistics for these production runs are below.

<table>
<thead>
<tr>
<th>Standard Method (i = 1)</th>
<th>New Cooling Rate (i = 2)</th>
<th>New Temp (i = 3)</th>
<th>New Clay Mix (i = 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_1 = 2$</td>
<td>$n_2 = 2$</td>
<td>$n_3 = 2$</td>
<td>$n_4 = 2$</td>
</tr>
<tr>
<td>$\bar{y}_1 = 16$</td>
<td>$\bar{y}_2 = 34$</td>
<td>$\bar{y}_3 = 14$</td>
<td>$\bar{y}_4 = 6$</td>
</tr>
<tr>
<td>$s_1 = \sqrt{18}$</td>
<td>$s_2 = \sqrt{8}$</td>
<td>$s_3 = \sqrt{8}$</td>
<td>$s_4 = \sqrt{8}$</td>
</tr>
</tbody>
</table>

(We will follow Ledolter and Swersey and treat the response variable as an instance of "variables" data rather than as an instance of "attributes" data, and use the one-way normal model rather than trying to employ Binomial analyses.)

9. 95% confidence limits for the standard deviation of lot percentages of cracked pots are

a) 6.29 and 30.19.

b) 3.77 and 86.78.

c) 1.94 and 9.32.

d) 1.91 and 9.15.

e) None of a) through d) is a correct completion of the sentence.

10. A margin of error applicable to any one of the sample means, $\bar{y}_i$, as representing a corresponding long run percentage of cracked pots $\mu$, based on two-sided 95% confidence limits is

a) impossible to determine based on the given information.

b) 20.61

c) 9.00

d) 6.36

e) possible to determine, but not close to any of b) through d).
11. The data summarized on page 6 produce \( t \cdot s_{\text{pooled}} \sqrt{\frac{1}{n_i} + \frac{1}{n_j}} = 9.0 \). This indicates

a) that exactly one of the new production methods clearly reduces pot cracking.

b) that exactly one of the new production methods clearly increases pot cracking.

c) that exactly one of the new methods clearly increases pot cracking and exactly one clearly reduces pot cracking.

d) that the results of the study are completely inconclusive.

e) None of a) through d) is a correct completion of the sentence.

Thinking of the 2-level factors A, B, and C as potentially providing a \( 2^3 \) factorial structure for a more complete study of the pot production process, we might call the current levels of the factors the low (−) levels and the new ones the high (+) levels. As it turns out,

- the new/high (+) level of Cooling Rate (A) is faster and cheaper than the present one,
- the new/high (+) level of Temperature (B) is physically higher and more expensive than the present one, and
- the new/high (+) level of Clay Mix is simply a different clay mix available at the same price as the one presently in use.

A full \( 2^3 \) factorial would involve all 8 different possible combinations of levels of the three factors.

12. From this factorial point of view, the "one-factor-at-a-time" experimental plan consisting of the four combinations represented in the table on page 6

- is a half fraction of the full \( 2^3 \) factorial.
- provides for estimation of the main effects of all three factors if there are no two or three factor interaction effects on \( y \).
- fails to be as good as a "standard half fraction" plan because it doesn't provide full \( 2 \times 2 \) factorials in all pairs of factors.
- fails to have a simple way to understand its associated "alias/confounding structure."

a) None of the bullets above is a correct completion of the sentence.

b) Exactly 1 of the bullets above is a correct completion of the sentence.

c) Exactly 2 of the bullets above is a correct completion of the sentence.

d) Exactly 3 of the bullets above is a correct completion of the sentence.

e) All 4 of the bullets above are correct completions of the sentence.

Suppose that a replicated balanced full \( 2^3 \) factorial study with all sample sizes \( m = 3 \) is done on the flower pot production process, producing the 8 sample means listed on the next page and \( s_{\text{pooled}} = 2.0 \).

Also listed on the next page are the corresponding "cycle #2" values from application of the Yates algorithm. Complete the Yates algorithm and use your results as appropriate in what follows.
<table>
<thead>
<tr>
<th>combination</th>
<th>$\bar{y}_{comb}$</th>
<th>cycle #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>16</td>
<td>98</td>
</tr>
<tr>
<td>a</td>
<td>34</td>
<td>40</td>
</tr>
<tr>
<td>b</td>
<td>14</td>
<td>38</td>
</tr>
<tr>
<td>ab</td>
<td>34</td>
<td>16</td>
</tr>
<tr>
<td>c</td>
<td>6</td>
<td>−2</td>
</tr>
<tr>
<td>ac</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>bc</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>abc</td>
<td>16</td>
<td>4</td>
</tr>
</tbody>
</table>

13. A "± margin of error" to associate with any of the sample means in the table above based on 95% confidence limits
   a) is .87.
   b) is 2.45.
   c) is 4.24.
   d) is smaller in magnitude than a) above.
   e) is larger in magnitude than c) above.

14. The "± margin of error" for any of the fitted effects you computed in the Yates algorithm based on 95% two-sided confidence limits
   a) is .87.
   b) is 2.45.
   c) is 4.24.
   d) is smaller than a) above.
   e) is larger than c) above.

Regardless of how you answered 14., apply a ±1.5 margin of error criterion, and judge which $2^3$ factorial effects are detectable. Use your results in answering questions 15 through 17.

15. The sign of $b_2$ produced by the Yates algorithm
   a) is positive, but this has no statistical significance. If it had statistical significance, it would indicate that the new temperature increases the percentage of cracked pots.
   b) is negative, but this has no statistical significance. If it had statistical significance, it would indicate that the new temperature decreases the percentage of cracked pots.
   c) is positive, and this is statistically significant. It indicates that the new temperature increases the percentage of cracked pots.
   d) is negative, and this is statistically significant. It indicates that the new temperature decreases the percentage of cracked pots.
   e) None of responses a) through d) is correct.
16. Taking account of which effects are statistically detectable and the context of the problem given in the reading before question 12, Company X will almost surely wish to henceforth use
   a) process conditions represented by combination (1).
   b) process conditions represented by combination c.
   c) process conditions represented by combination bc.
   d) either process conditions represented by combination c or conditions represented by combination bc (they are equally attractive).
   e) None of responses a) through d) is correct.

17. Using a fitted model that includes only statistically detectable effects, a fitted or predicted percentage of cracked pots associated with the current method of process operation is closest to
   a) 12
   b) 13
   c) 14
   d) 15
   e) 16

Consider now an hypothetical context where 7 two-level factors A,B,C,D,E,F, and G are to be studied. \(2^7 = 128\) and rather than a full factorial, a \(1/4\) fraction study is contemplated (requiring data collection for 32 combinations of levels of the 7 factors). The set of generators

\[
F \leftrightarrow ABCD \quad \text{and} \quad G \leftrightarrow BCDE
\]

is under consideration for choosing a fractional factorial design.

18. For this choice of generators, what levels of F and G will be used when all of factors A,B,C,D, and E are at their low levels?
   a) low F and low G
   b) low F and high G
   c) high F and low G
   d) high F and high G
   e) It is impossible to tell from the given information.

19. For this choice of generators
   a) the lowest-order/simplest effect aliased with any 2-factor interaction is a 3-factor interaction.
   b) the lowest-order/simplest effect aliased with any 2-factor interaction is another 2-factor interaction.
   c) the lowest-order/simplest effect aliased with any 2-factor interaction is a main effect.
   d) the lowest-order/simplest effect aliased with any 2-factor interaction can not be determined until data are collected and analyzed.
   e) None of a) through d) is a correct completion of the sentence.
20. Data analysis for such an experiment
   • would involve a 5-cycle Yates algorithm.
   • would recognize that every effect has 3 aliases.
   • may leave some ambiguities of interpretation that require subsequent additional data collection to resolve.
   • lacking any replication in the data, would require normal plotting of the last 31 fitted sums of effects produced by the Yates algorithm.

a) None of the bullets above is a correct completion of the sentence.
b) Exactly 1 of the bullets above is a correct completion of the sentence.
c) Exactly 2 of the bullets above is a correct completion of the sentence.
d) Exactly 3 of the bullets above is a correct completion of the sentence.
e) All 4 of the bullets above are correct completions of the sentence.