IE 361 Exam 1 (Corrected)
Spring 2011

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

________________________________________________________

Name    Date
Below are 25 True-False Questions, worth 2 points each. Write one of "T" or "F" in front of each.

_____ 1. Modern quality assurance is fundamentally process-oriented.

_____ 2. If a production process is made to be consistent/physically stable, then it will of necessity produce good/functional product.

_____ 3. Most effective process improvement analysis is based on data mined from large general-purpose databases.

_____ 4. Shapes of histograms can provide clues to physical origins and thus clues about the operation of processes that generated the data being summarized.

_____ 5. Complicated multi-step production processes are most effectively monitored through "end-of-the-line" inspection where a whole final product can be inspected, and causes of problems can thus be easily diagnosed.

_____ 6. A bell-shaped histogram of consecutively-produced widget diameters is evidence that a production process is operating consistently over time, so nothing more can be revealed by plotting a run chart.

_____ 7. A Pareto diagram is used to focus attention on the biggest causes of process problems.

_____ 8. Without effective measurement systems, it is impossible to know whether a business or production process is performing well.

_____ 9. Without appropriate routine collection and analysis of process data, it is impossible to know whether a business or production process is performing well.

_____ 10. Measurement variation will typically inflate one's perception of process variation (based on the measurement of a sample of parts produced by a process).

_____ 11. When measurement is destructive, there is no possibility of evaluating the size of pure repeatability variation.

_____ 12. The width of a confidence interval for a standard deviation, $\sigma$, tells one about the size of $\sigma$.

_____ 13. In order to compare biases of two measurement devices, one needs at least two "standards" (items with known values of measurands).

_____ 14. Measurement device A is known to be linear, but is not known to be properly calibrated. I wish to know if device B is linear. That can be determined using A and B only if standards are available.

_____ 15. A gauge R&R study typically reveals which of several operators produces the most accurate measurements.
16. If widget diameters have actual standard deviation .01 mm and measurement has standard deviation .01 mm, then measured diameters can be expected to exhibit a standard deviation of .02 mm.

17. In an R&R context, limitations on the amount of information available on $\sigma_{\text{reproducibility}}$ related to a relatively small number of operators being included in the study can be overcome by use of a large number of parts.

18. If a gauge capability ratio (or precision to tolerance ratio) is at least 1.00, the gauge in question is probably adequate for checking conformance to the engineering specifications under study.

19. Industry standard range-based gauge R&R analyses fail to produce appropriate estimates for $\sigma_{\text{reproducibility}}$ and lack associated confidence interval methods.

20. Measurement precision can often be improved by finding an equation to use in replacing raw measurements with transformed or adjusted measurements.

21. In a go/no-go R&R study, it is theoretically impossible for two operators to each be perfectly consistent in their go/no-go calls for a part, and yet have different probabilities of calling "go."

22. Repeatability variance in a go/no-go R&R study is unlike that in a measurement R&R study, because it is assumed to vary "cell-to-cell." (If the part or operator changes, it typically changes.)

23. If there is no reproducibility variance in a go/no-go R&R study, then all operators must be individually perfectly consistent in their go/no-go calls.

24. Confidence limits $0.1 \pm 0.02$ for the difference in two "go" call rates for a fixed part by two different operators in a go/no-go study, $p_1 - p_2$, indicates that there is no clear different in the call rates.

25. In the estimation of $p_1 - p_2$ based on $\hat{p}_1 = .2, \hat{p}_2 = .3$, and $n_1 = n_2 = 10$, approximate 95% confidence limits are $-0.1 \pm 0.41$. 

The next 5 pages each have a 10 point "work out" problem on them (numbered W1, W2, W3, W4, and W5.). Answer all 5.
W1. Two operators made $m = 10$ go/no-go calls on each of $I = 5$ parts. The table below provides their "go" call rates. Make and interpret an appropriate 95% confidence interval for comparing overall (across all parts) "go" call rates for the two operators.

<table>
<thead>
<tr>
<th>Part</th>
<th>Operator #1 &quot;go&quot; Call Rate</th>
<th>Operator #2 &quot;go&quot; Call Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.2</td>
<td>.2</td>
</tr>
<tr>
<td>2</td>
<td>.1</td>
<td>.3</td>
</tr>
<tr>
<td>3</td>
<td>.8</td>
<td>.9</td>
</tr>
<tr>
<td>4</td>
<td>.4</td>
<td>.4</td>
</tr>
<tr>
<td>5</td>
<td>.9</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Interval:

Interpretation:
W2. 20 students each measured the size of a single Styrofoam packing peanut once. Their measurements produced a sample standard deviation of .014 in. Subsequently, a single student who missed class measured that same peanut 10 times. That person's measurements produced a standard deviation of .006 in. It is sensible here to say that the 20 measurements were observations each having (theoretical) variance \( \sigma^2_{\text{reproducibility}} + \sigma^2_{\text{repeatability}} \) and that the 10 measurements were observations each having (theoretical) variance \( \sigma^2_{\text{repeatability}} \).

This scenario is not exactly like any discussed in class, the modules, or the revision of V&J. But its basic structure is like one you've encountered, and a statistical method from class can be used to make approximate 95% confidence limits for \( \sigma_{\text{reproducibility}} \). Do this.
W3. Below is a JMP report from a data set collected to relate temperature to resistance of a carbon resistor. The report is for a fit of the model

\[ y = \beta_0 + \beta_1 x + \beta_2 x^2 + \beta_3 x^3 + \epsilon \]

to the \( x = \) temperature (°K) and \( y = \) resistance (Ω) data pairs from the study. Plotted is the curve fit by least squares and 99.5% prediction limits for \( y_{new} \) at each value of \( x \). (Simple linear regression corresponding to the simpler model \( y = \beta_0 + \beta_1 x + \epsilon \) is clearly not appropriate here, but this cubic modeling seems to be sensible.)

Consider the future use of this resistor to measure temperature.

What are 95% confidence limits for the repeatability standard deviation of measured resistance at a given temperature for this resistor?

What are 99.5% confidence limits for the actual temperature if a resistance of 13.0 Ω is observed for this carbon resistor. (Indicate on the JMP report how you obtained the interval.)
**W4.** Two digital calipers are used to measure a gauge block "known" to be a 2.000 in gauge block. Summary statistics for the two sets of measurements are below.

<table>
<thead>
<tr>
<th>Caliper #1</th>
<th>Caliper #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_1 = 5 )</td>
<td>( n_2 = 10 )</td>
</tr>
<tr>
<td>( \bar{y}_1 = 2.0012 \text{ in} )</td>
<td>( \bar{y}_2 = 1.9998 \text{ in} )</td>
</tr>
<tr>
<td>( s_1 = .0005 \text{ in} )</td>
<td>( s_2 = .0008 \text{ in} )</td>
</tr>
</tbody>
</table>

Give 95% confidence limits for the Caliper #1 bias for measuring 2.000 in.

Give 95% confidence limits for comparing Caliper #1 and Caliper #2 biases for measuring 2.000 in.
**W5.** Here are some summary statistics from a standard gauge R&R study involving 5 operators and 10 parts where every operator measures each part 4 times

\[ SSO_{\text{Operator}} = 10, \quad SSO_{\text{Operator} \times \text{Part}} = 6, \quad \text{and} \quad SSE = 20 \]

(units of sums of squares are \( \text{lb}^2 \)).

Find an estimate of \( \sigma_{\text{R&R}} \).

Approximate degrees of freedom for \( \hat{\sigma}_{\text{R&R}} \) are \( \hat{\nu} = 36.96 \). Use this fact and your value from above to give approximate 95% confidence limits for \( \sigma_{\text{R&R}} \).
IE 361 Exam 2
Spring 2011

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

_____________________________    ________________________
Name                          Date
Below are 25 True-False Questions, worth 2 points each. Write one of "T" or "F" in front of each.

_____ 1. The percent impurity in one fluid ounce of a liquid product is tested and plotted once per hour in a production facility. The appropriate control chart limits are \( p \) chart limits.

_____ 2. A mean number of non-conformities per unit plotted on Shewhart control chart can exceed 1.0.

_____ 3. The upper standards given control limit for ranges increases as the sample size increases.

_____ 4. The upper standards given control limit for standard deviations increases as the sample size increases.

_____ 5. Upper and lower standards given control limits for fractions non-conforming get further apart as the sample size increases.

_____ 6. A point plotting outside of control limits on a Shewhart chart always suggests process degradation.

_____ 7. A standard "\( \sigma \)" used in setting \( \bar{x} \) chart control limits represents only "process" variation.

_____ 8. Engineering specifications on dimension A are 1.00' ± .02', while specifications on dimension B are 1.00' ± .01'. Then samples of size \( n = 5 \) must produce \( \bar{x} \) chart control limits that are tighter for dimension B than for dimension A.

_____ 9. Engineering feedback control can play a part in establishing industrial process stability that is then monitored using statistical process control.

_____ 10. "Special cause variation" is another name for "process change" that Shewhart control charting is meant to detect.

_____ 11. Retrospective control limits are meant to help answer the question "Are process parameters at their standard values?"

_____ 12. Statistical tolerance limits are intended to indicate the requirements on a measurement in order for a corresponding item to be functional.

_____ 13. Statistical prediction limits are intended to locate most of the future output of a stable process based on a sample from that process.

_____ 14. \( C_{pk} \) is a measure of present process performance (rather than process potential).

_____ 15. If a 95% confidence interval for \( C_{pk} \) is \((1.5,1.7)\) then it is reasonably clear that a "6 sigma" process performance goal has been achieved.
16. The ARL concept is a tool for aiding the choice/design of a process monitoring scheme, in that it is a quantification of monitoring scheme performance under a particular model of process behavior.

17. The "Western Electric Alarm Rules" are meant to provide the ability to quickly detect non-random patterns on a Shewhart chart.

18. Tool wear in a turning process that would naturally make consecutively machined cylinders increase in size can potentially be compensated for by the use of engineering feedback control.

19. A physically stable process will of necessity produce acceptable product.

20. Trends on an individuals chart tend to make the corresponding value of $\overline{MR}/1.128$ "too small" as an estimate of "$\sigma$".

21. Two different machining centers produce supposedly identical cylinders. A consistent difference between those machines (in terms of diameters produced) if ignored would produce "sample" averages of two diameters from each machine that would tend to look "too/unbelievably stable."

22. Samples (or rational subgroups) of size $n = 1$ make completely reliable estimation of $\sigma$ impossible.

23. If a process has a number of known "knobs" that can be used to change an output variable, $y$, establishing a level of "baseline" variation for $y$ might be done by holding those fixed and control charting process output.

24. Lack of physical stability means that basic changes to process configuration or operation are necessary in order to reduce observed variation.

25. Normal plotting and confirmation of a normal distributional shape are necessary before it is possible to make any form of statistical prediction limits.

The next 5 pages each have a 10 point "work out" problem on them (numbered W1, W2, W3, W4, and W5). Answer all 5.
W1. Below are some means and standard deviations for samples of size \( n = 3 \) surface roughness measurements (units are \( \mu \)-inches).

<table>
<thead>
<tr>
<th>Sample</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>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{x} )</td>
<td>19.4</td>
<td>19.2</td>
<td>21.1</td>
<td>19.8</td>
<td>19.9</td>
<td>19.6</td>
<td>20.3</td>
<td>19.7</td>
<td>18.7</td>
<td>20.1</td>
</tr>
<tr>
<td>( s )</td>
<td>.3</td>
<td>1.5</td>
<td>2.0</td>
<td>1.6</td>
<td>1.8</td>
<td>1.3</td>
<td>.9</td>
<td>1.2</td>
<td>.7</td>
<td>.9</td>
</tr>
</tbody>
</table>

\[ \sum \bar{x} = 197.8, \quad \sum s = 12.2 \]

Suppose that process standards are \( \mu = 20 \) and \( \sigma = 1 \). Is there evidence of change from these standard values in these data? Show appropriate calculations and explicitly say whether there is any evidence of change from the process standard values.

Evidence of change from standard values? (Circle the correct response.)

In means? yes/no

In standard deviations? yes/no
W2. Below are numbers of radiators inspected and total leaks found in those inspections over a number of 1 hour periods.

<table>
<thead>
<tr>
<th>Period</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>
</tr>
</thead>
<tbody>
<tr>
<td>Leaks</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Number Inspected</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

\[ \sum \text{Leaks} = 16 \]

\[ \text{Total} = 20 \]

Determine whether there is any evidence of process instability in these data. Show appropriate calculations and say clearly where (if at all) there is evidence of instability.
**W3.** Below is a **JMP** report for \( n = 25 \) measured weld strengths (units are psi).

![Fitted Normal Parameter Estimates](image)

**Diagnostic Plot**

a) Why is consideration of the kind of plot shown here wise before considering process capability measures?

b) Specifications on such strengths are 1100 psi to 1800 psi. Give 95% confidence limits for \( C_{pk} \).
W4. Suppose that a pelletizing process is physically stable, producing constant fraction non-conforming $p$. Samples of size $n = 100$ are used to do Shewhart control charting with standard value $p = .2$.

a) What is the ARL if $p$ is at its standard value?

b) What is the ARL if $p$ is twice its standard value?
W5. Below is an artificial series of observations (samples of size $n = 1$) collected from consecutive items (suppose the units are inches).

$$2, 4, 6, 8, 10, 12, 14, 16, 18, 20$$

a) How does the best available estimate of "$\sigma$" here (based on control charting ideas) compare to the sample standard deviation? Provide some rationale why the larger of these is larger.

b) Set up control limits for future monitoring of individual measurements of this type using a process mean of 10 and an appropriate estimate of process standard deviation.
I have neither given nor received unauthorized assistance on this exam.

________________________________________________________
Name                Date
Below are 25 True-False Questions, worth 2 points each. Write one of "T" or "F" in front of each.

_____  1. Simulation and "statistical tolerancing" are both methods that can be used to approximate the standard deviation of a function of several random variables.

_____  2. "Statistical tolerancing" is more a data analysis tool than it is a "design" or "what if" tool.

_____  3. If a system input is highly variable, then the system output will of necessity be highly variable.

_____  4. If a system is highly sensitive to variation in one input, then the system output will of necessity be highly variable.

_____  5. Without replication in an experiment, there is no solid basis upon which to establish the level of background noise against which observed changes in response experimental-condition-to-experimental-condition can be judged.

_____  6. Replication in an experiment requires that every set of experimental conditions be "run" the same number of times, producing balanced data.

_____  7. $s_{\text{pooled}}$ is meant to measure variability in response $y$ for any fixed set of experimental conditions.

_____  8. If $s_1 = 2.0, s_2 = 1.5, s_3 = 5.1, \text{ and } s_4 = 3.4$, then it is impossible that $s_{\text{pooled}} = .4$.

_____  9. Rough/approximate 95% "margins of error" for sample means ($\bar{y}_i$) in an $r$-sample study are $2 \cdot s_{\text{pooled}}$.

_____  10. In a balanced data study, margins of error for a difference in two means $\bar{y}_i - \bar{y}_r$ are twice those for a single mean $\bar{y}_i$.

_____  11. Large sample sizes in experiments improve one's ability to estimate basic experimental variation, but do not much help improve the precision with which main effects and interactions are known.

_____  12. An experimental effect is statistically detectable exactly when it is of real-world/practical importance.

_____  13. One reason to consider the making of margins of error for linear combinations of sample means from an experiment, is that in factorial studies fitted main effects and interactions are such linear combinations.

_____  14. A fitted "A" main effect in a factorial study compares the average mean response at a fixed level of the factor with the overall average mean response.
15. The difference between two fitted "A" main effects in a factorial study is the difference between the two corresponding average sample means.

16. The presence of important interactions in a two-way factorial study means that it is possible to make blanket statements about the impact of a change in level of Factor A that will hold true across all levels of Factor B.

17. Fitted two-factor interactions in a two-way factorial study measure the difference between what is true about the response and what can be accounted for by considering the impact of the factors acting separately/individually on the response.

18. Three-way interactions in a three-way factorial measure the difference between what one would call \( A \times B \) two-factor interactions looking separately at mean responses on the various levels of Factor C.

19. Results of \( 2^p \) factorial experiments are most easily interpreted when \( p \)-way interactions are important and statistically detectable.

20. All of the values produced by the Yates algorithm have the same associated margin of error.

For questions 21-25: In a particular \( 2^{7-3} \) fractional factorial experiment, generators \( E \leftrightarrow AB \), \( F \leftrightarrow CD \), and \( G \leftrightarrow ABCD \) are used.

21. In this study, \( \frac{1}{8} \) th of all 128 possible combinations of two levels of each of factors A,B,C,D,E,F, and G are run.

22. The results of such an experiment will typically provide the same amount of information about the effects of Factors A,B,C,D,E,F, and G as would a full \( 2^7 \) factorial study.

23. In this study every \( 2^7 \) factorial effect has 7 "aliases." (Every \( 2^7 \) factorial effect is indistinguishable from 7 other \( 2^7 \) factorial effects.)

24. One combination of levels of the 7 factors included in the study is the combination abcd.

25. In this study, the E main effects are aliased with \( F \times G \) two-factor interactions.
W1. A plate with two circular holes in it must fit over 2 round pegs. The sketch below illustrates the situation.

Pegs of radii \( r_1 \) and \( r_2 \) mm are placed \( d_1 \) mm apart. The holes of radii \( r_3 \) and \( r_4 \) are placed \( d_2 \) mm apart. The plate will fit over the pegs provided

\[
0 < (r_3 + r_4 + d_2) - (r_1 + r_2 + d_1) \quad \text{and} \quad 0 < (d_1 - r_1 - r_2) - (d_2 - r_3 - r_4)
\]

So, for example, the variable

\[
c = d_1 - d_2 - r_1 - r_2 + r_3 + r_4
\]

is of interest. Suppose that means and standard deviations of the dimensions here are as follows.

<table>
<thead>
<tr>
<th>Variable</th>
<th>( \mu )</th>
<th>( \sigma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( d_1 )</td>
<td>20 mm</td>
<td>1 mm</td>
</tr>
<tr>
<td>( d_2 )</td>
<td>20 mm</td>
<td>1 mm</td>
</tr>
<tr>
<td>( r_1, r_2 )</td>
<td>6 mm</td>
<td>.1 mm</td>
</tr>
<tr>
<td>( r_3, r_4 )</td>
<td>7 mm</td>
<td>.1 mm</td>
</tr>
</tbody>
</table>

Assuming the dimensions are independent, find the mean (\( \mu_c \)) and standard deviation (\( \sigma_c \)) for \( c \).

\[
\mu_c = \underline{\ldots} \quad \text{and} \quad \sigma_c = \underline{\ldots}
\]
W2. Some so-called "tilttable tests" were done to compare angles at which vehicles experience lift-off of "high side" wheels and begin to roll over. Tests on \( r = 3 \) vans produced tangents of angles ("tilttable ratios") at which lift-off occurs summarized below. (Plug in completely, but you need not simplify.)

<table>
<thead>
<tr>
<th>Van #1</th>
<th>Van #2</th>
<th>Van #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>( n_1 = 4 )</td>
<td>( n_2 = 5 )</td>
<td>( n_3 = 3 )</td>
</tr>
<tr>
<td>( \bar{y}_1 = 1.093 )</td>
<td>( \bar{y}_2 = .968 )</td>
<td>( \bar{y}_3 = 1.020 )</td>
</tr>
<tr>
<td>( s_1 = .002 )</td>
<td>( s_2 = .003 )</td>
<td>( s_2 = .004 )</td>
</tr>
</tbody>
</table>

Van #1 was a minivan, and Vans #2 and #3 were full-sized vans.

A linear combination of means that could be used to compare the minivan to the two full-sized vans is

\[
L = \mu_1 - \frac{1}{2}(\mu_2 + \mu_3)
\]

Find 95% confidence limits for this quantity.
**W3.** Below are some summary statistics from a class project concerning stopping distances of a bicycle with smooth and reverse tread tires on dry and wet concrete. Lengths of $m = 6$ skids marks were measured under each set of conditions and processed to produce the values below. (Units are cm.)

<table>
<thead>
<tr>
<th></th>
<th>Dry Concrete</th>
<th>Wet Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth Tires</td>
<td>$\bar{y}<em>{11} = 360$ and $s</em>{11} = 19$</td>
<td>$\bar{y}<em>{12} = 367$ and $s</em>{12} = 26$</td>
</tr>
<tr>
<td>Reverse Tread Tires</td>
<td>$\bar{y}<em>{21} = 343$ and $s</em>{21} = 16$</td>
<td>$\bar{y}<em>{22} = 357$ and $s</em>{22} = 37$</td>
</tr>
</tbody>
</table>

Using 95% confidence limits find a margin of error to associate with each sample mean in the table.

Do some appropriate plotting below, and based on the plot and your margin of error say whether (and WHY) you think that Tire by Surface interactions are statistically detectable.
A $2^3$ factorial study with four sample sizes of 2 and four sample sizes of 1 produces $s_{\text{pooled}} = 1.5$ and the hypothetical sample means below.

<table>
<thead>
<tr>
<th>comb</th>
<th>$\bar{y}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>10</td>
</tr>
<tr>
<td>a</td>
<td>13</td>
</tr>
<tr>
<td>b</td>
<td>8</td>
</tr>
<tr>
<td>ab</td>
<td>11</td>
</tr>
<tr>
<td>c</td>
<td>16</td>
</tr>
<tr>
<td>ac</td>
<td>5</td>
</tr>
<tr>
<td>bc</td>
<td>14</td>
</tr>
<tr>
<td>abc</td>
<td>3</td>
</tr>
</tbody>
</table>

Which (if any) factorial effects are statistically detectable (based on 95% confidence limits for effects)?
**W5.** A $\frac{1}{8}$ th fraction of a $2^7$ factorial has defining relation

$$I \leftrightarrow ABE \leftrightarrow CDF \leftrightarrow ABCDG \leftrightarrow ABCDEF \leftrightarrow CDEG \leftrightarrow ABFG \leftrightarrow EFG$$

Suppose that (initially ignoring levels of factors E,F, and G) one does data analysis that leads to the conclusion that important effects are

- AB interaction + aliases
- CD interaction + aliases
- ABCD interaction + aliases

Give then 2 simple plausible interpretations of this outcome in terms of all 7 factors A,B,C,D,E,F, and G? (Which of the $2^7$ factorial effect are potentially important? Consider only interpretations involving main effects or possibly main effects and associated interactions.)

Possible interpretation #1:

Possible interpretation#2: