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.

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1. "Process Improvement"
   a) is promoted in modern business contexts through a variety of programs known by names ranging from "Total Quality Management" to "Six Sigma."
   b) is of concern in service industries.
   c) is of concern in manufacturing industries.
   d) Exactly 2 of the responses a) through c) are correct completions of the sentence.
   e) All of the responses a) through c) are correct completions of the sentence.

2. As typically used in the context of modern business process improvement paradigms, the word "control" refers to
   a) an activity that is fundamentally statistical.
   b) an activity having to do with process monitoring, aimed at verifying that no process change is taking place.
   c) activities undertaken only by upper management.
   d) Exactly 2 of the responses a) through c) are correct completions of the sentence.
   e) All of the responses a) through c) are correct completions of the sentence.

3. A straight-line trend "up" on a run chart of measured diameters of axels produced by a turning process suggests that for samples of, say, \( n = 10 \) consecutive axel diameters \( y \),
   a) sample means \( \bar{y} \) will increase approximately linearly with time.
   b) sample standard deviations \( s \) will increase approximately linearly with time.
   c) both sample means \( \bar{y} \) and sample standard deviations \( s \) will increase approximately linearly with time.
   d) neither sample means \( \bar{y} \) nor sample standard deviations \( s \) will change with time.
   e) nothing definitive can be said about what will happen to sample means \( \bar{y} \) or standard deviations \( s \).

4. Measurement validity, precision, and accuracy
   a) are all quantified in a gauge R&R study.
   b) can all be improved through careful calibration studies.
   c) in a statistical study can all be improved through increased samples sizes.
   d) Exactly 2 of the responses a) through c) are correct completions of the sentence.
   e) None of the responses a) through c) are correct completions of the sentence.

5. When two different devices are used to each make multiple measurements on the same unknown measurand
   a) the device biases can be compared.
   b) the device precisions can be compared.
   c) the two individual biases can be evaluated.
   d) Exactly 2 of the responses a) through c) are correct completions of the sentence.
   e) All of the responses a) through c) are correct completions of the sentence.
6. Unit-to-unit variation in a real characteristic of items produced on a production line can be quantified by a standard deviation of $\sigma_u = .1$, while measurement variation associated with observing that characteristic can be quantified by a standard deviation of $\sigma_{\text{measurement}} = 1.0$.

Should actual unit-to-unit variation double (to $\sigma_u = .2$) one should expect observed variation in the characteristic (seen in single measurements made on different units and quantified by a standard deviation) to
a) decrease.
b) remain the same.
c) increase by about 1.5%.
d) increase by about 50%.
e) increase by about 100%.

Fact: The upper 2.5% point of the $F_{4,4}$ distribution is about 9.60.

Viscosities of paint samples are measured by a paint manufacturer using a single "viscometer" in units of "Krebs." Viscosities of specimens drawn from two different batches of paint made from the same formula are measured (once per specimen). $n_1 = 5$ specimens from the first batch and $n_2 = 5$ specimens from the second batch have sample means and standard deviations of measured viscosities $\bar{y}_1 = 90.2$ Krebs, $\bar{y}_2 = 92.3$ Krebs, $s_1 = .7$ Krebs, and $s_2 = .4$ Krebs.

7. Based on 95% confidence limits made from the values above, one can conclude
a) that there is a clear difference in both average and variability of viscosity for specimens from these two batches.
b) that there is a clear difference in average viscosity for specimens but there is no clear difference in variability of viscosity for specimens from these two batches.
c) that there is no clear difference in average viscosity but is a clear difference in variability of viscosity for specimens from these two batches.
d) that there is no clear difference in either average or variability in viscosity for specimens from these two batches.

e) None of the responses a) through c) are correct completions of the sentence.

8. In order to use data like those summarized before question 7 to compare mean viscosity for two paint batches, one must implicitly assume
a) that the viscometer is perfectly calibrated.
b) that the viscometer is a "linear" measurement device.
c) that the viscometer has a GCR of less than .1 for viscosity measurement.
d) Exactly 2 of the responses a) through c) are correct completions of the sentence.
e) None of the responses a) through c) are correct completions of the sentence.

(For questions 9 and 10) Combine the information about Batch 1 given before question 7 with the following. Single specimens were drawn from $n = 9$ additional batches of paint made from this formula (you might call those Batch 3, Batch 4, …, Batch 11) and single measurements of viscosity were made. These measurements had sample mean and sample standard deviation respectively $\bar{y} = 92.8$ Krebs and $s = 1.1$ Krebs. Further, calibration studies have established that the viscometer is linear and reads about .3 Krebs high when measuring viscosity.
9. 95% confidence limits for a process mean viscosity for paint of this type
   a) are 92.5±.85 Krebs.
   b) are 92.8±.85 Krebs.
   c) are 93.1±.85 Krebs.
   d) can be determined from the given information, but none of answers a) through c) are correct.
   e) can not be determined from the given information.

10. Approximate 95% confidence limits for a batch-to-batch standard deviation of actual viscosity
   a) can not be determined from the given information.
   b) are .23 Krebs and 33.3 Krebs.
   c) are .44 Krebs and 5.31 Krebs.
   d) are .74 Krebs and 2.11 Krebs.
   e) None of responses a) through d) is a correct completion of the sentence.

(For questions 11 and 12) Continue the paint production context of questions 7 through 10. Below is part of a JMP report from a "one-way random effects" analysis of a study where 4 specimens were drawn from each of 5 different batches of paint, and viscosity was measured. (The nominal variable Batch was used in the Fit Model routine as a "random" factor with response Viscosity.)

11. In units of Krebs, 95% confidence limits for the standard deviation of batch mean viscosities
   a) are not available based on the given information.
   b) are 0 and 1.34.
   c) are 0 and 1.79.
   d) are .56 and 1.17.
   e) are .31 and 1.36.

12. In units of Krebs, 95% confidence limits for the standard deviation of measured viscosities if a single specimen were to be retested many times
   a) are not available based on the given information.
   b) are 0 and 1.34.
   c) are 0 and 1.79.
   d) are .56 and 1.17.
   e) are .31 and 1.36.
Below is an ANOVA table from a gauge R&R study where the same optical gauge was used to measure diameters of $I = 10$ small plastic parts, $m = 3$ times each, by $J = 4$ different operators. The original data were in $10^{-3}$ inches.

<table>
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<tr>
<th>Source</th>
<th>SS</th>
<th>df'</th>
<th>MS</th>
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</thead>
<tbody>
<tr>
<td>Parts</td>
<td>27.0</td>
<td>9</td>
<td>3.00</td>
</tr>
<tr>
<td>Operators</td>
<td>6.0</td>
<td>3</td>
<td>2.00</td>
</tr>
<tr>
<td>Parts×Operators</td>
<td>86.4</td>
<td>27</td>
<td>3.20</td>
</tr>
<tr>
<td>Error</td>
<td>96.0</td>
<td>80</td>
<td>1.20</td>
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<tr>
<td>Total</td>
<td>215.4</td>
<td>119</td>
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</table>

13. Based on the values in the table above, a single number estimate of the repeatability standard deviation, $\sigma_{\text{repeatability}}$, 
   a) can not be determined. 
   b) is $0.79 \times 10^{-3}$ inch. 
   c) is $1.10 \times 10^{-3}$ inch. 
   d) is $1.35 \times 10^{-3}$ inch. 
   e) is $1.73 \times 10^{-3}$ inch.

14. In this context, an estimate of $\sigma_{\alpha \beta}$ turns out to be about .25 times an estimate of $\sigma$, while an estimate of $\sigma_{\text{reproducibility}}$ is about .72 times this estimate of $\sigma$. This suggests that 
   a) reproducibility variation is smaller than repeatability variation. 
   b) operator "nonlinearities" are not the largest contributor to reproducibility variation. 
   c) one should not hope that improving operator-to-operator measuring consistency will produce an order-of-magnitude improvement in measurement precision. 
   d) Exactly 2 of the responses a) through c) are correct completions of the sentence. 
   e) All of the responses a) through c) are correct completions of the sentence.

15. In this context, specifications on the part diameter being checked were $\text{some value} \pm 2 \times 10^{-3}$ inch and it turns out that approximate 95% confidence limits on $\sigma_{R&R}$ based on the ANOVA table are $1.17 \times 10^{-3}$ inch to $1.60 \times 10^{-3}$ inch. Approximate 95% confidence limits for a precision to tolerance ratio here 
   a) are 1.76 and 2.40 and indicate that the gauge is clearly adequate for checking conformance to these specifications. 
   b) are 1.76 and 2.40 and provide no definitive conclusion about the adequacy of the gauge for checking conformance to these specifications. 
   c) are 1.76 and 2.40 and indicate that the gauge is clearly not adequate for checking conformance to these specifications. 
   d) can be computed from the information given but are not 1.76 and 2.40. 
   e) None of the responses a) through d) is a correct completion of the sentence.
A chemical analysis for copper content (in ppm) was made by means of flame atomic absorption spectroscopy. \( n = 6 \) standards of concentration \( x \) were tested and percent transmittance values, \( y \), were observed. Use the information on this report to answer questions 16 and 17. (The solid line is the least squares line fit to the data and the dotted ones give 95% prediction limits for a new \( y \) at each \( x \).)

16. The plot suggests that
a) there is some question whether \( y \) should really be treated as linear in \( x \) over the whole range of concentrations 5 ppm to 51 ppm.
b) if one does treat \( y \) as approximately linear in \( x \), the repeatability standard deviation associated with measuring transmittance is large.
c) if one does treat \( y \) as approximately linear in \( x \), the concentration corresponding to a read value of percent transmittance is very poorly determined.
d) Exactly 2 of the responses a) through c) are correct completions of the sentence.
e) All of the responses a) through c) are correct completions of the sentence.

17. 95% confidence limits for a concentration, \( x \), associated with a 40% transmittance are
a) roughly 1.5 ppm to 43.5 ppm.
b) roughly 23.9 ppm \( \pm \) 2(8.8) ppm.
c) \(-1.445 \text{ ppm} \pm 2.776(0.2345) \text{ ppm}.
d) 74.61 ppm \( \pm 2.776(7.738) \text{ ppm}.
e) 5.3 ppm to 25.4 ppm.
18. In a "gauge R&R" study where \( J \) operators each make \( m \) "Go/No-Go" calls on parts, 
a) for a single part, perfect "repeatability" means that a given operator makes all "Go" calls or makes all "No-Go" calls.
b) for a single part, perfect "reproducibility" means that every operator makes the same number of "Go" calls.
c) across \( I \) parts, perfect "R&R" requires that each part has the same number of "Go" calls.
d) Exactly 2 of the responses a) through c) are correct completions of the sentence.
e) All of the responses a) through c) are correct completions of the sentence.

(For questions 19-20) Here is a small part of a data set from a study of Go/No-Go inspection. Each operator (without being aware that parts were being re-inspected) made 50 Good/Defective calls on each part represented below in the course of regular visual inspections. The values in the table are \( \hat{p} \) values (fractions of "Defective" calls made by the operators).

<table>
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<tr>
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<td>5</td>
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19. Considering only Part 1, approximate 95% confidence limits for the difference in long run fractions of "Defective" calls made by the two operators (say, Operator 2 minus Operator 1) 
a) are .10 ± .01.
b) are .10 ± .14.
c) are .10 ± .15.
d) can not be determined from the given information.
e) can be determined from the given information, but none of answers a) through c) are correct.

20. Presuming that the 5 parts represented in the table are a random sample of parts the operators will inspect, 95% confidence limits for comparing the average (across all parts) fraction (across many calls) of "Defective" calls for Operators 1 and 2 (Operator 2 minus Operator 1) 
a) are .02 ± .12 and provide clear evidence that Operator 2 tends to make more "Defective" calls than Operator 1.
b) are .02 ± .12 and provide clear evidence that Operator 2 tends to make fewer "Defective" calls than Operator 1.
c) are .02 ± .12 and provide no clear evidence about which operator tends to make the most "Defective" calls.
d) can be determined from the information provided, but are not close to .02 ± .12.
e) None of the responses a) through d) above is a correct answer.