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

__________________________________________
Name                                      Date
1. Measurement and the subject of statistics are fundamentally related because
   a) measurement error has a negative effect on what of real world importance can be learned from (statistical) data collection and analysis.
   b) statistics can help quantify the impact of measurement error.
   c) how data are collected (statistical planning) affects what sources of measurement error impact (degrade) the real information content of (statistical) data.
   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. Measurement and quality assurance are fundamentally related because
   a) without the ability to measure adequately, one cannot know what is going on in a process.
   b) modern automatic data acquisition systems allow huge amounts of information to be archived and used in guaranteeing good quality.
   c) quality of conformance typically cannot be reliably assessed without the ability to measure adequately.
   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. A bimodal histogram of widget diameters is potentially indicative of
   a) two different machines or operators at work cutting those diameters.
   b) two different measuring methods being used to measure diameters.
   c) an opportunity for process improvement if the bimodality is traced to two different versions of some physical element of the cutting process.
   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.

4. Below are 4 (bullet) statements. How many of them are true?
   - Improvement of a measurement system used to observe a process is only a preliminary to improvement of process fundamentals.
   - The "C" in the Six-Sigma DMAIC acronym refers to the use of automatic/digital "control" systems.
   - Reduction of variation of essentially any kind typically makes products and processes work better.
   - Benchmarking typically provides insight into what changes will enable an organization to leapfrog its competition in terms of effective business practice.
   a) None of the statements are true.
   b) Exactly 1 statement is true.
   c) Exactly 2 statements are true.
   d) Exactly 3 of the statements are true.
   e) All of the statements are true.

5. If a measurement device is not "linear" (in the meaning of the word employed in metrology)
   a) average measurement is a quadratic function of measurand.
   b) there is no way to develop a calibration equation for the device.
   c) Neither a) nor b) above is a correct completion of the sentence.
   d) Both a) and b) are correct completions of the sentence.
6. Two blow-mold machines (#1 and #2) make nominally "identical" plastic bottles. Two nominally "identical" burst testers (#1 and #2) measure burst strength of some bottles produced. Of course, burst testing is destructive, and once tested, a bottle cannot be retested or used. Below are 4 (bullet) statements. How many of them are true?

- It is impossible (by simply burst testing bottles directly from production) to ascertain the repeatability standard deviation of tester #1.
- It is impossible (by using either or both testers) to reliably assess the actual burst strength variation (measurand/part-to-part variation) produced by blow-mold machine #1.
- It is impossible to use the testers (#1 and/or #2) in any way to make a meaningful comparison of mean burst strengths produced by the blow-mold machines (#1 and #2).
- It is impossible to use bottles from (either or both) the blow-mold machines to compare tester biases.

a) None of the statements are true.
b) Exactly 1 statement is true.
c) Exactly 2 statements are true.
d) Exactly 3 of the statements are true.
e) All of the statements are true.

7. Below are 4 (bullet) statements about range-based gauge R&R calculations. How many of them are true?

- They are rarely used in industry.
- The usual "AIAG" (Automotive Industry Action Group) version of them is technically wrong in that the reproducibility standard deviation under the two-way random effects model is not correctly estimated.
- They lead easily to confidence limits for repeatability and reproducibility standard deviations.
- They are more reliable than corresponding ANOVA-based gauge R&R calculations.

a) None of the statements are true.
b) Exactly 1 statement is true.
c) Exactly 2 statements are true.
d) Exactly 3 of the statements are true.
e) All of the statements are true.

8. A reproducibility variance

a) in a measurement context is the variance of operator-specific biases or mean measurements associated with a particular part.
b) in a 0/1 or go/no-go context is the variance of operator-specific "call-1" rates $p_j$ associated with a specific part.
c) measures operator-to-operator variation in measurement or "call-1" rates in a 0/1 or go/no-go context.
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.
9. A gauge capability ratio
a) compares process (or part-to-part) variation to a spread in engineering requirements $U - L$.
b) should be small (no more than .1).
c) compares process (or part-to-part) variation to R&R variation.
d) Exactly 2 of responses a) through c) are correct completions of the sentence.
e) None of responses a) through c) are correct completions of the sentence.

10. Modern process-oriented quality assurance
a) is fundamentally an activity for upper management and rarely reaches to front line employees.
b) employs a wide spectrum of tools, ranging from very simple ones like Ishikawa diagrams and histograms to fairly complicated tools of statistical analysis.
c) is not really applicable to the service sector.
d) Only responses a) and b) are correct completions of the sentence.
e) Only responses b) and c) are correct completions of the sentence.
A gauge block (a standard for length) that is made to be exactly 2.000 inch is measured $n = 5$ times with a particular caliper with the results (in inches) below

$$2.011, 2.015, 2.010, 2.009, 2.010$$

Find 95% confidence limits for the bias of the caliper for measuring 2.000 inch.
A particular machined dimension was measured twice for each of 5 machined parts (units were inches). A JMP printout for a one-way random effects analysis run on the 10 resulting measurements is below.

What are 95% confidence limits for the part-to-part standard deviation of actual dimension?

What are 95% confidence limits for the measurement standard deviation?
In a standard gauge R&R study on a precision balance, AVOVA-based calculations produce \( \sigma_{R\&R} = .0024 \text{ g} \) and \( \nu_{R\&R} = 17.2 \).

Give approximate 95% confidence limits for the standard deviation that would be associated with many operators each making a single measurement of the weight of a single specimen on this balance.

Tomorrow, an operator weighs a specimen and gets the value 19.823 g. Propose and defend what you consider to be an appropriate "± uncertainty" to associate with this value.
14. Below is a small table representing part of the results from Go/NO-Go "gauge R&R" study, based on \( m = 10 \) conforming/non-conforming calls per part by each operator.

<table>
<thead>
<tr>
<th>Part</th>
<th>Operator 1</th>
<th>Operator 2</th>
<th>Operator 3</th>
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<tr>
<td>1</td>
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<td>5</td>
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Give 95% approximate limits for comparing Operators 1 and 2 on Part 1. Is there a clear difference in how they judge Part 1? Explain.

Give 95% confidence limits for comparing Operators 2 and 3 across all parts. Is there a clear difference in how they judge these parts? Explain.
15. In a small calibration study, a metric caliper is used to measure some steel gauge blocks twice each. Gauge block sizes \( x \) are in inches, while measurements \( y \) are in mm. A JMP report for a simple linear regression of \( y \) on \( x \) is below. (The least squares line and 95% two-sided prediction limits for \( y_{\text{new}} \) are shown on the plot.)

If tomorrow a value of 4.5 mm is read on the caliper, give 95% confidence limits for the true size of the dimension being measured (in inches).

We have identified the SLR parameter \( \sigma \) as a kind of repeatability standard deviation. Describe a (fairly unusual, but nevertheless possible) scenario for the collection of the calibration data, where a more natural interpretation is as an R&R standard deviation.