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. "Common cause variation"
   a) produces some level of variation in plotted values on any properly functioning control chart.
   b) forms a baseline against which one attempts to judge the presence or lack of process instability.
   c) can typically only be reduced through fundamental changes in how a process is configured or operated or observed.
   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. Comparison of a plotted statistic $Q$ to control limits for it
   - tells one when to physically intervene in the operation of a process.
   - tells one when intervention in the operation of a process is not justified.
   - tells one when process output is and is not meeting engineering requirements.
   - is sensible only after engineering specifications for process output have been established.
   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. If a production process has been physically stable for some time
   - a control chart set up to monitor it may nevertheless produce out-of-control signals because of measurement process instability.
   - process monitoring should cease and the corresponding resources be redirected.
   - process improvement efforts can have no further positive effect on its behavior.
   - common cause variation is necessarily small enough as to be negligible.
   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.

Below are sample means and ranges from 10 samples of size $n = 3$. Use the information from these samples to answer questions 4 through 6.

<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>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{x}$</td>
<td>8.4</td>
<td>9.4</td>
<td>7.6</td>
<td>12.5</td>
<td>10.5</td>
<td>9.0</td>
<td>14.1</td>
<td>11.7</td>
<td>10.6</td>
<td>9.0</td>
<td>102.8</td>
</tr>
<tr>
<td>$R$</td>
<td>6.6</td>
<td>4.2</td>
<td>7.1</td>
<td>4.2</td>
<td>3.1</td>
<td>1.8</td>
<td>11.9</td>
<td>2.3</td>
<td>3.6</td>
<td>15.1</td>
<td>59.9</td>
</tr>
</tbody>
</table>

4. Consider standards given control charting for both $\bar{x}$ and $R$, with standards $\mu = 10.0$ and $\sigma = 3.0$.
   a) The $\bar{x}$ chart and $R$ chart both produce out-of-control signals.
   b) The $\bar{x}$ chart produces out-of-control signals, but the $R$ chart does not.
   c) The $\bar{x}$ chart produces no out-of-control signals, but the $R$ chart produces signals.
   d) Neither chart produces out-of-control signals.

5. Consider retrospective control charting for both $\bar{x}$ and $R$.
   a) The $\bar{x}$ chart and $R$ chart both produce out-of-control signals.
   b) The $\bar{x}$ chart produces out-of-control signals, but the $R$ chart does not.
   c) The $\bar{x}$ chart produces no out-of-control signals, but the $R$ chart produces signals.
   d) Neither chart produces out-of-control signals.
6. Ignore any lack of stability that you found indicated by the ranges on the previous page and use the values there to estimate $\sigma$. Based on this estimate, in turn set an upper control limit for future sample standard deviations ($s$) based on samples of size $n = 5$. (Remember that the samples represented in the table were of size $n = 3$.) This $UCL_s$ is closest to

a) 17.40  
b) 15.42  
c) 8.05  
d) 7.39  
e) 6.95

7. The values of "control chart constants" in Table A.1 of SQAME suggest that for sampling from a particular normally distributed stable process, as sample size $n$ increases

a) the mean size of sample ranges will increase without bound.  
b) the mean size of sample standard deviations will approach that of the population standard deviation.  
c) Both a) and b) are correct completions to the sentence.  
d) Neither a) nor b) is a correct completion to the sentence.

8. Suppose that process parameters are $\mu = 0.0$ and $\sigma = 2.0$ for the diameters of some axels turned on a particular lathe (where units are $10^{-4}$ inch above some nominal value). Suppose further that axel diameters are normally distributed and specifications on diameters are $0.0 \pm 2.0$ inch. A sample of $n = 7$ of these axels will be produced. Below are 3 statements about what can be expected to happen in this production. How many of them are true?

• There is an approximately 68% chance that the first diameter produced meets specifications.  
• The chance that all 7 diameters produced meet specifications is less than 10%.  
• By the Chebyschev inequality of Stat 231, the chance is large (75% or more) that the sample median diameter, $\tilde{x}$, is between $-2.0$ and $2.0$.

a) All 3 are correct.  
b) Exactly 2 are correct.  
c) Exactly 1 is correct.  
d) None are correct.  
e) Not enough information is given to tell how many are correct.

9. In a large insurance company claims processing center, a study of the accuracy with which a particular class of claims is handled (as judged by a specially trained company auditor) indicates that about 10% of claims of this type are seriously mishandled by ordinary adjustors. Ongoing training of adjustors is instituted in an effort to reduce this mishandling rate, and monthly sampling of cases will be done to monitor the fraction of improperly handled claims. Suppose that a standards-given control chart will be used in the monitoring.

a) A chart based on sample size $n = 50$ will allow for eventual indication of a process degradation, but not a process improvement.  
b) A chart based on sample size $n = 100$ will allow for eventual indication of either a process degradation or a process improvement.  
c) A chart based on sample size $n = 100$ will typically be more sensitive to process degradation than will be one based on a sample size $n = 50$.  
d) Exactly two of a) through c) are correct completions of the sentence.  
e) All of a) through c) are correct completions of the sentence.
10. An ultrasound non-destructive evaluation technique is used to inspect jet engine turbine blades of a common age in a fleet of Boeing 737’s owned by an airline. The numbers of blades tested and numbers of blades determined to have serious internal cracks in 10 consecutive one-month periods are below.

<table>
<thead>
<tr>
<th>Month</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>Tested</td>
<td>100</td>
<td>80</td>
<td>60</td>
<td>100</td>
<td>120</td>
<td>120</td>
<td>60</td>
<td>80</td>
<td>60</td>
<td>100</td>
<td>880</td>
</tr>
<tr>
<td>With Cracks</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>12</td>
</tr>
</tbody>
</table>

The data in the table

a) provide no evidence of change over time in the fraction of turbine blades in the fleet with detectable serious internal cracks.

b) provide clear evidence of a degradation in turbine blades in the fleet if the historical standard is 1% of blades failing this inspection.

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.

11. In the context of problem 10, instead of simply calling a blade "non-conforming" if any serious internal cracks are detected, one might instead count total cracks detected in each month's inspections (where a single blade may account for more than one crack). If the historical standard is that 1% of blades have detectable serious internal cracks,

a) based on a Poisson distribution, a sensible mean number of detectable cracks per blade under historical standard conditions is \(-\ln(.99) = .0101\).

b) then 100 blades producing 4 detectable cracks spread among 4 blades would produce an "out of control" signal on the basis of the 4 blades, but not on the basis of the 4 cracks total.

c) then 100 blades producing 4 detectable cracks spread among 4 blades would produce an "out of control" signal on the basis of the 4 cracks total, but not on the basis of the 4 blades with cracks.

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

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

12. "Stratification"

- can occur when systematically different process streams are sampled in regular fashion and the systematic differences are ignored in control charting.
- can lead to apparently "super-stable" control charting results.
- can mask process problems that should be addressed.
- is a potential concern in manufacturing problems, but not in service contexts.

a) All of the above are correct completions of the sentence.

b) Exactly three of the above are correct completions of the sentence.

c) Exactly two of the above are correct completions of the sentence.

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

e) None of the above is a correct completion of the sentence.
13. Suppose that for some process summary statistic $Q$, a standard mean is $\mu_Q = 10.0$ and a standard standard deviation is $\sigma_Q = 1.0$. A series of observed values of this statistic is listed and then plotted below.

<table>
<thead>
<tr>
<th>Period, $t$</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>$Q_t$</td>
<td>10.2</td>
<td>12.7</td>
<td>7.5</td>
<td>10.7</td>
<td>11.3</td>
<td>12.2</td>
<td>11.6</td>
<td>11.4</td>
<td>12.6</td>
<td>13.2</td>
</tr>
</tbody>
</table>

A Shewhart chart using the Western Electric Rules is used to do process monitoring. At what period is the process first declared to be "out of control"?

- a) at period 3
- b) at period 8
- c) at period 9
- d) at period 10
- e) None of a) through d) is correct.

14. Below are 3 statements about average run lengths for a process monitoring scheme. How many of them are true?

- Ideally, the ARL for a monitoring scheme would be infinity for standard process behavior.
- Ideally, the ARL for a monitoring scheme would be 1.0 if there is any change from standard process behavior.
- "Nearly ideal" ARLs for a monitoring scheme can only be had for the price of very large sample sizes.

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

15. How many of the following statements about "process control" methods are true?

- "Control" methods are an essential part of Six Sigma programs.
- Unless action is taken on out-of-control signals, a control chart contributes nothing toward good process behavior.
- An engineering feedback control algorithm prescribes exactly what changes to make in a manipulated variable (some process physical parameter) on the basis of measurements from the process.
- Both statistical process control methods and engineering feedback control methods aim to produce the best possible behavior for a fixed process configuration (as opposed to guiding experimental search for new and better process structures).
a) All of the above are true statements.
b) Exactly three of the above are true statements.
c) Exactly two of the above are true statements.
d) Exactly one of the above is a true statement.
e) None of the above is a true statement.

16. 11 consecutive samples of size $n = 1$ from a process are as below

<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>
<th>11</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x$</td>
<td>1.04</td>
<td>1.65</td>
<td>1.98</td>
<td>2.47</td>
<td>3.02</td>
<td>3.43</td>
<td>2.88</td>
<td>2.48</td>
<td>2.06</td>
<td>1.56</td>
<td>1.05</td>
<td>2.147</td>
</tr>
<tr>
<td>$MR$</td>
<td>.61</td>
<td>.33</td>
<td>.49</td>
<td>.55</td>
<td>.41</td>
<td>.55</td>
<td>.40</td>
<td>.42</td>
<td>.50</td>
<td>.51</td>
<td>.51</td>
<td>.477</td>
</tr>
</tbody>
</table>

Further, $\frac{.477}{1.128} = .423$ while $s = .789$

and a plot of these points is

![Plot of data points]

a) .423 is the best available estimate of $\sigma$, but neither .423 nor .789 appears to be sensible as a measure of process short term variability.
b) .789 is the best available estimate of $\sigma$, but neither .423 nor .789 appears to be sensible as a measure of process short term variability.
c) If instead of reversing itself at period 6 the trend in the data had continued unabated, $s$ would have been smaller than the reported value of .789.
d) Both a) and c) are true.
e) Both b) and c) are true.

17. Below is a normal plot of a sample of size $n = 40$ measurements of a critical part dimension taken from items produced on a milling machine.

![Normal plot of data]
This plot
  a) shows clearly that the process was not stable over the data collection period.
  b) indicates that $C_{pk}$ will be a practically meaningful measure of performance for this process.
  c) shows that the process distribution of the part dimension is "short-tailed to the left" (or "long-tailed to the right") relative to the shape of a normal distribution.
  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.

Thicknesses (in cm) of a batch of $n = 9$ machined stainless steel boiler nozzles have $\bar{x} = 1.6272$ cm, $s = .0281$ cm, $\min x_i = 1.575$ cm, and $\max x_i = 1.655$ cm. We'll assume that specifications on this thickness are $1.625 \pm .050$ cm and that the machining process is physically stable. Use these facts to answer questions 18 through 20.

18. How "sure" should one be that a 10th nozzle thickness will be between 1.575 cm and 1.655 cm?
   a) 70%
   b) 80%
   c) 90%
   d) 95%
   e) None of the above are close to correct.

19. Assuming thickness to be normally distributed, 95% confidence limits for a capability ratio measuring current process performance (as opposed to process potential)
   a) are .401 and 1.136.
   b) are .426 and 1.105.
   c) are .214 and .920.
   d) are .271 and .863.
   e) None of the above are close to correct.

20. Again assuming hardness to be normally distributed, one can be 95% sure that 99% of all thicknesses
   a) are $1.6272 \pm 2.306(.0281)$.
   b) are $1.6272 \pm 3.355(.0281)$.
   c) are $1.6272 \pm 4.581(.0281)$.
   d) are $1.6272 \pm 4.633(.0281)$.
   e) None of the above are close to correct.