42.10 Which of the following phrases relating to ISO 9000 are correct (three correct answers): (a) certified by the International Standards Office located in Geneva, Switzerland, (b) developed by the International Organization for Standardization located somewhere in Europe, (c) establishes standards for the quality systems and procedures used by a facility, (d) establishes standards for the products and services delivered by a facility, and (e) registration in ISO 9000 obtained through a third-party agency that certifies the facility's quality systems?

Answer. (b), (c), and (e).

42.11 The two basic types of inspection are inspection by variables and inspection by attributes. The second of these inspections uses which one of the following: (a) destructive testing, (b) gaging, (c) measuring, or (d) nondestructive testing?

Answer. (b).

42.12 Automated 100% inspection can be integrated with the manufacturing process to accomplish which of the following (two best answers): (a) better design of products, (b) feedback of data to adjust the process, (c) 100% perfect quality, and (d) sortation of good parts from defects?

Answer. (b) and (d) are mentioned in the text.

42.13 Which one of the following is an example of contact inspection: (a) coordinate measuring systems, (b) machine vision, (c) radiation techniques, (d) scanning laser systems, and (e) ultrasonic techniques?

Answer. (a).

42.14 Which one of the following is the most important application of vision systems: (a) inspection, (b) object identification, (c) safety monitoring, or (d) visual guidance and control of a robotic manipulator?

Answer. (a).

Problems

Note: Problems identified with an asterisk (*) in this set require the use of statistical tables not included in this text.

Process Capability and Tolerances

42.1 An automatic turning process is set up to produce parts with a mean diameter = 6.255 cm. The process is in statistical control and the output is normally distributed with a standard deviation = 0.004 cm. Determine the process capability.

Solution: Process capability $PC = \mu \pm 3\sigma = 6.255 \pm 3(0.004) = \mathbf{6.255 \pm 0.012}$ **cm**
The upper and lower limits of the process capability range are: 6.243 to 6.267 cm

42.2 * In Problem 42.1, the design specification on the part is: diameter = 6.250 ±0.013 cm. (a) What proportion of parts fall outside the tolerance limits? (b) If the process were adjusted so that its mean diameter = 6.250 cm and the standard deviation remained the same, what proportion of parts would fall outside the tolerance limits?

Solution: (a) Given process mean μ = 6.255 cm and σ = 0.004 cm and tolerance limits 2.237 to 2.263. On the lower side of the tolerance limit, using the standard normal distribution,
z = (6.237 - 6.255)/0.004 = -4.50. Conclusion: there are virtually no defects on the lower side of the tolerance. On the upper side of the tolerance limit, z = (6.263 - 2.255)/0.004 = +2.00
Using tables of the standard normal distribution, Pr(z > 2.00) = 0.0227
The proportion of defects with the current process mean = **0.0227 = 2.27%.**

(b) Given process mean $\mu = 6.250$ cm and $\sigma = 0.004$ cm and tolerance limits 6.237 to 6.263. On the lower side of the tolerance limit, $z = (6.237 - 6.250)/0.004 = -3.25$. Using tables of the standard normal distribution, $\Pr(z < -3.25) = 0.0006$. On the upper side of the tolerance limit, $z = (6.263 - 6.250)/0.004 = +3.25$.
Using tables of the standard normal distribution, $\Pr(z > 3.25) = 0.0006$
The proportion of defects with the current process mean = 0.0006 + 0.0006 = **0.0012 = 0.12%.**

42.3 A sheet-metal bending operation produces bent parts with an included angle = 92.1°. The process is in statistical control and the values of included angle are normally distributed with a standard deviation = 0.23°. The design specification on the angle = 90 ± 2°. (a) Determine the process capability. (b) If the process could be adjusted so that its mean = 90.0°, determine the value of the process capability index.

Solution: (a) $PC = 92.1 \pm 3(0.23) = 92.1° \pm 0.69°$.
The upper and lower limits of the process capability range are: 91.41° to 92.79°.

(b) If $\mu = 90°$
$T = 92° - 88° = 4°$
$PCI = 4°/(6 \text{ x } 0.23°) =$ **2.9** $\rightarrow$ virtually no defects.

42.4 A plastic extrusion process produces round extrudate with a mean diameter = 28.6 mm. The process is in statistical control and the output is normally distributed with standard deviation = 0.53 mm. Determine the process capability.

Solution: Process capability $PC = \mu \pm 3\sigma = 28.6 \pm 3(0.53) =$ **28.6 ± 1.59 mm**
The upper and lower limits of the process capability range are: 27.01 to 30.19 mm.

42.5 * In Problem 42.4, the design specification on the diameter is 28.0 ± 2.0 mm. (a) What proportion of parts fall outside the tolerance limits? (b) If the process were adjusted so that its mean diameter = 28.0 mm and the standard deviation remained the same, what proportion of parts would fall outside the tolerance limits? (c) With the adjusted mean at 28.0 mm, determine the value of the process capability index.

Solution: (a) Given process mean $\mu = 28.6$ mm and $\sigma = 0.53$ mm and tolerance limits 26.0 to 30.0 mm. On the lower side of the tolerance limit, using the standard normal distribution,
$z = (26.0 - 28.6)/0.53 = -4.01$. Conclusion: there are virtually no defects on the lower side of the tolerance.
On the upper side of the tolerance limit, $z = (30.0 - 28.6)/0.53 = +2.64$
Using tables of the standard normal distribution, $\Pr(z > 2.64) = 0.0041$
The proportion of defects with the current process mean = **0.0041 = 0.41%.**

(b) Given process mean $\mu = 28.0$ mm and $\sigma = 0.53$ mm and tolerance limits 26.0 to 30.0 mm.
On the lower side of the tolerance limit, $z = (26.0 - 28.0)/0.53 = -3.77$. Using tables of the standard normal distribution, $\Pr(z < -3.77)$ = approx. 0.0001
On the upper side of the tolerance limit, $z = (30.0 - 28.0)/0.53 = +3.77$
Using tables of the standard normal distribution, $\Pr(z > 3.77)$ = approx. 0.0001
The proportion of defects with the current process mean = 0.0001 + 0.0001 = **0.0002 = 0.02%.**

(c) Process capability index $PCI = 4.0/(6 \text{ x } 0.53) =$ **1.258**

Control Charts

42.6 In 12 samples of size $n = 7$, the average value of the sample means is $\bar{\bar{x}} = 6.860$ cm for the dimension of interest, and the mean of the ranges of the samples is $\bar{R} = 0.027$ cm. Determine (a) lower and upper control limits for the $\bar{x}$ chart and (b) lower and upper control limits for the R chart. (c) What is your best estimate of the standard deviation of the process?

Solution: (a) $\bar{x}$ chart: $\bar{x}$ = 6.860 cm = CL

LCL = $\bar{x}$ - $A_2\bar{R}$ = 6.860 - 0.419(0.027) = **6.8487 cm**

UCL = $\bar{x}$ + $A_2\bar{R}$ = 6.860 + 0.419(0.027) = **6.8713 cm**

(b) R chart: $\bar{R}$ = 0.027 = CL

LCL = $D_3\bar{R}$ = 0.076(0.027) = **0.0205 cm**

UCL = $D_4\bar{R}$ = 1.924(0.027) = **0.0519 cm**

(c) The $\bar{x}$ chart is based on ± 3 $\sigma_x/\sqrt{n}$

Therefore, $A_2\bar{R} = 3\ \sigma_x/\sqrt{n}$

$\sigma_x = A_2\bar{R}\sqrt{n}/3$ = 0.419(0.027)$\sqrt{7}$/3 = **0.00998 cm**

42.7 In nine samples of size n = 10, the grand mean of the samples is $\bar{\bar{x}}$ = 100 for the characteristic of interest, and the mean of the ranges of the samples is $\bar{R}$ = 8.5. Determine (a) lower and upper control limits for the $\bar{x}$ chart and (b) lower and upper control limits for the R chart. (c) Based on the data given, estimate the standard deviation of the process?

Solution: (a) $\bar{x}$ chart: $\bar{x}$ = 100 = CL

LCL = $\bar{x}$ - $A_2\bar{R}$ = 100 - 0.308(8.5) = **102.618**

UCL = $\bar{x}$ + $A_2\bar{R}$ = 100 + 0.308(8.5) = **97.382**

(b) R chart: $\bar{R}$ = 8.5 = CL

LCL = $D_3\bar{R}$ = 0.223(8.5) = **1.8955**

UCL = $D_4\bar{R}$ = 1.777(8.5) = **15.1045**

(c) The $\bar{x}$ chart is based on ± 3 $\sigma_x/\sqrt{n}$

Therefore, $A_2\bar{R} = 3\ \sigma_x/\sqrt{n}$

$\sigma_x = A_2\bar{R}\sqrt{n}/3$ = 0.308(8.5)$\sqrt{10}$/3 = **2.7596**

42.8 Ten samples of size n = 8 have been collected from a process in statistical control, and the dimension of interest has been measured for each part. The calculated values of $\bar{x}$ for each sample are (mm) 9.22, 9.15, 9.20, 9.28, 9.19, 9.12, 9.20, 9.24, 9.17, and 9.23. The values of R are (mm) 0.24, 0.17, 0.30, 0.26, 0.26, 0.19, 0.21, 0.32, 0.21, and 0.23, respectively. (a) Determine the values of the center, LCL, and UCL for the $\bar{x}$ and R charts. (b) Construct the control charts and plot the sample data on the charts.

Solution: $\bar{\bar{x}} = \Sigma\bar{x}/\text{m} = \Sigma\bar{x}/10$

= (9.22 + 9.15 + 9.20 + 9.28 + 9.19 + 9.12 + 9.20 + 9.24 + 9.17 + 9.23)/10 = 9.20

$\bar{R} = \Sigma R/10$ = (0.24 + 0.17 + 0.30 + 0.26 + 0.27 + 0.19 + 0.21 + 0.32 + 0.21 + 0.23)/10 = 0.24

(a) $\bar{x}$ chart: $\bar{x}$ = **9.20 mm = CL**

LCL = $\bar{x}$ - $A_2\bar{R}$ = 9.20 - 0.373(0.24) = **9.1105 mm.**

UCL = $\bar{x}$ + $A_2\bar{R}$ = 9.20 + 0.373(0.24) = **9.2895 mm.**

R chart: $\overline{R}$ = **0.024 = CL**

LCL = $D_3\overline{R}$ = 0.136(0.24) = **0.0326 mm.**

UCL = $D_4\overline{R}$ = 2.114(0.0133) = **0.4474 mm.**

(b) Student exercise.

42.9 Seven samples of 5 parts each have been collected from an extrusion process that is in statistical control, and the diameter of the extrudate has been measured for each part. The calculated values of $\overline{x}$ for each sample are (inch) 1.002, 0.999, 0.995, 1.004, 0.996, 0.998, and 1.006. The values of R are (inch) 0.010, 0.011, 0.014, 0.020, 0.008, 0.013, and 0.017, respectively. (a) Determine the values of the center, LCL, and UCL for $\overline{x}$ and R charts. (b) Construct the control charts and plot the sample data on the charts.

Solution: $\overline{\overline{x}} = \Sigma\overline{x}/7$ = (1.002 + 0.999 + 0.995 + 1.004 + 0.996 + 0.998 + 1.006)/7 = 1.000

$\overline{R} = \Sigma R/7$ = (0.010 + 0.011 + 0.014 + 0.020 + 0.008 + 0.013 + 0.017)/7 = 0.0133

(a) $\overline{x}$ chart: $\overline{x}$ = **1.000 in = CL**

LCL = $\overline{x} - A_2\overline{R}$ = 1.000 - 0.577(0.0133) = **0.9923 in**

UCL = $\overline{x} + A_2\overline{R}$ = 1.000 + 0.577(0.0133) = **1.0077 in**

R chart: $\overline{R}$ = **0.0133 = CL**

LCL = $D_3\overline{R}$ = 0(0.0133) = **0**

UCL = $D_4\overline{R}$ = 2.114(0.0133) = **0.0281 in**

(b) Student exercise.

42.10 A p chart is to be constructed. Six samples of 25 parts each have been collected, and the average number of defects per sample was 2.75. Determine the center, LCL and UCL for the p chart.

Solution: $\overline{p}$ = 2.75/25 = **0.11 = CL**

LCL = $\overline{p} - 3\sqrt{p(1-p)/n}$ = $0.11 - 3\sqrt{0.11(0.89)/25}$ = 0.11 - 3(0.0626) = **-0.078 → 0**

UCL = $\overline{p} + 3\sqrt{p(1-p)/n}$ = $0.11 + 3\sqrt{0.11(0.89)/25}$ = 0.11 + 3(0.0626) = **0.298**

42.11 Ten samples of equal size are taken to prepare a p chart. The total number of parts in these ten samples was 900 and the total number of defects counted was 117. Determine the center, LCL and UCL for the p chart.

Solution: $\overline{d}$ = 117/10 = 11.7.

$\overline{p}$ = 11.7/90 = **0.13 = CL**

LCL = $\overline{p} - 3\sqrt{p(1-p)/n}$ = $0.13 - 3\sqrt{0.13(0.87)/90}$ = 0.13 - 3(0.03545) = **0.024**

UCL = $\overline{p} + 3\sqrt{p(1-p)/n}$ = $0.11 + 3\sqrt{0.13(0.87)/90}$ = 0.11 + 3(0.03545) = **0.236**

42.12 The yield of good chips during a certain step in silicon processing of integrated circuits averages 91%. The number of chips per wafer is 200. Determine the center, LCL, and UCL for the p chart that might be used for this process.

Solution: Use p = 1 - 0.91 = **0.09 = CL**

LCL = $\overline{p} - 3\sqrt{p(1-p)/n}$ = $0.09 - 3\sqrt{0.09(0.91)/90}$ = 0.09 - 3(0.0202) = **0.0293**

UCL = $\overline{p} + 3\sqrt{p(1-p)/n}$ = $0.11 + 3\sqrt{0.09(0.91)/90}$ = 0.09 + 3(0.0202) = **0.1507**

42.13 The upper and lower control limits for a p chart are: LCL = 0.19 and UCL = 0.24. Determine the sample size n that is used with this control chart.

Solution: $\bar{p} = 0.5(\text{UCL} + \text{LCL}) = 0.5(.24 + .10) = 0.17$

$\text{UCL} - \text{LCL} = 0.24 - 0.10 = 0.14 = 6\sqrt{p(1-p)/n} = 6\sqrt{0.17(0.83)/n}$

$(0.14)^2 = 6^2\,(0.17 \times 0.83/n)$

$0.0196 = 36(0.17)(0.83)/n = 5.0796/n$

$n = 5.0796/0.0196 = 259.2 \rightarrow$ **259**

42.14 The upper and lower control limits for a p chart are: LCL = 0 and UCL = 0.20. Determine the minimum possible sample size n that is compatible with this control chart.

Solution: $p = 0.5(\text{UCL} + \text{LCL}) = 0.5(.20 + 0) = 0.10$

$\text{LCL} = p - 3\sqrt{p(1-p)/n} = 0$

Therefore, $p = 3\sqrt{p(1-p)/n}$

$0.10 = 3\sqrt{0.10(0.90)/n}$

$(0.10)^2 = 0.01 = 3^2\,(0.10)(0.90)/n = 0.81/n$

$n = 0.81/0.01 =$ **81**

42.15 Twelve cars were inspected after final assembly. The number of defects found ranged between 87 and 139 defect per car with an average of 116. Determine the center and upper and lower control limits for the c chart that might be used in this situation.

Solution: **CL = 116**

$\text{LCL} = \bar{c} - 3\sqrt{\bar{c}} = 116 - 3\sqrt{116} = \mathbf{83.7 \rightarrow 83}$

$\text{UCL} = \bar{c} + 3\sqrt{\bar{c}} = 116 + 3\sqrt{116} = \mathbf{148.3 \rightarrow 148}$

Quality Programs

42.16 A foundry that casts turbine blades inspects for eight features that are considered critical-to-quality. During the previous month, 1,236 castings were produced. During inspection, 47 defects among the eight features were found, and 29 castings had one or more defects. Determine DPMO, DPM, and DUPM in a Six Sigma program for these data and convert each to its corresponding sigma level.

Solution: Summarizing the data, $N_u = 1236$, $N_o = 8$, $N_d = 47$, and $N_{du} = 29$. Thus,

$$DPMO = 1{,}000{,}000\frac{47}{1236(8)} = 4753$$

The corresponding sigma level is about 4.1 from Table 42.3.

$$DPM = 1{,}000{,}000\frac{47}{1236} = 38{,}026$$

The corresponding sigma level is about 3.3.

$$DUPM = 1{,}000{,}000\frac{29}{1236} = 23{,}463$$

The corresponding sigma level is about 3.4.

42.17 In the previous problem, if the foundry desired to improve its quality performance to the 5.0 sigma level in all three measures of DPM, how many defects and defective units would they produce in an annual production quantity of 15,000 castings? Assume the same eight features are used to assess quality.

Solution: Summarizing the data, N_u = 15,00, N_o = 8, and N_d and N_{du} are unknown. To achieve a 5.0 sigma level, they would produce 233 dpm. Thus, for defects per million opportunities,

$$DPMO = 1{,}000{,}000\frac{N_d}{15000(8)} = 233$$

Rearranging, N_d = 233(15,000)(8)/1,000,000 = 27.96, rounded up to 28 defects in 15,000 total castings.

Similarly, if the 5.0 sigma criterion were used for defects per million units,

$$DPM = 1{,}000{,}000\frac{N_d}{15000} = 233$$

Rearranging, N_d = 233(15,000)/1,000,000 = 3.495 defects in 15,000 total castings.

Finally, if the 5.0 sigma criterion were used for defective units per million units,

$$DUPM = 1{,}000{,}000\frac{N_{du}}{15000} = 233$$

N_{du} = 233(15,000)/1,000,000 = 3.495 defective units in 15,000 total castings.

42.18 The inspection department in an automobile final assembly plant inspects cars coming off the production line against 55 quality features considered important to customer satisfaction. The department counts the number of defects found per 100 cars, which is the same type of metric used by a national consumer advocate agency. During a one-month period, a total of 16,582 cars rolled off the assembly line. These cars included a total of 6045 defects of the 55 features, which translates to 36.5 defects per 100 cars. In addition, a total of 1955 cars had one or more of the defects during this month. Determine DPMO, DPM, and DUPM in a Six Sigma program for these data and convert each to its corresponding sigma level.

Solution: Although the inspection department uses number of defects per 100 cars, a Six Sigma program uses defects per million as its metric. Summarizing the data, N_u = 16,582, N_o = 55, N_d = 6045, and N_{du} = 1955. Thus,

$$DPMO = 1{,}000{,}000\frac{6045}{16582(55)} = 6628$$

The corresponding sigma level is about 4.0 from Table 42.3.

$$DPM = 1{,}000{,}000\frac{6045}{16582} = 364{,}552$$

The corresponding sigma level is about 1.8.

$$DUPM = 1{,}000{,}000\frac{1955}{16582} = 117{,}899$$

The corresponding sigma level is about 2.7.

42.19 A company produces a certain part whose most important dimension is 37.50 ±0.025 in. If the tolerance is exceeded, the customer will return the part to the manufacturer at a cost of $200 in rework and replacement expenses. (a) Determine the constant k in the Taguchi loss function, Eq. (42.13). (b) The company can add a finish grinding operation that will allow the tolerance to be reduced to ±0.010 in. Using the loss function from part (a) what is the value of the loss associated with this new tolerance?

Solution: (a) In Eq. (42.13), the value of (x – N) is the tolerance 0.025 in. The loss is the expected cost of rework and replacement, which is $200. Using this cost in the loss function, the value of k can be determined as follows:

$$200 = k(0.025)^2 = 0.000625k$$

$$k = 200/0.000625 = \$320{,}000$$

Accordingly, the Taguchi loss function is $L(x) = 320{,}000(x - N)$.

(b) The value of the loss for a tolerance of 0.010 is $L(x) = 320{,}000(0.010)^2 = \$32.00$

42.20 The additional operation in the preceding problem will add \$2.00 to the current cost of the part, which is \$13.50. If the rate of returns from the customer at the tolerance of ±0.025 in is 2.1%, and it is expected to drop to zero returns using the new tolerance, should the company add the finish grinding operation to the manufacturing sequence for the part? Answer this question using the basic cost and return rate data without consideration of the Taguchi loss function.

Solution: The basic cost and return rate data are that 2.1% of the parts are returned, and it costs \$200 for each one that is returned. Comparing the cost per part with and without the grinding operation, we have

Without the grinding operation, cost/pc = \$13.50 + 0.021(\$200) = 13.50 + 4.20 = \$17.70

With the added operation, cost/pc = 13.50 + 2.00 = \$15.50

The calculation favors the addition of the grinding operation.

Laser Measurement Technologies

42.21 A laser triangulation system has the laser mounted at a 35° angle from the vertical. The distance between the worktable and the photodetector is 24.0000 in. Determine (a) the distance between the laser and the photodetector when no part is present and (b) the height of a part when the distance between the laser and photo-detector is 12.0250 in.

Solution: (a) L with no part when $D = 0$: $D = H - L \cot A$;
$0 = H - L \cot A$; $L = H/\cot A = H \tan A$
$L = 24.0000 \tan(35) =$ **16.8050 in**

(b) $D = H - L \cot A = 24.0000 - 12.0250 \cot(35)$
$D = 24.0000 - 12.0250(1.42815) =$ **6.8265 in**

42.22 A laser triangulation system is used to determine the height of a steel block. The system has a photosensitive detector that is located 750.000 mm above the working surface and the laser is mounted at a 30.00° angle from the vertical. With no part on the worktable, the position of the laser reflection on the photo sensor is recorded. After a part is placed on the worktable, the laser reflection shifts 70.000 mm toward the laser. Determine the height of the object.

Solution: Need to find the distance of the reflection from the laser.
L with no part when $D=0$: $D = H - L \cot A$; $0 = H - L \cot A$; $L = H/\cot A = H \tan A$
$L = 750 \tan(30) = 433.0127$ mm
L with part = 433.0127 – 70 = 363.0127 mm
$D = H - L \cot A = 750 - 363.0127 \cot(30) = 750 - 363.0127(1.732) =$ **121.262 mm**